Physics Day

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ST. LOUIS

Suggestions for Making Measurements

with sponsorship from

Vernier
SOFTWARE

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SUGGESTIONS FOR MAKING MEASUREMENTS

It is a very good idea to read all of the questions for a ride before you start working on them. Many of the measurements that you will need can be taken while standing in line waiting for the ride. Use your time efficiently!

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 stopwatch 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 measure a time two or three times and then average them.

DISTANCE

Since you are not allowed to interfere with the normal operation of the rides, you will not be able to directly measure many 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, i.e. 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 made by noting 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.

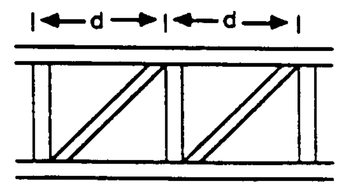
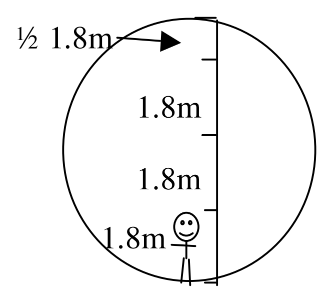


figure a

Comparing a known height or length to an unknown height or length: For example, if a friend of known height can stand next to the object of unknown height, estimate how many times taller the structure is than the friend. In the example to the right, the circle is 3.5 times as tall as the 1.8 meter-tall person, so the circle must be 6.3 meters tall.



Triangulation: For measuring height by triangulation, a sextant such as that shown in figure b on the following page can be constructed.

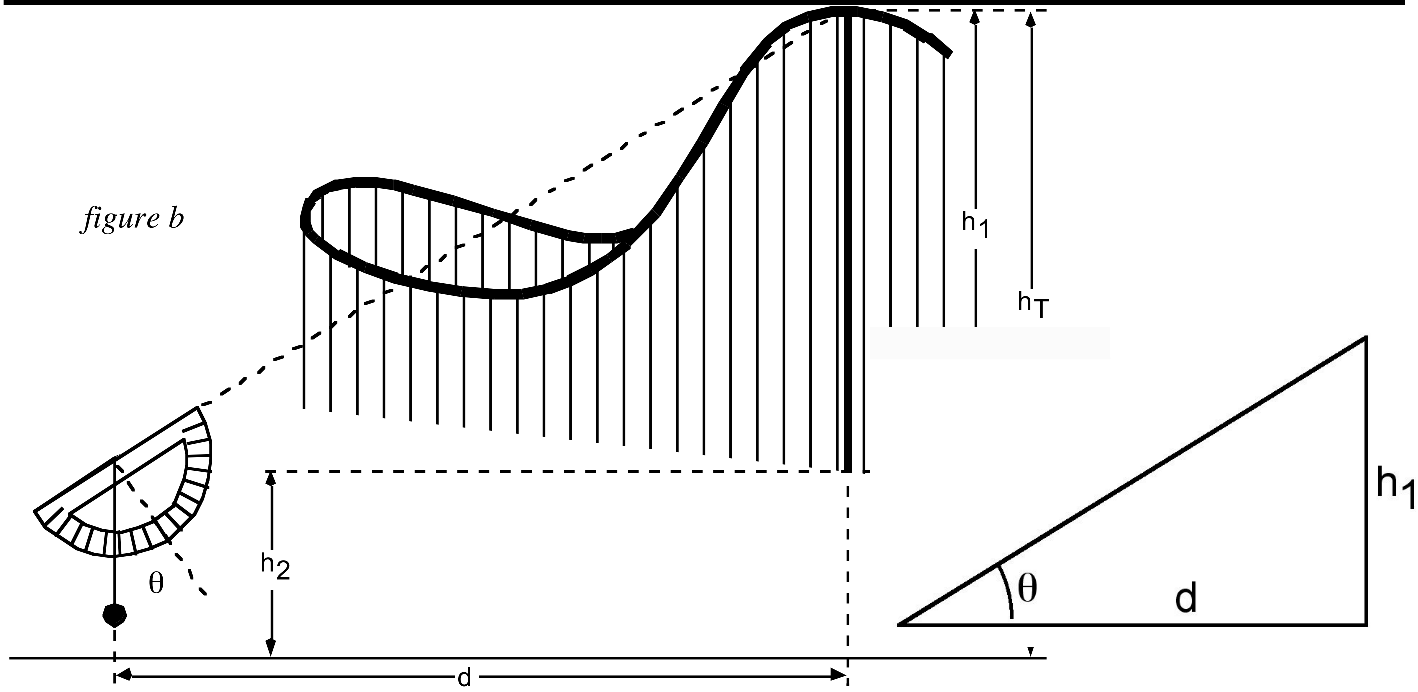
Suppose the height h_T, of the Screamin' Eagle must be determined.

