1 #
Name
Date

2 #
Name
Date

Midway Physics
at the Fair

3 #
Name
Date

Chapin High School
Robert Schiferl

2 *Observing Rides*

Many interesting observations about science can be made while enjoying the State Fair, not all of them requiring calculations. In this section we have made a list of some of them. There are other observations also, and we hope you will keep a good sharp eye out for things we did not include.

- Could you figure out the height of the rocket at the front gate using only its shadow and a yardstick?
- As a Ferris wheel turns, a mark on the side moves in a circular path. Why is this so? As you sit in the moving seat of the Ferris wheel, sometime your feet are "inside" the wheel and sometimes they are "outside" Draw a diagram to represent the path of the mark and the path of your feet. Do your feet move in a circular path?
- Try to diagram the paths of the more complicated rides. Mark where they are going fastest. Mark where the change in direction is sharpest and mark where the change in speed is greatest.
- If you carry a scale on the Ferris Wheel, do you expect things to weigh the same all around the trip? What would you expect at the top, bottom, and the two sides? Assume the wheel turns smoothly. Can you think of a way to test your ideas using a simpler method than riding a Ferris Wheel?
- If you carry a pendulum onto a merry-go-round would you expect its time-of-swing (period) to be different from that on the

ground? How about other rides – such as the Ferris wheel or a roller coaster?

- What factors make it hard to toss a ring over a peg to win a prize? Look carefully at what happens, and see if you get some ideas.
- Look in the mirror at the fun house. Is there a connection between the way the mirror is shaped and the way your image is shaped? Try your ideas for differently shaped mirrors.
- What will happen if a skinny driver in a bumper car runs head-on into a heavy driver in a bumper car? What happens if one or the other car is not moving?
- Why does the bumper car ride have a ceiling? Can you draw an electrical circuit diagram for the bumper car ride?
- Are the rides and Midway illuminated primarily by incandescent or by florescent lamp bulbs? Why?

3 *Ride Physics*

In this section we will discuss how you can apply physics principles to some of the rides at the South Carolina State Fair. Analyze several of the rides mentioned in this booklet and then use those rides as starting places for investigating other rides. One of the measurable aspects of fair rides is the force that they exert on you and the acceleration you feel. The force and acceleration are connected through Newton's second law; $F = ma$, where F is the force in Newtons (N), m is the mass in kilograms (kg), and a is the acceleration in meters per second per second (m/s^2). When the only force on you is the force of gravity your weight is $W = mg$, where g is the acceleration of gravity (9.81 m/s^2). When you feel "pushed down" at the bottom of a roller-coaster loop you experience an apparent weight greater than your normal weight. When your apparent weight is twice your normal weight we say you experience a force of "two g's". That is because you experience the acceleration of gravity plus the acceleration of the ride's motion. At another point on the ride you could be almost lifted from your seat. This is an example of less than one g because you feel lighter than your normal weight. The downward acceleration of gravity is the same, but your acceleration due to the ride cancels some of the effect of gravity. One of the objects of ride physics is to measure and calculate the acceleration of a rider.

3.1 Roller Coasters; Non-looping and Looping, Clothoids

A roller coaster provides a good example of conservation of energy. The train is pulled to the top of a high hill and let go (Fig. B1). The train then plunges down the other side of the hill. It then rises up another hill to plunge down again, perhaps with twists and turns to the left and right.

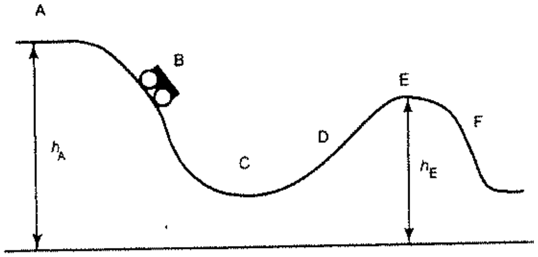


Figure B1

We can understand the motion of a roller coaster by considering conservation of mechanical energy. Assume the car is hauled up to point A. At point A the total mechanical energy is equal to the total mechanical energy at point E, as it is at all of the points on the track. (For the purpose of getting a general understanding, we are omitting the energy converted into heat by friction. You may want to try to estimate the magnitude of frictional effects in a more refined analysis. However you can best understand things by leaving frictional effects out at the start.) Thus the sum of the potential energy (PE) and kinetic energy (KE) is the same at points A and E.

