

***Instruction Manual and
Experiment Guide for the
PASCO scientific Model
ME-9426A***

012-03776E

AMUSEMENT PARK PHYSICS

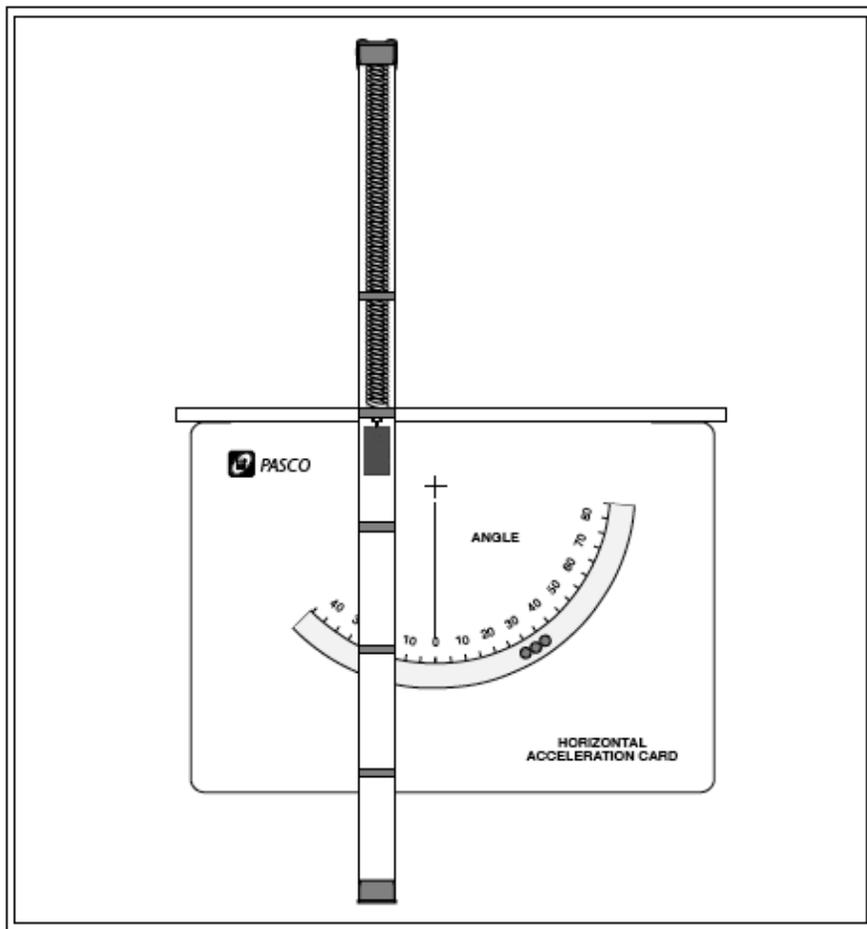


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1. The carton must be strong enough for the item shipped.
2. Make certain there is at least two inches of packing material between any point on the apparatus and the inside walls of the carton.
3. Make certain that the packing material can not shift in the box, or become compressed, thus letting the instrument come in contact with the edge of the box.

Address: PASCO scientific

10101 Foothills Blvd.

P.O. Box 619011

Roseville, CA 95678-9011

Phone: (916) 786-3800

FAX: (916) 786-8905

email: techsupp@pasco.com

web: www.pasco.com

Introduction

Over the past few years, an increasing number of high school physics classes have been taking one day a year to visit an amusement park for an open air physics lab. With a few simple instruments - a vertical accelerometer, a horizontal accelerometer (that doubles as a sextant), and a piece of string marked out in meters - students make measurements that allow them to analyze the motion of the various rides. It's an invigorating form of laboratory physics, mentally and physically. It's one thing to watch a lab cart rolling on a table. It's quite another thing to be in the lab cart yourself.

Description

The Model ME-9426A Amusement Park Physics (15 pack) provides material for 15 vertical accelerometers and 15 horizontal accelerometers. The kit also includes a ball of string that can be marked off in meters for distance measurements, and plastic bags for protecting accelerometers, paper, etc., from some of the more aquatic rides. The only materials you'll need that aren't provided are scissors, masking tape, pliers, clear plastic tape, and an amusement park. The accelerometers are designed to be assembled by the students, themselves. Instruction sheets are included with the kits.

