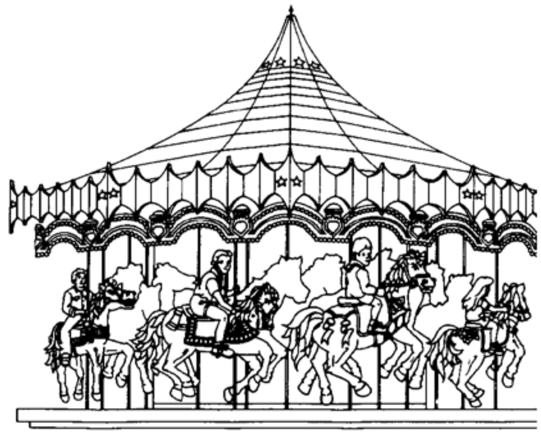
The Carrousel

The Carrousel is a giant rotating platform. Use the concepts of rotational kinematics and dynamics to answer the following questions.



1. Measure the period of rotation.
   (Hint: See Appendix B.)

2. What is the angular velocity ω?

3. Calculate the tangential speed v_T
   a. For the inner ring of the carrousel. (r_i = 5.3 m)

   b. For the outer ring. (r_o = 7.2 m)

4. What is the centripetal acceleration a_c
   a. For the inner ring?

   b. For the outer ring?

   c. What are the values of a. and b. in g's? How does these compare to the g's experienced on other rides in the park, such as the Storm Runner?

5. Calculate the centripetal force F_c experienced by a rider on the
    a. Inner ring.

    b. Outer ring.

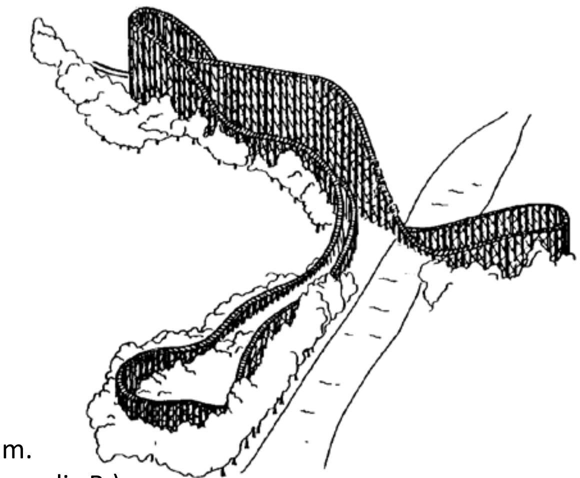
6. Measure the centripetal force using your accelerometer (either handheld or electronic).
    a. F_c = ___________N

    b. Compare this value with the one you calculated in number 5.

7. Suppose an outer ring rider's shoe flew off their foot.
    a. How fast and in what direction (with respect to the radius of the ride) would the shoe be flying? (Hint: Draw a diagram.)

    b. The ride is 0.264 m off the ground. How far will the shoe fly before reaching the ground?

THE COMET



1. What are some things that would keep this roller coaster from being an ideal situation?

2. Find the total energy of the train with m = 4309kg and l = 12.19m at the top of the first hill of h = 24.4 m. (Hint: to find the speed at the top of the hill, see Appendix B.)

3. Find the total energy at the bottom of the hill.

4. Calculate the energy lost from the top of the hill to the bottom.

5. Find the percentage of energy lost from the top to the bottom of the hill.

6. Draw a graph of height vs. time for the first hill. Height should go on the vertical axis and time should go on the horizontal axis. Assume that the bottom of the hill is at y=0 and the train starts going down the hill at t=0. (Hint: Use a stopwatch to measure how long it takes for the car to go from the top of the hill to the bottom of the hill.)

7. Draw a graph of vertical velocity vs. time for the first hill. The velocity should go on the vertical axis and time should go on the horizontal axis. Assume the car has an initial vertical velocity v_0=0 and starts to go down the hill at t=0.

8. Draw a graph of acceleration vs. time for the first hill. The acceleration should go on the vertical axis and time should go on the horizontal axis. Assume the car starts going down the hill at t=0.

