Computer
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Bungee Jump Accelerations

In this experiment, you will investigate the accelerations that occur during a bungee jump. The graph below records the acceleration *vs.* time for an actual bungee jump, where the jumper jumped straight upward, then fell vertically downward. The positive direction on the graph is upward.

For about the first 2 seconds, the jumper stands on the platform in preparation for the jump. At this point the acceleration is 0 m/s^2. In the next short period of time, the jumper dips downward then pushes upward, both accelerations showing up on the graph. Between about 2.5 seconds and 4.5 seconds, the jumper is freely falling and the acceleration is near – 9.8 m/s^2.

When all of the slack is out of the bungee cord, the acceleration begins to change. As the bungee cord stretches, it exerts an upward force on the jumper. Eventually the acceleration is upward although the jumper is still falling. A maximum positive acceleration corresponds to the bungee cord being extended to its maximum.

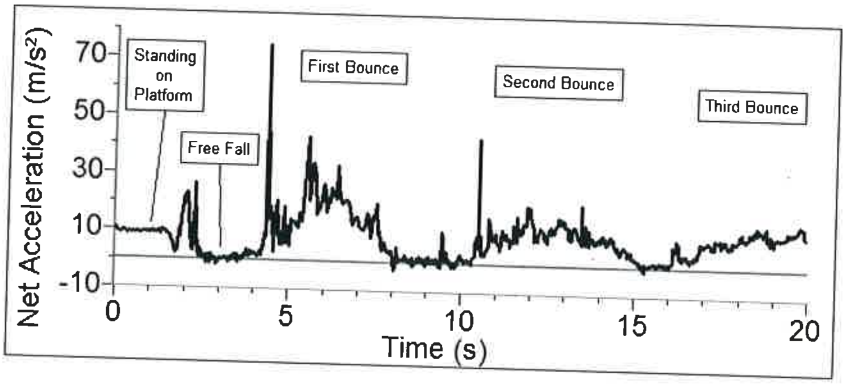


Figure 1

In your experiment, a block of wood or a toy doll will substitute for the jumper, and a rubber band will substitute for the bungee cord. An Accelerometer connected to the "jumper" will be used to monitor the accelerations.

OBJECTIVES

- Use an Accelerometer to analyze the motion of a bungee jumper from just prior to the jump through a few oscillations after the jump.
- Determine where in the motion the acceleration is at a maximum and at a minimum.
- Compare the laboratory jump with an actual bungee jump.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Low-g Accelerometer or WDSS
bungee jumper (wooden block or small doll)
bungee cord (long, flexible rubber band)
ring stand

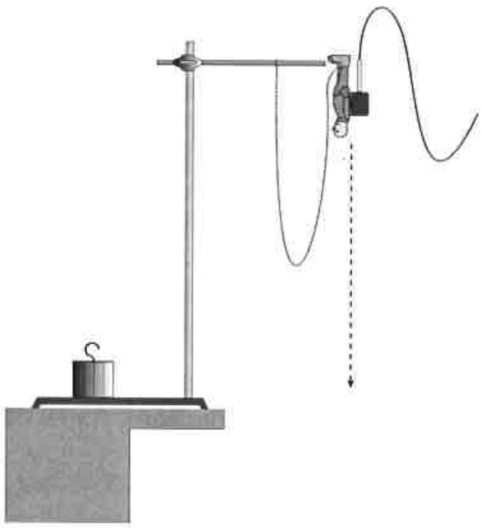
PRELIMINARY QUESTIONS

1. Think about the forces acting on the bungee jumper at the lowest point of the jump. Draw a free-body diagram indicating the forces acting on the jumper. The force vectors with greater magnitude should be represented by longer arrows. Label the force vectors.
2. Study the graph of the acceleration during an actual bungee jump (Figure 1). On the graph, label the time corresponding to the lowest position during the jump.
3. What was the acceleration at that point? Was the direction of the acceleration up or down?
4. Label the time where the jumper reached the highest position during the first bounce.
5. What was the magnitude of the acceleration at that time? Was the direction of the acceleration up or down?
6. How long was the bungee cord used in the real bungee jump? Hint: Consider how long the jumper fell before the cord started pulling on him.

PROCEDURE

Part I The Jump–Step by Step

1. Connect the Vernier Low-g Accelerometer to Channel 1 of the interface. Attach a block of wood or small doll (your jumper) to the Accelerometer. The arrow on the Accelerometer should be pointing upward (toward the hook if using a block, or toward the feet of the doll).
2. Tie the rubber band to the hook on the wooden block or to the feet of the doll. Tie the other end of the rubber band to a rigid support, such as a large ring stand. Adjust the length of the cord so that the block or doll does not hit the floor when dropped.



3. Open the file "07 Bungee Jump" in the *Physics with Vernier* folder. The Accelerometer is calibrated so that it reads, only for the vertical direction, zero acceleration when at rest and –9.8 m/s^2 when in free fall. You will do this in Steps 5 and 6.
4. Hold the bungee jumper stationary on the table, with the Accelerometer arrow pointing up. Click [Ø Zero] to define the state as zero acceleration.
5. Click [▶ Collect] to begin collecting data. Do not release the jumper. When data collection has finished, select a region of the graph by dragging the mouse pointer across it. Determine the mean (average) acceleration by clicking the Statistics button, [Statistics]. It should be near zero. This value represents the acceleration of the jumper prior to jumping.

6. Repeat Step 5, but this time drop the jumper and let it free fall. Make sure it is oriented properly (arrow pointed up). Catch the jumper while the cord is still slack. Determine the average acceleration during the fall. It should be close to -9.8 m/s^2.