About This Manual

This manual includes some basic information on using the accelerometers. It also includes three experiments that do not require an amusement park: two experiments for playgrounds, and one for elevators.

We haven't included amusement park experiments for

two reasons. The first is that the rides vary greatly from park to park. The second is that experimental information is readily available from other sources. See your local PTRA (Physics Teacher's Resource Agent) for information.

Other

The American Association of Physics Teachers (AAPT) *Amusement Park Physics* handbook, edited by Carole Escobar, is a collection of the various materials written and circulated by individual teachers. *Amusement Park Physics* presents all the information you need both to plan a trip to a park and to use the physics of amusement parts rides in your classes. The handbook includes a teacher's guide, practice problems, information on accelerometers, a measurements reference, laboratory exercises, reproducible student worksheets, and reprinted resource articles. (ISBN 0-917853-53-9 © 1994). See the AAPT web site:

www.thephysicsstore.com

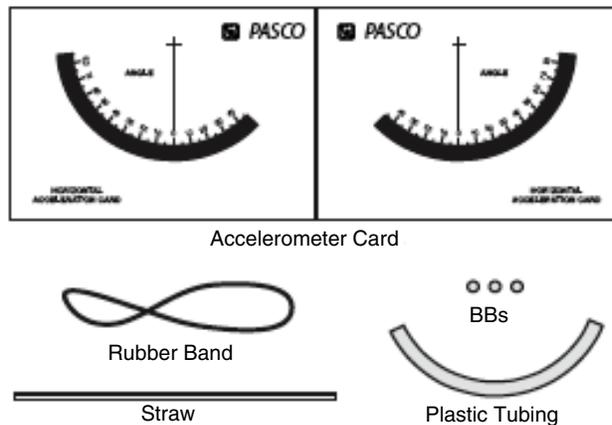
It's quite possible that there is already an Amusement Park Physics Day planned at a park near you, and materials may be available that are applicable to that particular park.

See the PASCO web site at www.pasco.com for more information on PASCO interfaces, equipment, and software.

Materials

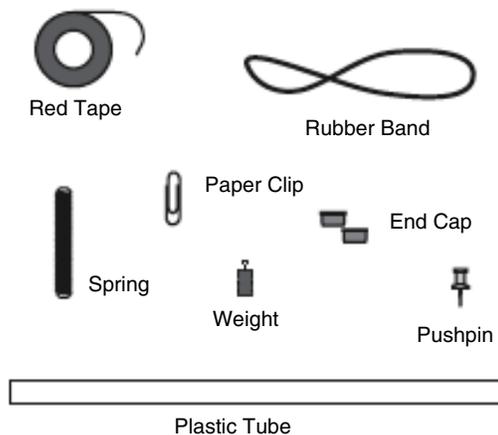
Materials Included for Building Horizontal Accelerometers

- Accelerometer Card 15 ea.
- Rubber Band 15 ea.
- Straw 15 ea.
- BBs 45 ea.
- Plastic Tubing 2.4 m



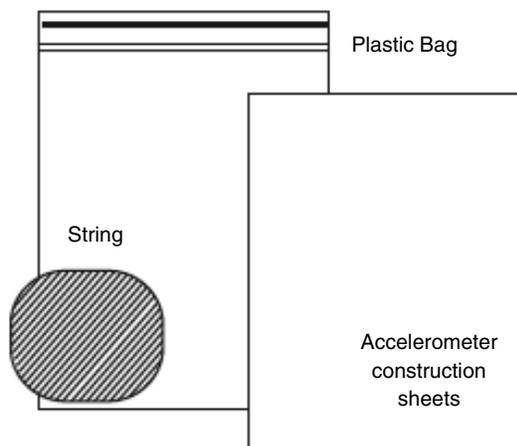
Materials Included for Building Vertical Accelerometers

- Springs 15 ea.
- Plastic Tube (30 cm long) 15 ea.
- End Cap (for plastic tube) 30 ea.
- Pushpin 1 ea.
- Weight (10 g) 15 ea.
- Paper Clip (#3) 15 ea.
- Red Tape (3 mm wide) 1 roll
- Rubber Band 15 ea.



