

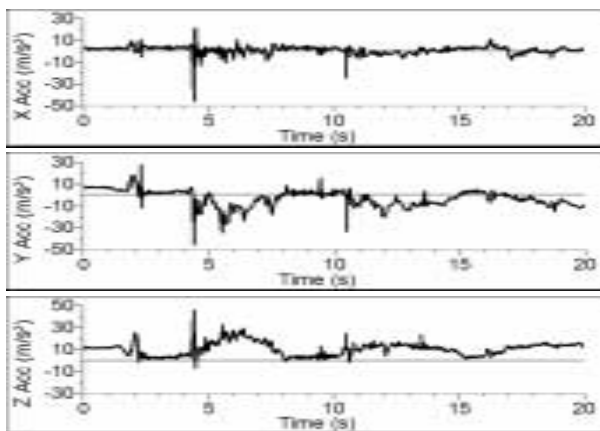
# 3-Axis Accelerometer

(Order Code 3D-BTA<sup>1</sup>)

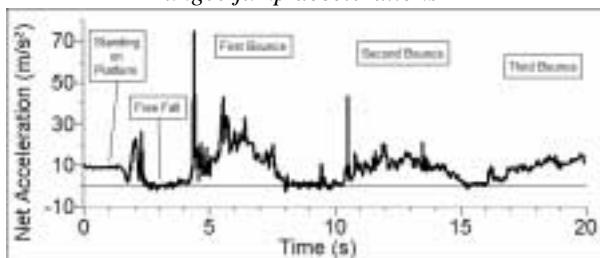
The 3-Axis Accelerometer consists of three  $-5$  to  $+5$  g accelerometers mounted in one small block. Using the appropriate data collection hardware and software, you can graph any of these components, or calculate the magnitude of the net acceleration. The 3-Axis Accelerometer can be used for a wide variety of experiments and demonstrations, both inside the lab and outside. There are sample data collected with the 3-axis Accelerometer



A 3-Axis Accelerometer was used to collect data during a bungee jump. The first three graphs show the three component accelerations. The next graph shows the net acceleration calculated as the square root of the sum of the squares of the component accelerations.



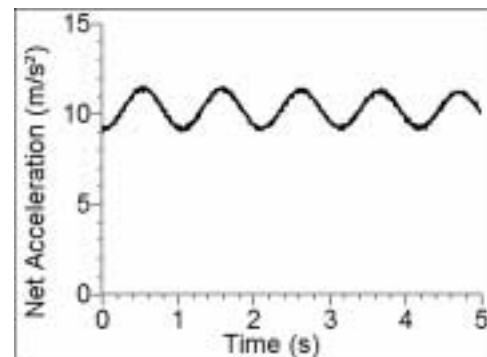
*Bungee jump accelerations*



*Net acceleration*

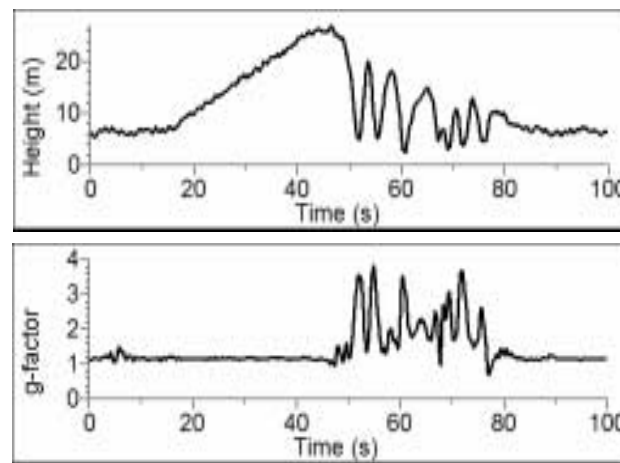
Below is a sample graph made using the 3-Axis Accelerometer mounted on a pendulum. The pendulum is swinging through a wide angle, so the angle of the

accelerometer is changing significantly. A simple, one-dimensional accelerometer would not have done this job as well. In this case, only the net acceleration is graphed. (See the April 1995 issue of *The Physics Teacher* for a discussion of the acceleration of a pendulum.)



*Acceleration of a pendulum bob*

The graph below shows data collected on a ride called the Vortex. A 3-Axis Accelerometer and a Barometer were used in this experiment. A video taken during data collection can be viewed in the Sample Movies folder of *Logger Pro 3*. These data were collected by Clarence Bakken. For more information on data collection in an amusement park visit our web site, [www.vernier.com/cmat/datapark.html](http://www.vernier.com/cmat/datapark.html), and download the Data Collection at the Amusement Park manual.