1. Measure the distance between you and the ride. You can pace off the distance, or in some cases this will be provided.
2. Measure the height of the sextant above the ground.
   Sextant height h_2,=____________ m.
3. Take a sighting at the highest point of the ride.
4. Read off the angle of elevation.
   angle of elevation θ = ___________ °.

Practice finding the height of your school flagpole using triangulation before you come to Six Flags!

Suggestions for Making Measurements

figure b



Then since

$h_1/d = \tan\theta$

$h_1 = d(\tan\theta)$

The height of the ride (h_T) is the sum of the distance from the ground to the sextant (h_2) and the distance from the sextant to the top of the ride(h_1).

$h_T = h_1 + h_2$

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:

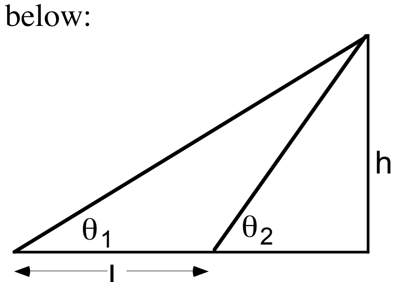


figure c

Knowing $\boldsymbol{\theta_1}$, $\boldsymbol{\theta_2}$, and **L**, the height **h** can be calculated using the expression:

$$h = \left[\frac{\sin\theta_1 \sin\theta_2}{\sin(\theta_2 - \theta_1)}\right] L$$

SPEED

1. In linear motion, the average speed of an object is given by: $\bar{v} = \frac{\Delta x}{\Delta t}$

where $\bar{v}$ represents the average speed of the object, Δx represents the distance traveled by the object and Δt represents the time required to travel that distance.

2. In circular motion, where tangential speed is constant: $\bar{v} = \frac{\Delta x}{\Delta t} = \frac{\text{Circumference of Ride}}{\text{Period of Revolution}} = \frac{2\pi r}{T}$

where r is the radius of the ride and T is the time for the ride to make one revolution.

3. 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 train's speed then is given by:

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{\text{length of train}}{\text{time to pass point}}$$

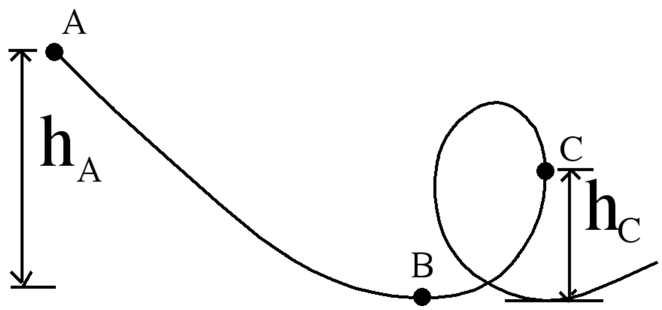
4. In a situation where it can be assumed that total mechanical energy is conserved, the speed of an object can be calculated using energy considerations. Suppose the speed at point C is to be determined (see figure d). From the principle of conservation of energy if follows that:

$$PE_A + KE_A = PE_C + KE_C$$

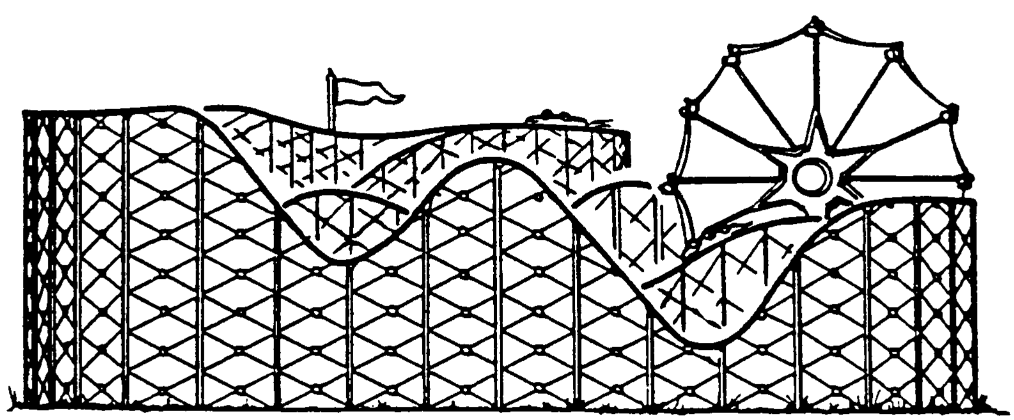
$$mgh_A + \tfrac{1}{2}mv_A^2 = mgh_C + \tfrac{1}{2}mv_C^2$$

Since mass is constant, solving for v_C

$$v_C = \sqrt{2g(h_A - h_C) - v_A^2}$$



Thus by measuring the speed of the train at point **A**, and the heights $\mathbf{h_A}$ and $\mathbf{h_C}$,, the speed of the train at point **C** can be calculated.