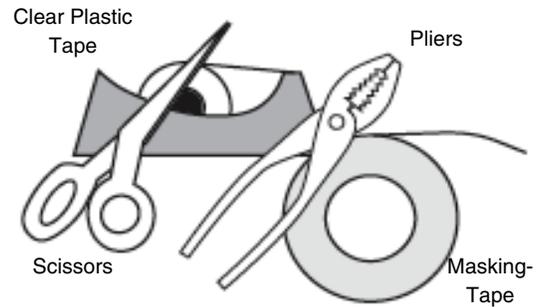
Also Included

- Plastic "Zip-Loc" Bag 15 ea.
- Accelerometer Construction Sheet 15 ea.
- String 1 roll
- Pushpin 1 ea.
- Bumper Sticker (not shown) 25 ea.



You will need to supply

- Scissors
- Masking Tape
- Clear Plastic Tape
- Pliers



Accelerometers: Theory and Operation

Accelerometers measure accelerations by measuring forces. The vertical accelerometer in this kit consists of a cylindrical weight 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 weight, 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 weight 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 weight by the spring.

Calibration of the device can be in newtons for the spring

force, or, in the ratio $\frac{F_s}{m} = a$

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

cylinder, or $\frac{F_s}{m} = 9.8 \frac{m}{s^2}$.

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

cylinder is given by: $F_{net} = F_s - mg$

where mg is the weight of the cylinder.

A diagram of the spring and weight 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".

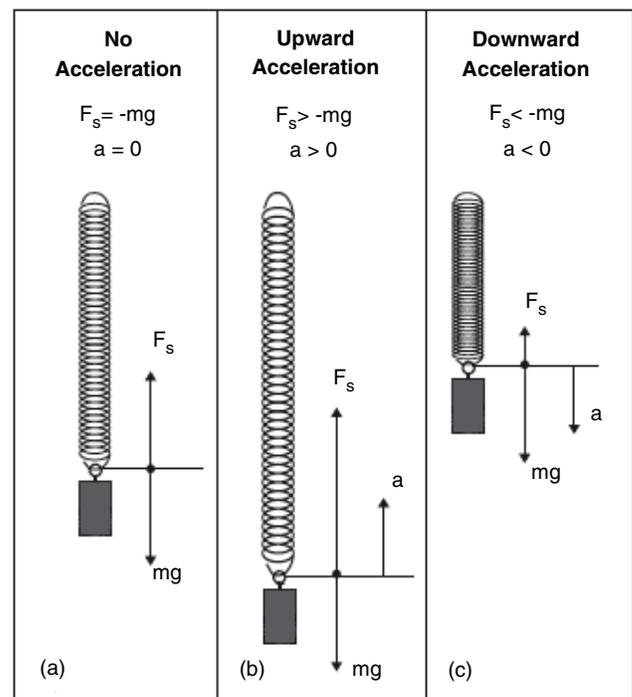


Figure 1: Diagram of the Vertical Accelerometer

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

If the weight 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 weight will be below the "1g" position.

If the weight 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 cylinder 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 weight 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 cylinder 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 due 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 weight, 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 cylinder 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 q 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 :

$$\tan \theta = \frac{ma}{mg}$$

and

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

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

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

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.

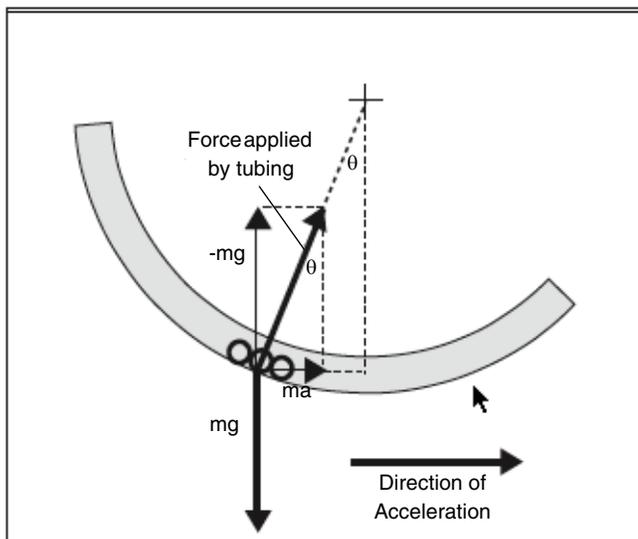


Figure 2: Diagram of the Horizontal Accelerometer

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

$$a = \frac{v^2}{r}$$

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.

