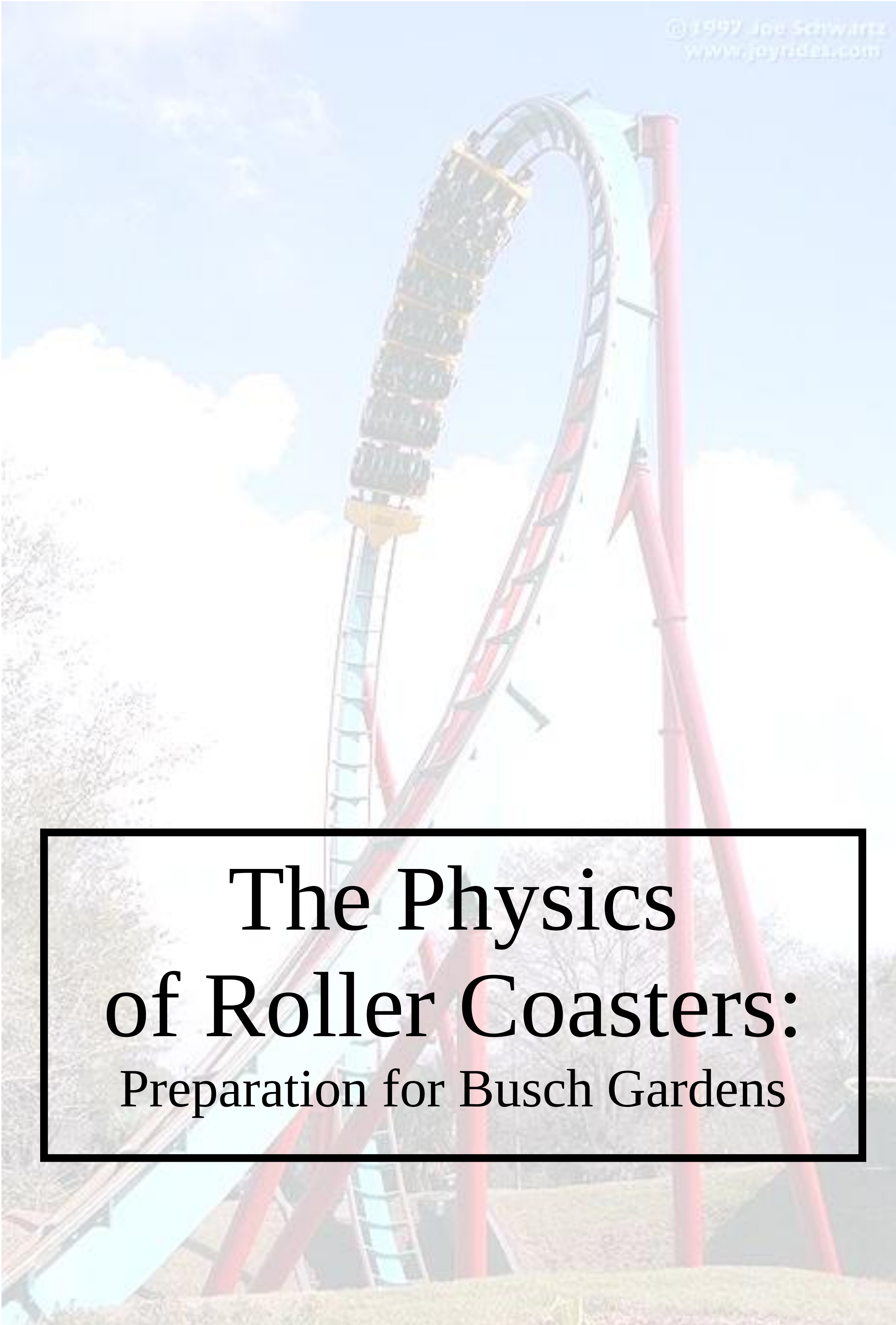



# The Physics of Roller Coasters:

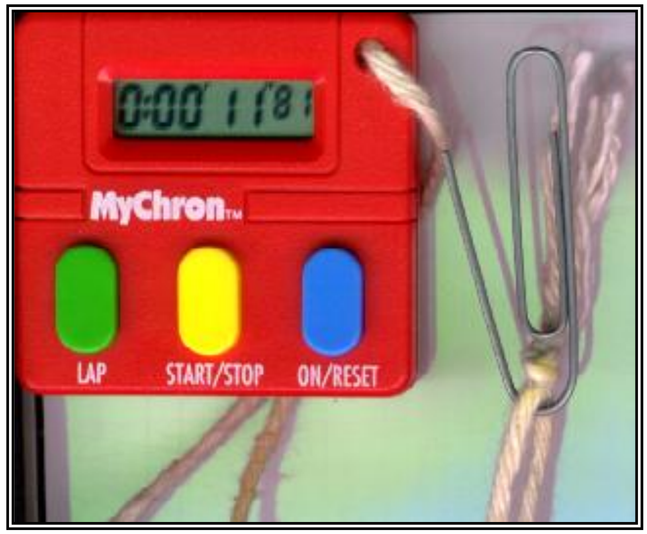
## Preparation for Busch Gardens

## A. The Physics of Rollercoasters

Using rollercoasters, it is possible to learn and apply all of the physics we have studied so far. From forces to speed and velocity, and then to distance and displacement, rollercoasters represent the a perfect example of physics in everyday life. The following notes contains information you will need to know before you ride. The notes will cover how to measure time, G-forces, and speeds.

