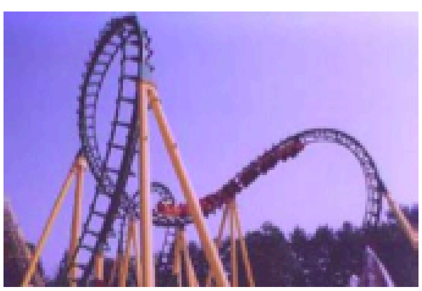
Physics Fun:

GENERAL INFO PACKET!

The Study of Mechanics, Energy, Force & Motion



Motion

There are two basic types of motion. Motion that is uniform and accelerated motion.

For an object moving with uniform motion, the velocity remains in the same direction and has constant magnitude (size). For uniform motion, forces are balanced. There are no net or resulting forces. Under these conditions calculating the velocity is straightforward.

$$\text{velocity} = \frac{\text{distance traveled}}{\text{time of travel}} = \frac{s \text{ or } d}{t}$$

This velocity is an average for the trip.

As soon as forces that do not cancel each other out act on an object, uniform motion no longer takes place. Whenever an unbalanced force acts on an object an acceleration is produced. Newton's second law of motion expresses the relationship among force, mass, and acceleration as F = ma.

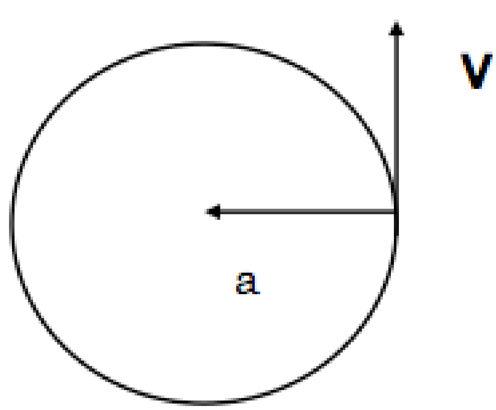
$$\text{Force} = \text{mass x acceleration} \quad \text{or} \quad \text{acceleration} = \frac{\text{Force}}{\text{mass}}$$

The acceleration of an object increases as the amount of force causing the acceleration increases. The larger the mass of the object, the larger the force needed to produce acceleration.

Acceleration is the change in velocity over a period of time. (How fast something is going faster.) This change can be in the speed (whether increasing or decreasing), in the direction of the motion, or in both.

$$\text{Acceleration} = \text{velocity} / \text{time} \qquad a = v / t$$

Acceleration occurs anytime there is a change in velocity. For objects moving in a curved path, velocity is changing even though speed may be constant. Velocity is a vector and therefore must have speed and direction. If your direction is changing, like on the Rotor, then there is acceleration toward the center of the Rotor. This acceleration is called centripetal acceleration.



centripetal acceleration = (velocity)^2 / divided by the radius

$$a_c = v^2 / r$$

ac = centripetal acceleration
v = velocity
r = radius of the circle

In the case of an object spinning in a circle, the size of the velocity (speed) is calculated by measuring the time for one complete spin and dividing this into circumference of the circle.

v = Circumference / time

If there is an acceleration, there must be an unbalanced force producing it. The force causing the circular motion is called centripetal force (Fc). This force causes the object to change direction, thereby creating the acceleration in the same direction (toward the center).

As stated previously;

$$F = ma$$

Newton's Second Law of Motion must also apply to circular motion.

Therefore: Fc = mac

If we substitute (v^2 / r) in for (ac), we find the equation needed to calculate centripetal force.

$$Fc = mv^2 / r$$

This force is easy to see and understand if you swing a rubber stopper on the end of a string. You can see your hand is producing the force which is transferred through the string to make the stopper follow the circular path. So your hand produces the force, which causes the centripetal acceleration.

In the Rotor, the wall produces the centripetal force. This force keeps you moving in a circular path by providing an acceleration on you toward the center. You, on the other hand, have the impression that there is a force throwing you toward the wall. This is very similar to being in an automobile at rest and the driver pushes the accelerator to the floor. If the car has a lot of horsepower, you feel like you are being pushed back in the seat. In reality, the seat is accelerating you forward. This "force" you feel back against the seat does not really exist. It's your inertia trying to keep you at rest. The only force is the seat accelerating you. So, in the Rotor, the force you feel out against the wall, called centrifugal force, is a fictitious force. You are reacting to the wall pushing on you!

Generally speaking, you might think of centripetal force as an action force and centrifugal force as a reaction force. Remember, centrifugal force is considered to be fictitious. It can only be observed in the accelerated frame of reference.

