Family Fun Since 1928

Class Playland

Playland Physics!

students will need:

• stopwatch • calculator • pencil

Dr. Neil Basescu
Associate Professor of Physics
Westchester Community College

Table of Contents

Special Symbols

questions requiring that you count items, such as horses on a carousel

⌛ questions requiring that you measure a time interval

Gondola Wheel

The Gondola Wheel's diameter is 72 feet. Using your knowledge of a circle's geometry,

a. How far do the riders travel in each cycle? _______ft

To measure the period (the time for one full cycle) when the wheel is at full speed, measure the time for six full-speed cycles and divide that time by six. That way the slight imprecision in your measurement of the period will be only one-sixth as much as if you had measured just one cycle.

b. What is the period of rotation? ________sec

Using your knowledge of distance, rate, and time,

c. How fast do the riders go? _________ft/sec

Using the fact that acceleration in uniform circular motion is speed squared divided by radius ($a_c = v^2/r$),

d. What is the riders' acceleration? _________ft/sec^2

e. Since 32 ft/sec^2 is "1 g" (the strength of gravity on the surface of our planet), divide your answer to the previous question by 32 to express the acceleration of this ride in g's. _________g's

In the case of uniform circular motion, acceleration points towards the center of the circle. The seats must also overcome the downward force of gravity. This means that at the bottom of the circle the seat exerts a force of 1+e times the passenger's weight, where "e" is the answer to question e above. At the top of the circle the seat's force is only 1-e times the passenger's weight.

f. What is the seat's upward force on a 100 pound rider at the bottom of the ride when it is moving at full speed? _________lbs.

g. What is the seat's upward force on a 100 pound rider at the top of the ride when it is moving at full speed? _________lbs.

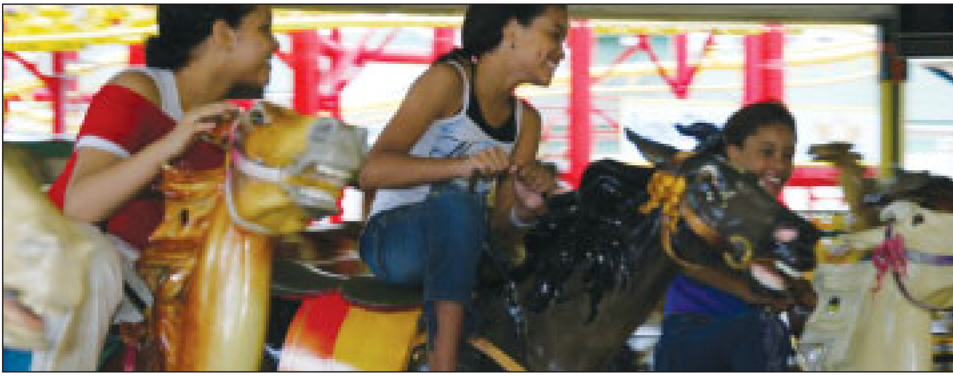
See if you feel this difference on the ride.

How about another difference? Compare the acceleration that you felt at the bottom of this ride at full speed with the acceleration that you feel at the bottom of your favorite swing. Is the swing also "uniform" circular motion?

h. Now for a tough one: What would the period of this ride have to be so that the seat would exert no force at all at the top of the ride, leaving the riders in momentary freefall? ________sec

Derby Racer

On this ride there are four horses spaced 3.0 feet apart along each radial line. The pole-to-pole distance between adjacent outermost horses in adjacent groups is 14.8 feet.



\# a. How many groups of four horses are there on the ride? ________

Naturally, you will also need the period of this ride. As always, measure the time for several full-speed trips and divide by the number of trips in order to minimize your timing error.

b. What is the period of rotation? ______sec

Note that, since this is a rigid rotating object, all the horses have the same period.

c. Is this true of all the planets in our solar system?_______________

In order to find the radius of the circle that the outside horses travel around you may use the fact that the circumference ($2\pi r$) is very close to the product of the spacing between adjacent horses and the answer to question a. *(The error is less than one percent.)*

d What is the radius of the circle that the outside horses move on? _________ft

Now you are ready to fill in the chart on the top of the next page, using your answer to question d and your knowledge of circular motion, in particular $v = 2\pi r/T$ and $a_c = v^2/r$.