## B. The Equipment You Use.

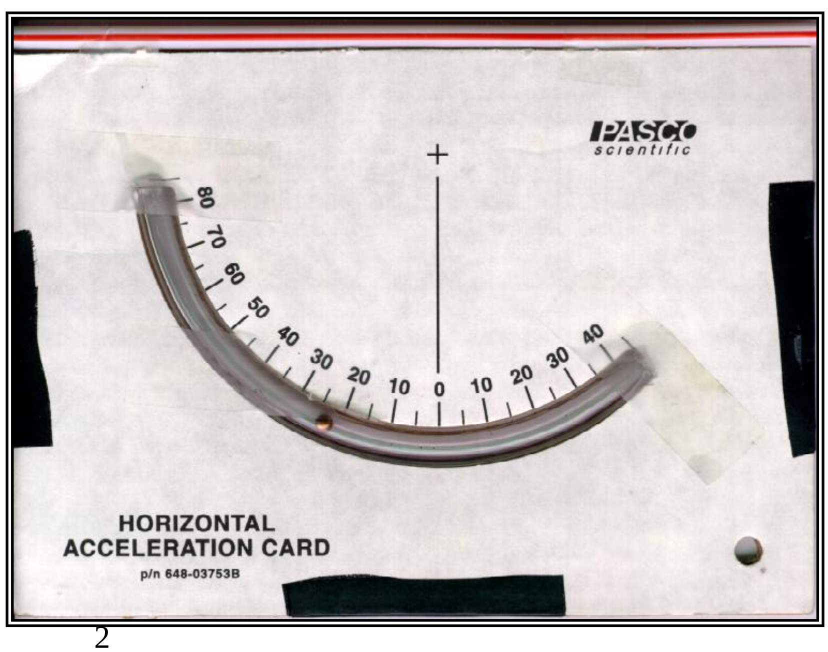
There are several pieces of equipment you will be using while at Busch Gardens:




1. **Stopwatch** – It is used for measuring time of passage of the roller coaster. If the display reads 0:00’11”$^{81}$ as shown in the picture on the right, this means the time is 11.81 seconds. Most of the times you will take on the coasters will be under 10 seconds long. The small raised numbers are in hundredths of seconds.

   The stopwatches sometimes display a scrambled screen, freeze, or display strange characters. If this happens, insert the attached paperclip into the small reset hole on the back of the stopwatch for at least 5 seconds. During this time, the display will clear. When you remove the paperclip, the stopwatch should work correctly. If not, try it again.

2. **Vertical Accelerometer**: It is used to measure the vertical accelerations, like on Python in a vertical loop, or on Scorpion in the first drop. It is used to measure acceleration due to gravity, or acceleration due to change of direction. The position of the mass in the picture on the left is at the ZERO G mark, since the picture was taken while the accelerometer was flat on a desk. However, when you are holding it, the mass will normally be at the second line, indicating 1 G. Each G is equal to the pull of gravity, which is 9.8 m/s$^2$. You can also think of each G as a multiplier of your weight. When you experience 3 G’s in a loop, multiply your weight by 3 and this is how much you weigh during that section of the ride.




3. **Horizontal Accelerometer** – Is used to measure horizontal accelerations which result from an acceleration due to a change of speed. You will use it on rides like Tanganyika Tidal Wave, during a splash, or on the Ubanga Banga Bumper Cars, during a collision. The horizontal accelerometer should always be held with the edge toward you. It should not be held with the

face, as currently shown, toward you.

## C. What do we measure on the roller coasters?

You will be recording 2 primary measurements on the roller coasters.  TIME, and ACCELERATION.

1. **Time** is ALWAYS measured off the roller coaster, from a point where you can see the coaster-train as it passes.  The time will be used to calculate the velocity of the roller coaster.  The time will also be used to indirectly determine the potential and kinetic energy of the roller coaster as certain places.

2. **Acceleration** is always measured on the roller coaster, using either the vertical accelerometer, or the horizontal accelerometer.  These will be used to calculate the forces involved during the ride.