$$KE_A + PE_A = KE_E + PE_E$$
$$\tfrac{1}{2} mv_A^2 + mgh_A = \tfrac{1}{2} mv_E^2 + mgh_E$$

$$h = d(\tan\theta) + 1.5\ meters$$
$$V_{coaster} = \sqrt{2g(h_A - h_E)}$$
$$a_{meter} = g(\tan\theta) \qquad a_{calculated} = \frac{4\pi^2 r}{T^2}$$

TABLE D–6 Trigonometric Functions

Angle	sin	cos	tan	Angle	sin	cos	tan
0°	.0000	1.0000	.0000	45°	.7071	.7071	1.0000
1°	.0175	.9998	.0175	46°	.7193	.6947	1.0355
2°	.0349	.9994	.0349	47°	.7314	.6820	1.0724
3°	.0523	.9986	.0524	48°	.7431	.6691	1.1106
4°	.0698	.9976	.0699	49°	.7547	.6561	1.1504
5°	.0872	.9962	.0875	50°	.7660	.6428	1.1918
6°	.1045	.9945	.1051	51°	.7771	.6293	1.2349
7°	.1219	.9925	.1228	52°	.7880	.6157	1.2799
8°	.1392	.9903	.1405	53°	.7986	.6018	1.3270
9°	.1564	.9877	.1584	54°	.8090	.5878	1.3764
10°	.1736	.9848	.1763	55°	.8192	.5736	1.4281
11°	.1908	.9816	.1944	56°	.8290	.5592	1.4826
12°	.2079	.9781	.2126	57°	.8387	.5446	1.5399
13°	.2250	.9744	.2309	58°	.8480	.5299	1.6003
14°	.2419	.9703	.2493	59°	.8572	.5150	1.6643
15°	.2588	.9659	.2679	60°	.8660	.5000	1.7321
16°	.2756	.9613	.2867	61°	.8746	.4848	1.8040
17°	.2924	.9563	.3057	62°	.8829	.4695	1.8807
18°	.3090	.9511	.3249	63°	.8910	.4540	1.9626
19°	.3256	.9455	.3443	64°	.8988	.4384	2.0503
20°	.3420	.9397	.3640	65°	.9063	.4226	2.1445
21°	.3584	.9336	.3839	66°	.9135	.4067	2.2460
22°	.3746	.9272	.4040	67°	.9205	.3907	2.3559
23°	.3907	.9205	.4245	68°	.9272	.3746	2.4751
24°	.4067	.9135	.4452	69°	.9336	.3584	2.6051
25°	.4226	.9063	.4663	70°	.9397	.3420	2.7475
26°	.4384	.8988	.4877	71°	.9455	.3256	2.9042
27°	.4540	.8910	.5095	72°	.9511	.3090	3.0777
28°	.4695	.8829	.5317	73°	.9563	.2924	3.2709
29°	.4848	.8746	.5543	74°	.9613	.2756	3.4874
30°	.5000	.8660	.5774	75°	.9659	.2588	3.7321
31°	.5150	.8572	.6009	76°	.9703	.2419	4.0108
32°	.5299	.8480	.6249	77°	.9744	.2250	4.3315
33°	.5446	.8387	.6494	78°	.9781	.2079	4.7046
34°	.5592	.8290	.6745	79°	.9816	.1908	5.1446
35°	.5736	.8192	.7002	80°	.9848	.1736	5.6713
36°	.5878	.8090	.7265	81°	.9877	.1564	6.3138
37°	.6018	.7986	.7536	82°	.9903	.1392	7.1154
38°	.6157	.7880	.7813	83°	.9925	.1219	8.1443
39°	.6293	.7771	.8098	84°	.9945	.1045	9.5144
40°	.6428	.7660	.8391	85°	.9962	.0872	11.4301
41°	.6561	.7547	.8693	86°	.9976	.0698	14.3007
42°	.6691	.7431	.9004	87°	.9986	.0523	19.0811
43°	.6820	.7314	.9325	88°	.9994	.0349	28.6363
44°	.6947	.7193	.9657	89°	.9998	.0175	57.2900
45°	.7071	.7071	1.0000	90°	1.0000	.0000	∞