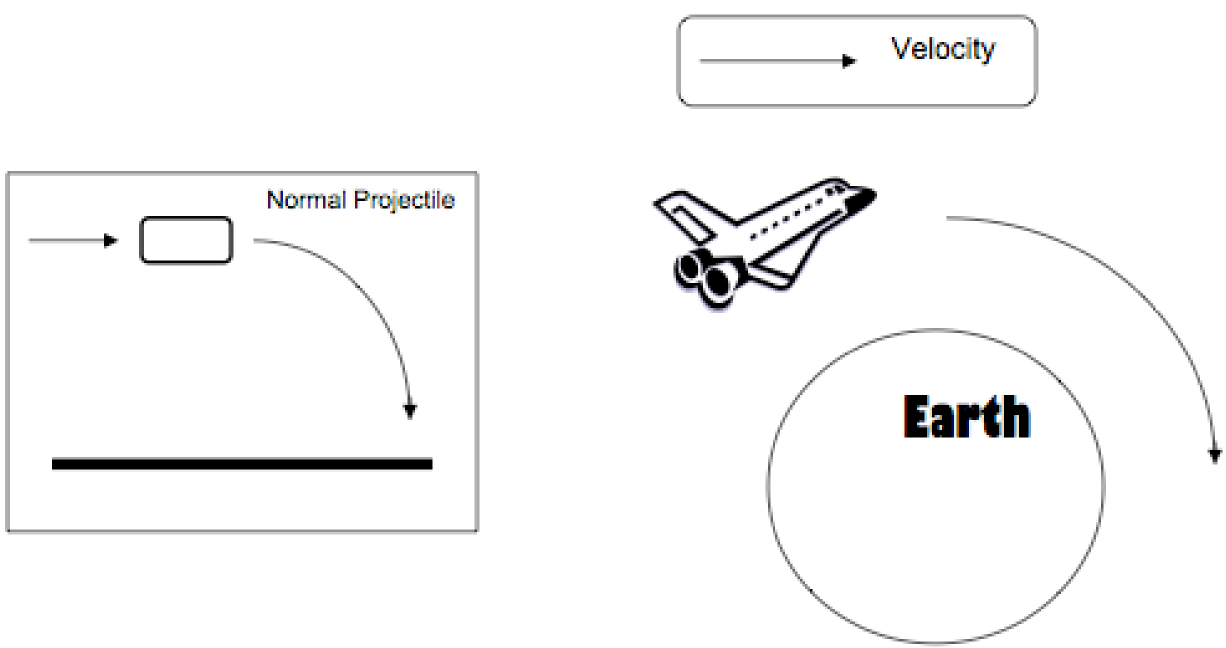
These forces are also found on many other rides at Lake Compounce! Any ride which moves in a circular or curved path will produce centripetal and centrifugal forces.

Earth Gravity and G - Forces

Gravity refers to the force of attraction between objects. All objects exert a gravitational force. Any two objects with mass attract each other, and the strength of this force depends on the mass of the objects and the distance between them. The larger or more massive the object, the greater the force.

Some forces can act from a distance without actual contact between the two objects. We are accustomed to the gravity of Earth. When you are standing still the force exerted on you by the Earth produces your weight. This is also referred to as one "g". Gravity causes free-falling objects on the Earth to change their speeds at the rate of 9.8 m/s each second. That is a change in speed of 32 ft/s in each consecutive second. Therefore, a "g" is a unit of acceleration equal to the acceleration caused by gravity. When you feel heavier than normal you are experiencing a force greater then 1 g. When you feel lighter than normal you are experiences a force less than 1 g. You are weightless when you feel no forces (free fall).

On the roller coaster, when you go down a steep hill, you will get that "light stomach feeling" and will notice yourself lifting off the seat. You have just experienced weightlessness. Imagine the shuttle astronauts having this same feeling continually for several days. This may give you an idea of why many astronauts have what is known as space or motion sickness. While the shuttle is in orbit, it is falling. With its tremendous horizontal velocity, as it falls the Earth curves away from it. So it never hits the Earth, it falls in an orbit.



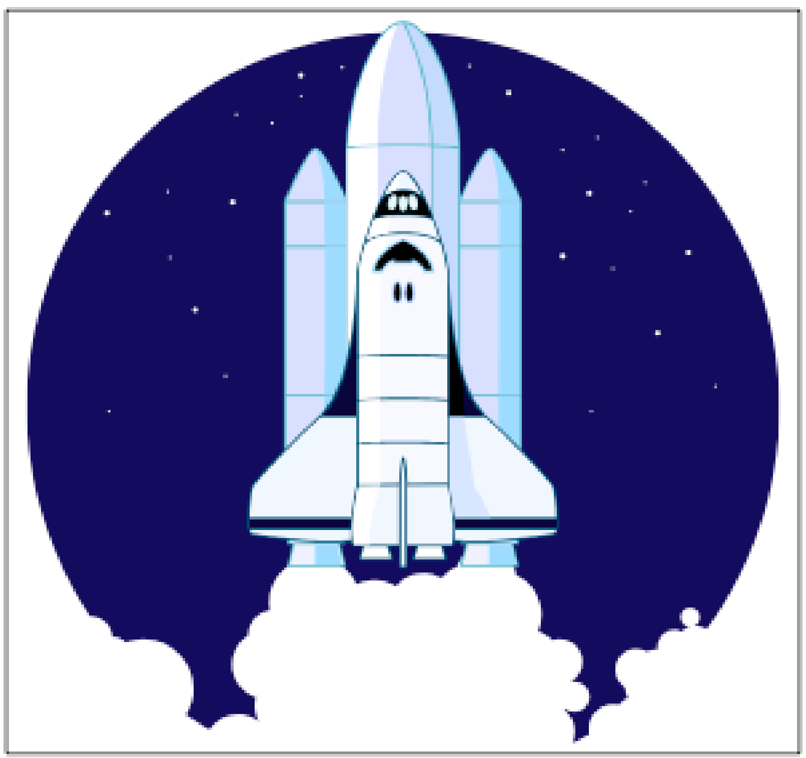
G – Force Information:

Definition: The ratio produced when the force felt by an object is divided by the force that the object would feel while motionless on the Earth's surface.

$$g - \text{force} = \frac{\text{Force}}{\text{weight}}$$

Examples of g- forces:

Shuttle in Orbit	0	g's
The Moon	.165	g's
Mars	.38	g's
Shuttle Lift Off	3.0	g's
Sun	28	g's



Energy Transformations

There are many energy transformations that occur at Lake Compounce.
The main energies used to make calculations involve gravitational potential energy and kinetic energy. Potential energy is energy that is stored. Kinetic energy is energy of motion.