7. Let the jumper hang from the bungee cord. Pull the jumper down 5 cm and release the jumper, creating an up-and-down oscillation similar to a mass suspended from a vibrating spring. Click ▶ Collect and observe the graph. Determine the point in the motion where acceleration is both positive in direction and has a maximum magnitude. Does this occur when the jumper is at the bottom, middle, or top of the oscillation?

Part II A Complete Jump

8. Lift the bungee jumper to the height of the ring stand, as shown in Figure 2. The bungee cord should be hanging to the side and the Accelerometer cable should be clear of the jump path. Make sure that the Accelerometer arrow is pointing up. The connection point between the bungee cord and the jumper should also be pointing upward.

9. Click ▶ Collect to start collecting data. Wait 1 s and release the bungee jumper so that it falls straight down with a minimum of rotation. Let the jumper bounce a few times. Be sure that the Accelerometer cable still has some slack when the jumper reaches the lowest point.

10. Repeat the measurement until you have a satisfactory set of data. A successful run should include a minimum of rotation, a section of free fall before the cord starts to pull on the jumper, and a few bounces, with at least the first bounce high enough to cause the cord to again go slack. The acceleration *vs.* time graph for the laboratory jump should show features similar to the graph of the real bungee jump. Print or sketch your final graph.

DATA TABLE

Time (s)	Acceleration (m/s^2)	Direction of motion (up or down)

ANALYSIS

1. Examine the data by clicking the Examine button, [examine icon], and move the mouse to determine the acceleration at eight different points on the graph. Make sure that you choose points during the initial rest, free fall, when the cord is taut, and several bounces. Indicate the direction of the motion using *up, down* or *at rest.*

2. Perform the same analysis on your bungee jump as was done on the real bungee jump in the Preliminary Questions section.

3. How well does the laboratory jump compare with the real jump? Discuss the similarities and differences.

4. How could you improve the correlation between the lab jump and the real jump?

EXTENSIONS

1. Place a Motion Detector on the floor during a jump. Examine the Motion Detector data (position *vs.* time and velocity *vs.* time graphs) of the jump. How do these data compare to the Accelerometer data? Which sensor do you think is a better tool for the analysis of the jump? Explain.

2. Capture the laboratory bungee jump or a real bungee jump on video. View the video tape and match the Accelerometer graph with the video of the jump.

3. Repeat the experiment with a jumper of different mass. What are the similarities and differences between the two sets of data? Discuss some methods that might be used by operators of commercial bungee jumps to assure the safety of jumpers of different weights.

4. Connect the bungee cord to a Force Sensor to examine the bungee cord tension during the jump.

5. Use reference books or the Internet to find a reference that documents the accelerations experienced by the Shuttle astronauts during takeoff and re-entry. How do the accelerations experienced by the astronauts compare to the maximum acceleration experienced by a bungee jumper?

Computer
18
Momentum, Energy and Collisions

The collision of two carts on a track can be described in terms of momentum conservation and, in some cases, energy conservation. If there is no net external force experienced by the system of two carts, then we expect the total momentum of the system to be conserved. This is true regardless of the force acting between the carts. In contrast, energy is only conserved when certain types of forces are exerted between the carts.

Collisions are classified as *elastic* (kinetic energy is conserved), *inelastic* (kinetic energy is lost) or *completely inelastic* (the objects stick together after collision). Sometimes collisions are described as *super-elastic*, if kinetic energy is gained. In this experiment you can observe most of these types of collisions and test for the conservation of momentum and energy in each case.

OBJECTIVES

- Observe collisions between two carts, testing for the conservation of momentum.
- Measure energy changes during different types of collisions.
- Classify collisions as elastic, inelastic, or completely inelastic.

MATERIALS

computers
Vernier computer interface
Logger *Pro*
two Vernier Motion Detectors
dynamics cart track
two low-friction dynamics carts with magnetic and Velcro™ bumpers

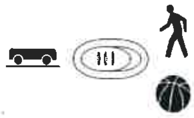
PRELIMINARY QUESTIONS

1. Consider a head-on collision between two billiard balls. One is initially at rest and the other moves toward it. Sketch a position *vs.* time graph for each ball, starting with time before the collision and ending a short time afterward.
2. As you have drawn the graph, is momentum conserved in this collision? Is kinetic energy conserved?

PROCEDURE

1. Measure the masses of your carts and record them in your data table. Label the carts as cart 1 and cart 2.
2. Set up the track so that it is horizontal. Test this by releasing a cart on the track from rest. The cart should not move.
3. Practice creating gentle collisions by placing cart 2 at rest in the middle of the track, and release cart 1 so it rolls toward the first cart, magnetic bumper toward magnetic bumper. The carts should smoothly repel one another without physically touching.

4. Place a Motion Detector at each end of the track, allowing for the 0.15 m minimum distance between detector and cart. Connect the Motion Detectors to the DIG/SONIC 1 and DIG/SONIC 2 channels of the interface. If the Motion Detectors have switches, set them to Track.



5. Open the file "18 Momentum Energy Coll" from the *Physics with Vernier* folder.
6. Click ▶ Collect to begin taking data. Repeat the collision you practiced above and use the position graphs to verify that the Motion Detectors can track each cart properly throughout the entire range of motion. You may need to adjust the position of one or both of the Motion Detectors.
7. Place the two carts at rest in the middle of the track, with their Velcro bumpers toward one another and in contact. Keep your hands clear of the carts and click Ø Zero. Select both sensors and click OK. This procedure will establish the same coordinate system for both Motion Detectors. Verify that the zeroing was successful by clicking ▶ Collect and allowing the still-linked carts to roll slowly across the track. The graphs for each Motion Detector should be nearly the same. If not, repeat the zeroing process.