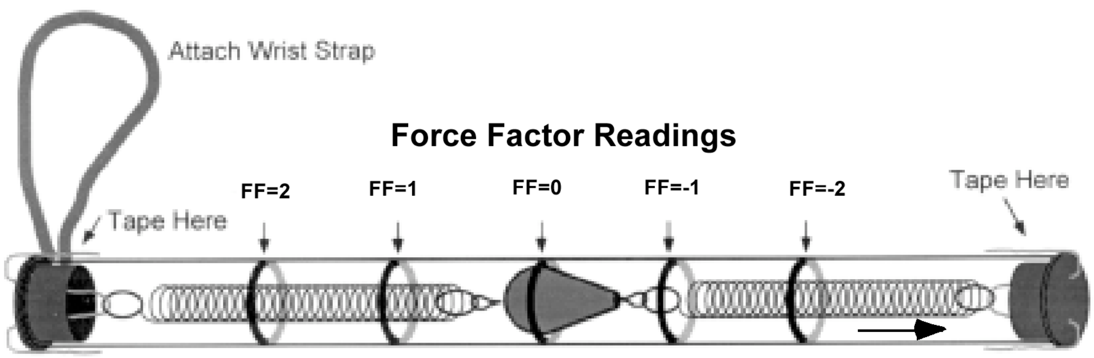


ACCELERATION

An Important Note About Force Factor Meters vs. Accelerometers!

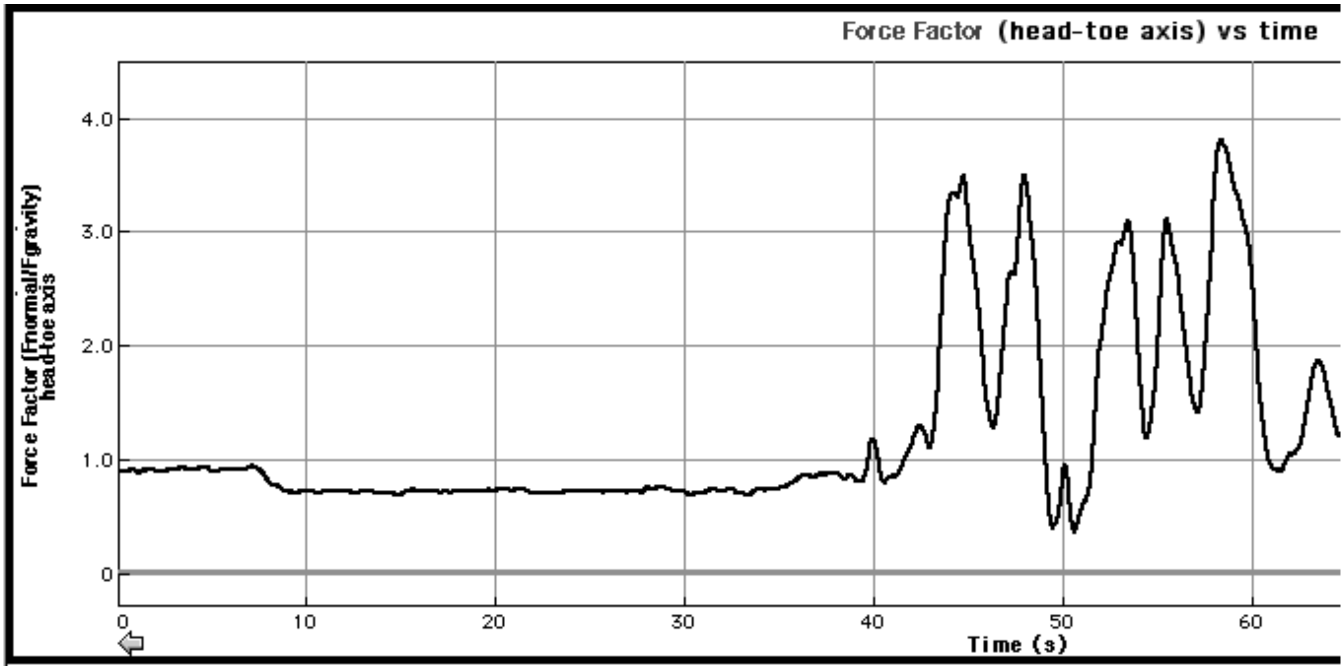
Please note that the handheld or electronic devices that are commonly called “accelerometers” are not really accelerometers! These devices, that we call Force Factor meters, can be calibrated to measure the ratio of the normal force in the direction of measurement to the magnitude of the gravitational force. That ratio, the Force Factor, is really a multiplier that can be used to find the normal force on an object. In other words, the Force Factor in a given direction multiplied by the magnitude of the gravitational force on an object equals the normal force on that object in that direction. Because of this, the labels on the graphs included in the materials do not read Acceleration vs. Time, but rather Force Factor vs. time.