When an object is lifted from the ground or rest position it acquires potential energy. The amount of energy can be expressed as:

$$Ep = mgh$$

where: m = mass (kg)
g = acceleration due to gravity (m/s2)
h = height above starting position (m)

Energy is measured in units called JOULES.

When the object drops, the potential energy that it has is changed to kinetic energy as the object falls. At the bottom of its fall, the object is moving at its fastest velocity which indicates it has its maximum kinetic energy. This kinetic energy can be expressed as:

$$Ek = 1/2\ mv^2$$

where: m = mass (kg)
v = velocity (m/s)

Conversion of energy requires that the total potential at the top must be equal to the total kinetic at the bottom. If you calculate the potential energy at the top and set it equal to ($1/2\ mv^2$)the maximum velocity at the bottom can be calculated.

$$mgh = \frac{1}{2}mv^2$$

v = velocity (m/s)

$$\frac{2\ mgh}{m} = v^2$$

g = acceleration due to gravity (9.8 m/s/s)

$$\sqrt{2gh} = v$$

h = height (m)

Work & Power

Work is produced by a force acting on an object moving through a distance.

Work = Force x distance

$W = Fd$ where:

W = work (joules)
F = Force (newtons)
d = distance (meters)

Notice the unit for work (joules) is the same as the units of energy. Energy is the ability to do work. If work is done to lift an object, that work reappears as potential energy.

Power is the rate of doing work, or how fast work is done.

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{W}{t} = \frac{Fd}{t}$$

Where;

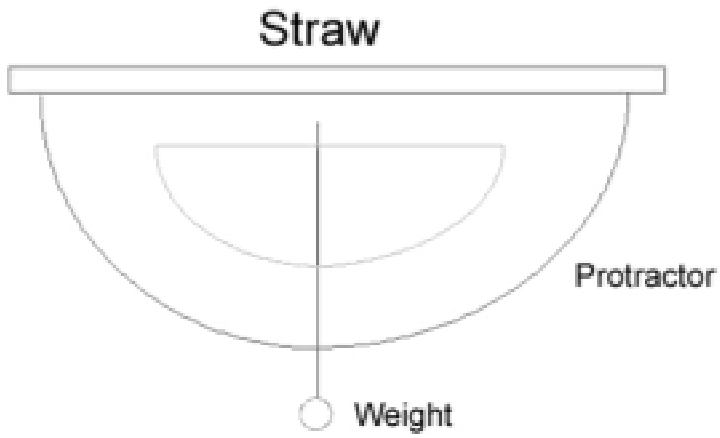
P = power (watts)
W = work (joules)
t = time (seconds)

Power in watts can be converted to horsepower using the following conversion:

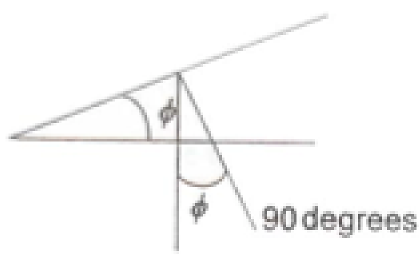
1 hp = 746 watts

An Angle on Distance

To determine the height of a ride use a simple “protractor” elevation finder.



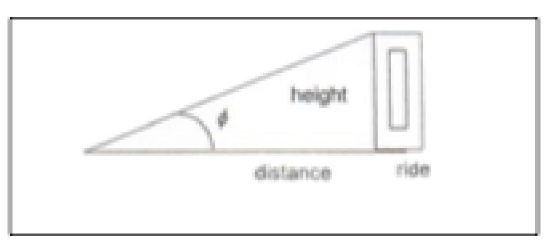
Have one student sight through the straw at the top of the ride. Another student reads the angle on the protractor. The angle read is then subtracted from 90 degrees.