Part I: Magnetic Bumpers

8. Reposition the carts so the magnetic bumpers are facing one another. Click ▶ Collect to begin taking data and repeat the collision you practiced in Step 3. Make sure you keep your hands out of the way of the Motion Detectors after you push the cart.
9. From the velocity graphs you can determine an average velocity before and after the collision for each cart. To measure the average velocity during a time interval, drag the cursor across the interval. Click the Statistics button to read the average value. Measure the average velocity for each cart, before and after collision, and enter the four values in the data table. Delete the statistics box.
10. Repeat Step 9 as a second run with the magnetic bumpers, recording the velocities in the data table.

Part II: Velcro Bumpers

11. Change the collision by turning the carts so the Velcro bumpers face one another. The carts should stick together after collision. Practice making the new collision, again starting with cart 2 at rest.
12. Click ▶ Collect to begin taking data and repeat the new collision. Using the procedure in Step 9, measure and record the cart velocities in your data table.
13. Repeat the previous step as a second run with the Velcro bumpers.

Part III: Velcro to Magnetic Bumpers

14. Face the Velcro bumper on one cart to the magnetic bumper on the other. The carts will not stick, but they will not smoothly bounce apart either. Practice this collision, again starting with cart 2 at rest.
15. Click ▶ Collect to begin data collection and repeat the new collision. Using the procedure in Step 9, measure and record the cart velocities in your data table.
16. Repeat the previous step as a second run with the Velcro to magnetic bumpers.

DATA TABLE

Mass of cart 1 (kg)	Mass of cart 2 (kg)

Run number	Velocity of cart 1 before collision (m/s)	Velocity of cart 2 before collision (m/s)	Velocity of cart 1 after collision (m/s)	Velocity of cart 2 after collision (m/s)
1		0		
2		0		
3		0		
4		0		
5		0		
6		0		

Run number	Momentum of cart 1 before collision (kg•m/s)	Momentum of cart 2 before collision (kg•m/s)	Momentum of cart 1 after collision (kg•m/s)	Momentum of cart 2 after collision (kg•m/s)	Total momentum before collision (kg•m/s)	Total momentum after collision (kg•m/s)	Ratio of total momentum after/before
1		0					
2		0					
3		0					
4		0					
5		0					
6		0					

Run number	KE of cart 1 before collision (J)	KE of cart 2 before collision (J)	KE of cart 1 after collision (J)	KE of cart 2 after collision (J)	Total KE before collision (J)	Total KE after collision (J)	Ratio of total KE after/before
1		0					
2		0					
3		0					
4		0					
5		0					
6		0					

ANALYSIS

1. Determine the momentum (*mv*) of each cart before the collision, after the collision, and the total momentum before and after the collision. Calculate the ratio of the total momentum after the collision to the total momentum before the collision. Enter the values in your data table.

2. Determine the kinetic energy ($\frac{1}{2}mv^2$) for each cart before and after the collision. Calculate the ratio of the total kinetic energy after the collision to the total kinetic energy before the collision. Enter the values in your data table.

3. If the total momentum for a system is the same before and after the collision, we say that momentum is *conserved*. If momentum were conserved, what would be the ratio of the total momentum after the collision to the total momentum before the collision?

4. If the total kinetic energy for a system is the same before and after the collision, we say that kinetic energy is *conserved*. If kinetic were conserved, what would be the ratio of the total kinetic energy after the collision to the total kinetic energy before the collision?

5. Inspect the momentum ratios. Even if momentum is conserved for a given collision, the measured values may not be exactly the same before and after due to measurement uncertainty. The ratio should be close to one, however. Is momentum conserved in your collisions?

6. Repeat the preceding question for the case of kinetic energy. Is kinetic energy conserved in the magnetic bumper collisions? How about the Velcro collisions? Is kinetic energy consumed in the third type of collision studies? Classify the three collision types as elastic, inelastic, or completely inelastic.

EXTENSIONS

1. Using a collision cart with a spring plunger, create a super-elastic collision; that is, a collision where kinetic energy increases. The plunger spring should be compressed and locked before the collision, but then released during the collision. Measure momentum before and after the collision. Is momentum conserved in this case? Is energy conserved?

2. Using the magnetic bumpers, consider other combinations of cart mass by adding weight to one cart. Are momentum or energy conserved in these collisions?

3. Using the magnetic bumpers, consider other combinations of initial velocities. Begin with having both carts moving toward one another initially. Are momentum and energy conserved in these collisions?

4. Perform the momentum and energy calculations for the data tables using a spreadsheet.

Computer
19

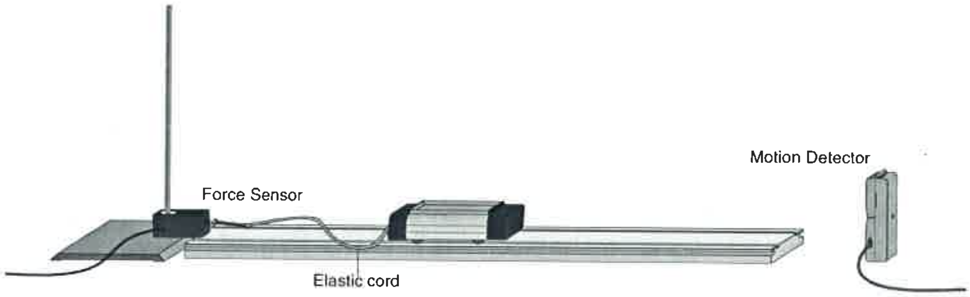
Impulse and Momentum

The impulse-momentum theorem relates impulse, the average force applied to an object times the length of time the force is applied, and the change in momentum of the object:

$$\overline{F}\Delta t = mv_f - mv_i$$

Here we will only consider motion and forces along a single line. The average force, $\overline{F}$, is the *net* force on the object, but in the case where one force dominates all others it is sufficient to use only the large force in calculations and analysis.