A Appendices

A.1 Formulas

Summary of kinematic equations for constant acceleration. The bar over the v means average. The initial values of time, position, and velocity to be 0, 0, and v_0, respectively.

$$d = \bar{v}t \qquad d = \tfrac{1}{2}(v_0 + v)t \qquad d = v_0 t + \tfrac{1}{2}at^2$$

$$v = v_0 + at \qquad v^2 = v_0^2 + 2ad \qquad a_c = \frac{v^2}{r} = \frac{\left(\frac{2\pi r}{T}\right)^2}{r} = \frac{4\pi^2 r}{T^2}$$

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

Formulas from dynamics and energy. (Use 9.8 m/s^2 for g.)

$$F = ma \qquad F = \frac{mv^2}{r} = \frac{m\left(\frac{2\pi r}{T}\right)^2}{r} = \frac{4\pi^2 mr}{T^2}$$

$$PE = mgh \qquad KE = \frac{1}{2}mv^2 \qquad W = Fd$$

Conversion Factors

1 inch = 2.54 cm (exact)
1 ft = 30.48 cm (exact)
1 m = 39.37 in.

1 h = 3600 s
1 d = 86,400 s
1 kg = 1000 g

1 lb = 4.45 N
1 kg has a weight of 2.21 lbs

Therefore we can calculate the speed at E if we know the heights h_A and h_E. If the train is moving slowly at the top of the first hill (A) we can neglect the term $\frac{1}{2}mv_A^2$ to find

$$v_E = \sqrt{2g(h_A - h_E)}.$$

To make the ride more exciting the roller coaster designers may put a loop - or even two loops- in the track, as shown in Fig. B2. They must choose the maximum height of the loop, and also

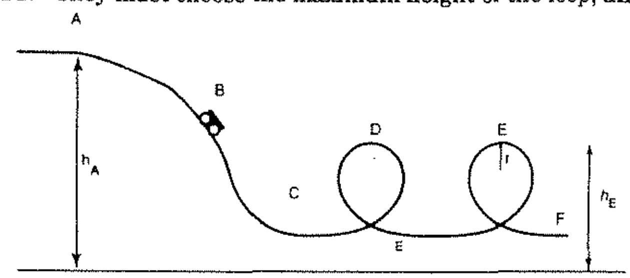


Figure B2

the shape of the loop. You can estimate the maximum height of the loop, or to turn the question around, can you estimate what fraction of the initial potential energy at A is lost to friction if the car has a given speed at position E and height h_E.

If the loops were circular the riders would experience 6 g's at the bottom and would just barely hang on (0 g's) at the top of the loop. This is under the assumption that the coaster enters the loop at a given speed at C and is slowed by the force of gravity as it coasts up to the top of the loop at D. Humans can not tolerate 6 g's in this situation so another shape rather than a circle is used for the loop.

The shape that is used is part of a spiral called a clothoid. A clothoid spiral (Fig. B3a) is useful for joining trajectories and is sometimes used in highway and railroad interchanges.

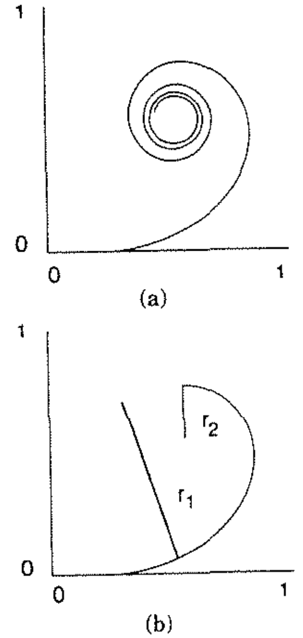
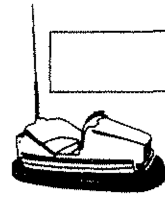


Figure B3

The radius of curvature of a clothoid varies linearly with the arc length, starting at the origin, and the center of curvature is not a fixed point, but depends on where you are on the curve (Fig. B3b). Thus when entering the loop at a given speed v your centripetal acceleration v^2/r need not be too large. However, when you have reached the top of the loop, now with a lower speed v, the radius of curvature has decreased so that v^2/r will be large enough so that the net force will hold you in your seat.