Derby Racer cont'd

	radius (ft)	speed (ft/s)	acceleration (ft/s^2)	acceleration (g's)
outer				
2nd				
3rd				
inner				

e. Compare these accelerations with the acceleration of the Gondola Wheel. Is the big difference due mostly to the difference between the two rides' radii or their speeds? __________

Now you know why there is a minimum height requirement! Let's do one other thing before moving along. Let's convert the speeds in units of ft/s to the more familiar units of mi/hr (also known as "mph"). A foot per second is 1/5280 miles per 1/3600 hours, so

1 ft/s = (1/5280 mi)/(1/3600 hr) = 3600/5280 mi/hr = 15/22 mi/hr.

f. Multiply the speed of the outer horses expressed in ft/s by 15/22 to see what it is in mph. _________mph

g. Can you ride a bike this fast? _________

h. In this small a circle? __________

SuperFlight

This ride has a 1300 ft long track.

a. How much time does one complete trip take? ________sec

b. What is the average speed in ft/s? ________ft/s.

c. What is the average speed in mi/hr? ________mi/hr.

After a clever upward spiral to give the cars their initial potential energy they fall along the track due to gravity. Ignoring a little bit of friction, each car's total energy, kinetic ($mv^2/2$) plus potential (mgh), is the same all along the track. In particular

$$KE_{highest} + PE_{highest} = KE_{lowest} + PE_{lowest}$$

Next we insert the meaning of each term:

$$mv_{highest}{}^2/2 + mgh_{highest} = mv_{lowest}{}^2/2 + mgh_{lowest}$$

cancel the masses:

$$v_{highest}{}^2/2 + gh_{highest} = v_{lowest}{}^2/2 + gh_{lowest}$$

and solve for v_{lowest}:

since $v_{highest}$, the velocity at the highest point on the ride, is just about 0 and $h_{highest} - h_{lowest}$ is the vertical drop, $v_{lowest}{}^2/2$ = vertical drop x g, and

$$v_{lowest} = (2 \times g \times \text{the vertical drop})^{1/2}$$

This formula applies to all situations where something falls from rest with negligible friction. We'll use it again for the Log Flume and the Playland Plunge. Here, on the SuperFlight, from the highest to the lowest points is a drop of approximately 40 feet.

d. Using the bold formula, what is a good initial estimate for v_{lowest}, the velocity of the car at its lowest point? _________ft/s

Actually, with all those twists and turns, the actual maximum speed is only 77% of the amount calculated above. The lost energy goes to heating up the rails through friction.

e. What is the actual maximum speed in units of mph? _________mi/hr

If this sounds a little tame just remember: half the time you're upside-down!

The Whip

On this machine, riders get whipped around on a circle within a circle. The hinge that each car is attached to moves around semicircles of radius 10.0 feet at the end of each ride.

a. Measure the period of rotation. (HINT: Ignore the cars. Just look at the red polygons.) ________sec

b. Calculate the speed of the hinge ($2\pi r/T$). ___________ft/s

c. Is this the hinge speed on the straight segments too, or just when they are going around the turns?___________

d. Next calculate the acceleration (v^2/r) of the hinge. __________ft/s^2

Now let's add the whip! This means taking account of another radius and another period besides the ones we just worked out. As each car enters the big semicircle at either end it whips around on its hinge. It whips about 150° (150/360 of a circle) in about 1 second, so this circular motion superposed onto the bigger circular motion has a period of about 360/150 or 2.4 seconds. The horizontal distance from the rider's head to the hinge that each car is attached to is 5.5 ft. The rider's speed *relative to the hinge* is just 2π times this 5.5 ft divided by 2.4 second period.