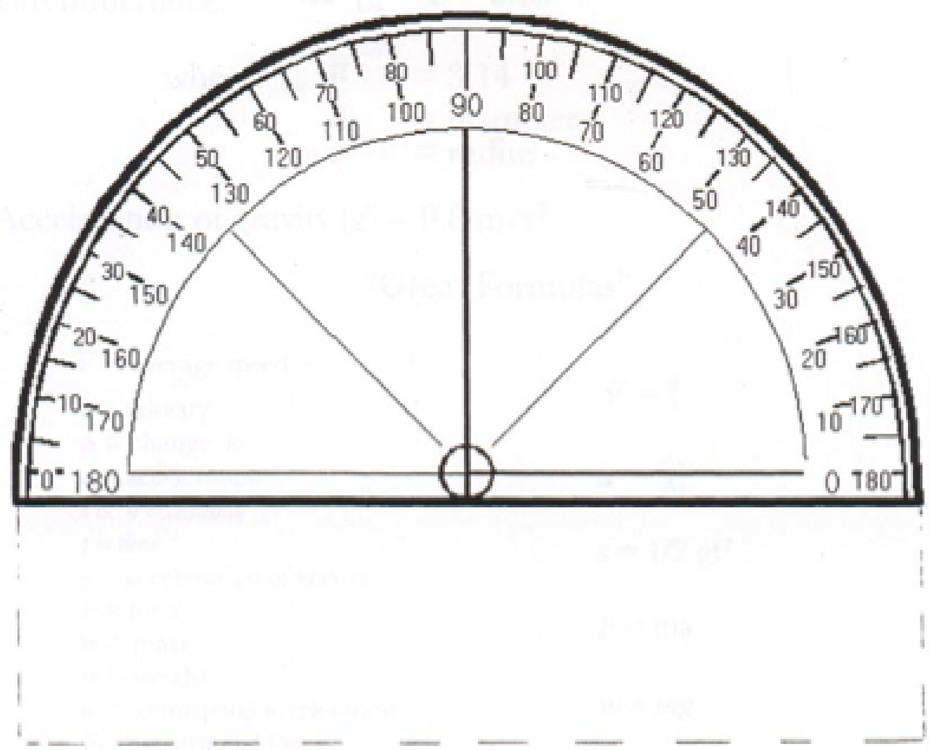
To calculate the height of the ride you will also need the distance between the student and the ride.

$$\tan \Phi = \frac{height}{distance}$$

$$h = d\,(\tan\Phi)$$



(Remember to add the height of your eye to the ground.)



1. Cut out the protractor including the dashed line section.

2. Trace the protractor part only on a piece of cardboard, such as the back of a tablet.

3. Glue or staple the cardboard to the back of the paper protractor.

4. Roll the top section around a straw and tape.

5. Punch a hole and tie a 9 inch string of heavy black thread through the hole. On the other end tie a metal nut, washer, or fish sinker.

6. Follow the directions on the page titled “An Angle on Distance.”

The Vertical Accelerometer

Accelerometers measure accelerations by measuring forces. The vertical accelerometer in this kit consists of a lead sinker hung from a spring. Its operation can be understood in terms of Hooke's law:

$$F_s = -kx;$$

where F_s is the force applied by the spring to the sinker, x is the extension of the spring, and k is a constant that depends on the spring. The negative sign indicates that the force is in the direction opposite to the extension. As the force applied by the spring to the sinker increases, the stretch increases in direct proportion. Thus the position of the end of the spring indicates the amount of force being applied to the sinker by the spring.

Calibration of the device can be in newtons for the spring force, or, in the ratio

$$F_s / m = \text{an acceleration}$$

since the mass of the sinker remains constant for all uses. With the unstretched spring position taken as the zero point, the weight of a single sinker defines the position corresponding to a restoring force which has magnitude equal to the weight of the sinker, or

$$F_s / m = 9.8\ \text{m/sec}^2$$

Note that if the device is calibrated in units of "g" instead of m/sec^2, it should be pointed out that the unit "g" used here is related to the local acceleration due to gravity only in that it has the same magnitude. Since the symbol "g" means local gravitational field strength, a reading of 2.0 g on an accelerometer does not mean that the gravitational field has increased. It means that the rider feels a force which is twice the magnitude of the rider's weight.

When the device is held vertically, the net force on the sinker is given by:

$$F_{net} = F_s - mg;$$

where mg is the weight of the sinker.

A diagram of the spring and sinker is shown in Figure 1. When the accelerometer is held at rest (1a), the spring force is equal to the weight but in the opposite direction, so the net acceleration is zero.

$$F_{net} = 0 = F_s - mg$$

$$F_s = mg$$

and the scale reads "1g".

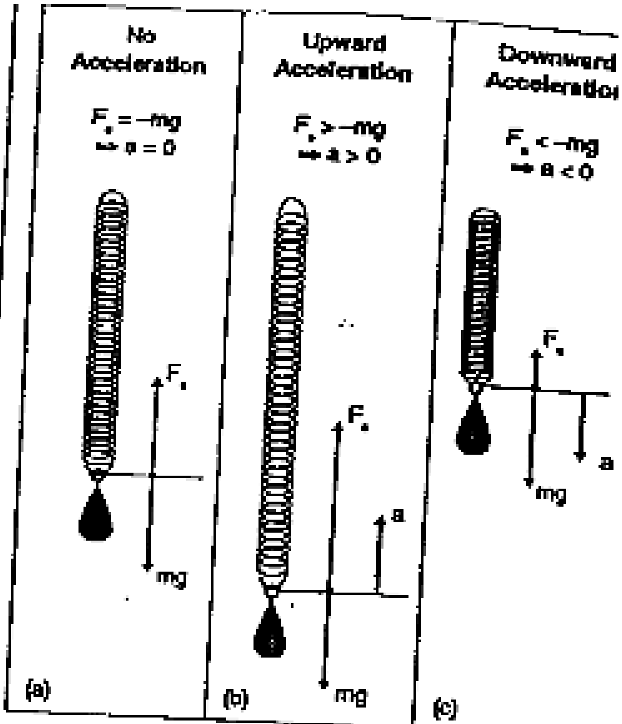


Figure 1 Diagram of the Vertical Acceleromete

All the spring is doing is supporting the weight of the sinker. This is also true if the device is moving up or down with constant velocity.