The South Carolina State Fair
Bumper Cars Worksheet

Name:____________________
Teacher:____________________

Bumper cars obey Newton's three laws of motion. According to the first law, objects (like the people in the cars) tend to keep moving in the direction they are going. So when the bumper car you are in is moving and gets hit so it stops, your body tends to keep moving. Also, when your car is stopped and suddenly moves as it is hit from behind, your body tends to stay in place----or move backwards as the car jolts forward.

Impulse and momentum are what Newton described as the "quantity of motion". Impulse is the product of a force and time interval over which it acts. This impulse is transferred to an object, giving it momentum. Momentum is the product of the mass and velocity of an object. Velocity is the speed in a specific direction.

When your car crashes into another car that is stopped, some of the momentum is transferred to the other car from yours, making the other car move. Some of your momentum is converted into an impulse that causes the other bumper car to move. It will have momentum equal to the impulse it received. The rubber bumpers that surround the cars slow down the transfer of momentum, making the crashes less severe and reducing the risk of injuries.

1. Bumper cars can only work when you have a closed electrical circuit. How do you close the circuit and make the car go?____________________________

2. How do you stop the car---open the circuit?____________________________

3. How do the fair ride operators get all the cars to stop at the same time at the end of the ride?____________________________

4. Why do cars have rubber bumpers?____________________________

5. Describe what happens to you when your car is moving, is hit by another car, and stops suddenly. Explain using Newton's laws of motion.____________________________

6. Describe what happens to your body when your car is stopped, is hit from behind, and suddenly moves forward. Explain using Newton's laws.____________________________

Rotating Platform (Rainbow)

1. When the ride is going full speed, do you feel lighter or heavier at the botoom of the circle?____________________

2. How do you feel at the top of the circle?____________________

3. What happens when the ride is halfway down? ____________________
   Halfway up?____________________

4. What forces do you feel at the top of the circle?____________________

5. Does it make a difference if you sit on the left or the right side of the car?__________
   How?____________________

Rotating Swing

1. How do you feel when the ride is moving, but not tilted?____________________

2. How do you feel when the ride is going down when tilted?____________________

3. How do you feel when the ride is going up when tilted?____________________

4. Which goes higher----an empty swing or one with someone in it?____________________

5. What do you feel as the speed increases?____________________

6. What happens to the seats as the speed increases?____________________

3.2 Rotating Rides and Swings

Perhaps the simplest rotating ride is a merry-go-round. You can still make some interesting measurements on it. Fig. B4 is a schematic diagram of a merry-go-round with two rows of horses. Here we will not include the up-and-down motion of the horses, so make your measurements standing on the rotating platform. The horizontal component of the centripetal acceleration of is $a_c = v^2/r$ for a horse at a distance r from the axis of rotation and moving at a speed v.

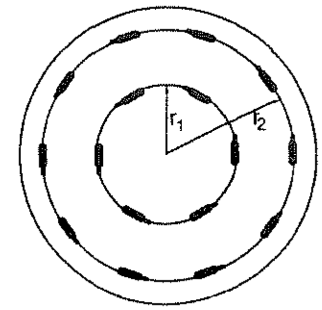


Figure B4

In terms of the period T - the time for one complete rotation- we can write

$$a_c = \frac{\left(\frac{2\pi r}{T}\right)^2}{r} = \frac{4\pi^2 r}{T^2}.$$

Because the period T is the same for all horses, no matter what their distance from the axis, we can write the ratio of the centripetal acceleration at two different distances r_1 and r_2 as

$$\frac{a_c(1)}{a_c(2)} = \frac{r_1}{r_2}.$$

You should determine r_1 and r_2 and measure $a_c(1)$ and $a_c(2)$ with your horizontal accelerometer and see how your measurements compare with the formula above.

Another simple ride is sometimes called The Rotator. (Fig. B5). Riders stand with their backs against the wall in a cylindrical chamber that can be rotated about its vertical central axis. When the ride has

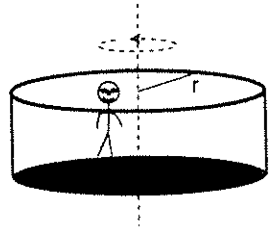


Figure B5

reached a certain speed the floor drops down and the riders are held against the wall by frictional forces. Can you estimate the minimum coefficient of friction between the riders and the wall needed to keep them from falling?