e. What is the rider's speed relative to the hinge? _______________ft/s^2

f. The acceleration *relative to the hinge* is the square of the speed you calculated for question e divided by the 5.5 foot radius. What is the rider's acceleration relative to the hinge? __________ft/s^2

g. To get the rider's maximum speed during the whip, just add your answers to question b and e. __________ft/s

h. To get the rider's maximum acceleration during the whip, just add your answers to question d and f. __________ft/s^2

Finally, let's convert the answers for v_{max} and a_{max} to units of mi/hr and g's to get a better feel for them.

i. To convert from ft/s to mi/hr multiply the answer to question h by 15/22.
v_{max} = __________mi/hr

j. To convert from ft/s^2 to g's divide the answer to question h by 32.
a_{max} = __________g's

The maximum acceleration should come out to about four times as much as the outer horses on the Derby Racer! Does it feel that way to you?

Dragon Coaster

No way I'm getting on that thing! The track is 3400 feet long, with an 80 foot vertical range. The turns have radii of 35 to 45 feet, and the top speed on the straightaways is 40 mph.

Let's just compare this ride to the SuperFlight.

a. Which do you think is tougher on the stomach and why? ________________________________
____
____

b. Which do you think is louder (not counting screams) and why?________________
____

Crazy Mouse

This ride starts with a 40° climb over a horizontal distance of 33.3 feet.

a. Using basic trigonometry, calculate the vertical climb. ___________ft

b. How long does the climb take? ___________sec

c. How fast does a car move during the climb? ____________ft/s

As the car falls through the ride it makes several 180° turns of radius 8.3 feet, each in about 1.8 seconds.

d. What does this mean the period of the circular motion must be? __________sec

e. What is the car's speed as it makes the semicircles? ___________ft/s

f. What is the car's acceleration as it makes the semicircles? _________ft/s^2

Finally, as usual, let's convert the speed and acceleration to units of mi/hr and g's to get a better feel for them.

g. To convert from ft/s to mi/hr multiply the answer to question e by 15/22. __________mi/hr

h. To convert from ft/s^2 to g's divide the answer to question f by 32. __________g's

How does this acceleration compare to the accelerations of other rides? __________________

Double Shot

This ride launches up to 12 brave passengers 70 feet straight up. The hydraulic compressors run on a whopping 200 amps of electric current. They accelerate the rider from 0 to 44 ft/s in just 0.46 seconds.

a. What is the rider's maximum speed expressed in miles per hour? _________mi/hr

b. What is the rider's upward acceleration? __________ ft/s^2

c. What is the rider's upward acceleration expressed in g's? ___________g's

d. How much force does the seat exert on a 100 lb. rider during this upward acceleration? ___________lbs.

The downward trip is freefall.

e. What is the rider's downward acceleration expressed in g's? ___________g's

f. How much force does the seat exert on a 100 lb. rider during this downward acceleration? ___________lbs.

g. The maximum total allowed passenger weight is 2040 lbs. What is the maximum average passenger weight if every seat is filled?

SkyFlyer

Like the Gondola Wheel, the SkyFlyer involves vertical circular motion. The difference is that while the Gondola Wheel moves at uniform speed, the SkyFlyer starts from rest at the top of the circle and falls freely, first one way, then the other. The rider's radius of motion is 25 feet. If there were no counterweights, all of the passenger car's potential energy at the top of the circle (mgh) would be converted to kinetic energy ($mv^2/2$) at the bottom of the circle, for a much rougher ride than with the counterweights.

a. How long does a full circle take? ___________s

b. What is the distance traveled during a full circle? ____________ft

c. What is the average speed? ____________ft/s

d. Assume a maximum speed of about twice the average. What is the maximum speed expressed in mi/hr? ___________mi/hr

e. Where in the cycle does the maximum speed occur?