If the sinker is accelerating upward, the spring must exert not only the weight but enough additional upward force to provide the acceleration (1b). With F_s greater than mg, the net acceleration is greater than zero and upward. In this case, the spring will have stretched more than when at rest and the sinker will be below the "1g" position.

If the sinker is accelerating downward (1c), the spring must be applying less force than the weight. It will have stretched less than when at rest and the sinker will be above the "1g" position. In this case, the weight helps to accelerate the mass downward.

The device registers the acceleration as seen in the frame of reference of the rider. Consider the sinker of the accelerometer to be a "plumb bob". Its direction response is the same as that of a plumb bob. In this case, the amount of stretch of the spring gives the weight of the sinker in the combined gravitational and acceleration fields of the ride.

You cannot tell the gravitational field in one direction from an acceleration in the opposite direction. You cannot feel the difference between a force due to gravity and a force du to the ride pushing on you. The scale readings give what you feel is the local gravitational field. Since it registers the acceleration in the reference frame of the rider, the accelerometer readings agree with what the rider "feels."

A negative or downward acceleration occurs after the tops of roller coaster hills, when an elevator begins its downward trip, or when one begins to slide downhill. Riders have a sinking feeling because less force is being applied upward than they are accustomed to. On some rides the downward force is partly a push from the safety bar. This downward push feels as if the rider has suddenly become lighter and is rising out of the seat. Sure enough, the accelerometer reads less than one "g."

Upward or positive accelerations are felt in elevators as they begin to rise, and at the bottom of vertical loops on roller coasters and swings. As the elevator begins to rise, the floor must push up with a force greater than the rider's weight. The rider interprets this as an increase in downward force and feels heavier. The accelerometer spring, stretching to provide the additional force for the sinker, registers more than one "g." Both the direction and magnitude of the readings agree with the rider's feeling of an altered gravitational field.

Upside down, at the top of a vertical circle such as a roller coaster loop or rotating ride, the rider may feel little if any force from the seat. The rider feels almost "weightless". At the same point the accelerometer shows little if any pull being applied by the spring. They are in agreement. At the bottom of the same loop the strong upward push from the seat feels like a force pushing the rider down into the ground. This upward force is applied to the sinker by the spring which stretches strongly giving a large reading. In both cases, the rider sees the spring being pulled "down" toward the rider's seat, which conforms with what the rider feels.

The Horizontal Accelerometer

With horizontal accelerometers, as opposed to vertical accelerometers, there is not the same confusion between the subjective experience and the accelerometer reading. At rest, the BB's in the horizontal accelerometer settle to the bottom of the curved plastic tube. There is no horizontal force applied and no horizontal acceleration.

When the BB's are above the bottom, as in Figure 2, the inside of the curved plastic tube applies a force to them. The applied force has a vertical component equal to the weight of the BB's and a horizontal component equal to the mass of the BB's times their horizontal acceleration. The applied force acts along the line making the angle θ with the vertical, center line of the accelerometer.

Since the components are perpendicular to one another and the horizontal force, ma, is opposite the angle θ:

$$\tan\theta = ma/mg;$$

and

$$ma = mg\tan\theta.$$

We can divide both sides by the mass of the BB's to get:

$$a = g\tan\theta;$$

where a, the horizontal acceleration, is always directed forward toward the front of the device.

To measure the horizontal acceleration in the direction you are moving, just hold the accelerometer level with the straw pointed in the direction you are moving.

Multiply g by the tangent of the angle to the center of the BB.

a = 1g at 45°   a = ½g at ___

a = 2g at ___   a = 3g at ___

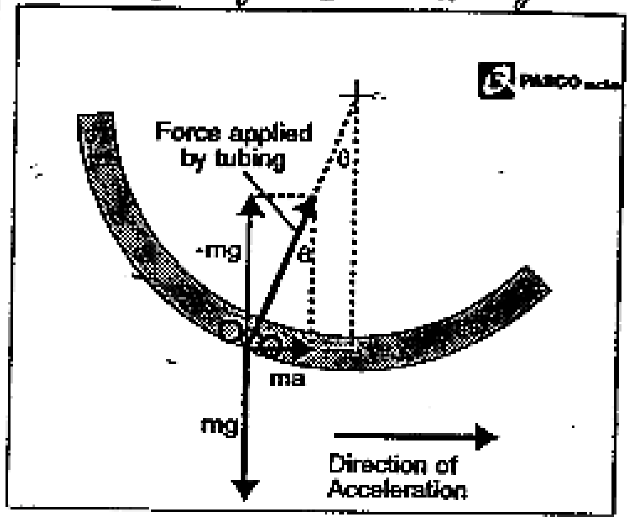


Figure 2 Diagram of the Horizontal Accelerometer

To use the horizontal accelerometer to measure horizontal centripetal accelerations, hold it perpendicular to the direction in which you are headed and as level as possible. For example, on the rotor ride at an amusement park, where you are in a rotating cylinder feeling mashed to the wall, hold the accelerometer with the short side pressed to the wall. It will be level with the floor and, since you are traveling sideways, perpendicular to the direction of travel.