For this experiment, a dynamics cart will roll along a level track. Its momentum will change as it reaches the end of an initially slack elastic tether cord, much like a horizontal bungee jump. The tether will stretch and apply an increasing force until the cart stops. The cart then changes direction and the tether will soon go slack. The force applied by the cord is measured by a Force Sensor. The cart velocity throughout the motion is measured with a Motion Detector. Using Logger *Pro* to find the average force during a time interval, you can test the impulse-momentum theorem.



OBJECTIVES

- Measure a cart's momentum change and compare to the impulse it receives.
- Compare average and peak forces in impulses.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Motion Detector
Vernier Force Sensor
dynamics cart and track
clamp
elastic cord
string
500 g mass

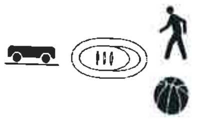
PRELIMINARY QUESTIONS

1. In a car collision, the driver's body must change speed from a high value to zero. This is true whether or not an airbag is used, so why use an airbag? How does it reduce injuries?
2. You want to close an open door by throwing either a 400 g lump of clay or a 400 g rubber ball toward it. You can throw either object with the same speed, but they are different in that

the rubber ball bounces off the door while the clay just sticks to the door. Which projectile will apply the larger impulse to the door and be more likely to close it?

PROCEDURE

1. Measure the mass of your dynamics cart and record the value in the data table.
2. Connect the Motion Detector to DIG/SONIC 1 of the interface. If the Motion Detector has a switch, set it to Track. Connect the Force Sensor to Channel 1 of the interface. If your Force Sensor has a range switch, set it to 10 N.



3. Open the file "19 Impulse and Momentum" in the *Physics with Vernier* folder. Logger *Pro* will plot the cart's position and velocity *vs.* time, as well as the force applied by the Force Sensor *vs.* time.
4. Optional: Calibrate the Force Sensor.
   a. Choose Calibrate ▸ CH1: Dual Range Force from the Experiment menu. Click [Calibrate Now].
   b. Remove all force from the Force Sensor. Enter a **0** (zero) in the Reading 1 field. Hold the sensor vertically with the hook downward and wait for the reading shown for CH1 to stabilize. Click [Keep]. This defines the zero force condition.
   c. Hang the 500 g mass from the sensor. This applies a force of 4.9 N. Enter **4.9** in the Reading 2 field, and after the reading shown for CH1 is stable, click [Keep]. Click [Done] to close the calibration dialog.
5. Place the track on a level surface. Confirm that the track is level by placing the low-friction cart on the track and releasing it from rest. It should not roll. If necessary, adjust the track.
6. Attach the elastic cord to the cart and then the cord to the string. Tie the string to the Force Sensor a short distance away. Choose a string length so that the cart can roll freely with the cord slack for most of the track length, but be stopped by the cord before it reaches the end of the track. Clamp the Force Sensor so that the string and cord, when taut, are horizontal and in line with the cart's motion.
7. Place the Motion Detector beyond the other end of the track so that the detector has a clear view of the cart's motion along the entire track length. When the cord is stretched to maximum extension the cart should not be closer than 0.15 m to the detector.
8. Click [Zero], select Force Sensor from the list, and click [OK] to zero the Force Sensor.
9. Practice releasing the cart so it rolls toward the Motion Detector, bounces gently, and returns to your hand. The Force Sensor must not shift and the cart must stay on the track. Arrange the cord and string so that when they are slack they do not interfere with the cart motion. You may need to guide the string by hand, but be sure that you do not apply any force to the cart or Force Sensor. Keep your hands away from between the cart and the Motion Detector.
10. Click [▸ Collect] to take data; roll the cart and confirm that the Motion Detector detects the cart throughout its travel. Inspect the force data. If the peak exceeds 10 N, then the applied force is too large. Roll the cart with a lower initial speed. If the velocity graph has a flat area when it crosses the time-axis, the Motion Detector was too close and the run should be repeated.
11. Once you have made a run with good position, velocity, and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse. Choose an interval corresponding to a time when the elastic was initially relaxed, and the cart was moving at approximately constant speed away from the Force Sensor. Drag the mouse

pointer across this interval. Click the Statistics button, , and read the average velocity. Record the value for the initial velocity in your data table. In the same manner, choose an interval corresponding to a time when the elastic was again relaxed, and the cart was moving at approximately constant speed toward the Force Sensor. Drag the mouse pointer across this interval. Click the statistics button and read the average velocity. Record the value for the final velocity in your data table.

12. Now record the time interval of the impulse. There are two ways to do this. Use the first method if you have studied calculus and the second if you have not.

    - Method 1: Calculus tells us that the expression for the impulse is equivalent to the integral of the force vs. time graph, or

    $$\overline{F}\Delta t = \int_{t_{initial}}^{t_{final}} F(t)dt$$

    On the force *vs.* time graph, drag across the impulse, capturing the entire period when the force was non-zero. Find the area under the force *vs.* time graph by clicking the Integral button, . Record the value of the integral in the impulse column of your data table.

    - Method 2: On the force *vs.* time graph, drag across the impulse, capturing the entire period when the force was non-zero. Find the average value of the force by clicking the Statistics button, , and also read the length of the time interval over which your average force is calculated. The number of points used in the average divided by the data rate of 50 Hz gives the time interval Δt. Record the values in your data table.