Log Flume

This ride involves a couple of falls into water – first a 25 footer, then a 35 footer.

a. What would be the final speed for each fall if there were no friction (HINT: You can use the bold formula on page 4.) ___________ft/s and __________ft/s

Actually there's plenty of friction so the final speeds are only about half as much as your answers to question a. At the bottom of each fall the water stops the boat in about 2 seconds.

b. What is the boat's deceleration during those 2 second time intervals?
___________ft/s^2 and __________ft/s^2

Just as the water exerts a force on the boat, the boat exerts a force on the water making a big splash. This is an example of one of the fundamental laws of motion at work!

c. Which one? ___________

The ride uses just over 170,000 gallons of water.

d. Using a 2-inch diameter, high pressure hose with a discharge rate of 3 gallons/second, how long did it take to fill it up? ____________hours

Playland Plunge

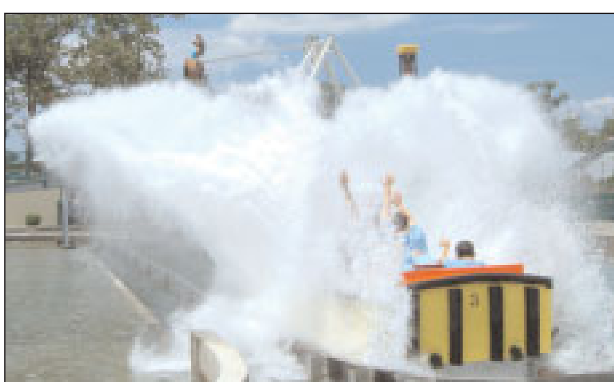
The vertical drop for the Playland Plunge is listed as 15 meters.

a. Convert this drop to units of feet. ___________ft

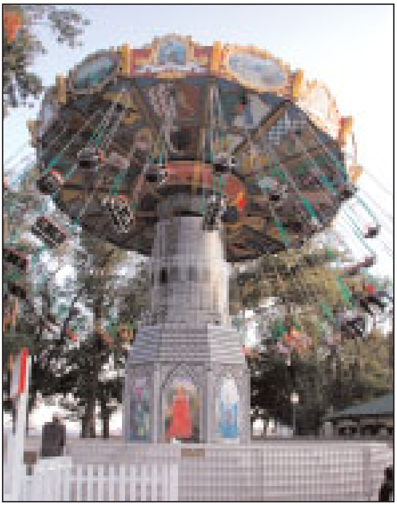
b. Using the bold formula on page 4, what would the boat's final speed be in the absence of friction? ____________ft/s

c. Using the conversion explained on page 3, express this speed in miles/hr ___________mi/hr

d. The actual maximum speed is 34 mi/hr. What percentage of the boat's potential energy is lost to friction during the plunge? ___________%



Dream Machine



This ride is right out of the physics textbooks. Naturally, the faster it spins the greater the angle (from vertical) the swings ride at. Ignoring the slight tip of the entire apparatus, estimate that angle. _________ Later on you can compare your estimate with the result of your calculation for question e.

a. What is the period (T) of circular motion at full speed? _________sec

b. How many outermost seats are there? _____________

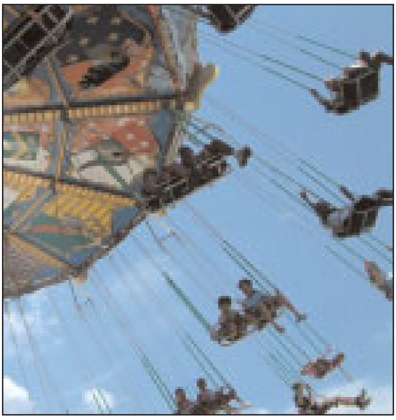
c. Just as you did for the Derby Racer, calculate the radius of the circle formed by the outermost seats at rest by multiplying your answers to questions b by the distance between adjacent outermost seats (7.5 ft), and dividing by 2π. ____________ft

d. The radius of the circles the riders make is actually 11 feet larger than this because of the significant angle of the swings. What is the radius of the rider's actual motion? _____________ft

e. Inserting $g = 32\ ft/s^2$ and the values of T and r from questions a and e into the formula $\tan\theta=4\pi^2r/(gT^2)$. Calculate the value of θ. ___________deg

Is it in reasonable agreement with your initial estimate?

f. Calculate the rider's speed using $v = 2\pi r/T$. _____________ft/s



g. Express this speed in mi/hr. _____________mi/hr

h. Calculate the rider's centripetal acceleration using $a_c = 4\pi^2 r/T^2$. _____________ft/s^2

i. Express the centripetal acceleration in g's _____________g's.