Using the Horizontal Accelerometer as a Sextant

The horizontal accelerometer can be used to measure the heights of objects that are too high to measure directly, such as measuring the height from the ground to the top

of King Kong's head, in Figure 3. You can measure these distances with reasonable accuracy using just the accelerometer, a piece of string that is marked out in meters, and a little trigonometry. The procedure is as follows:

1. Measure the distance S with a piece of string marked out in meters.

S is the horizontal distance between your point of observation and a point directly below the object of interest.

2. Sight through the straw to the top of King Kong's head, and measure the angle θ on the accelerometer.

θ is the angle that the center BB aligns with on the horizontal accelerometer. It is also the angle between your horizontal line of sight and your line of sight to the top of King Kong's head.

3. Measure h_0 , the vertical distance between the base of your height measurement and your observation point.

As long as the ground is level between you and the building on which King Kong is standing, h_0 is just the distance from the ground to your eyes.

4. Then:

$$H = h_0 + h_1 = h_0 + S \tan \theta.$$

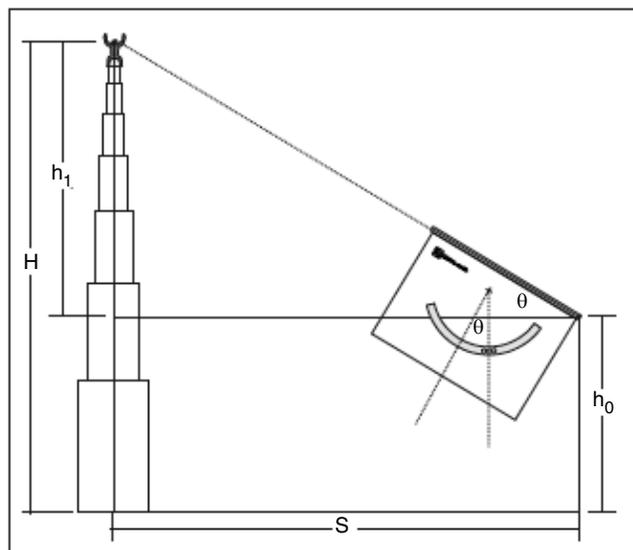


Figure 3: Measuring Heights with the Horizontal Accelerometer

Construction and other Tips

A. Vertical Accelerometer

When calibrating the vertical accelerometer, it is wise to employ Hooke's Law and a some foresight. In Figure 4, a thin, solid wire has been attached to a weight. By hooking the end of the wire onto the lower end of the spring just before lowering it into the tube, one can establish the "2g" point easily. Then pull the 2nd weight out the bottom of the tube and remove it, allowing the single weight to rise up to the "1g" point. With these two points determined, it is easy to finish calibrating the accelerometer.

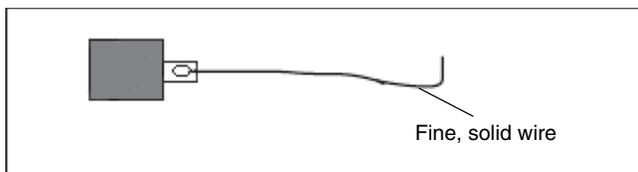


Figure 4: Method of calibrating Vertical Accelerometer

B. Horizontal Accelerometer

1. One method for constructing the horizontal accelerometer makes use of the rapid set-up time of hot glue. Put the clear tubing in one half of the cardboard, insert the three BB's. Now put hot glue in the places indicated in Figure 5. Pressing the two halves of the accelerometer together results in a completed project (except for the straw which can also be hot glued on) 15 seconds later. NOTE: Do not get hot glue in the end of the tube as the BB's tend to stick to the glue.