Before the motion begins, the BBs sit in the bottom of the tube. When the ride begins to rotate, a centripetal force is needed to make them go in a circle. The BBs will ride up the side nearest the wall, as if forced outward. In fact, the tube will be exerting a horizontal force on them directed in toward the center of the ride. They will ride up until the angle is large enough to give the necessary horizontal acceleration. In circular motion

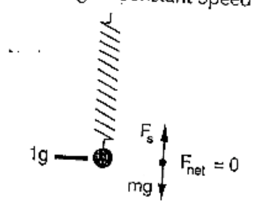
$$a = V^2/r;$$

where V is the linear speed along the circumference and r is the radius of the circle. As the ride picks up speed, the BBs will travel farther up the curve.

$$V = \frac{D}{T} = \frac{2\pi r}{T}$$

T = period

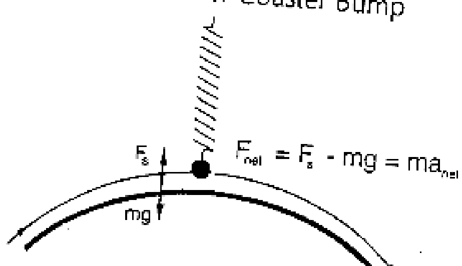
Vertical Accelerometer Physics
Standing Still or
Moving at Constant Speed



Spring force is equal to weight—
Net force is zero—
Net acceleration is zero.

RULE:
If you are "head upward," subtract 1 g from the reading on the accelerometer.

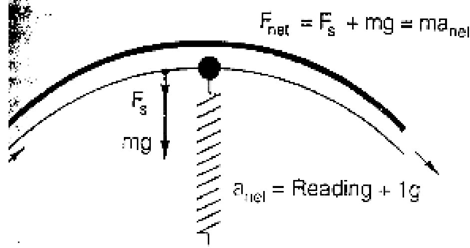
Vertical Accelerometer Physics
Top of a Roller Coaster Bump



Spring force is less than object's weight—
Net force is in downward direction—
Net acceleration is downward—
Net acceleration is negative.

RULE:
If you are "head upward," subtract 1 g from the reading on the accelerometer

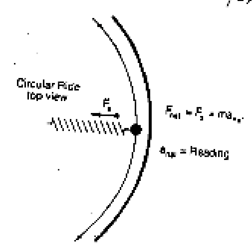
Vertical Accelerometer Physics
Top of a Vertical Loop
(Upside Down)



Spring force is in same direction as object's weight—
Net force is sum of both forces—
Net acceleration is downward—
Net acceleration is negative.

RULE:
If you are "head downward," add 1 g to your accelerometer reading.

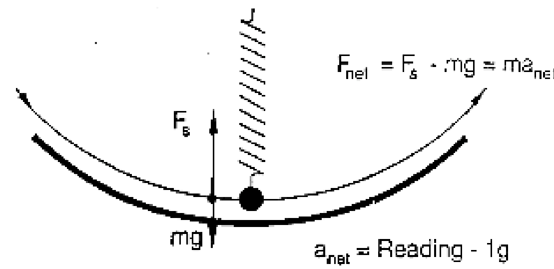
Vertical Accelerometer Physics
Circular Ride
(Accelerometer Sideways)



Object's weight is not a factor here—
Net force is in inward direction—
Net acceleration is inward.

RULE:
If you are "sideways," just take the reading on the accelerometer.

Vertical Accelerometer Physics
Bottom of Roller Coaster Dip
Bottom of a Loop



Spring force is larger than object's weight—
Net force is in upward direction—
Net acceleration is in upward direction—
Net acceleration is positive.

RULE:
If you are "head upward," subtract 1 g from the reading on the accelerometer.

MAKING MEASUREMENTS

TIME

The times that are required to work out the problems can easily be measured by using a watch with a second hand or a digital watch with a stop watch mode. When measuring the period of a ride that involves harmonic or circular motion, measure the time for several repetitions of the motion. This will give a better estimate of the period of motion than just measuring one repetition. You may want to make two or three measurements of the time, and then average your results.

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 the following methods. They will give you a reasonable estimate. Try to keep consistent units, e.g. meters, centimeters, etc., to make calculations easier.

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 and you can get the average distance per step. Knowing this, you can pace off horizontal distances.

My pace = _ ________ m

Ride Structure: Distance estimates can be obtained by making use of regularities in the structure of the ride. For example, tracks may have regularly spaced cross-members as shown in ***figure a.*** The distance d can be estimated, and by counting the number of cross members, distances along the track can be determined. This method can be used for both vertical and horizontal distances.

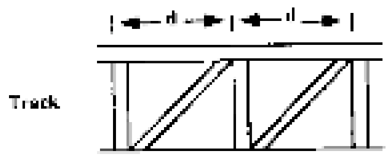


Figure a

Triangulation: For measuring height by triangulation, an astrolabe such as that shown in ***figure b*** can be used (see next page).

Practice this with the school flagpole before you come to the park.

Suppose the heights h_T of the **roller coaster** must be determined.