If the angle were 45° the centripetal acceleration would be 1 g. Since the angle is a little less than 45°, the centripetal acceleration should be a little less than 1 g. Is it?

Carousel

The analysis here is similar to the analysis for the Derby Racer. The pole-to-pole distance between adjacent horses is 8.7 feet.

a. How many outside horses are there on the ride? ________

b. Measure the period of rotation for the ride at full speed. __________sec

c. Find the radius of the circle that the outside horses travel around, using the fact that the circumference ($2\pi r$) is very close to the product of the 8.7 foot pole-to-pole distance and the answer to question a. _____________ft

d. The error in this method is even less than it was for the Derby Racer. Can you say why? ___________________

Using your knowledge of circular motion ($v = 2\pi r/T$ and $a_c = v^2/r$) calculate

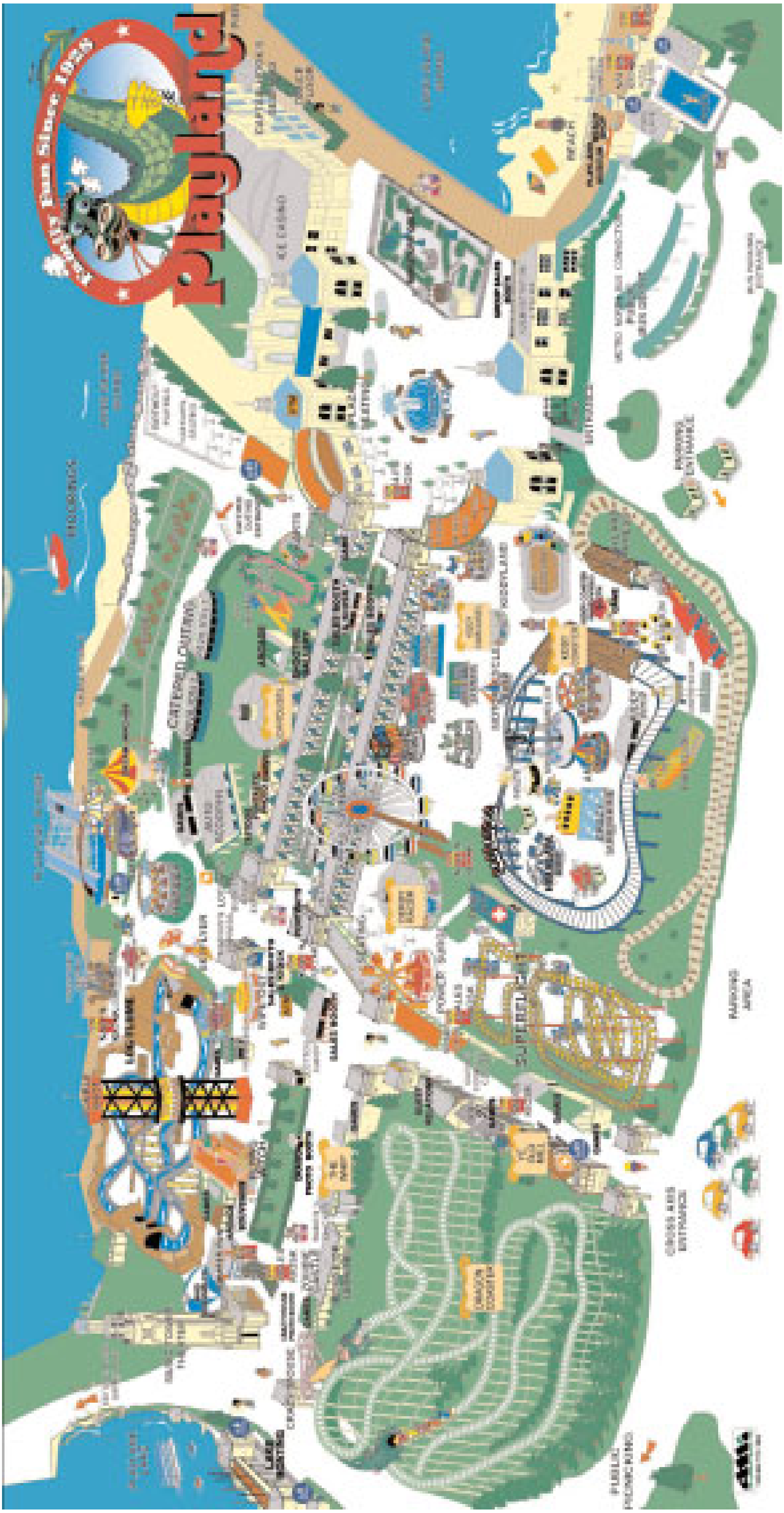
e. the speed (v) __________ft/s and

f. the centripetal acceleration (a_c) ____________ft/s^2.

g. Express the speed in mi/hr ____________hi/hr

h. Express the centripetal acceleration in g's ______________g's

i. Can you ride a bike this fast in this small a circle? __________


Playland
Family Fun Since 1928

Answers

Gondola Wheel
a. 226 ft
b. 24 sec
c. 9.4 ft/sec
d. 2.5 ft/s2
e. 0.077 g's
f. 107.7 lbs.
g. 92.3 lbs.
h. 6.7 sec

Derby Racer
a. 14
b. 10.7 s
c. no
d. 33 ft.
e. no
f. 33 ft.
chart: 33, 19.4, 11.4, 0.36
30, 17.6, 10.3, 0.32
27, 15.9, 9.3, 0.29
24, 14.1, 8.3, 0.26
g. speeds
h. 13.2 mph
i. yes
j. no

SuperFlight
a. 38 sec
b. 34 ft/s
c. 23 mi/hr
d. 50.6 ft/s
e. 27 mi/hr

The Whip
a. 7.0 sec
b. 9.0 ft/s
c. straight segments too
d. 8.0 ft/s2
e. 14 ft/s
f. 38 ft/s^2
g. 23 ft/s
h. 46 ft/s
i. 16 mi/hr
j. 1.4 g's

Dragon Coaster
a. The SuperFlight
(it flips over)
b. this ride (more friction)

Crazy Mouse
a. 28 ft
b. 20 sec
c. 1.4 ft/s
d. 3.6 sec
e. 14.5 ft/s
f. 25.3 ft/s^2
g. 10 mi/hr
h. 0.8 g's

Double Shot
a. 30 mi/hr
b. 96 ft/s2
c. 3 g's
d. 400 lbs.
e. 1 g
f. 0 lbs.
g. 170 lbs.

SkyFlyer
a. 8.5 sec
b. 157 ft
c. 18.5 ft/s
d. 25 mi/hr
e. at the bottom

Log Flume
a. 40 ft/s, 47 ft/s
b. -10 ft/s^2, -12 ft/s^2
c. Newton's Third Law
d. 16 hours

Playland Plunge
a. 49.2 ft
b. 56 ft/s
c. 38 mi/hr
d. 20 %

Dream Machine
a. 6.0 sec
b. 14
c. 16.7 ft
d. 27.7 ft/s
e. 43.5°
f. 27.7 ft/s
g. 20 mi/hr
h. 30.4 ft/s^2
i. 0.95 g's

Carousel
a. 18
b. 17.6 sec
c. 23.4 ft
e. An 18-agon is closer to a circle than a 14-agon.
f. 8.4 ft/s
f. 3.0 ft/s^2
g. 5.7 mi/hr
h. 0.093 g's
i. yes