Fahrenheit

For safety reasons, please do not take data collection devices on this ride. All the questions below can be answered through observation and utilization of the concepts of kinematics, work, power and special relativity.

1. The height of the first hill is 37m. The speed at the bottom of the first hill is 26 m/s. This portion of the track is above the ground. Find the height of the track at the bottom of the hill. (Hint: Assume the velocity at the top of the first hill is zero.)

2. Putting on your physics hat, assume the acceleration of the train from the top of the first hill to the bottom is constant, the path is straight and disregard all the work the engineers put into the specific design of the drop.
    a. Calculate the downward acceleration of the train. (Hint: To measure t, see Appendix B.)

    b. Compare this to freefall by converting it to g's.

3. Find the work needed to get the train of m =1000 kg to the top of the first hill. (Hint: Assume the ascent is vertical.)

4. Find the power needed to pull the train up. (Hint: To measure t, see Appendix B.)

5. Fahrenheit uses drive wheels of r = 0.997m and chains to pull the ride up the hill. Now, since we're physicists and not engineers, we'll just assume one chain, one wheel, and one driving motor. How much torque must the drive wheel exert to pull up the car?

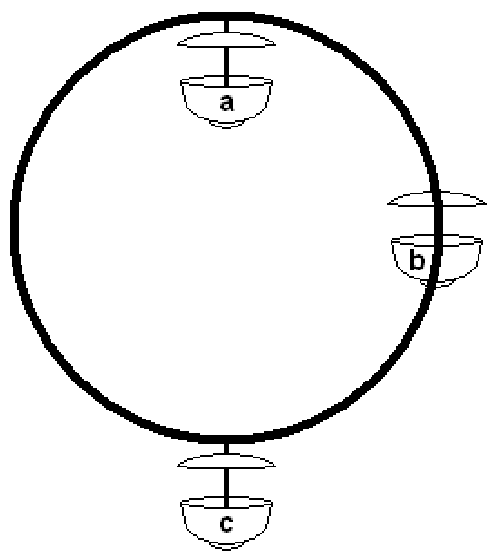
Ferris Wheel

Measure the period T of the Ferris Wheel. (Hint: See Appendix B.)

1. Find the angular frequency.

2. Find the tangential velocity if the diameter of the wheel is 26.82 m.

3. Find the magnitude and direction of the centripetal acceleration at the following points.
    a. At the top of the wheel.
    b. On the side of the wheel.
    c. At the bottom of the wheel.



4. Draw in the centripetal force at points a, b and c in the diagram above.

5. Draw in the normal force on the cart at A, B, and C.

Lightning Racer

Split your group into two smaller groups and answer the following questions:

1. Group 1: Find the average velocity of the green train over the 1036 m long track. (Hint: see Appendix B.)

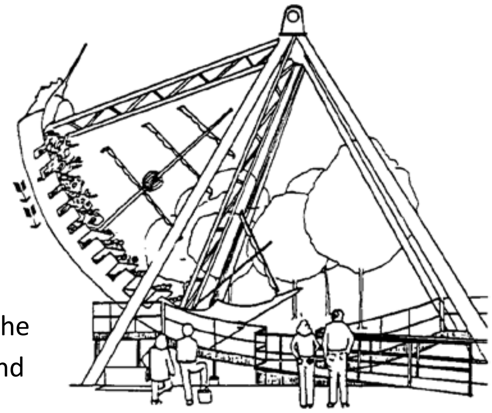
   Group 2: Find the average velocity of the red train over the 1036 m long track. (Hint: see Appendix B.)

2. Compare your values from question 1. Which car had the highest average velocity? Did that car win?

3. How is it physically possible for one car to beat the other, assuming the cars and tracks were built identically? Give at least two possible reasons.

4. If the highest hill for each train is 27.43 m, what is the top speed that the coasters can reach? Assume that the trains have no velocity at the top of the hill.

The Pirate



The Pirate is very much like a large pendulum. Using that idea, conservation of energy and conservation of momentum, answer the following questions.