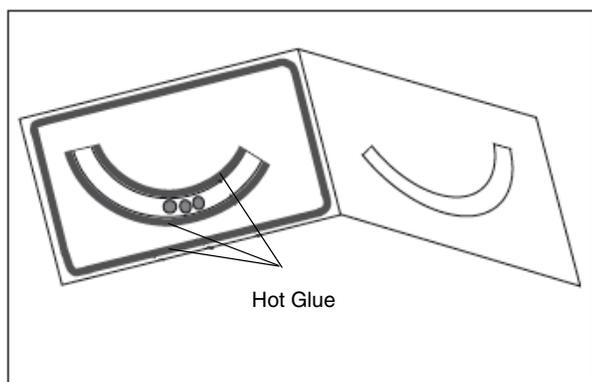


Figure 5: Using Hot Glue to Construct the Horizontal Accelerometer

2. For students using simple calculators (no trig functions), a helpful aide is to reproduce the table of tangents and glue it to the side of the horizontal accelerometer. Both the acceleration and the heights of rides depends upon the tangent value.
3. Also for ease of use, the student may wish to put the length of his/her pace on the side of the horizontal accelerometer if this is the method being used to measure horizontal distances.
4. Other uses of the accelerometers:
 - a. Use the vertical accelerometer to measure the acceleration achieved when jumping upwards, or to measure the stopping acceleration when jumping down from a chair seat. The basic principle of the device can be clearly learned before going to the park.
 - b. Accelerometers can be employed on mass transit to measure motion, including buses, light rail and subway systems.
 - c. The horizontal accelerometer can be used to sight star altitudes.

Table 1: Table of Tangents

| Angle | Tangent | Angle | Tangent |
|-------|---------|-------|---------|
| 0 | 0.00 | 45 | 1.00 |
| 5 | 0.09 | 50 | 1.19 |
| 10 | 0.18 | 55 | 1.43 |
| 15 | 0.27 | 60 | 1.73 |
| 20 | 0.36 | 65 | 2.14 |
| 25 | 0.47 | 70 | 2.75 |
| 30 | 0.58 | 75 | 3.73 |
| 35 | 0.70 | 80 | 5.67 |
| 40 | 0.84 | 85 | 11.40 |

Experiment 1: Playground Physics / Merry-Go-Round

Objective

In this lab you will experiment with centripetal accelerations on a playground merry-go-round.

Discussion

On a merry-go-round, we experience the sensation of being "thrown outward". Physics students know that this is really inertia trying to keep us moving in a straight line. However, by exerting the right amount of inward or centripetal force, we can successfully stay in a circular path (and on the merry-go-round). This force is usually supplied by friction between our shoes and the ride and/or friction between our hands and the bars of the merry-go-round. How does this force change with varying distance from the center of the ride? How does this force depend on the speed of rotation of the ride?

At least two people are needed to carry out this lab, although three or more would be better. A stopwatch or digital wristwatch and one or more horizontal accelerometers are needed to conduct the lab. Additionally, a measuring device capable of measuring to the nearest 0.1 meter is needed.

Procedure

1. Measure off several distances from the center of rotation. Place the lateral accelerometer at one distance, holding it against a bar if necessary to keep it from moving, and holding it so that it is level. The middle BB should be at 0° . Record the distance, R , in Table 1. Note: Several riders, each with a lateral accelerometer, could be positioned simultaneously at different distances.
2. Push the merry-go-round until it is moving at a steady, but relatively slow angular speed.
3. Measure the time it takes to go once completely around at the current speed, or better yet, the time to go five times around and divide by five to get the average period of rotation, T . While the merry-go-round is turning, the person on the ride measures the angle that the center BB moves to, θ . Record the period and angle in Table 1.
4. Repeat step 3 with at least three different speeds of rotation, holding the accelerometer steady at the same radius. Record the appropriate values in the data table.
5. Repeat step 3 after moving the accelerometer to a new radius. Try to rotate the merry-go-round at the same speed it was turned during the first trial.

Analysis

1. For each trial, calculate the tangential speed, the speed that the accelerometer was travelling around its circular path, $v = 2\pi R/T$. Record your calculated values in Table 2.
2. For each trial, calculate the centripetal acceleration, $a_c = v^2/R$ or $a_c = 4\pi^2 R/T^2$.
3. For each trial, calculate the "measured acceleration" from the angle of the BB's, $a_c = g \tan \theta$.
4. Compare the calculated and the measured acceleration values for each trial. Were the results identical? Similar? What type of percentage difference did you get in your results?
5. When the merry-go-round was going at approximately the same speed, how did the measured acceleration vary with the radius? Was it linear? What was the mathematical relationship?
6. When the accelerometer was held at the same radius, what was the relationship between the measured acceleration and the speed? Was it linear? What was the mathematical relationship?
7. Finally, what are some of the sources of possible error in this experiment? .