13. Perform a second trial by repeating Steps 10–12, record the information in your data table.

14. Change the elastic material attached to the cart. Use a new material, or attach two elastic bands side by side.

15. Repeat Steps 10–13, record the information in your data table.

DATA TABLE

Mass of cart	kg

Trial	Final Velocity v_f	Initial Velocity v_i	Average Force F	Duration of Impulse Δt	Impulse
Elastic 1	(m/s)	(m/s)	(N)	(s)	(N·s)
1					
2					

Elastic 2					
1					
2					

Trial	Impulse $F\Delta t$ (N·s)	Change in momentum (kg·m /s) or (N·s)	% difference between Impulse and Change in momentum (N·s)
Elastic 1			
1			
2			
Elastic 2			
1			
2			

ANALYSIS

1. From the mass of the cart and change in velocity, determine the change in momentum as a result of the impulse. Make this calculation for each trial and enter the values in the second data table.

2. If you used the average force (non-calculus) method, determine the impulse for each trial from the average force and time interval values. Record these values in your data table.

3. If the impulse-momentum theorem is correct, the change in momentum will equal the impulse for each trial. Experimental measurement errors, along with friction and shifting of the track or Force Sensor, will keep the two from being exactly the same. One way to compare the two is to find their percentage difference. Divide the difference between the two values by the average of the two, then multiply by 100%. How close are your values, percentage-wise? Do your data support the impulse-momentum theorem?

4. Look at the shape of the last force *vs.* time graph. Is the peak value of the force significantly different from the average force? Is there a way you could deliver the same impulse with a much smaller force?

5. Revisit your answers to the Preliminary Questions in light of your work with the impulse-momentum theorem.

6. When you use different elastic materials, what changes occurred in the shapes of the graphs? Is there a correlation between the type of material and the shape?

7. When you used a stiffer or tighter elastic material, what effect did this have on the duration of the impulse? What affect did this have on the maximum size of the force? Can you develop a general rule from these observations?

EXTENSIONS

1. Try other elastic materials, doing the same experiment.

Computer
21
Accelerations in the Real World

The portability of LabQuest and the LabPro interfaces make them ideal tools for studying accelerations that occur outside the physics laboratory. Some interesting situations are the automobile and amusement park rides, as well as high-speed elevators, motorcycles, and go-carts.

The Accelerometer measures the acceleration in a specific direction. You will need to choose an appropriate time scale and direction to hold the Accelerometer to obtain meaningful information. Obtaining acceleration data from independent kinematics measurements can transform an informal study into a scientific inquiry.

This lab highlights several situations where you can collect real-world acceleration data. A general procedure is given which you will modify, depending upon which study is performed. After the general procedure you will find several suggestions for acceleration investigations. You will need to plan an experiment around the motion to be studied, adjusting data collection parameters as needed.

OBJECTIVES

- Measure acceleration in a real-world setting.
- Compare the acceleration measured to the value calculated from other data.

MATERIALS

computer	Logger *Pro*
Vernier computer interface	Vernier Low-g Accelerometer

GENERAL PROCEDURE

The following steps will guide you through configuring the LabPro interface to collect acceleration data so that you need to carry only the interface and sensor. After collecting data, the computer is reconnected and data are then transferred to the computer for analysis.

You will probably need to modify either the time between samples or the number of points collected for your particular circumstances. Adjust these values as you design your experiment.

1. Connect the Vernier Low-g Accelerometer to Channel 1 on the LabPro interface.

2. Set up LabPro for remote data collection.
   a. Put fresh batteries in the LabPro.
   b. Open the file "21 Real World Accelerations" from the *Physics with Vernier* folder. Change the experiment length as needed by clicking the Data Collection button, and entering the desired experiment length. Click [Done] to accept the change.

c. Instead of clicking the ▶ Collect button, choose Remote ▶ Remote Setup ▶ LabPro from the Experiment menu. A warm-up message may be displayed. Click on it to dismiss it. Then, a summary of your setup will be displayed.
d. Click OK to prepare the LabPro.
e. Disconnect the LabPro from the computer. The Lab Pro will be ready to collect data when the amber LED is illuminated.
f. If it has not already been saved, save the experiment file so it can be used to later retrieve the data from LabPro.

3. Collect data.
   a. Check to see that the amber LED is illuminated on the LabPro
   b. When you are ready to collect data, press the START/STOP button.
   c. When data collection is complete, the yellow LED will flash briefly. You can also stop data collection early by pressing the START/STOP button before data collection is finished.

4. Retrieve the data.
   a. Start Logger *Pro* if it is not already running.
   b. Open the experiment file used to set up LabPro.
   c. Attach LabPro to the computer.
   d. If a Remote Data Available window appears, click the YES button. Click OK to accept the default to retrieve remote data into the current file. If a window does not appear when the interface is reconnected, choose Remote ▶ Retrieve Remote Data from the Experiment menu and follow the on-screen instructions.
   e. The data will be retrieved.

AUTOMOBILES AND MOTORCYCLES

Linear Acceleration on a Straight Road

The accelerometer and interface can record the acceleration of a motor vehicle. A good motion to study is speeding up from rest, followed by slowing to a stop. Initially program the interface to collect data for 30 seconds, although you may find that this time should be shortened or extended. Zero the Accelerometer with the arrow held horizontally.

Place the Accelerometer in a horizontal direction with the arrow of the Accelerometer aligned with the direction of the motion. Press START/STOP just before starting the vehicle. Accelerate to a safe speed, and then slow to a stop. Keep the vehicle moving in a straight line and keep it on a level section of roadway for this experiment.

Ask the driver to maintain a constant acceleration while speeding up, as well as a constant acceleration when slowing down. Compare different vehicles; compare acceleration patterns with automatic and manual transmissions. For an independent acceleration measurement, take velocity *vs.* time data during the trial, either by calling out times and recording the instantaneous velocities, or perhaps by videotaping the speedometer. Compare the accelerations you obtain with the accelerations that are recorded by the interface.

Centripetal Acceleration in Corners

When a vehicle turns a corner, a centripetal acceleration is present. By placing the axis of the Accelerometer horizontally and perpendicular to the forward direction, you can record the accelerations in curvilinear motion. Initially program the interface to collect data for 30 seconds, although you may find that this time should be shortened or extended. Set up a path that has several curves of measured radii as well as straight sections. A parking lot not used on weekends would be best. Practice until the driver can maneuver through the course while maintaining a steady speed. Place the Accelerometer in the horizontal direction so it is stable relative to the vehicle and perpendicular to its motion, arrow pointing to the inside of curve. Accelerate to the planned speed and keep the vehicle moving at a constant speed. Press START/STOP just before entering the test section containing the curves.

For an independent acceleration measurement from kinematics, you will need to know both the radii of the turns and the speed of the vehicle. During turns, a motorcyclist must lean the bike towards the center of the turn to successfully complete the turn. In this case, the experimenter must take care to hold the axis of the Accelerometer level with the ground throughout the trial.

Questions

1. For the motion along a straight line, is the acceleration of a motorized vehicle constant? If not, why do you suspect the rate is larger during part of the run than another part? How does the acceleration while speeding up compare to the deceleration while stopping? Why do you suppose this pattern is true? Characterize the ability of your driver to accelerate the vehicle at a constant rate.

2. For the cornering motions, how do the calculated accelerations from kinematics (v^2/R) compare to the accelerations measured with the interface? How do the measured accelerations compare to the acceleration due to gravity, or g?

ELEVATORS

Take the interface and Accelerometer to a building that has a high-speed elevator and a height of six stories or more. Zero the Accelerometer with the arrow vertical. Initially program the interface to collect data for 90 seconds. You will want to adjust this time depending on the transit time of your elevator.

Enter the elevator and place the Accelerometer against the elevator wall with its arrow pointing upward. Do not hold it in your extended hand, because the motion of your arm will change the acceleration measurement.

Program the elevator to stop at two floors on the way up, then program it to stop at two floors on the way back down. Press START/STOP to start data collection when the doors close on the elevator.

Other Data

If you can determine the height of a single story, you can collect data on floor *vs.* time to obtain velocities while the elevator is ascending or descending. A video camera could be used to record these data. Compare the velocity you obtain this way with the area under the acceleration *vs.* time graph.

Questions

3. How large is the acceleration when the elevator begins? How large is the acceleration when the elevator has been underway for a few seconds? How large is the acceleration when the elevator is slowing to a stop on its way up? What does the sign of the acceleration indicate?

4. (requires calculus) How does the area under the acceleration graph while speeding up compare to the area under the graph while it is slowing down? Why should these two areas be equal magnitude but of opposite signs?

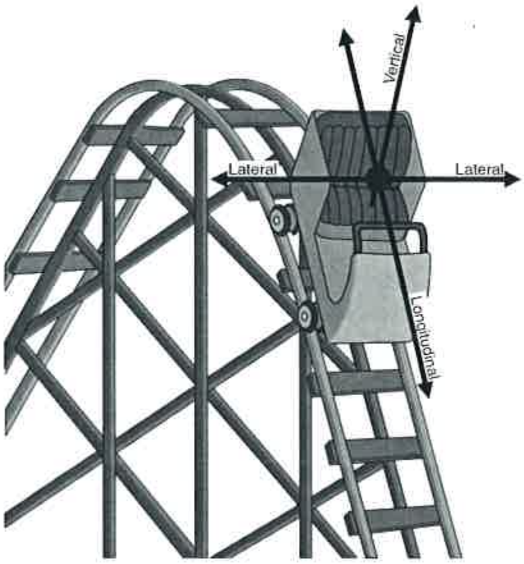
5. Can you determine which direction the elevator is moving (upwards or downwards) by the size or direction of the accelerations? Explain your answer.

6. If you make a run while holding the Accelerometer in your hand (arm in front of your body), how does the resulting acceleration compare to that recorded while the Accelerometer is fixed rigidly to the elevator itself?

AMUSEMENT PARKS

Many amusement parks feature a Physics Day where students take instruments on the rides and perform calculations. Using the interface, the data collection can be extended so that the ride characteristics can be studied in more detail than is possible with traditional methods. Several categories of study are suggested below.

For any ride it is essential that you plan your data collection carefully. It is best to concentrate on a single portion of a ride, such as a particular loop or corner of a roller coaster. Decide which part of the ride you want to study, and estimate the length of time you will need to collect data. You may want to measure the time interval while watching others on the ride. The time between samples can then be calculated by dividing the desired time interval by the number of points you want to collect.



Along with planning the data collection parameters, you must plan the orientation of the Accelerometer during the ride. Which axis of the acceleration do you want to record? Hold or fasten the Accelerometer so the arrow is parallel to this axis. The direction of the arrow will correspond to positive acceleration.

When describing the directions of accelerations on an amusement park ride, it is convenient to have a common vocabulary. The diagram defines the terms vertical, lateral and longitudinal. These designations are from the frame of reference of the rider.

Dips: Most roller coasters feature a dip following the first major climb, as well as several others during the course of the ride. If you know the speed of the train at the top of the hill and the vertical distance to the bottom, the speed of the train at the bottom can be calculated using conservation of energy. Knowing the radius of the curve at the bottom, the acceleration due to circular motion can be calculated using kinematics.

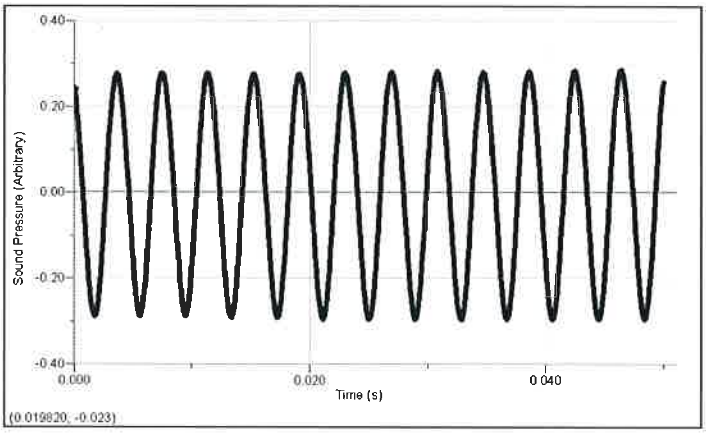
Computer
32
Sound Waves and Beats

Sound waves consist of a series of air pressure variations. A Microphone diaphragm records these variations by moving in response to the pressure changes. The diaphragm motion is then converted to an electrical signal. Using a Microphone and a computer interface, you can explore the properties of common sounds.

The first property you will measure is the *period*, or the time for one complete cycle of repetition. Since period is a time measurement, it is usually written as *T*. The reciprocal of the period (1/*T*) is called the *frequency*, *f*, the number of complete cycles per second. Frequency is measured in hertz (Hz). $1\text{ Hz} = 1\text{ s}^{-1}$.

A second property of sound is the *amplitude*. As the pressure varies, it goes above and below the average pressure in the room. The maximum variation above or below the pressure mid-point is called the amplitude. The amplitude of a sound is closely related to its loudness.

When two sound waves overlap, their air pressure variations will combine. For sound waves, this combination is additive. We say that sound follows the principle of *linear superposition*. Beats are an example of superposition. Two sounds of nearly the same frequency will create a distinctive variation of sound amplitude, which we call beats. You can study this phenomenon with a Microphone, lab interface, and computer.



OBJECTIVES

- Measure the frequency and period of sound waves from tuning forks.
- Measure the amplitude of sound waves from tuning forks.
- Observe beats between the sounds of two tuning forks.

MATERIALS

computer
Vernier computer interface
Vernier Microphone
Logger *Pro*
2 tuning forks or electronic keyboard

PRELIMINARY QUESTIONS

1. Why are instruments tuned before being played as a group? In which ways do musicians tune their instruments?

2. Given that sound waves consist of series of air pressure increases and decreases, what would happen if an air pressure increase from one sound wave was located at the same place and time as a pressure decrease from another of the same amplitude?

PROCEDURE

1. Connect the Microphone to Channel 1 of the computer interface.

2. Open the "32 Sound Waves" file in the *Physics with Vernier* folder. The computer will take data for just 0.05 s to display the rapid pressure variations of sound waves. The vertical axis corresponds to the variation in air pressure and the units are arbitrary. Click [Ø Zero] to center waveforms on the time axis.

Part I Simple Waveforms

3. Produce a sound with a tuning fork or keyboard, hold it close to the Microphone and click [▶ Collect]. The data should be sinusoidal in form, similar to the sample on the front page of this lab. If you are using a tuning fork, strike it against a soft object such as a rubber mallet or the rubber sole of a shoe. Striking it against a hard object can damage it. If you strike the fork too hard or too softly, the waveform may be too rough; try again.

4. Note the appearance of the graph. Count and record the number of complete cycles shown after the first peak in your data.

5. Click the Examine button, [x=]. Drag the mouse between the first and last peaks of the waveform. Read the time interval Δt, and divide it by the number of cycles to determine the period of the tuning fork waveform.

6. Calculate the frequency of the tuning fork in Hz and record it in your data table.

7. In a similar manner, determine amplitude of the waveform. Drag the mouse across the graph from top to bottom for an adjacent peak and trough. Read the difference in y values, shown on the graph as Δy.

8. Calculate the amplitude of the wave by taking half of the difference dy. Record the value in your data table.

9. Make a sketch of your graph or print the graph.

10. Save your data by choosing Store Latest Run from the Experiment menu. Hide the run by choosing Hide Data Set from the Data menu and selecting Run 1 to hide.

11. Repeat Steps 3–9 for the second frequency. Store the latest run. It will be stored as Run 2. Then hide Run 2.

Part II Beats

12. Two pure tones with different frequencies sounded at once will create the phenomenon known as beats. Sometimes the waves will reinforce one another and other times they will

combine to a reduced intensity. This happens on a regular basis because of the fixed frequency of each tone. To observe beats, strike your tuning forks at the same time (simultaneously) or simultaneously hold down two adjacent keys on the keyboard and listen for the combined sound. If the beats are slow enough, you should be able to hear a variation in intensity. If the beats are rapid a single rough-sounding tone is heard.

13. Collect data while the two tones are sounding. You should see a time variation of the sound amplitude. When using tuning forks, strike them equally hard and hold them the same distance from the Microphone. When you get a clear waveform, choose Store Latest Run from the Experiment menu. The beat waveform will be stored as Run 3.

14. The pattern will be complex, with a slower variation of amplitude on top of a more rapid variation. Ignoring the more rapid variation and concentrating in the overall pattern, count the number of amplitude maxima after the first maximum and record it in the data table.

15. Click the Examine button, ⌧. As you did before, find the time interval for several complete beats using the mouse. Divide the difference, Δt, by the number of cycles to determine the period of beats (in s). Calculate the *beat frequency* in Hz from the beat period. Record these values in your data table.

DATA TABLE

Part I Simple Waveforms

Tuning fork or note	Number of cycles	Δt (s)	Period (s)	Calculated frequency (Hz)

Tuning fork or note	Amplitude (V)

Tuning fork or note	Parameter A (V)	Parameter B (s^{-1})	$f = B/2\pi$ (Hz)

Part II Beats

Number of cycles	Δt (s)	Beat (s)	Calculated beat frequency (Hz)

ANALYSIS

Part I Simple Waveforms

1. In the following analysis, you will see how well a sine function model fits the data. The displacement of the particles in the medium carrying a periodic wave can be modeled with a sinusoidal function. Your textbook may have an expression resembling this one:

$$y = A\sin(2\pi\ f\ t)$$

In the case of sound, a longitudinal wave, the *y* refers to the change in air pressure that makes up the wave. *A* is the amplitude of the wave (a measure of loudness), and *f* is the frequency. Time is represented with *t* and the sine function requires a factor of 2π when evaluated in radians.

Logger *Pro* will fit the function $y = A * \sin(B*t + C) + D$ to experimental data. A, B, C, and D are parameters (numbers) that Logger *Pro* reports after a fit. This function is more complicated than the textbook model, but the basic sinusoidal form is the same. Comparing terms, listing the textbook model's terms first, the amplitude *A* corresponds to the fit term A, and $2\pi f$ corresponds to the parameter B. The time is represented by *t*, Logger *Pro*'s horizontal axis. The new parameters C and D shift the fitted function left-right and up-down, respectively and are necessary to obtain a good fit. Only the parameters A and B are important to this experiment. In particular, the numeric value of B allows you to find the frequency *f* using $B = 2\pi f$. Choose Show Data Set from the Data menu and select Run 1 to show the waveform from the first tone. Keep the other runs hidden. Click the Curve Fit button, , and select Run 1 from the list of columns. Select "A*sin(B*t +C) + D (Sine)" from the list of models. Click [Try Fit] to perform the curve fit.

Click [OK] to return to the graph. The model and its parameters appear in a floating box in the upper left corner of the graph. Record the parameters *A* and *B* of the model in your data table.

2. Since *B* corresponds to $2\pi f$ in the curve fit, use the curve fit information to determine the frequency. Enter the value in your data table. Compare this frequency to the frequency calculated earlier. Which would you expect to be more accurate? Why?

3. Compare the parameter *A* to the amplitude of the waveform. Hide Run 1 and show Run 2, the waveform of the second tone. Repeat Steps 1–4 for Run 2.

Part II Beats

4. Is there any way the two individual frequencies can be combined to give the beat frequency you measured earlier? Compare your conclusion with information given in your textbook.

EXTENSIONS

1. The beats you observed in Run 3 resulted from the overlap of sound waves from the two tuning forks. How would the data you recorded compare to a simple addition of the waveforms from the forks individually? If the sound waves combined in air by linear addition, then the algebraic sum of the data of the individual waveforms should be similar to data of the beats. The following steps will help you perform the addition:
   a. Show Run 3 only (the waveform of the actual beats).
   b. Choose New Calculated Column from the Data menu. Give the column the name of "Sum."
   c. Click once in the equation field to place the cursor there. Choose Run1:Sound Pressure from the Variables (Columns): menu, type the addition symbol "+", and choose Run2:Sound Pressure from the Variables (Columns) menu. The resulting equation will read "Run1:Sound Pressure"+ "Run2:Sound Pressure".
   d. Click Done. Click No if Logger *Pro* asks if you want to select a specific Data Set.
   e. A new column, representing the sum of the two waveforms, will be created in each Data Set.
   f. Drag the Sum column header of Run 3 from the data table area to the y axis area to plot the Sum column.
   g. Click on the y-axis label to show the y-axis selection dialog and uncheck all but the Sum column in Run 3. Click [OK]. You now see the mathematical sum of the Runs 1 and 2. Rescale the graph if needed. Now use the y-axis label dialog to display only the actual data of the beats. (It is hard to see with both plots on screen at once, so look at one at a time.) How is the sum similar to the real data? How are they different? Do the graphs support the model of additive sound wave superposition? What if the superposition rule were multiplicative? Would that change the graph?

2. There are commercial products available called *active noise cancellers*, which consist of a set of headphones, microphones, and some electronics. Intended for wearing in noisy environments where the user must still be able to hear (for example, radio communications), the headphones reduce noise far beyond the simple acoustic isolation of the headphones. How might such a product work?

3. The trigonometric identity

$$\sin x + \sin y = 2\sin\left(\frac{x+y}{2}\right)\cdot\cos\left(\frac{x-y}{2}\right)$$

   is useful in modeling beats. Show how the beat frequency you measured above can be predicted using two sinusoidal waves of frequency f_1 and f_2, whose pressure variations are described by $\sin(2\pi f_1\, t)$ and $\sin(2\pi f_2\, t)$.

4. Most of the attention in beats is paid to the overall intensity pattern that we hear. Use the analysis tools to determine the frequency of the variation that lies inside the pattern (the one inside the envelope). How is this frequency related to the individual frequencies that generated the beats?

5. Examine the pattern you get when you play two adjacent notes on a keyboard. How does this change as the two notes played get further and further apart? How does it stay the same?