1. In an ideal situation, what is the relationship between the potential energy PE of the ship at the top of its swing and the kinetic energy KE at the bottom of the swing?

2. What are some things that keep this from being an ideal situation?

3. The maximum height of the boat is 13.6 m and the mass of the boat (when full) is 9548 kg.

    a. Calculate what the speed of the boat should be at the bottom of its swing if energy is conserved.

    b. Find the speed of the boat at the bottom of its swing using the directions on Appendix B.

4. How much energy did the boat lose and why?

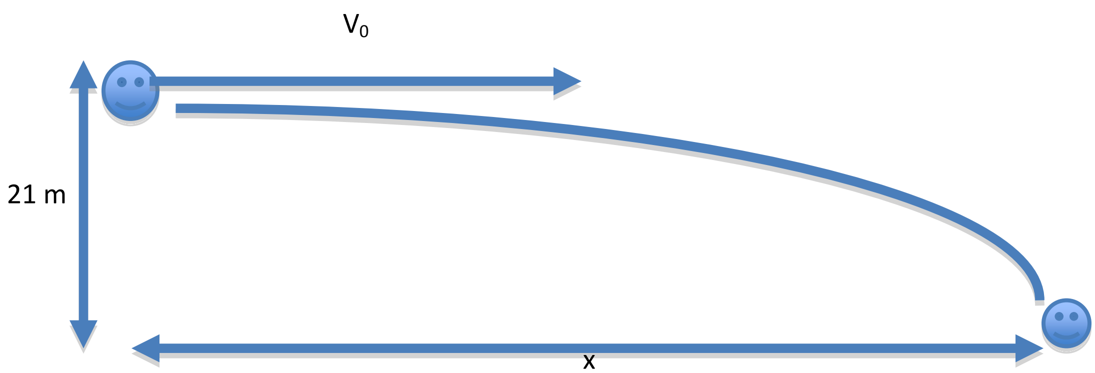
5. Draw a rough sketch of kinetic energy vs. time for three periods, with t=0 at the base of the swing. You sketch should have a vertical axis for kinetic energy, a horizontal axis, and labels for when the boat is at the top of the swing and at the bottom of the swing. Values need not be exact.

6. Draw a rough sketch of potential energy vs. time for three periods, with t=0 at the base of the swing. Label this graph as you did for the previous problem.

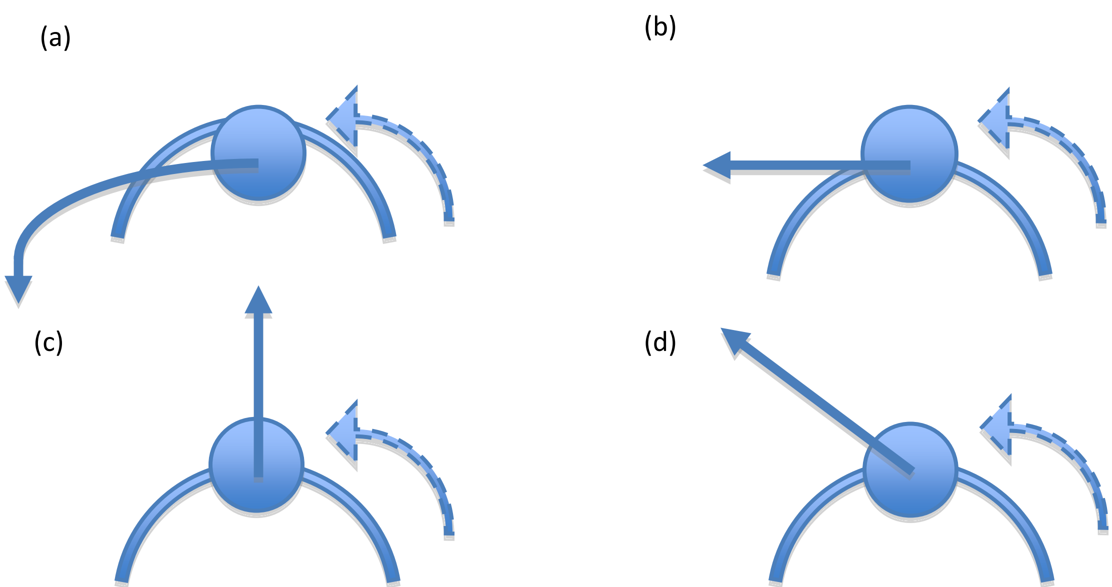
7. Draw a rough sketch of total energy vs. time for three periods, with t=0 at the base of the swing.