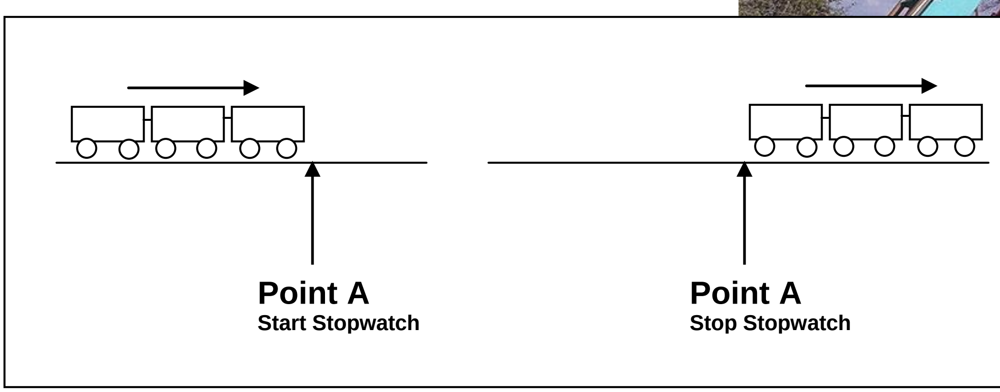
## D. Taking a measurement for time:

To record the time, there are two ways that you can record the passage of the coaster-train on the tracks:

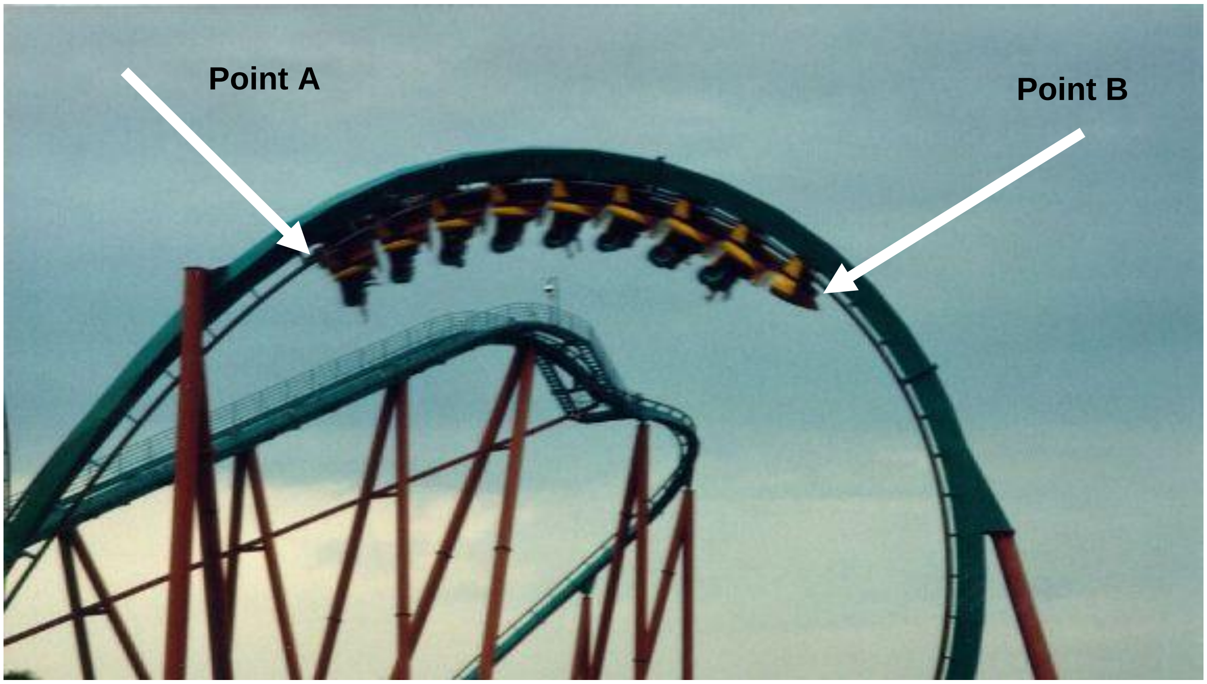
1. *Time of passage of car train past a specific point on the track* – Watching a point at specific point, start the stopwatch as the front of the car passes the point then stop the stopwatch when the rear of the car has passed.

   For example in the picture shown here, start the stopwatch when the front of the car reaches the arrow.  Then, when the back of the car has reached the arrow, stop the stopwatch.

   Also, check out the diagram below.  It is another example of a car passing a single point and recording the time.