*Data collected on the Vortex*

## Collecting Data with the 3-Axis Accelerometer

This sensor can be used with the following interfaces to collect data:

- Vernier LabQuest™ as a standalone device or with a computer
- Vernier LabPro® with a computer, TI graphing calculator, or Palm® handheld
- Vernier SensorDAQ™

<sup>1</sup> If you ordered a 3D-DIN, you have received a 3D -BTA with a three BTA-DIN adapter.

- CBL 2™

Here is the general procedure to follow when using the 3-Axis Accelerometer:

1. Connect the 3-Axis Accelerometer to the interface.
2. Start the data-collection software<sup>2</sup>.
3. The software will identify the 3-Axis Accelerometer and load a default data-collection setup. You are now ready to collect data.

### Data-Collection Software

This sensor can be used with an interface and the following data-collection software.

- **Logger Pro 3** This computer program is used with LabQuest, LabPro, or Go!Link.
- **Logger Pro 2** This computer program is used with ULI or Serial Box Interface.
- **Logger Lite** This computer program is used with LabQuest, LabPro, or Go!Link.
- **LabQuest App** This program is used when LabQuest is used as a stand-alone device.
- **EasyData App** This calculator application for the TI-83 Plus and TI-84 Plus can be used with CBL 2, LabPro, and Vernier EasyLink. We recommend version 2.0 or newer, which can be downloaded from the Vernier web site, [www.vernier.com/easy/easydata.html](http://www.vernier.com/easy/easydata.html), and then transferred to the calculator. See the Vernier web site, [www.vernier.com/calc/software/index.html](http://www.vernier.com/calc/software/index.html) for more information on the App and Program Transfer Guidebook.
- **DataMate program** Use DataMate with LabPro or CBL 2 and TI-73, TI-83, TI-84, TI-86, TI-89, and Voyage 200 calculators. See the LabPro and CBL 2 Guidebooks for instructions on transferring DataMate to the calculator.
- **Data Pro** This program is used with LabPro and a Palm handheld.
- **LabVIEW** National Instruments LabVIEW™ software is a graphical programming language sold by National Instruments. It is used with SensorDAQ and can be used with a number of other Vernier interfaces. See [www.vernier.com/labview](http://www.vernier.com/labview) for more information.

**NOTE:** This product is to be used for educational purposes only. It is not appropriate for industrial, medical, research, or commercial applications.

### Specifications

Power:	30 mA @ 5 VDC
For each axis:	
Range:	±49 m/s <sup>2</sup> (±5 g)
Accuracy:	±0.5 m/s <sup>2</sup> (±0.05 g)
Frequency Response:	0–100 Hz
Resolution	
13-bit (with SensorDAQ)	0.0780639 m/s <sup>2</sup>

<sup>2</sup> If you are using Logger Pro 2 with either a ULI or SBI, the sensor will not auto-ID. Open an experiment file for the 3-Axis Accelerometer in the Probes & Sensors folder.

12-bit (with LabPro LabQuest,      0.1561279 m/s<sup>2</sup>

Go!Link, ULI, or SBI)

10-bit (with CBL 2)                    0.6245117 m/s<sup>2</sup>

Stored calibration information:

Slope                                        22.92 m/s<sup>2</sup>/V

Intercept                                    -51.751 m/s<sup>2</sup>

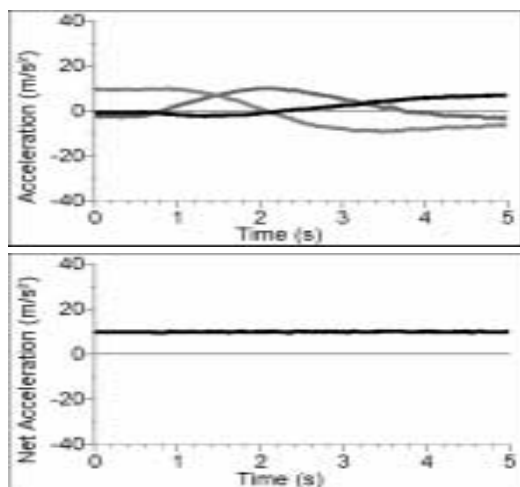
### How the Accelerometer Works

The 3-Axis Accelerometer contains three acceleration-sensing integrated circuits (IC's), along with the associated electronics. It is functionally equivalent to three of our Low-g Accelerometers (LGA-BTA) mounted in a small block at orthogonal angles. Each of the accelerometers measures acceleration along one line and produces a signal on one of the three outputs. These three axes and three outputs are labeled X, Y, and Z. The IC sensors are similar to those originally designed to control the release of air bags in an automobile. This IC is micro-machined with very thin “fingers” carved in silicon. These fingers flex when accelerated. They are arranged and connected like the plates of a capacitor. As the fingers flex, the capacitance changes, and a circuit included in the IC monitors the capacitance, converting it into a voltage. An op-amp circuit amplifies and filters the signal from the IC. The net result is that the voltage varies in a linear way with acceleration.