Roller Soaker

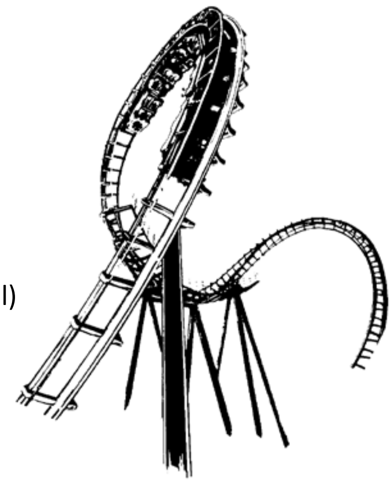
1. If the cart is moving at 9.2 m/s and you want to take advantage of the soak-the-people-below-you feature of this ride, at what horizontal distance x should you pull the lever? Assume that the water will be released from the maximum height of the ride h = 21 m.



2. If you are going around a turn (assume it is a perfect semi-circle,) and you pull the lever to release all the water, which path will the water take? (Note: This is an aerial view, looking straight down on the cart taking the turn.)



Sidewinder



Analyze the Sidewinder using the ideas of energy conservation, power and work.

1. The ride starts out by lifting the train of mass 8255 kg (when full) to the top of a hill of height 36.9 m behind the station.

    a. What is the Potential energy at the top of the hill?

    b. What should be the speed at the bottom in an ideal situation?

2. Since this is not an ideal situation, energy was lost during the run from the top of the hill to the station.

    a. What is the speed of the train at the bottom of the hill? The length of the train is 18.3 m. (Hint: see Appendix B.)

    b. How much energy was lost?

c. Assuming your laptop uses 90 Watts of power to run, how long could you have powered it using the energy lost by the roller coaster?

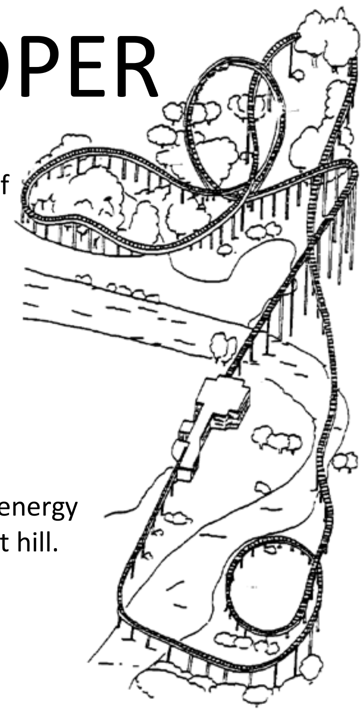
d. If you pay $0.10 kW/hr for electricity, how much was that energy worth?

3. Gravity does work whenever the height of an object is changed.

   a. How much work did it do between the station and when the train was lifted to its highest point?

   b. How much work did it do between the time when the train was released and when it came back through the station?

SOOPERDOOPERLOOPER



1. Determine the speed at the top of the first hill. The length of the train is 12.95 m. (Hint: see Appendix B.)

2. Use the answer from question one and the conservation of energy to determine the theoretical speed at the bottom of the first hill. The first hill has a height h of 24.69 m.

3. What is the experimental speed at the bottom of the first hill? Is there a difference? Why? (Hint: see Appendix B.)

4. Calculate the percent difference in the experimental and theoretical data for questions 2 and 3.

5. The height of the loop is 16.15m. Use the conservation of energy to determine the speed at the top of the loop.

6. Find the centripetal force at the top of the loop.

7. Draw and label a force diagram representing the train when it is at the top of the loop.

8. Using your value of the centripetal force and your force diagram, explain what you feel at the top of the loop.

Storm Runner

For safety reasons, please do not take data collection devices on this ride. All the questions below can be answered through observation and utilization of the concepts of kinematics, work, power and special relativity.

