UNDERSTANDING A FORCE-METER

The force-meter indicates the force exerted on a rider in the direction in which the device is pointing as multiple of the rider's own weight. This number can be called a force-factor. If the meter when pointing forward on a ride registers 1.5, a force 1.5 times as large as the normal gravitational force on the mass is being used to make the mass accelerate. In this situation, a force 1.5 times the rider's normal weights is pushing on his or her back. A 200 pound rider would experience a force of 300 pounds.

When the meter is held vertically (parallel to the backbone) on roller coasters, it can be used to find the force that seat exerts on the rider. When the meter reads 1, the rider feels a seat force equal to his or her normal weights. At this point, the seat is pushing up with a force equal to the rider's normal weight balancing the force of gravity.

A meter reading of 2 means that mass needs twice its normal weights to keep it moving with the spring. The rider is then feeling an upwards force from the seat equal to twice normal weights. A 200 pound rider would feel an upwards push of 400 pounds and a 150 pound rider a force of 300 pounds. The riders are experiencing a force-factor of 2. Because we interpret the upward force of a seat as indicating the downward pull of gravity, riders feel as if they are heavier, as if, somehow, gravity has gotten bigger.

When the meter, held vertically, reads 0, the seat is exerting no force at all. The only time this happens is when the seat and rider are in some form of free fall. This can be when they are coming over the top of a coaster hill or actually falling. The meter actually does read 0 on free fall rides and at certain points on roller coasters.

Another interesting case is when the rider is upside down. If the ride goes through the inverted part of a loop fast enough, the meter will read anywhere from .2 to 1.5. The rider is being forced into a curved motion smaller than the curve a ball thrown into the air would follow. The rider may fell lighted than usual but does not feel upside down. This is particularly evident where the repetitive motion gives riders a chance to get used to the motion and start to notice sensations.

Upside down, on rides that go slowly enough, riders can pull "negative" force-factors. This means that without some sort of harness contraption riders would fall out of the ride. They feel decidedly upside down as they feel the harnesses holding them in. Power Dive® actually stops upside down and riders hang from their harness. On most rides, however, riders pass through the inverted loops with large enough force-factors to convince them that they are still right side up.

MAKING A FORCE METER

PURPOSE: To create a meter for measuring forces at the amusement park.

OBJECTIVES: To build a meter and understand how to use it.

GENERAL STATEMENT: A mass on a spring or rubber band can be used as a meter to measure the forces experienced on rides in terms of the force gravity normally exerts on a person or object. When the force-factor is defined as force experienced divided by normal weight, it turns out that on a give ride all objects, regardless of mass, experience the same multiple of normal weight.

MATERIALS:

Clear tennis ball container or 1 foot section of plastic tubing used to cover fluorescent lights and a pair of end caps, (Tubes are available at commercial lighting supply centers and home improvement stores), #1 paper clips, three 2 oz. fishing sinkers, several #18 rubber bands, indelible pen.

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

Part 2. Unbend paper clip to create a "U". Lay the free end of the rubber band across the U near one side. Slide the sinker through the rubber band loop and pull it tight.

Part 3. Poke the ends of the U up through the top of the cover so that the weight will hang close to one side of the can. Push paper clip up against the top, bend the ends back across the top and tape down. Slide the string through the hole of the sinker and tie the ends together. Connect the small paper clip to the string loop. For the tennis can, the loop need not be very long. For the plastic tubing, make the string loop long enough so that the masses can be threaded through the tube and hang out the bottom.

Part 4. TO MARK FORCE-FACTOR CALIBRATIONS
Hang two additional sinker on the small clip. Hold the top against the edge of the can. Place a strip of tape on the can level with the line on the permanent sinker, and label it force-factor = 3.

Remove one extra sinker and place a strip of tape on the can level with the line on the permanent sinker, and label it force-factor = 2.

Remove everything but the permanent sinker. Insert the sinker into the can and tape the top on securely. Mark midline of sinker as force-factor = 1.

* If you use a spring, the marks should be evenly spaced. Twice the force give twice the stretch.

* If you use a rubber band, the marks are not evenly spaced because rubber bands are not linear. Double the force does not double the stretch.

Part 5. Estimate the "0" or "weightless" position. Turn the can on its side, jiggle to the unextended position for the rubber band, and mark with a strip of tape for force-factor = 0.

* Tape a rubber band chain onto the meter as a wrist strap. It will hold onto the meter on an exciting ride but will break if necessary.