Other rides begin rotating in a horizontal plane and then tip up until the axis of rotation is almost horizontal. In these rides the riders may stand against a wall, as in the

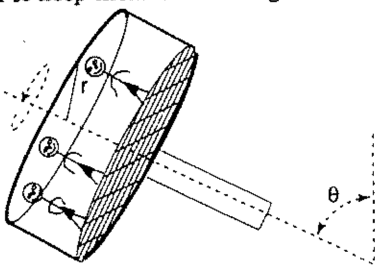
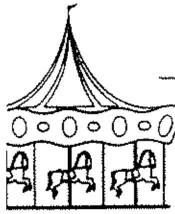


Figure B6

Round Up or they may be in cars or cages, as in the Enterprise. Taking the Round Up as an example, (Fig. B.6) note that in the horizontal position the acceleration -or force- is just that of the Rotator. As the circling ride is tipped up the force changes as you go around because the force exerted on you due to the ride is always toward the center of rotation but the force of gravity is always downward. We can write

$$F = F_{wall} \pm F_{gravity},$$



The South Carolina State Fair
The Carousel and Other Centripetal Force Rides Worksheet

Name:________________
Teacher:________________

The law of conservation of energy governs and helps explain the operation of many of the rides at the fair. Newton's three laws of motion are especially important on rides that go in a circle such as the merry-go-round and the ferris wheel. As you go around on a ride in a circle, centripetal force causes you to feel as though you are being thrown to the outside of the circle. The force of gravity pulling toward the Earth can be counterbalanced by centripetal force causing you to feel "weightless", or the two forces can be compounded causing you to feel heavier.

As you ride, feel the forces acting on your body and note where you are when the forces occur. Try to experience the ride as if it were a science experiment. Answer the following questions as you ride the Carousel, the Ferris Wheel, the Rotating Platform (Rainbow), and the Swinging Chairs or Rotating Swing.

Carousel or Merry-Go-Round

1. As the ride turns, is your body thrown slightly to the inside or outside?____________
2. Do all the animals go up and down at the same time?________________
3. Does the animal next to you move up and down as you do?________________
4. Do you feel slightly lighter or heavier when your horse is going up?____________
5. What about when it's going down?______________________________
6. Do you feel differently when riding a horse on the outside vs. the inside of the ride? ____________________If so, how?____________________________

Ferris Wheel

1. When the ferris wheel is turning at the fastest rate, do you feel lighter or heavier at the bottom of the circle?________________________
2. How do you feel at the top of the circle?______________________________
3. Do the forces get stronger or weaker as the speed increases?________________

Rotational Type Rides

Activity Sheet

Name____________________ Date_____________

People in your group.

Sketch: Make a sketch of the ride with all the appropriate labels.

Data: Record the data you acquired from your instruments and observations.

Basic Equations: Calculations should be done on another sheet and attached to this sheet.

Problems:

- Determine the maximum speed of the ride.
- Where does the maximum and minimum acceleration occur?
- What is the average linear and angular speed of the ride?
- Calculate the frequency and period of rotation.
- Compare the calculated acceleration with the acceleration you measured with an accelerometer.
- Calculate the centripetal acceleration and force on a 70 kg person.
- What prevented you from falling off the ride?

where F is the net force you feel while riding the Round Up, F_{wall} is the constant towards -the-center force on you by the Round Up supports, and $F_{gravity}$ is the force of gravity (inward at the top and outward at the bottom).

Thus for a completely vertical Round-Up with constant angular speed the acceleration away from the center at the top would be

$$a = \frac{4\pi^2 r}{T^2} - g,$$

and the acceleration away from the center at the bottom would be

$$a = \frac{4\pi^2 r}{T^2} + g.$$

To be more precise we note that the Round-Up is tilted up to an angle $\phi < 90°$. When the angle between the plane of the rotating platform and vertical plane is ϕ , the correct result is

$$a = \sqrt{g^2 + \left(\frac{4\pi^2 r}{T^2}\right)^2 \mp 2g\left(\frac{4\pi^2 r}{T^2}\right)\cos\phi}',$$

where the minus sign is for the top and the plus sign is for the bottom.