1. Stand and watch the Storm Runner launch. How many g's of acceleration do you think a rider will feel?

2. Record the time it takes for the car to reach its top speed (from the time it launches to the time that it reaches the start of the first hill). (See Appendix B.)

   a. t_{launch} = _________s

   b. Considering that that portion of the track is 45 long, what is the average acceleration of the train?

   c. What is it in g's?

3. A certain Ferrari[1] can go from 0-60mph in 3.1s. What is the average acceleration of the car? Keep in mind that 1 m/s = 2.237 mph. Compare this with the Storm Runner.

[1]http://www.carspecsdirectory.com/Eagle_Ferrari.htm

4. Calculate the force on an average rider with a mass of 68 kg.

   a. Due to the acceleration of the coaster.

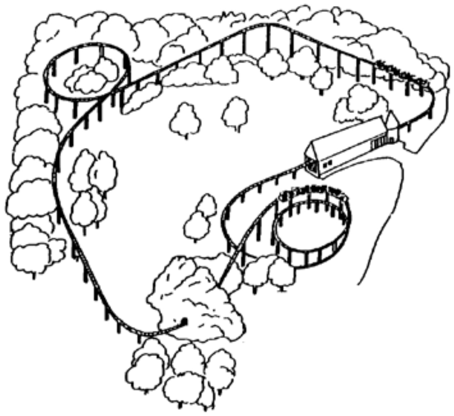
   b. And due to the acceleration of the Ferrari.

5. Calculate the work done on the coaster during its launch period. The mass of the full train is 10,660 kg.

6. How much power was used to launch the train?

7. According to Einstein's theory of Special Relativity, when an object is moving at close to the speed of light, it experiences a length contraction ΔL according to an observer at rest in another frame. Suppose the Storm Runner was launched a speed of 0.7c. What would be the length contraction ΔL? The original length of the train L_0 = 11.98 m.

Trailblazer

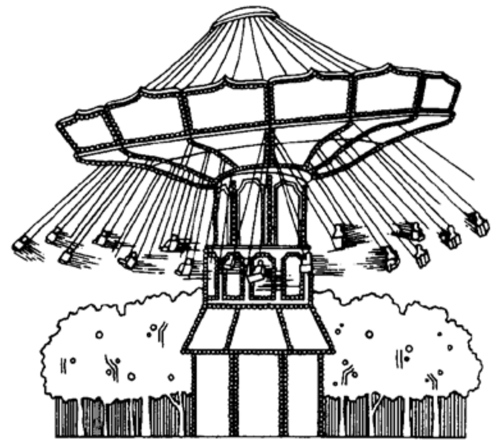


1. Determine the speed v of the roller coaster as it moves around the final horizontal loop. (Hint: see Appendix B.) Note: the train is 14.6 m long.

2. While riding the ride, use your vertical accelerometer to measure the centripetal acceleration a_c in the loop. If you are using a handheld non-electronic one, hold it perpendicular to the safety bar with the bottom of the tube pointing to the floor of the car. If you are using an electronic accelerometer, hold it so that “down” is considered to be toward the center of the circle.