Table 1:

| Trial # | Radius (m) | Period (s) | Angle (°) |
|---------|------------|------------|-----------|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |

Table 2:

| Trial # | Tangential Speed (m/s) | Centripetal Acceleration (m/s ²) | Measured Acceleration (m/s ²) |
|---------|------------------------|--|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |

Experiment 2: Playground Physics / The Swing

Objective

In this lab you will measure the maximum acceleration on a swing and compare this to a value arrived at through the principles of conservation of energy and centripetal force.

Discussion

On a swing, we see a number of important physical phenomena, including simple harmonic motion, driven harmonic motion, inertia, conversion of energy between gravitational potential and kinetic, and centripetal force. In this experiment, we use the latter two ideas to calculate an acceleration and then compare the results with the acceleration we actually measure. At least two people are needed to carry out this lab. They will need both a horizontal and a vertical accelerometer.

Procedure

1. Person A begins swinging with the vertical accelerometer. Person B takes up a position to the side so that he/she can see and measure the angle of the swinger's motion.
2. Person A on the swing keeps the vertical accelerometer pointed upwards along the chain or rope, and will focus on reading the maximum value as he/she passes through the bottom-most point of the swing. This value will be recorded as a_{\max} .
3. Person B, to the side, will use the lateral accelerometer to measure the maximum angle that the swinger moves to during the swing. Line the straw side of the accelerometer up with the chain. The angle θ that is indicated on the accelerometer is going to be 90° minus the angle from the vertical. The angle measured should be recorded as well as its complement. See Figure 1.
4. When the person on the swing gets to a point where the observer on the ground has a good reading on the maximum angle, write down both the angle and the maximum acceleration. Repeat in this manner for at least three different angles, then change places and repeat. Use Table 3 to record your data.
5. Finally, determine the length of the swing. You can use one person's height and then scale up, or pace off a horizontal distance and use the lateral accelerometer to determine the height, or use an appropriate measuring device. With the swinger seated, you can approximate his/her center of mass as being close to the seat.

Analysis

1. Use trigonometry as shown below to calculate the difference in heights of the swinger between the maximum height and the bottom of the swing for each trial. Record your calculations in Table 4. NOTE: This value can actually be measured directly with a measuring tape by pulling the swing back to the angle determined by person B.
2. Apply conservation of energy between gravitational potential (G.P.E.) and kinetic (K.E.) to determine the maximum velocity at the bottom of the swing. Note that the equations give $mg\Delta h = \frac{1}{2}mv^2$, so the mass divides out.
3. The acceleration at the bottom of the swing has two parts: gravity and centripetal. We can show that the centripetal acceleration is just v^2/L , where L is the length of the swing. Calculate this value and convert to g 's by dividing your result by 9.8 m/sec^2 . Add the $1g$ due to gravity to get the total acceleration.
4. Compare the values you calculated and the corresponding values

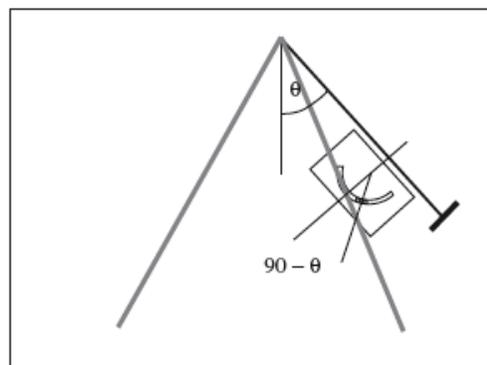


Figure 1

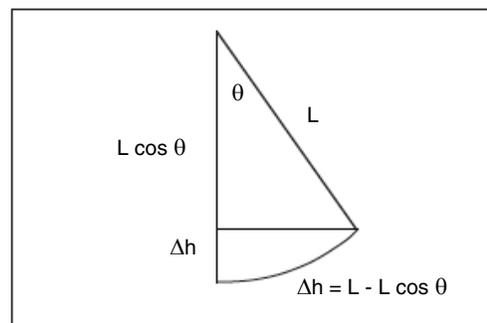


Figure 2

measured on the swing. Examine the situation and suggest areas where your calculations could have been off due to approximations.