When a rotating swing has a vertical axis as shown in Fig. B7 the angle θ at which the swingers ride is given by the formula below where R is the distance from the axis of rotation and T is the time for one revolution.

$$\tan\theta = \frac{\frac{mv^2}{R}}{mg} = \frac{4\pi^2 R}{gT^2}.$$

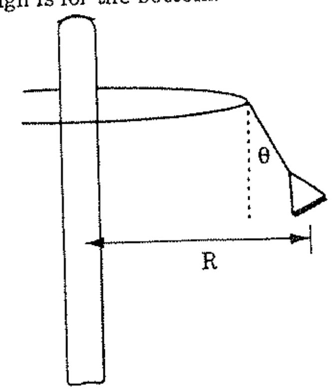


Figure B7

What does this formula predict about the angles of the riders compared to the angles of the riderless swings? Is the answer the same for the Wave Swinger, which has a tilted axis of rotation?

3.3 Compound Motion Rides

The motion of some rides is so complicated that it is unrealistic to try to derive a formula that gives, say, the acceleration as a function of time. Figure B8 is a schematic of a ride called the Scrambler. Each car moves in a circle

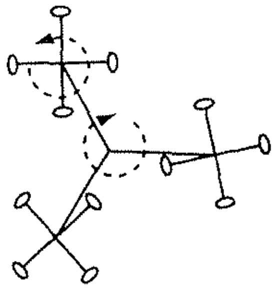


Figure B8

about an axis which itself moves in a circle. On some rides there also may be up-and-down motion or in-and-out motion. Observe the rides and make a rough sketch. Determine where the maximum change in velocity will occur and check your predictions by making measurements with your accelerometer.

3.4 Ride Data

Here we have listed some, but not all, of the parameters of several rides. You will need to make some measurements for yourself.

G - FORCE

This is a relatively new ride at the South Carolina State Fair
The claim is that it gives 4 g's.
Platform, 4 rpm.
Beam, 5 rpm.
Carousel, 0 to 17 rpm no quicker than 15 seconds.
Break time, 17 to 0 rpm no quicker than 9 seconds.

DOPPLE LOOP

Double looping roller coaster.
Height of first drop: 104 ft.
Height of loop: 45 ft.

The South Carolina State Fair
The Roller Coaster
Physical Science Activity Worksheet

Name:________________
Teacher:________________

As you ride the roller coaster, conduct the experiment as if you are the experiment, and consider the questions below:

1. How does the size of the hills change during the ride?________________

2. Do you move faster or slower when you are at the top of the hill?________________

3. Do you move faster or slower when you are at the bottom of the hill?________________

4. As you go up a hill, do you gain or lose speed?________________

5. As you go down a hill, do you gain or lose speed?________________

6. As you go up a hill, do you feel heavier, lighter, or the same?________________

7. As you go down a hill, do you feel heavier, lighter, or the same?________________

8. When the ride makes a turn, are you pushed into the turn or away from it?________________
8a. Which way are the curves banked ? (sloped toward the inside or outside of the turn?) ________
Why?________________

9. Where was the kinetic energy greatest during the ride?________________

10. Where was the potential energy greatest during the ride?________________

11. List any simple machines involved in the operation of this ride:________________

12. Identify 3 sources of friction.________________

13. Make a diagram on the back of this sheet of the roller coaster track layout. Label the following: Minimum potential energy, G; maximum potential energy, X; minimum kinetic energy, K; maximum kinetic energy, M; weightless sensation, W; heavy sensation, H.

6 *Activity Sheets*

Roller Coaster Type Rides

Activity Sheet

Name____________________ Date______________

People in your group.

Sketch: Make a sketch of the ride with all the appropriate labels.

Data: Record the data you acquired from your instruments and observations.

Basic Equations: Calculations should be done on another sheet and attached it to this sheet.

Problems:

- Why is the second hill shorter than the first?
- Assuming no friction how much potential energy was stored on the first climb?
- Determine the gravitational potential energy on the second hill.
- Label the sections on your sketch that represent the greatest kinetic energy.
- Determine the average and the maximum velocity of the ride.
- Where does the maximum and minimum acceleration occur.
- Compare the calculated acceleration with the acceleration you measured with an accelerometer

ENTERPRISE

Tilting circular ride.
Diameter of wheel: 55 ft.
Rotation speed: 13.5 rpm.
Angle with the horizontal: maximum 87°.