3. Using the values from the two previous questions, determine the radius of the loop.

Wave Swinger



1. Calculate the period of the wave swinger.
   (Hint: See Appendix B.)

1. Find the angular velocity of the chairs for each radii.
   a. Inner radius r_i = 6.9 m

   b. Middle radius r_m = 8.1 m

   c. Outer radius r_o = 9.3 m

2. Find the tangential velocity for each of the radii.
   a. Inner

   b. Middle

   c. Outer

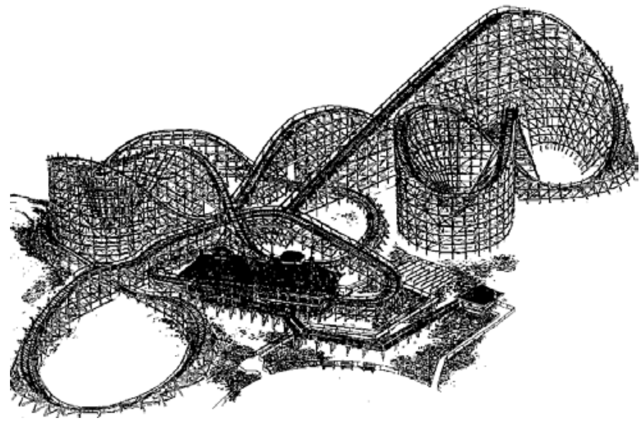
3. Find the centripetal acceleration for the inmost radius.

4. Draw a force diagram for one of the chairs on the inner radius.

5. At what angle with respect to the vertical do the chairs hang?

6. What would the angular velocity of the chairs have to be rotating in order to be hanging at 45 degrees?

The Wildcat



1. Draw a force diagram labeling the various forces you experience while going through the horizontal cyclone. Note: the horizontal cyclone is the last horizontal loop. It can easily be seen from where you will be waiting in line.

2. Find the tangential velocity in the cyclone. The length of the train is 12.95 m. (Hint: see Appendix B.)

3. Calculate the centripetal acceleration in the cyclone if the radius is 18.59 m.

4. Compare your value from number 3 to an experimental value obtained from an accelerometer.

5. Use a horizontal accelerometer to measure the average stopping force (in g’s) at the end of the ride and record your value below.

6. Using your stopwatch, find the approximate speed just prior to slowing down at the end of the ride. Then find the amount of time it takes for the train to come to a complete stop. Using these values, determine the average acceleration at the end of this ride.

7. Using the acceleration found in number 6, calculate the stopping force experienced at the end of this ride.

8. Which force on this ride is greater? The force experienced in the cyclone or the force experienced while slowing down at the end of this ride?

Wild Mouse

1. Using the electronic or handmade horizontal accelerometer, find the centripetal acceleration of one of the switchbacks. This will be your experimental value for a_c. (For the handheld, $A_c = \tan\theta =$ ____ g's)

2. Assuming that the speed is constant through the switchback, use the acceleration found in question 1 to calculate the speed of the car. The radius of the corner is 2.74 meters.

3. Calculate what the period would be if the car traveled the full circle. This will be your theoretical value for T.

4. Calculate the period experimentally. (Hint: see Appendix B.)

5. Calculate the speed experimentally. (Hint: see Appendix B.)

6. Find the centripetal acceleration using the speed from question 5. This will be your theoretical value for a_c.

7. Compare the values you obtained for the centripetal acceleration as well as those you calculated for the period. What factors could account for differences between the two?

8. Compare this ride's acceleration and speed to other horizontal accelerations found in the park, such as the carrousel and the trailblazer.

Appendix A

Linear Motion and Momentum	Symbol	Meaning	SI Unit	SI Prefix
$x = x_0 + v_0t + ½at^2$	x	Position	meter	m
$v^2 = v_0^2 + 2ax$	v	Velocity	meter/second	m/s
$v_{average} = \Delta x / \Delta t$	a	Acceleration	meter/sec^2	m/s^2
$a_{average} = \Delta v / \Delta t$	p	Momentum	Newton-sec	N·s or kg·m/s
$p = mv$	m	Mass	kilogram	kg
$p_{total} = p_1^i + p_2^i + ... = p_1^f + p_2^f + ...$	t	Time	Second	s
Rotational Motion and Momentum	ω	Angular Velocity	radians/sec	1/s
$\omega = 2\pi f = 2\pi/T$	*f*	Frequency	Hertz	Hz or 1/s
$T = 1 / f$	T	Period	Second/Rev.	s
$v_{Tangential} = \omega r$	r	Radius	meter	m
$a_{Tangential} = v_{Tangential}^2 / r$	F	Force	Newton	N
Force and Torque	τ	Torque	Newton-Meter	N·m
$F_{net} = F_1 + F_2 + ... = ma_{net}$	θ	Angle	Degrees	°
$F_{centripetal} = ma_{Tangential}$	E	Energy	Joules	J
$\tau = F\Delta x \sin\theta$	KE	Kinetic Energy	Joules	J
Work and Energy	PE	Potential Energy	Joules	J
$E_{tot} = KE + PE$	W	Work	Joules	J
$KE = ½mv^2$	P	Power	Watt	W or J/s
$PE = mgh$	h	Height	meter	m
$W = F\Delta x \cos\theta$	L	Length	meter	m
$W = P/\Delta t$	L_0	Original Length	meter	m
Modern Physics	c	Speed of Light	meter/sec	m/s
	g	Acceleration due to gravity		m/s^2