SPEED

In linear motion, the average speed of an object is given by:

$$v_{ave} = \frac{\Delta d}{\Delta t}$$

In circular motion, where tangential speed is constant:

$$v_{ave} = \frac{\Delta d}{\Delta t} = \frac{2\pi r}{\Delta t}$$

If you want to determine the speed at a particular point on the track, measure the time that it takes for the length of the train to pass that particular point. The trains speed then is given by:

$$v_{ave} = \frac{\Delta d}{\Delta t} = \frac{\text{length of train}}{\text{time to pass point}}$$

In a situation where it can be assumed that total mechanical energy is conserved, the speed of an object can be calculated using energy considerations. Suppose the speed at point C is to be determined (see figure d). From the principle of conservation of total mechanical energy it follows that:

$$PE_A + KE_A = PE_C + KE_C$$

$$mgh_A + 1/2mv_A^2 = mgh_C + 1/2mv_C^2$$

Since mass is constant, solving for v_c

$$v_c = \sqrt{2g(h_A - h_c) + v_A^2}$$

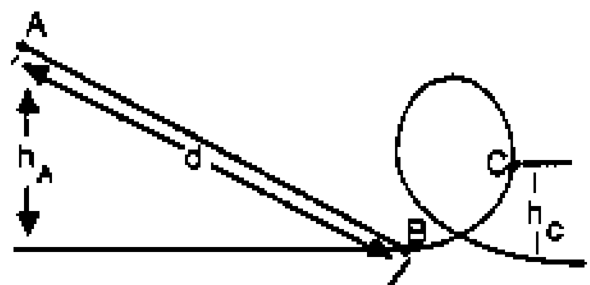


figure d

Thus by measuring the speed of the train at point A, and the heights h_A and h_C, the speed of the train at point C can be calculated.

ACCELERATION

Accelerometers are designed to record the "g forces" felt by a passenger. Accelerometers are usually oriented to provide force data perpendicular to the track, longitudinally along the track, or laterally to the right or left of the track (see figure e).