Force Factor Meters



Above: The two-spring Force Factor meter can measure positive and negative Force Factors.
Below, at Left: A single-spring homemade Force Factor meter. Oriented vertically, the current reading is a Force Factor of 1.0, meaning that the upward normal force on the meter equals the gravitational force on the meter.

Above Center and Above Right: Vernier’s 3-axis “accelerometer” and their Wireless Dynamics Sensor System are devices that would be secured in a data vest worn by someone riding the ride. Because these sensors are fixed in orientation relative to the rider, the coordinate axes for measurement are named head-to-toe, front-to-back, and side-to-side. Coordinate axis names like “vertical” are clearly problematic when analyzing data taken while looping and spinning on rides. Typical data from the electronic force Factor Meters looks like the section of the data from “Batman – the Ride” shown below.



EXAMPLES USING THE FORCE FACTOR METER:

- When you are at rest and the meter is pointing upward the Force Factor meter is calibrated to read a Force Factor of 1.0. This reading, really a multiplier of 1.0, means that you have a normal force upward on your body that is equal to the magnitude of the gravitational force on you.

- When you upside down at the top of a loop, on Mr. Freeze or Batman, and the Force Factor meter is pointed downward and reads 1.5. This reading means that you have a normal force on your body downward that is equal to 1.5 times the magnitude of the gravitational force on you.

- When you are slowing at the end of the Screamin’ Eagle ride and the Force Factor meter is pointing in the direction you are moving and reads -0.7. This reading means that you have a normal force acting that is opposite the direction you are moving and equal to 0.7 times the magnitude of the gravitational force on you.

- These calibrations mean that in **any** orientation the Force Factor meter measures the ratio of the normal force on an object in the direction of measurement to the magnitude of the gravitational force on that object.

Remember that the Force Factor meter allows you to calculate only the normal force on the object not the net force and you need to consider all of the forces acting on the object by creating a freebody diagram in order to calculate the acceleration.

Useful Formulas	Key to Symbols	
$\bar{\vec{v}} = \frac{\Delta\vec{x}}{\Delta t}$	$\vec{x}$	position
$\bar{\vec{a}} = \frac{\Delta\vec{v}}{\Delta t}$	$\Delta\vec{x}$	displacement
$\vec{v}_f = \vec{v}_o + \vec{a}\Delta t$	Δx	distance traveled
$\vec{v}_f^2 = \vec{v}_o^2 + 2\vec{a}\Delta\vec{x}$	Δt	elapsed time
$\Delta\vec{x} = \vec{v}_o\Delta t + \frac{1}{2}\vec{a}\Delta t^2$	v	speed
$\vec{F}_{net} = m\vec{a}$	$\vec{v}$	velocity
$\vec{p} = m\vec{v}$	$\vec{v}_i$	initial velocity
$\vec{F}_{net}\Delta t = \Delta\vec{p}$	$\vec{v}_f$	final velocity
$a_c = \frac{v^2}{r}$	$\bar{\vec{v}}$	average velocity
$\vec{F}_c = \frac{mv^2}{r}$	$\vec{a}$	acceleration
$v = \frac{2\pi r}{T}$	$\bar{\vec{a}}$	average acceleration
$W = \vec{F}\cdot\Delta\vec{x}$	a_c	centripetal acceleration
$P = \frac{W}{\Delta t}$	$\vec{F}$	force
$KE = \frac{1}{2}mv^2$	$\vec{F}_{net}$	net force
$PE_{grav} = mgh$	F_c	centripetal force
$T = 2\pi\sqrt{\frac{L}{g}}$	$\vec{p}$	momentum
	W	work
	PE_{grav}	gravitational potential energy
	KE	kinetic energy
	T	period of revolution or period of oscillation