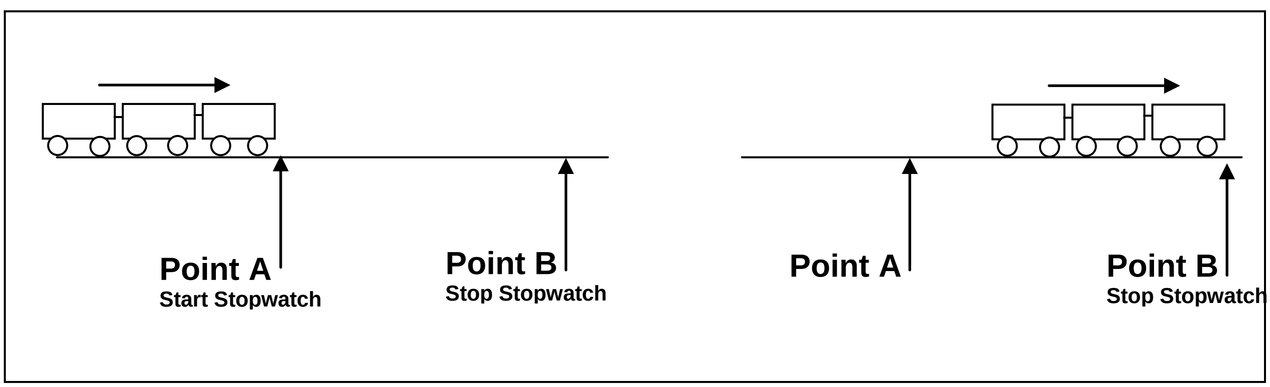



2. *Time it takes car to move from one point to another point on the track* – When the *front* of the car moves past point A, start the stopwatch. When the *front* of the car moves past point B, stop the stopwatch.




In the picture above, the distance is very small between point A and point B. Sometimes, the distance between A and B can be quite large. For example, on Kumba, you will be measuring the time between point A at the top of the first hill, and point B, the point just after the Carousel.

Another way of looking at this can be seen in the picture below:



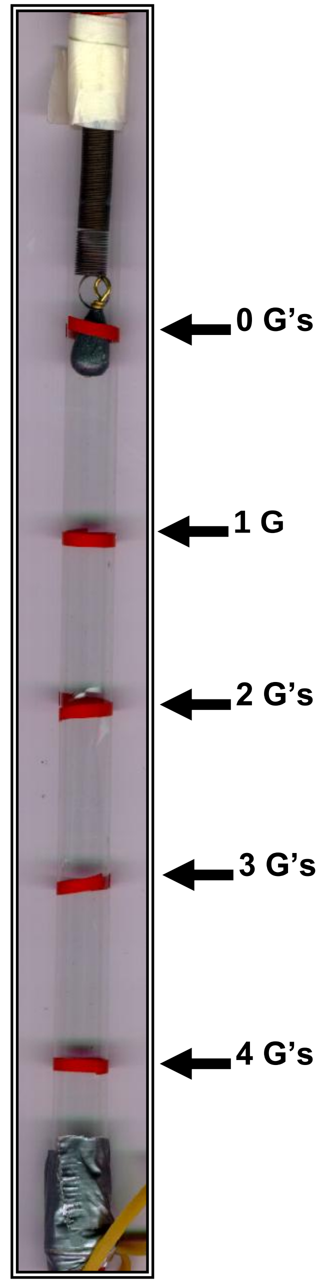

One important thing to consider is that even though these pictures show you starting the stopwatch when the FRONT of the coaster passes point A then stopping it when the front passes point B, you can also do the same thing with any part of the coaster. For example, if the middle of the coaster passes point A, you can record it from that point to the middle of the coaster passing point B. Or, record the time as the back passes point A until the back passes point B. Whatever you do, you must be consistent.

## E. Taking a measurement for acceleration.

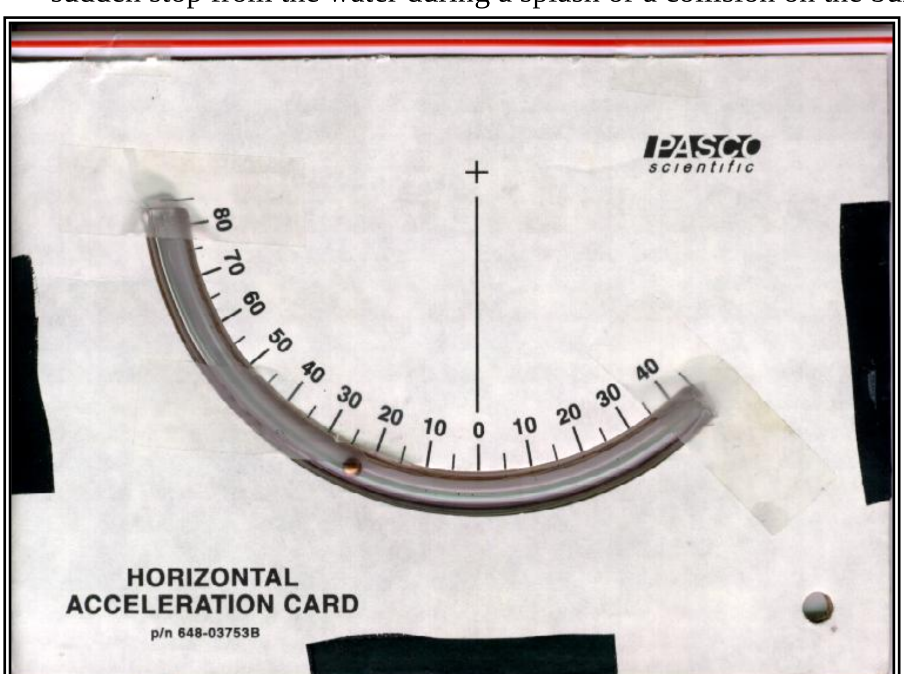
There are two ways and two pieces of equipment used to measure acceleration:

1. Vertical Accelerations are those accelerations that occur from a change in direction. Whenever you turn through a loop or a corner, you undergo an acceleration. To measure the acceleration due to change of direction, use the Vertical Accelerometer shown to the right. Each line represents 1 G. A G, or gravitational force, is equal to the pull of gravity. Since gravity pulls on you at a rate of 9.8 $m/s^2$, the mass at the third line represents 2 G's, or an acceleration of 19.6 $m/s^2$ . The first line represents 0 G's. When you see 0 G's, you are in a state of freefall!

   To properly use the vertical accelerometer, hold the tube in your hand, with the rubber band around your wrist. At all times hold the tube vertical, or perpendicular to the floor. (Make sure the bottom points down to the floor of the roller coaster at all times, allowing the mass to move up and down in the tube freely.) Watch the mass inside the tube carefully, remember where you are on the roller coaster and record your data after you get off the coaster.




2. Horizontal Accelerations are those accelerations that occur from speeding up or slowing down. The horizontal accelerometer must be held so the bottom edge is parallel to the boat or bumper car. The balls in the tube must be allowed to move toward and away from you so that a proper reading can be recorded. The ball reading will be in degrees, but a simple chart on the roller coaster worksheets will be provided to covert the degrees into G's. The acceleration you experience results from a sudden stop from the water during a splash or a collision on the bumper cars.



## F. Speed and Velocity

Speed indicates how long an object takes to move over a prescribed distance. The distance can be the length of a car train, or the length of the entire track on which the car travels.

Velocity is similar to speed, but has the added part of indicating a direction of travel. At Busch Gardens, the direction is assumed and will not be specifically stated. Also, the displacement will be provided. We will use the following formula shown here in the box:

$$V = \frac{\Delta d}{\Delta t} = \frac{d_f - d_i}{t_f - t_i}$$

**V = velocity**
**d = displacement**
**t = time**
**$d_f$ = final position**
**$d_i$ = initial position.**
**$t_f$ = final time**
**$t_i$ = initial time**

$\Delta$ = Is the Greek letter Delta, which represents "change of"

Times are used from the stopwatch readings. Initial and final position will be provided on the worksheets. (Initial position is zero.)

## G. Acceleration

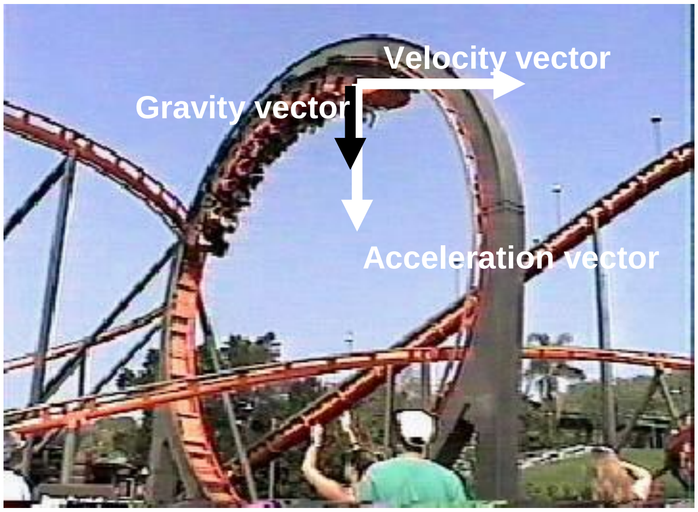
Acceleration is strictly defined as a change of velocity. But hidden within velocity are two parts: Magnitude (Speed) and Direction. Therefore, if you experience an acceleration, you either have to change the speed or direction.

$$A = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

**A = acceleration**
**v = velocity**
**t = time**
**$v_f$ = final velocity**
**$v_i$ = initial velocity**
**$t_f$ = final time**
**$t_i$ = initial time**

A change of speed is easy to relate to acceleration. If you speed up, or slow down, you accelerate.

Although not commonly considered, a change of direction results in acceleration. If you turn the corner quickly, you feel a pull. The car pulls you into the CENTER of the turn.




It may feel as if you are being pushed to the outside, but remember from classroom demonstrations: The direction of the acceleration as you turn in a circle is toward the center of the circle.

Accelerations are directly recorded using either the vertical accelerometer or the horizontal accelerometer. For both, you must ride the ride.

## H. Forces

Forces are experienced when you feel a push or a pull. For example, go through a vertical loop and you feel the seat pushing into you. Forces are a direct result of acceleration. They can be felt anytime you undergo a change of direction or a change of speed. These are called unbalanced forces – when you undergo acceleration you feel the effect. But forces can be balanced. For example, a car traveling down the road at a constant speed is balancing the backward forces from friction. If a person reduces pressure on the gas pedal, the car changes speed, and there is a net force acting on the car. As long as constant pressure is applied to the gas pedal, the net force is ZERO because the acceleration is ZERO. When forces are in balance, it is harder to "feel" the forces. You notice them much more when you are speeding up, slowing down, or turning directions.

Forces are calculated using this formula:

To calculate forces, you will be using the vertical or horizontal accelerometer and converting acceleration, measured in "G's" to meters per second squared.

**F = m a**

**F = force**
**m = mass**
**a = acceleration**

**Example:** Using the formula for force, F=ma, you use your mass (1 kg = 2.2 lbs.) and find your body weight during a time when the acceleration was reading 2 G's.

- If your body weight were 220 pounds, your mass in the metric system would be 220 lbs / 2.2 lbs = 100 kg.

- Using F=ma and the data of 2 G's felt on the roller coaster, you find the Force experienced:

  F = ??
  m = 100 kg.
  a = 19.6 m/s^2

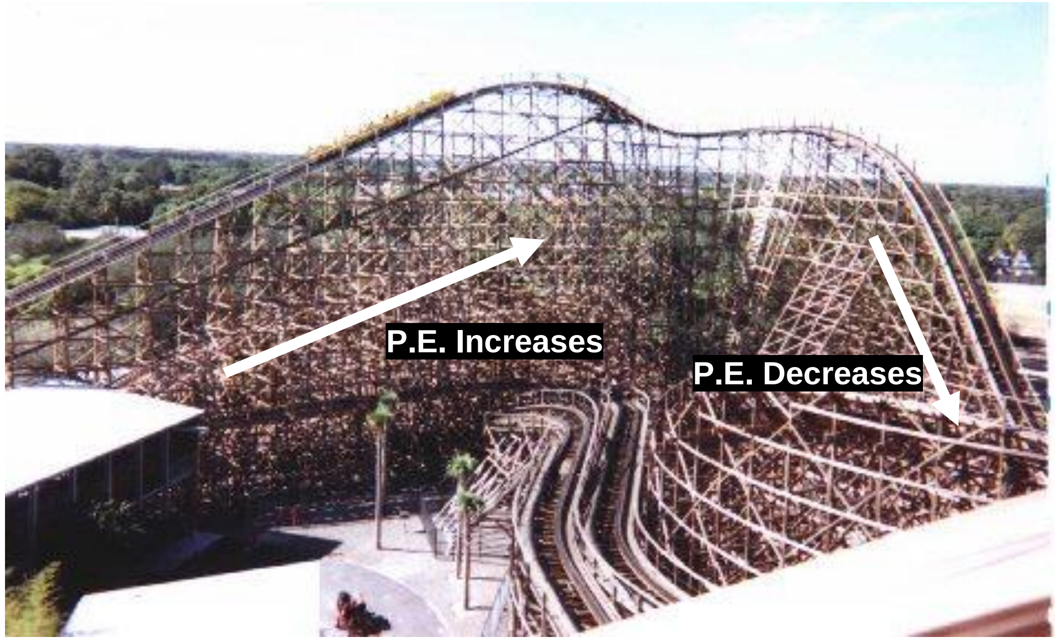
  F = (100 kg) x (19.6 m/s^2)

  F = **1960 Newtons**

  Keep in mind that this is TWICE your body weight since you have experienced 2 times the pull of gravity.

# I. Potential Energy

Potential Energy is the energy the coaster gains as it climbs the hills. The higher the hill, the higher the potential energy It is often called "the ability to do work." A way to think about this is that a coaster on a higher hill goes faster and is scarier because it increases the "ability to go faster."




Potential energy can be calculated by knowing the mass of the coaster and height of the hill:

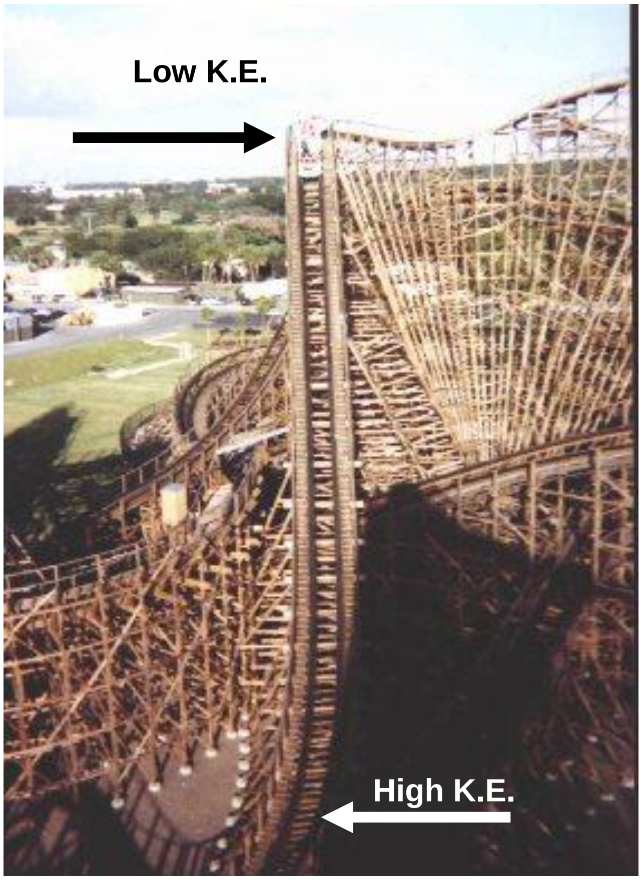
| | |
|---|---|
| **P.E. = mgh** | **P.E. = Potential Energy**<br>**m = mass**<br>**g = acceleration due to gravity**<br>**h = height** |

On the roller coasters, the vertical height is the important variable. It affects how much energy the car gains as it moves up and down hill. Although some hills are not steep, and others drop dramatically, if two hills are the same height, their potential energy is the same. (We are assuming that the mass of the car does not change from ride to ride, even though it does.)

## J. Kinetic Energy

As a coaster starts moving, potential energy is converted into kinetic energy, or the energy of motion. The faster a coaster moves, the higher the kinetic energy. Kinetic energy is always zero when the coaster is not moving.

Kinetic energy is calculated with the following formula:




| $$KE = {}^{1}/_{2}\, mv^2$$ | **KE = Kinetic Energy**<br>**m = mass**<br>**v = velocity** |
|---|---|

Kinetic energy and potential energy are in constant flux as the roller coaster moves down the tracks. As one decrease, the other increases, and vice versa.

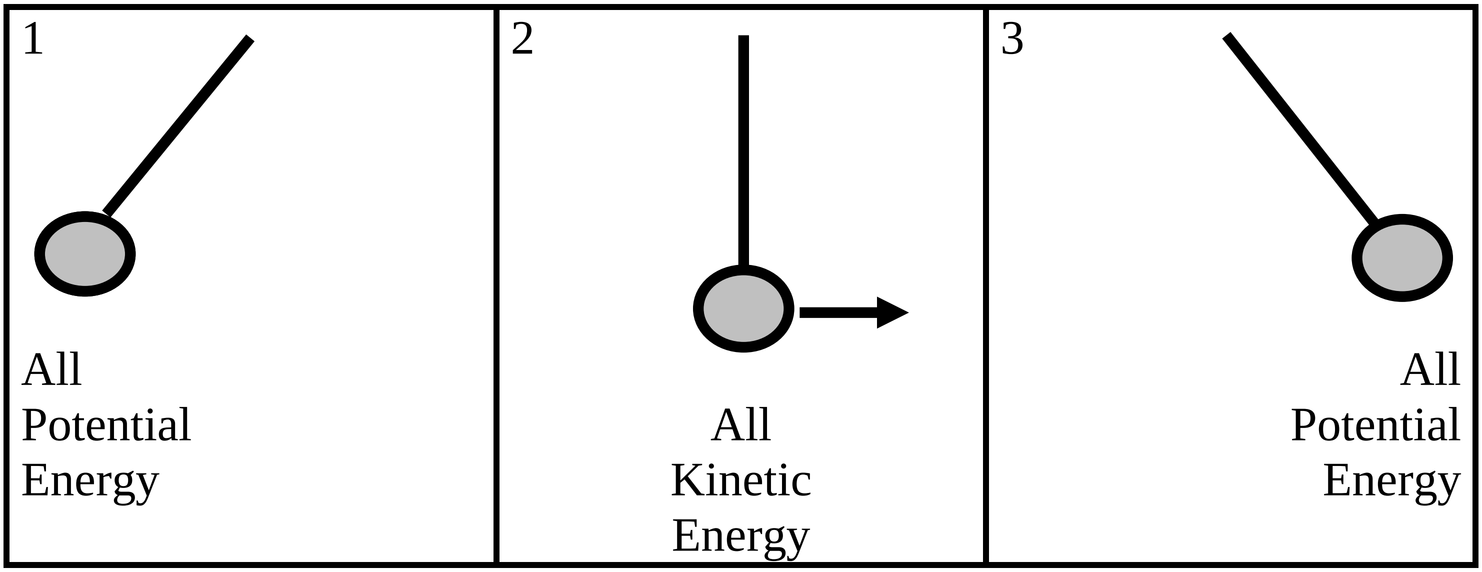
What stays the same (or at least should) is the **Total Energy**. Kinetic Energy, when added to Potential Energy equals the Total Energy of the ride. The problem is that friction reduces the total energy as the roller coaster travels on the track. We can find out how much energy loss there is by determining the total energy at the top of the first hill, where we assume we start out with 100% energy, then recalculate at other locations. Whatever the difference is between the top of the first hill and another place on the tracks is our energy loss.