POLAR EXPRESS OR THE HIMALAYA

Tilted compound motion.
Radius of the ride: 20 feet
Rotation speed: 4.8 seconds per revolution
Height gain to highest point of ride: 9 feet

GIANT WHEEL

A Ferris wheel
Radius: 52 ft.

ROUND UP

Tilted circular ride.
Radius of ride: 15 ft.
Rotation speed: 16 rpm
Angle with the horizontal: varies.

RAINBOW

A rotating horizontal platform.
Speed: 9-9.5 revolutions per minute
Length of arm: 30 ft.

WAVE SWINGER

Rotating swings.
Length of chain: 16 feet, 6 inches
Radius of rotation: 37 feet, 2 inches
Speed: 6 seconds for one revolution

WILD CAT

Corkscrew roller coaster.
Length of track: 560 m
Time for ride: 95 seconds
Length of car: 7 feet, 9 inches
Weight of car: 800 lb, holds 4 people
Length of first drop: 77 feet
Time for the first drop: 2 seconds
Height of the first hill: 46 feet
Radius of the first curve: 27 feet, 2 inches

4 *Measuring Rides*

4.1 Distance

To compare your measurements with your calculations you will need to measure distances: the diameter of the Himalaya or a merry-go round, the height of a roller coaster or a Ferris wheel. Ordinarily you can't just walk up to the rides and put a measuring tape on them, so some advanced preparation is necessary. You will need a tape measure or a calibrated string. Otherwise determine the length of your pace before you go. Sometimes you can take advantage of the fact that many rides have repeating equally-spaced supports. You can often use the process of triangulation to measure horizontal distances as well as vertical distances at the fair. To measure the height of a ride you need a protractor, soda straw, string, and weight as shown in Fig. C1. Tape the straw to the protractor and tie on the weight with the string. The same arrangement - minus the soda straw - can be used as a horizontal accelerometer.

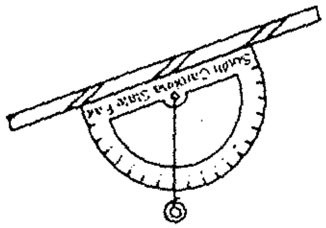


Figure C1

that position. Continue until you have marked 3 or 4 g. Remove all but the first weight and permanently attach the bottom cap and tether.

These notes are only intended to guide you if you chose make your own accelerometer. Use your ingenuity and devise an instrument that will do the job.

shows the angle, just as does the string in Fig. C4(a). This type of accelerometer has some advantage in that it is less disturbed by the wind.

Vertical Acceleration

The simplest vertical accelerometer is a spring scale. You can tape a weight to the hook and, holding the scale vertical, read off the weight under various conditions. The number of "g's" you experience in a given situation is the scale reading in that situation divided by the scale reading when you are not moving.

You can make a vertical accelerometer similar to those sold in kit form (Fig. C5). You need a clear plastic tube (3/4" to 1" is best), some small weights (fishing weights are good), some rubber bands or weak springs, some duct tape and glue, and a pencil or pen. You can make the caps from chair-leg caps or anything else that will fit.

First assemble the accelerometer as shown in the figure without the bottom cap. Hang one weight on the rubber band and mark "1 g" at the position at which the weight hangs in the tube. Now hang another identical weight under the first one and mark "2 g" at

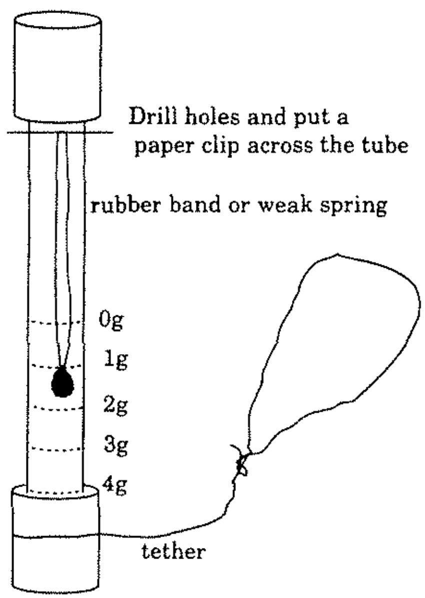


Figure C5

Sight through the straw as shown in Fig C.2 to find the angle θ.