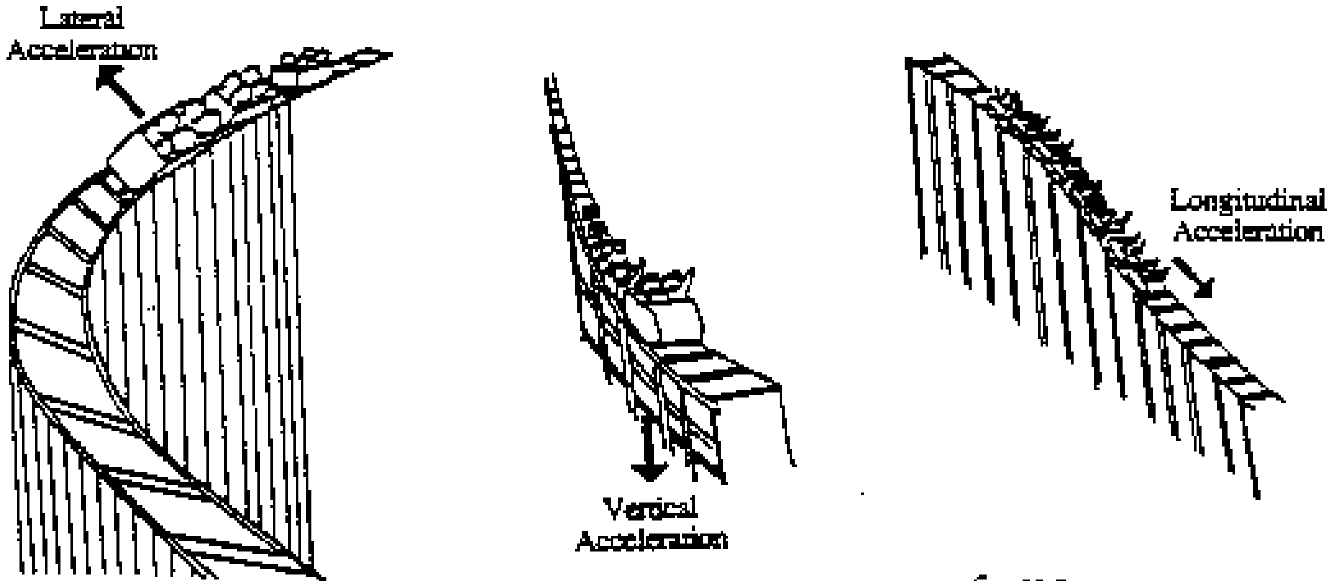


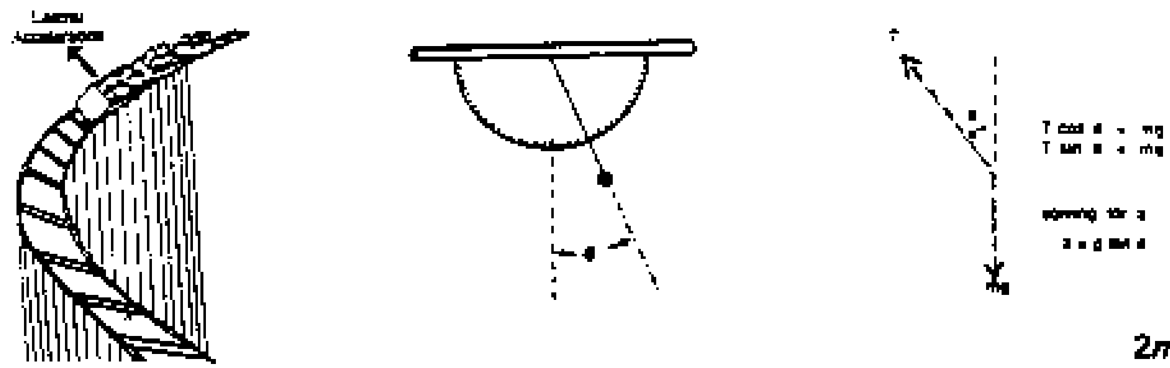
figure e

Accelerometers are calibrated in g's. A reading of 1 g equals an acceleration of 9.8 m/s2. As you live on earth, you normally experience the sensation of 1 g of acceleration vertically (no g's laterally or longitudinally). Listed below are the sensations of various g forces. These are rough estimates, but may be helpful in estimating accelerations on the various rides.

Accelerometer Reading	Sensation
3 g	3 times heavier than normal (maximum g's pulled by space shuttle astronauts)
2 g	twice normal weight
1 g	normal weight
0.5 g	half-normal weight
0 g	weightlessness (no force between rider and coaster)
-0.5 g	half-normal weight - but directed upward away from coaster seat (weight measured on bathroom scale mounted at rider's head)

LATERAL ACCELERATION

A. **SEXTANT**-The sextant discussed earlier as a triangulation instrument may also be used to measure lateral accelerations. The device is held with sighting tube horizontal, and weight swings to one side as you round a curve. By measuring the angle, acceleration can be determined. See drawing below:



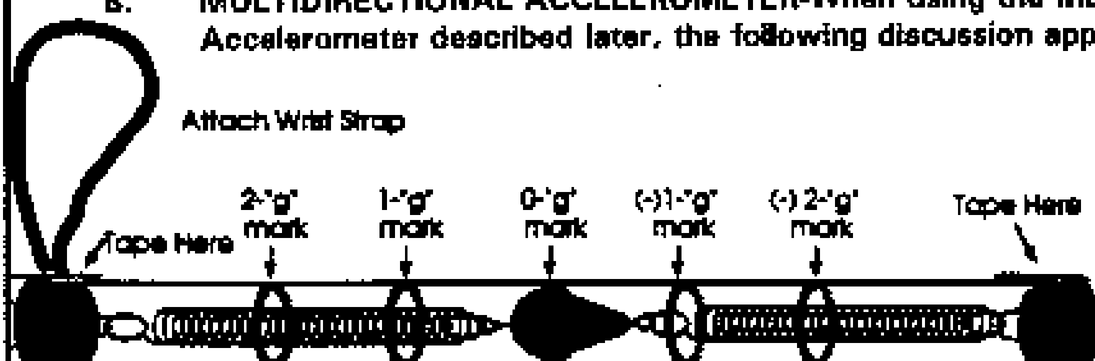
Centripetal Acceleration: With uniform circular motion remember that: $v = \frac{2\pi r}{t}$

and the centripetal accelartion is given by: ac = $a_c = \frac{v^2}{r} = \frac{4\pi^2 r}{t^2}$

where r is the radius of the circle and t is the period of rotation.

Thus centripetal acceleration can be measured on a ride.

B. **MULTIDIRECTIONAL ACCELEROMETER**-When using the Multidirectional Accelerometer described later, the following discussion applies:



Assuming that the two springs obey Hooke's Law - then:

$d_{stretched} \propto F_{measured}$

$F_{measured} = ma$

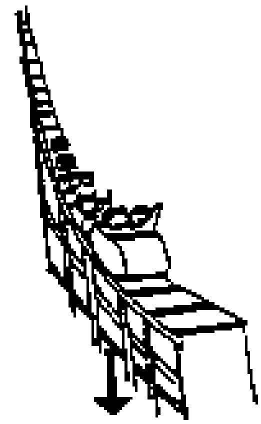
since the mass is constant

$F \propto a$

$d_{stretched} \propto a$

VERTICAL ACCELERATION

When using either accelerometer in a vertical mode, the device will read 1g when the acceleration is zero because of the earth's gravitational pull. Therefore, in order to determine the actual acceleration vertically, you must subtract 1g from the scale reading.



LONGITUDINAL ACCELERATION

Acceleration of a person on a ride can also be determined by direct calculation. Down an incline, the average acceleration of an object is defined as:

$$a_{ave} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\text{change in speed}}{\text{change in time}}$$

Using methods previously discussed it is possible to estimate speeds at both the top and bottom of the hill and the time it takes for the coaster to make the trip. Thus average acceleration can be found during that portion of the ride.

The multidirectional accelerometer can also be used to determine longitudinal acceleration by holding it parallel to the direction of acceleration.