1. Measure the distance between you and the ride. You can pace off the distance.

   distance **d:** __________ m

2. Measure the height of the sighting tube.

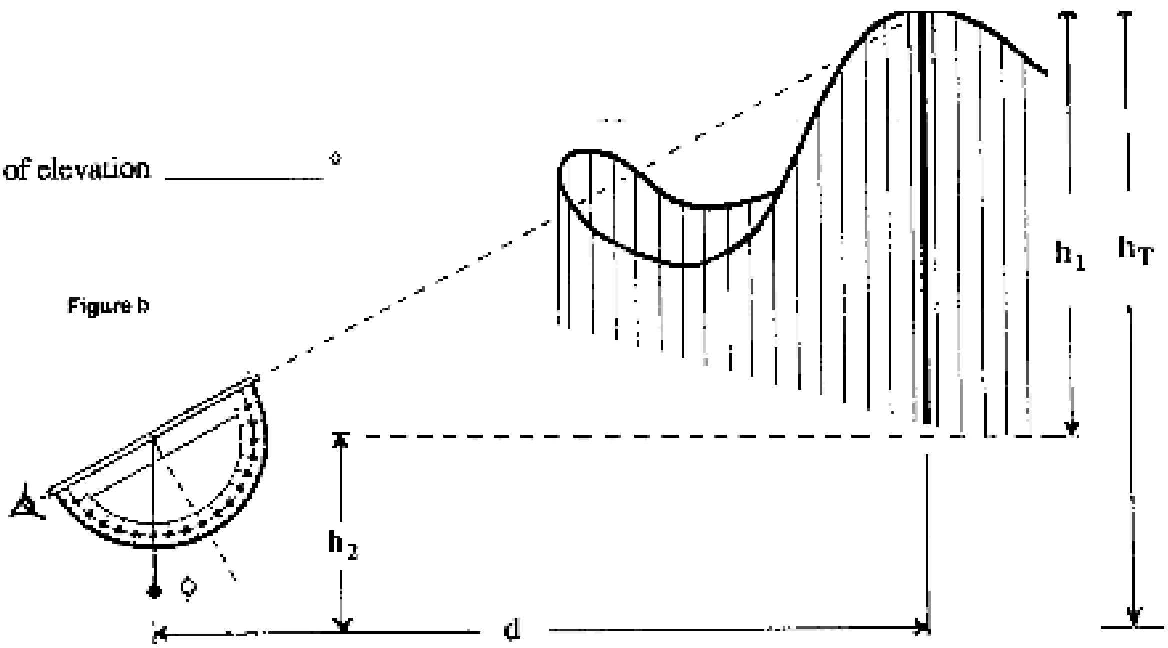
   sighting tube height h_2: h_2=_______ ____ m

3. Take a sighting at the highest point of the ride.

4. Read off the angle of elevation.

angle of elevation __________ °

Figure b



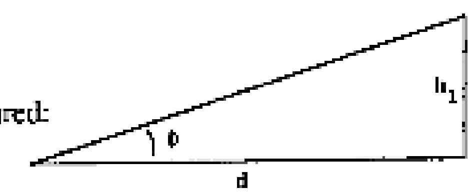
Then since

$h_1/d = \tan ø$

$h_1 = d\,(\tan ø)$

5. Look up the tangent value for the angle measured:

tangent value: __________



Angle	Tangent	Angle	Tangent	Angle	Tangent
0°	0.00	35°	0.70	70°	2.75
5°	0.09	40°	0.84	75°	3.73
10°	0.18	45°	1.00	80°	5.67
15°	0.27	50°	1.19	85°	11.43
20°	0.36	55°	1.43	90°	∞
25°	0.47	60°	1.73		
30°	0.58	65°	2.14		

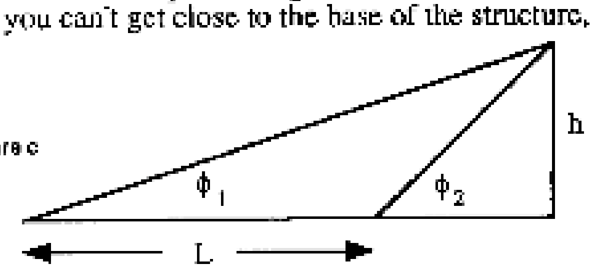
6. Multiply this tangent value by the distance from the ride: h_1 = __________ m

7. Add this product to the height of the sighting tube: h_2 = __________ m

This number is the height of the ride. h_T = __________ m

Other: There are other ways to measure distance. If you can think of one, use it. For example, a similar but more complex triangulation could be used. If you can't measure the distance **L** because you can't get close to the base of the structure, use the Law of Sines as in ***figure c*** below.

Figure c



Knowing φ_1, φ_2, and L, the height h can be calculated using the expression: $h = \left[\frac{\sin\phi_1 \cdot \sin\phi_2}{\sin(\varphi_2 - \varphi_1)}\right] \cdot L$

Vocabulary

acceleration The rate at which velocity changes. This occurs if there is change in speed or direction.

centrifugal force A reaction force to centripetal force, which you feel in a moving frame. This is a fictitious force. When your body responds to an acceleration you think there is a force pushing you back.

centripetal force A force acting toward the center which makes objects turn.

circumference The distant around a circular object.

diameter The distance across a circle through the center.

force A push or pull.

frame or reference Where you are when you make an observation. (eg. Earth frame or moving frame)

friction A force which opposes motion between objects in contact.

g force A multiplication factor which compares a force to a person's weight. (eg. 2 g's is twice your weight)

gravity A force of attraction between objects.

horsepower A unit established for comparison to the power of a horse. (1 hp = 746 watts)

inertia A property of matter which resists a change in its current state of motion.

joule A unit of work and / or energy in the metric system

kilogram A unit of mass in the metric system. (1000 grams)

kinetic energy The energy of motion. The energy an object has due to its velocity. KE = 1/2mv2

mass The amount of matter an object contains. Mass is unaffected by a change in gravity.

meter The basic unit of length in the metric system.

momentum A measure of how lard it is to stop a moving object. (mass x velocity)

newton A unit of force in the metric system.

parabola A curved path of an object moving at right angles to a gravitational field.

potential energy Stored energy. The energy an object has due to its position.

Gravitational potential energy = weight x height

power The rate of doing work. (P = work / time)

projectile An object which has been given kinetic energy and is moving with no self propulsion.

protractor A measuring device which indicates angles in degrees.

radius The distance from the center of a circle out to the edge.

watt The unit of power in the metric system. 1 watt = 1 joule / sec.

weight The force with which an object is pulled toward the Earth; measurement of force of gravity

weightlessness A condition in which you feel no forces acting on you.

work When a force acts on an object causing it to move through a distance. The amount of energy gained by an object that's moved is equal to the work needed to move it (no friction). Work = Force x distance

Systems of Measurement

System	*length*	*mass*	*time*	*area*	*volume*	*force*	*velocity*	*acceleration*	*work*	*energy*	*power*
Metric (MKS)	meter (m)	kg	sec (s)	m^2	m^3	newton (N)	m / s	m / s / s	joule (J)	joule (J)	watt (W)
Metric (CGS)	cm	gram (g)	sec (s)	cm^2	cm^3	dyne (dyn)	cm / s	cm / s / s	erg	erg	dyne-cm/ sec
English (FPS)	ft	slug (sl)	sec (s)	ft^2	ft^3	pound (lb)	ft / s	ft / s / s	ft-lb	ft-lb	ft-lb / sec

1 newton = 1 kg • m/ s^2
1 joule = newton • meter
1 watt = Newton • meter / s

Conversions

Energy:
1 erg = 10^{-7} joules
1 BTU = 1055 joules
Kilowatt • Hour = 3.6 x 10^{6} joules
1 calorie = 4.186 joules

Force:
1 dyne = 10^{-5} newtons
1 dyne = 2.247 x 10^{-6} lb
1 pound = 4.44 newtons

Volume:
1 liter = 10^{-3} m^3

Speed:
1 mph = .447 m / s

Mass:
1 atomic mass unit = 1.7 x 10^{-27} kg
1 kg = .0685 slug
1 slug = 14.59 kg

Power:
1 hp = 746 W
1 hp = 550 ft-lbs / sec

Angle:
1 degree = 1.745 x 10^{-2} rad

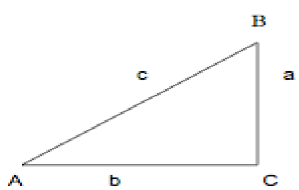
Length:
1 fermi = 10^{-15} meters
1 Angstrom = 10^{-10} m
1 inch = .0254 meters
1 foot = .3048
1 mile = 1609.3 meters

More Useful Science Stuff

Unit Prefixes for Powers of 10			
	Prefix	Symbol	Multiple
Greek	tera	T	12
	giga	G	9
	mega	M	6
	kilo	k	3
Latin	deci	d	-1
	centi	c	-2
	milli	m	-3
	micro	μ	-6
	nano	n	-9
	pico	p	-12

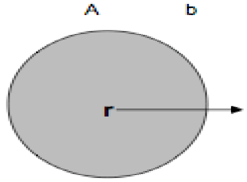
Math Help:

Right Triangle:



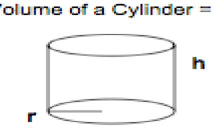
$c^2 = a^2 + b^2$
sin A = a/c
cos A = b/c
tan A = a / b

Circle:



Area of a Circle = πr^2
Circumference of a circle = $2 \pi r = \pi d$
Where r is the radius of the circle,
d is the diameter of the circle, and
π is approximately 3.14

Cylinders: Volume of a Cylinder = $\pi r^2 h$



Sphere: Volume of a sphere = $^4/_3 \pi r^3$

Reference Sheet:

$\bar{v} = s/t$

$a = \frac{\Delta v}{\Delta t}$

$s = ½\ gt^2$

$F = ma$

$w = mg$

$a_c = v^2/r$

$F_c = mv^2/r$

$W = Fd$

$P = W/t = Fd/t = F_v$

$s = v_i\Delta t + ½\ at^2$

$v^2 = 2as$

$v_m = \sqrt{gr}$

$\mu = F_f / F_n$

$F\Delta t = \Delta mv$

$m_1 v_1 = m_2 v_2$

$T = 1 / f$

$E_p = mgh$

$E_k = ½\ mv^2$

$T = 2\pi\sqrt{l/g}$

$\bar{v}$ = average speed

v = velocity

Δ = change in

s & d = distance

t = time

a = acceleration

v_m = minimum velocity

F = force

w = weight

g = acceleration due to gravity

r = radius of curvature

a_c = centripetal acceleration

F_c = centripetal force

m = mass

T = period

f = frequency

W = work

E_k = kinetic energy

E_p = potential energy

P = power

h = height

$F\Delta t$ = impulse

Δmv = change in momentum

l = length

F_f = force of friction

F_n = force normal to the surface