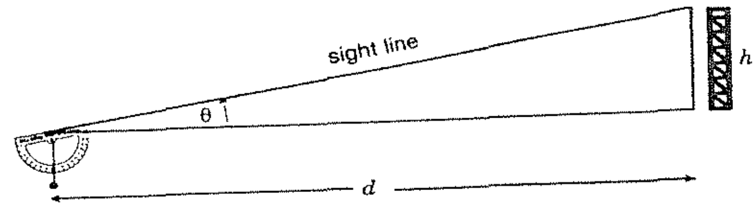


Figure C2

Measure the distance d. Then calculate the height h from

$$h = d \tan\theta.$$

Remember to add the distance from the protractor to the ground to get the total height.

In some cases you can not go - or reliably estimate the distance - to the base of a ride and you must measure two angles, θ_1 and θ_2, and a distance D to find the height H. (Fig C.3)

$$H = D\frac{\sin\theta_1 \sin\theta_2}{\sin\theta_1 - \sin\theta_2}.$$

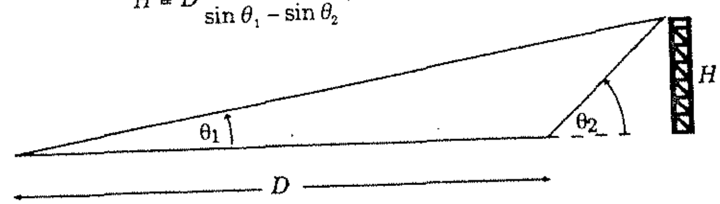


Figure C3

4.2 Speed

You may need to measure both average speed and instantaneous speed. In some cases they are the same, as for the riders on the Round Up. For other rides, such as roller coasters and The Scorpion, the average speed and the instantaneous speed are not the same.

To measure the average speed υ, use

$$\upsilon(\text{average}) = \frac{\text{total distance traveled for one trip}}{\text{time for one trip}} = \frac{D}{T}$$

You will need to measure distances D - directly or by one of the methods described above - and time. It is useful to have a digital watch with a stop-watch function.

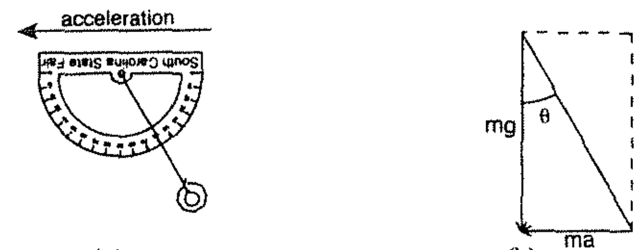
Instantaneous speeds can be a little harder to measure, especially when the speed is changing rapidly. Try to measure over shorter distances ΔD, thereby covering shorter times and satisfying

$$\upsilon(\text{instantaneous}) = \lim_{\Delta t \to 0} \frac{\Delta D}{\Delta t} = \frac{\text{short distance}}{\text{time to travel the short distance}}$$

4.2 Acceleration

Horizontal Acceleration

The same protractor, string and weight used to measure distances can be used to measure the horizontal component of acceleration (horizontal accelerometer). If the protractor is held as in Fig. C4(a) and moved with acceleration to the left, the weight will not hang straight down, but will make an angle θ with the vertical direction. We can use the value of this angle to tell us



(a) (b)

Figure C4

how much horizontal acceleration the protractor is undergoing. The weight swings away from the direction of the acceleration.

There are two forces on the weight W in Fig. C4(a), the force of gravity (weight) of the bob mg, and the horizontal force F that we apply when we accelerate the bob to the left. This force to change the motion is connected to the horizontal acceleration we give it through Newton's second law $F = ma$.

We see from Fig. C4(b)

$$\tan\theta = \frac{ma}{mg} \quad \text{or} \quad a = g\tan\theta.$$

Because we measure the accelerations in multiples of the acceleration of gravity g, the horizontal component of the acceleration is

$$\frac{a}{g} = \tan\theta$$

Thus in the example shown in Fig C4, a/g is tan(30°) = 0.577 and we say the rider experienced 0.58 g's

To make your readings accurate you must hold the base line of the protractor horizontal.

Another style of horizontal accelerometer can be made by bending a hollow tube to fit the curved side of a protractor. When the curved side is downward and the tube has one or two small balls in it, the position of the balls