Lets look at the following example for the conversion of potential energy into kinetic energy. A swinging pendulum (ball on a string) goes through phases.

1. Its starting speed is zero. Therefore, the kinetic energy is zero, and the pendulum has all potential energy. But as it starts to swing, the ball converts all of its potential energy to kinetic energy.

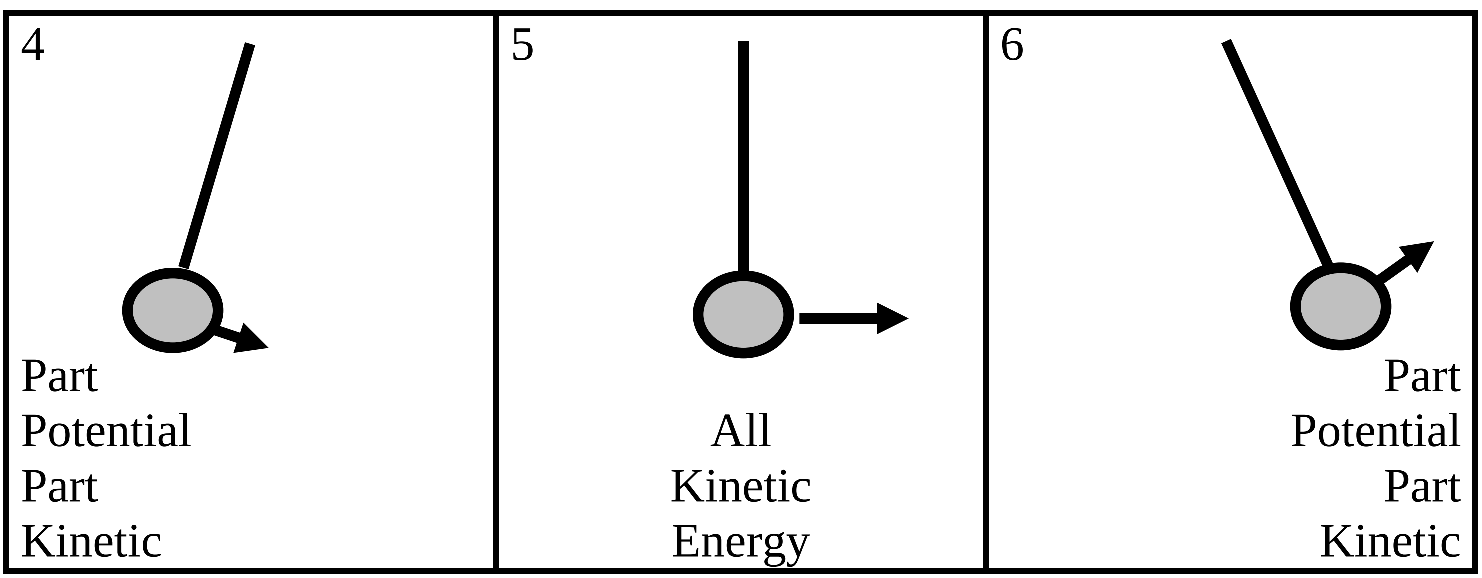
2. At the bottom of the swing, the pendulum has zero potential energy, and all kinetic energy. (Potential energy is zero because we assume that the height is zero at the bottom of the swing.)

3. As it starts to swing back up the other side, the pendulum slows, and the kinetic energy decreases. At the top, the speed is zero, so the kinetic energy is zero and the pendulum once again has all potential energy.




Below, are pictures of the pendulum in between the highest points at each end:

4. The pendulum is already moving and is half way between its highest (speed = 0) and lowest (speed = maximum) points. The kinetic energy is increasing and the potential energy is decreasing to zero.
5. The pendulum is at its fastest and the kinetic energy is at its greatest.
6. The pendulum is slowing. Kinetic energy is decreasing and the potential energy is increasing.




At each point, the TOTAL ENERGY remains constant. In an ideal world, the pendulum will keep moving back and forth without stopping. But in a real world, it slows down and eventually stops. Therefore, the total energy is also decreasing. The amount of total energy decrease is called ENERGY LOSS.

On a roller coaster, the cars MUST loose energy. Friction slows the coaster as it rolls. If it did not have any energy losses, the coaster would return to the station at the same speed that it was at the bottom of the first hill!