Length Contraction: $L = L_0\sqrt{\frac{1 - v^2}{c^2}}$

Constants

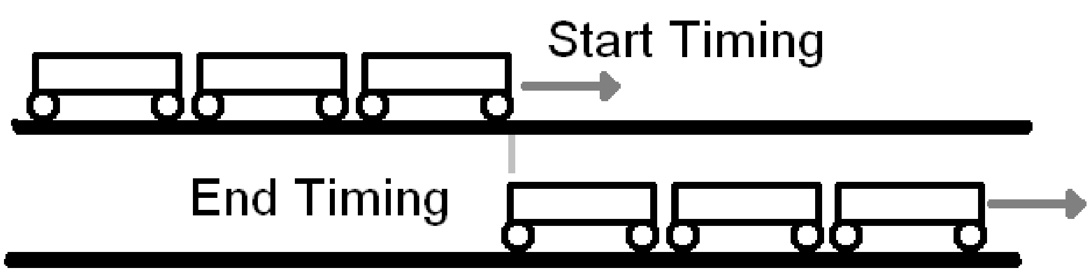
$c = 3.0 \times 10^8$ m/s

$g = 9.8$ m/s^2

Appendix B

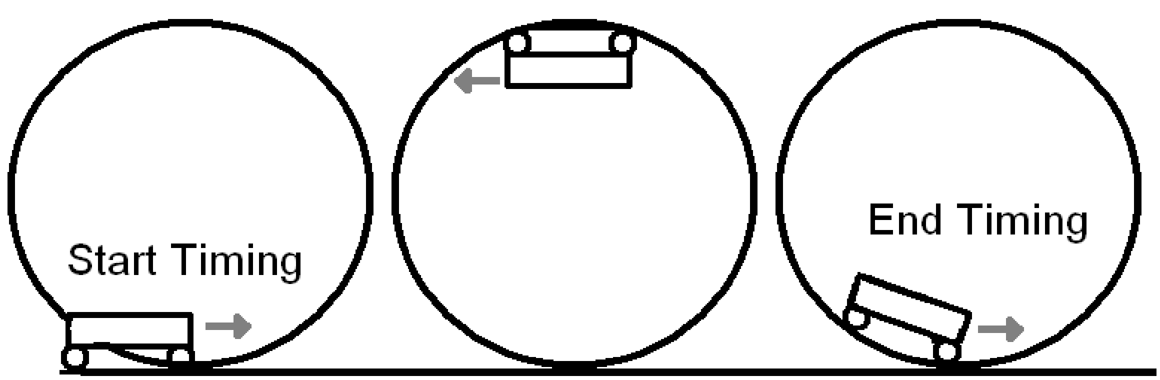
Measuring Speed of Ride

To find the speed of a ride, you need to know either a specific length of track or the length of the car/train. If you know the length of the train, and from the ground you can see the point where you want to know the speed, its simply using a stopwatch and timing how long it takes from the front of the ride to pass the point to the rear of the ride passing the same point. From this, divide the length of the train by the time you measured with the stopwatch. If you know the specific length of part of the track, measure when the front of the ride first hits the track, until the front of the ride hits the last part of the known track. It usually works best to take at least three measurements of the same value and use their average as your number.



Measuring Period of a Circular Part of a Ride

A period is a full revolution around a circle, so for a loop or a circular ride, use a stopwatch when the ride first enters the loop or at a specific point of the circle, and stop timing when the front of the ride exits the loop or reaches the same point of the circle. It usually works best to take at least three measurements of the same value and then use their average as your number.



Appendix C

SCIENTIFIC AMERICAN FRONTIERS

The Physics of Roller Coasters

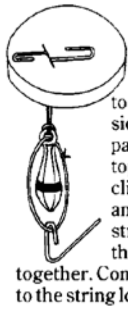
Building a Force Meter

On Scientific American Frontiers, high school students measure the G-forces they experience while riding a roller coaster. The device they use is a simple force meter they built themselves. In this activity, you will build your own force meter to measure the G-forces you feel during a ride on a roller coaster, swing or even a trip in an elevator.

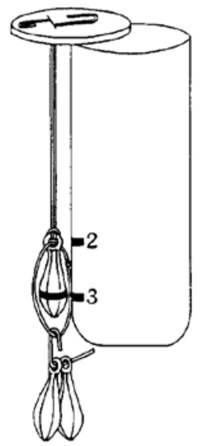
PROCEDURE

Step 1. Make a thick line across the widest part of one sinker. Push a rubber band through the eye of the sinker and loop one end of the rubber band through the other and pull tight.

Step 2. Unbend a paper clip to create a U. Hold the free end of the rubber band behind the U. Loop the other end with the sinker around the paper clip and through the top loop and pull it tight.

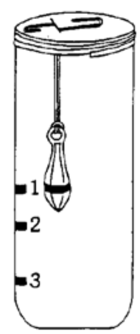


Step 3. Poke the ends of the U through the can lid so that the weight will hang close to but not touching one side of the can. Push the paper clip flush against the top; bend the ends of the clip back across the top and tape down. Slide the string through the eye of the sinker and tie the ends together. Connect the small paper clip to the string loop.



Step 4. Hang 2 more sinkers on the small clip. Hold the lid against the edge of the can with the weights hanging outside. Mark a heavy line where the permanent sinker hangs against the can as "3 G." Remove one extra sinker and mark the "2 G" level. Remove everything but the permanent sinker.

Step 5. Insert the suspended sinker into the can and tape the lid on securely. Mark the level of the sinker as "1 G" or normal. (Note: the marks are not evenly spaced because rubber bands are not linear. Double the force does not give double the stretch.)



Materials:

clear tennis ball container
(2) #1 (small) paper clips
(3) 2-oz. fishing sinkers with eye holes
several #18 rubber bands
indelible marker
8" piece of string

Step 6. Estimate the 0 G or "weightless" position. Turn the can on its side; jiggle the rubber band so it is in a resting, unextended position and mark "0 G" on the can. Tape a 3-rubber band chain onto the meter as a wrist strap. (It will hold the meter on an exciting ride but will break in an emergency.) Hold the meter inside the roller coaster car. *Remember, always follow the rules on amusement park rides.*

Calculations

Calculate the force you experience on a roller coaster ride by multiplying your body weight by the number of Gs noted on the force meter. At what point in the ride do you feel the heaviest? The lightest? When and why do you feel weightless?

Measuring G Forces on a Swing

You can also use your force meter to measure G-forces on a swing. When you are sitting still on a swing, it pushes up against your body with a force equal to your weight, and the rubber band pulls up with a force equal to the weight of the sinker. As the swing moves along its curved path, **centripetal force** pulls you in toward the center of the curve. Once the swing is moving, you and the sinker need additional centripetal force to pull you in toward the center of the curve. The faster the swing goes through its bottom curve, the more extra force is needed and the heavier you feel.

1. Hold the force meter along the chain of the swing and describe what happens to the meter as the swing goes all the way forward and back again. Where are the forces largest? You may need a partner to push you to keep the amplitude (size) of the swing's motion constant.

2. Repeat your readings with the swing going much higher. What happens to your speed? What happens to the forces registered?

3. Concentrate on your seat while you are watching the meter. Do you actually feel heavier and lighter when the meter indicates you should?

4. Compare your readings with your classmates, using the same swing going to the same height. Be sure the meter is at the same spot on the swing chain. Does body weight make a difference?

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