Data

Table 3:

| Trial # | Swinger | Measured Acceleration (g's) | Maximum Angle θ |
|---------|---------|-----------------------------|------------------------|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |

Table 4:

| Max. Angle θ | Complementary Angle θ | Height Diff. Δh | Maximum Velocity v_{max} | Centripetal Acceleration a_c | Maximum Acceleration a_{max} |
|---------------------|------------------------------|-------------------------|----------------------------|--------------------------------|--------------------------------|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |
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Experiment 3: Elevator Physics

Objective

During this lab you will determine the vertical accelerations in an elevator using an accelerometer. You will also analyze the motion of an elevator.

Discussion

The net force on the mass in the accelerometer is given by the relationship

$$: \quad \mathbf{F}_s - \mathbf{mg} = \mathbf{F}_{\text{net}} = \mathbf{ma}_{\text{net}}$$

where \mathbf{F}_s is the force applied by the spring to the mass, and \mathbf{mg} is the weight due to gravity of the mass. When the mass is at rest or moving with constant speed in an upward or downward direction, the upward pull of the spring is equal in magnitude to the downward pull of the weight. In these cases, the net force is zero and the net acceleration of the mass is zero. If the accelerometer is calibrated to read "1g" when it is at rest, that recognizes the 1g effect of gravity. To get the net acceleration of zero, you subtract 1g from the reading. If the mass is accelerating upward, it will be in a position below "1g" or at a reading greater than 1g. Again, the net acceleration can be determined by subtracting 1g from the accelerometer reading. The reading will still be above zero (positive) indicating an upward acceleration. If the mass is accelerating downward, it will be above the "1g" position, or a reading of less than 1g. Subtracting 1g will yield a negative net acceleration in agreement with the downward acceleration of the mass.

Procedure

Hold the accelerometer vertical by pressing it to the wall of the elevator. Take readings in each of the following instances (see Table 5).

Table 5:

| | Trial 1 | Trial 2 | Trial 3 |
|-------------------|---------|---------|---------|
| Standing still | | | |
| Beginning ascent | | | |
| Middle of ascent | | | |
| Slowing ascent | | | |
| Stopped | | | |
| Beginning descent | | | |
| Middle of descent | | | |
| Slowing descent | | | |
| Stopped | | | |

Questions

1. Are the magnitudes of the accelerations different at the beginning of the ascent than in the middle of the ascent?
Explain why this is so.
2. Are the magnitudes of the accelerations different at the middle of the ascent than at the middle of the descent?
Explain why this is so.

3. How does the starting acceleration compare with the stopping acceleration? Was it the same during the ascent as it was during the descent?
4. Were the acceleration values constant during any of the periods of acceleration, or did they vary? How did they vary? Were they all the same pattern?
5. How did you feel in each of the situations where you took readings? Compare your feelings with the accelerometer readings.

Mathematical

If instructed, take a new set of readings, adding in the time for which each interval to occur, the distance over which it occurred and the net acceleration.

Table 6:

| | Time | Distance | Net Acceleration |
|-------------------|------|----------|------------------|
| Standing still | | | |
| Beginning ascent | | | |
| Middle of ascent | | | |
| Slowing ascent | | | |
| Stopped | | | |
| Beginning descent | | | |
| Middle of descent | | | |
| Slowing descent | | | |
| Stopped | | | |

Questions

1. What was the average speed going up?
2. What was the average speed going down?
3. Use your acceleration values and times to calculate distances for each of the accelerations. How do your calculated values compare with the ones measured (or estimated)?
4. What was your average speed during the periods where you were moving at a constant speed?

Use your data to construct a distance vs time and a velocity vs time graph.

6. Do these graphs accurately reflect the motion you experienced on the elevator? Explain your feelings at different places during the experience.

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

email: techsupp@PASCO.com

Tech support fax: (916) 786-3292

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

- If your problem is computer/software related, note:
 - Title and Revision Date of software.
 - Type of Computer (Make, Model, Speed).
 - Type of external Cables/Peripherals.
- If your problem is with the PASCO apparatus, note:
 - Title and Model number (usually listed on the label).
 - Approximate age of apparatus.
 - A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)
 - If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.
- If your problem relates to the instruction manual, note:
 - Part number and Revision (listed by month and year on the front cover).
 - Have the manual at hand to discuss your questions.

Notes: