State Fair Field Trip

Each student must complete this and three of the other activities at the fair to receive credit.

Student Name____Teacher Key__________

Questions - Quantitative

As you ride to the fair grounds discover some of the PHYSICS on the way. Show all work!

A. Starting Up

1. As you pull away from the school or from a stoplight, find the time it takes to go from stopped (v_i)(0) to (v_f) 20 miles per hour. You may have to get someone up front to help on this.

   t = ___(~9)_________ sec.

2. Convert 20 mph to m/s. (1.0 mph = 0.44 m/s) Velocity (**v**) = ___8.8 m/s____

3. Find the average acceleration of the bus in m/s^2.

$$\text{Ave. acceleration} = \frac{\Delta\text{velocity}}{\text{time}} = \frac{v_f - v_i}{t}$$

   a = ___(~ 0.98)______

4. Using your mass in kilograms (1 kg of mass weighs 2.2 lbs), calculate the average force on you as the bus starts up. **F** = **ma** (Multiply your mass times the answer in #3) **F =** __(vary)____**N**

5. How does this compare to the force gravity exerts on you (your weight in Newtons)? (Force calculated in #4) divided by (Force gravity normally exerts - 9.8m/s) = _(vary)__ G's

Questions - Qualitative

1. As you start up, which way do you FEEL thrown, forward or backward?
   backward

2. If someone were watching from the side of the road, what would that person see happening to you in relation to the bus?
   you went backward as the bus went forward

   What would that person see happening to you in relation to the ground underneath you?
   that you and the bus went forward

3. Describe the sensation of going at a constant speed. Do you feel as if you are moving? Why or why not? (Try to ignore the effects of road noise.)
   No, no acceleration is taking place

4. If your eyes are closed, how can you tell when the bus is going around a curve? Try it and report what you notice. (Do NOT fall asleep!)
   At first you still try to move n the old direction the bus was going, causing you to lean or sway

Teacher Background:

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. That 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. Our bus ride to the fair helps us understand the fundamental concepts of forces and motion – a large chunk of our 8th grade State Science Teachers.

Investigation #1: The Wild Cat Roller Coaster

Questions - Qualitative

1. Did you sit in the front or back of the train? __(varies)___ Do you think your position in the train affect your ride? (Ask a friend who sat in a different part of the train to share their opinion on this.)

2. Where on the ride did you experience the greatest acceleration? In which direction was it? Why there and not another place?
At the bottom of the dips where the downward velocity is suddenly changed to upward velocity. The acceleration is upward but you feel pushed down into the seat. The biggest effect is there because the cars are moving the fastest so the changes in velocity happen the quickest.

3. Was there a place on this ride where you felt like you were being lifted out of your seat? Where was it? How did the ride create that feeling?
Yes. When going over the tops of the lower hill your body want to keep moving up but the cars are being pulled down by the track Also, going down hills. Making a quick drop makes your body feel temporary weightlessness until your body sort of catches up with the car.

4. Why do you think the second hill was smaller than the first?
Making hills lower ensures that you have enough kinetic energy to get over them. (This allows for slowing of the cars due to friction.)

Questions- Quantitative *(Show your work!)*

1. Calculate the average rate of speed for the whole ride. Round to the nearest tenth.

Length of the Track	560m
Length of the Ride	95 sec
Average Speed for the Whole Ride	___5.9_ m/s

2. Calculate your average speed going down the first hill. (**d / t = s**) Round to the nearest tenth.

Length of first drop	77 feet
Time of first drop	_2_ sec.
Average speed	_38.5_ ft./s

Teacher Background:

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.

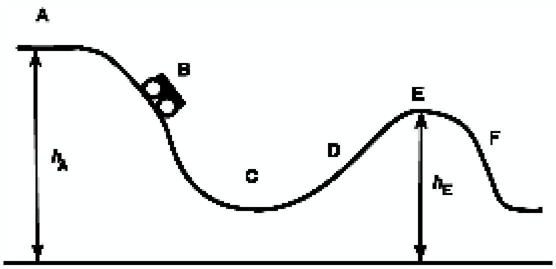

Figure B1

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.

$$\mathrm{KE_A} + \mathrm{PE_A} = \mathrm{KE_E} + \mathrm{PE_E},$$
$$\tfrac{1}{2}mv_{\mathrm{A}}^2 + mgh_{\mathrm{A}} = \tfrac{1}{2}mv_{\mathrm{B}}^2 + mgh_{\mathrm{B}}.$$

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 $\tfrac{1}{2}mv_{\mathrm{A}}^2$ to find

$$v_{\mathrm{E}} = \sqrt{2g\left(h_{\mathrm{A}} - h_{\mathrm{E}}\right)}.$$

WILD CAT DATA
Corkscrew roller coaster.
Length of track: 560 m
Time for ride: 95 seconds
Length of car: 7 feet, 9 inches
Weight of car: 800 lbs., 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

Investigation #2: The Dopple Looping

Questions – Qualitative

1. Draw and label the key parts of the ride: Lift, Initial Descent, Loop(s), etc.

(drawing should show basic parts listed above)

Put a mark on your profile to indicate the position of the train every 1 seconds.

2. Is there a place where the riders go at a constant speed? Where? How did you determine they were going at a constant speed there? (Be specific)

Yes. Going up the first hill. Everyone was sitting straight in their seat.

Questions- Quantitative

1. List 2 places where the riders are speeding up. Are there any energy changes going on in each of these sections? Describe. Do the riders feel any net forces or accelerations in each of these sections? Describe the direction of any net forces and indicate why they feel the net force in this direction.

Location on Ride	Energy Changes	Net Forces/Direction
(a) down the hill	PE decreases KE increases	gravity/down
(b) out of the loop	PE decreases KE increases	gravity/down

2. List 2 places where the riders are slowing down. Are there any energy changes going on in each of these sections? Describe. Do the riders feel any net forces or accelerations in each of these sections? Describe the direction of any net forces and indicate why they feel the net force in this direction.

Location on Ride	Energy Changes	Net Forces/Accelerations
(c)going up a hill	PE increases KE decreases	gravitational/down
(d) going up the loop	PE increases KE decreases	Gravity/down

3. For the whole ride, where does the largest force or acceleration occur? In which direction is that force? Why do you think the largest value occurs here and why is it in the direction you indicate?

Largest forces are at the bottom of the initial hill and coming out of the loops. The force is up. The force is exerted by the track (and thus the car) and it must overcome gravity and also change your direction rapidly.

Teacher Background:

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 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.

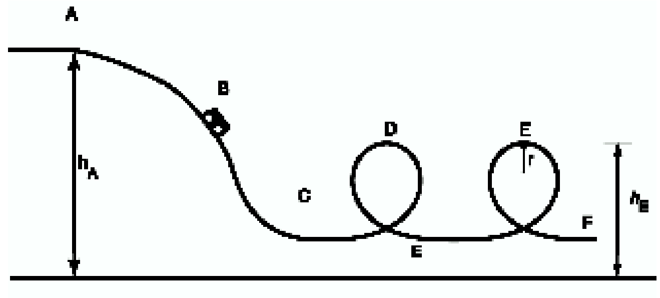

Figure B2

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.

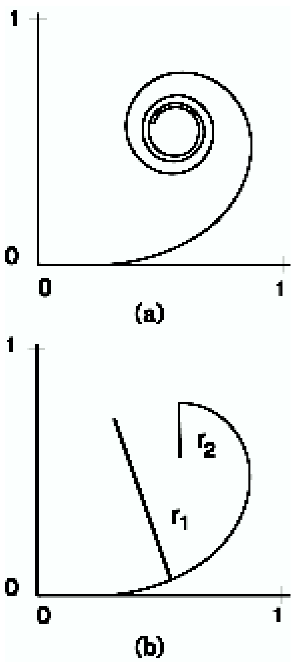

Figure B3

Investigation #3 The Drop of Fear

Questions - Quantitative: *(Show your work!)*

CALCULATING DISTANCE:
Since you cannot interfere with the normal operation of the rides, you will not be able to directly measure heights, diameters, etc. All but a few of the distances can be measured remotely using one or another of the following methods. They will give you a reasonable estimate. Consistently use one basic unit of distance - meters or feet.
Pacing: Determine the length of your stride by walking at your normal rate over a measured distance. Divide the distance by the number of steps, giving you the average distance per step. Knowing this, you can pace off horizontal distances.
I walk at a rate of _____ paces per _________....or....My pace = ________
Triangulation: For measuring height by triangulation, a horizontal accelerometer can be used. Suppose the height **h** of a ride must be determined. First the distance **L** is estimated by pacing it off (or some other suitable method). Sight along the accelerometer to the top of the ride and read the angle. Add in the height of your eye to get the total height.

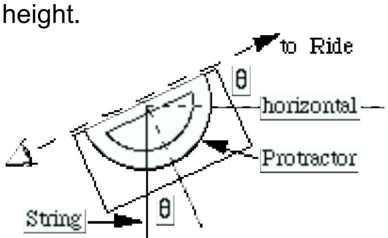

Figure B

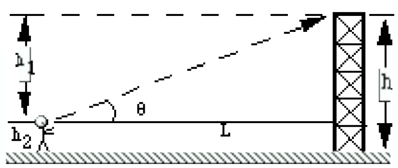

Figure B:

tan _ = h_1 / L , h_1 = L tan _ h_2 = height of eye from ground
h = total height of ride = h_1 + h_2

1. Use the triangulation instrument to determine the height of this ride. __(~52 m)____.

2. How many seconds did it take for the seat take to drop? __(~2)____sec.

3. What, then, is the rate of speed for this ride. _(~26 m/s)___

Questions – Qualitative

4. At what point of the ride did you experience a feeling of being weightless?

During the drop and before the brakes are applied.

Teacher Background:

Free Fall - Galileo first introduced the concept of free fall. His classic experiments led to the finding that all objects free fall at the same rate, regardless of their mass. According to legend, Galileo dropped balls of different mass from the Leaning Tower of Pisa to help support his ideas. A freely falling body is an object that is moving under the influence of gravity only. These objects have a downward acceleration toward the center of the earth. Newton later took Galileo's ideas about mechanics and formalized them into his laws of motion.

How do free-fall rides work?
Free-fall rides are really made up of four distinct parts: the ride to the top, the momentary suspension, the downward plunge, and the stop at the end. In the first part of the ride, force is applied to the car to lift it to the top of the free-fall tower. The amount of force that must be applied depends on the mass of the car and its passengers. The force is applied by motors, and there is a built-in safety allowance for variations in the mass of the riders.

After a brief period in which the riders are suspended in the air, the car suddenly drops and begins to accelerate toward the ground under the influence of the earth's gravity. The plunge seems dramatic. Just as Galileo and Newton explain in their theories of free fall, the least massive and most massive riders fall to the earth with the same rate of acceleration. If the riders were allowed to hit the earth at that speed, coming to a sudden stop at the end of the ride, there would certainly be serious injuries. The Drop of Fear employs magnetic braking to bring the riders to a stop. The braking force is quite large (4 gs).

Investigation #4 – The Wave Swinger

Questions – Qualitative:

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

2. How do you feel when the ride is going down when tilted? (varies)

3. How do you feel when the ride is going up when tilted? (varies)

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

Virtually no difference.

5. What do you feel as the speed increases? (varies)
Larger forces that make you swing farther outward.

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

They swing farther out.

Questions – Quantitative:

1. Estimate the angle of the swings at full speed (at rest = 0°). __50-55___°

2. Estimate the angle of the top of the ride as it tilts. __5-10___°

3. How long does it take the ride to make one complete rotation? _6__ sec.

4. Estimate the radius of the path of the riders in the outer chairs. _11 m or 37 ft_.

5. Compute the circumference of the rider's path in meters. _70__m
(2 π x 11 m)

6. Now calculate the approximate speed of the riders by dividing the answer you got for #5 (distance) by the answer you got for #3 (time). _12___m/s

7. Now calculate the centripetal acceleration of the riders from the relation $a = v^2/r$, where v is the speed and r is the radius. a = _13 m/s.

8. How does this acceleration compare to g? ___*a* is comparable to *g*; it is a little larger than *g*____ .

Teacher Background:

When a rotating swing has a vertical axis as shown in Fig. B7 the angle 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.

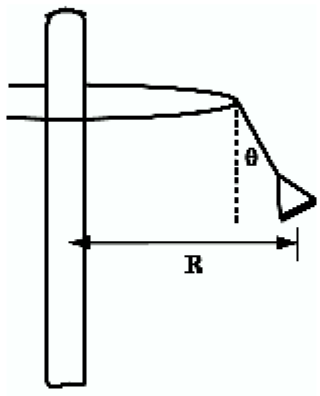

Figure B7

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

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?

WAVE SWINGER
Rotating swings.
Length of chain: 16 feet, 6 inches
Radius of rotation: 37 feet, 2 inches
Speed: 6 – 8 seconds for one revolution

Investigation #5 - The Merry Go Round

Questions – Qualitative

1. Draw a simple drawing as if you were above the merry go round showing the direction of its spin.

(circle w/ arrow going counterclockwise)

2. Do you think that those who are on the outside row of animals experience the ride in a different way than those in the inner row? Explain.
Yes, they go faster than those in the smaller circle inside, because they travel a longer path in the same time.

3. If you were to carry a pendulum onto the merry go round, would you expect its time-of-swing (period) to be different than that on the ground? *Yes, because the forces on it are different.*

Questions- Quantitative *(Show your work!)*

DATA:

Time to complete one revolution	__13__ sec.
Number of horses or other animals along the outer edge of ride	__15___
Estimated distance nose to nose between two adjacent animals along the outer edge of ride	_3_____m

1. Use the number of animals and the spacing between them to calculate the circumference of the ride (show method clearly)

15 x 3 = 45 m

2. Use the circumference and the time to determine the speed of an outside rider (show your method).

45 m/13 sec. = 3.5 m/s

3. Use the circumference to determine the radius of the ride (or use another method). Show your work.
($C = 2\pi R$, so $R = C/2\pi$)

Teacher Background:

Carousels are not considered "thrill machines" by any stretch of the imagination. Still, carousels are as reliant on the laws of motion as their more exciting cousins, the roller coasters. It's theoretically possible that, allowed to spin out of control, a carousel could gain enough speed so that the riders would be thrown off. Thankfully, runaway carousels are not the least bit common.

Are some horses moving faster than others?
With all of its beauty and seeming simplicity, the carousel is a delicate balance of motion and forces. All of the horses move through one complete circle in the same amount of time. The horses on the outside of the carousel have to cover more distance than the inside horses in this of time. This means the horses on the outside have a faster linear speed than those at the hub.

What if they're galloping?
On some carousels, the horses go up and down in a galloping motion simulating what it might be like to ride a real horse. For these carousels, the ride designer had to approach the problem of movement around the central axis differently. In a normal carousel, each horse maintains a constant acceleration, radius, and tangential speed (speed tangent to the circular path of the carousel). If you add a gallop to some of the horses, you must consider the forces needed to change that horse's position upward or downward as it goes around the track. In designing with these forces in mind, you also need to take into account the mass of the horse and its rider.

Perhaps the simplest rotating ride is a merry-go-round. You can still make some interesting measurements on it. Figure 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.

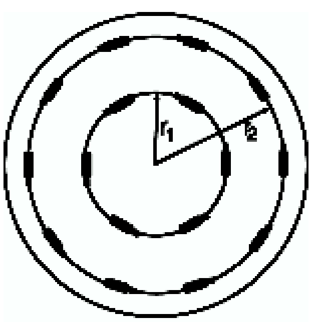

Figure B4

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*.

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

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

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. (The will be small.)

Investigation #6 - The Scrambler

Questions – Qualitative

1. Add arrows to the drawing to show the difference in directions of spin in this ride.

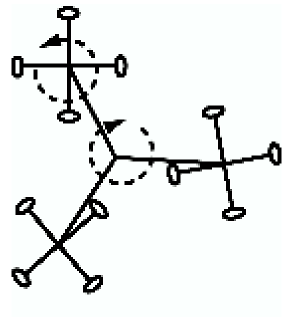

Figure B8

2. Which side of the car experiences the greatest amount of pressure? Explain how and why you know this.

Questions- Quantitative *(Show your work!)*

Notice that the riders are brought to a momentary stop at one edge of the ride and then moved quickly to the other side of the ride in a motion that is approximated by a straight line that is the diameter of the circle defined by the extreme positions.

1. Estimate the diameter of the extreme path in meters. ________ m

2 Find the time to move from one extreme edge to the other: ________ s

3. Compute the average speed along that path by dividing the distance by the time: ________ m/s

4. The speed goes rapidly from0 to a maximum and back to 0 as the car is swung from one side to the other. To a good approximation the maximum speed is twice the average speed.
Compute the maximum speed: _______ m/s.

5. Can you calculate the acceleration during the time in which the car is being accelerated from 0 to the maximum speed?________ m/s^2

Teacher Background:

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 about an axis which itself moves in a circle. In some rides there a so may be up-and-down motion or in-and-out motion.

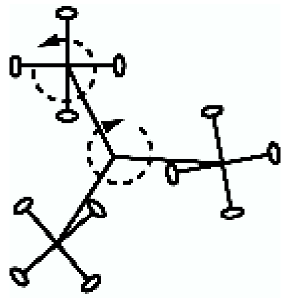

Figure B8

The combined motions cause the path of the rider to be approximately a straight line. Using that approximation, the velocity of the rider starts from an instantaneous zero and grows rapidly to a maximum at the mid point of the path and then decreases rapidly to zero again. If we treat as if the acceleration is constant during each half of the path, then the graph of velocity vs. time is a triangle and the average velocity is half of the maximum velocity (speed). The acceleration during the first part of the path is the maximum speed divided by half the time to swing from one extreme position to the next. Go measure the times and distances. You will be surprised at how fast the ride moves and how big the accelerations are.

Extra Credit

Many interesting observations about science can be made while enjoying the State Fair, not all of them requiring calculations. Here's a few ideas you can get extra credit for answering.

• 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?