Each of the outputs is labeled with X, Y, or Z. This corresponds with the directions shown on the label on the sensor. Accelerations are normally measured in either meters per second per second (m/s<sup>2</sup>) or g's. One g is the acceleration due to gravity at the Earth's surface, or 9.8 m/s<sup>2</sup>. This accelerometer will measure accelerations in the range of -5 g (-49 m/s<sup>2</sup>) to +5 g (+49 m/s<sup>2</sup>) in each direction.

This is a range of accelerations which a human body could experience without damage. Many collisions will produce much larger accelerations. In fact, dropping the Accelerometer on a hard surface from even a few centimeters can produce accelerations of a hundred g's. The 3-Axis Accelerometer will not be damaged by accelerations up to 1000 g's.

When properly calibrated, when the arrow representing an axis points upward, that channel reads +9.8 m/s<sup>2</sup>. When an axis arrow points down, that channel should read -9.8 m/s<sup>2</sup>. When an axis arrow is held horizontally, that channel will read zero. In most cases, data collection software can be used to create a New Column to calculate the square root of the sum of the squares of the accelerations. It will be equal to 9.8 m/s<sup>2</sup> when the 3-Axis Accelerometer has no acceleration, and zero when it is in free fall. The orientation of the 3-Axis Accelerometer does not matter. To understand how this works, try holding the 3-Axis Accelerometer in your hand and very slowly rotate it about all three axes. The graph below shows the result. The graph has all three components of acceleration and the net acceleration (the square root of the sum of the squares of the accelerations). The bottom graph is the net acceleration. Notice that it stays near 9.8 m/s<sup>2</sup> throughout all of this rotation.



*Rotating the 3-Axis Accelerometer*

The 3-Axis Accelerometer is designed to measure small accelerations with minimal electronic noise. The noise is typically on the order of  $0.5 \text{ m/s}^2$  peak to peak. The offset voltage (voltage output at  $0 \text{ m/s}^2$ ) will drift somewhat with temperature.

Vernier produces three other accelerometers:

- 25-g Accelerometer (ACC-BTA). Use for collision experiments or for centripetal acceleration experiments with larger accelerations.
- Low-g Accelerometer (LGA-BTA). This is a, one-dimensional version of the 3-Axis Accelerometer.
- Wireless Dynamics System Sensor (WDSS). A 3-axis accelerometer, altimeter, and force sensor in one unit that communicates wirelessly with your computer.

This sensor is equipped with circuitry that supports auto-ID. When used with LabQuest, LabPro, Go! Link, SensorDAQ, EasyLink, or CBL 2, the data-collection software identifies the sensor and uses pre-defined parameters to configure an experiment appropriate to the recognized sensor.

### Do I Need to Calibrate the 25-g Accelerometer?

You should not need to calibrate this sensor. Each sensor is calibrated prior to being shipped to you. The measurement being made by this sensor is complex and can be difficult to analyze, so be sure to read the Frequently Asked Questions below. In most experiments you can simply use the default calibration, but then use the software's zeroing option and zero the sensor along the axes.

Most accelerometers, including this one, sense gravity as well as acceleration. This can make results more difficult to understand, but it provides an easy calibration method. Calibration may be done using the acceleration due to gravity. To calibrate the sensor for measuring acceleration in the horizontal direction, position the Accelerometer with the arrows pointing down for the first calibration point. Define this as  $-9.8 \text{ m/s}^2$  or  $-1 \text{ g}$ . Rotate the Accelerometer so the arrows point up and use the reading for the second calibration point. Define this as  $+9.8 \text{ m/s}^2$  or  $+1 \text{ g}$ . The Accelerometer will then read 0

with no acceleration when held horizontally. Repeat this procedure for each axis. If you want to calibrate for measuring acceleration in the vertical direction, follow the procedure above, but define the first calibration point as  $0 \text{ g}$  or  $0 \text{ m/s}^2$  and the second point as  $2 \text{ g}$  or  $19.6 \text{ m/s}^2$ .

### Using the 3-Axis Accelerometer as a Single Axis Accelerometer

Since the 3-Axis Accelerometer is equivalent to three Low-g Accelerometers, you can use just one channel of it to study acceleration along a single axis. Just mount the accelerometer so that a particular axis is in the direction of interest and monitor just that channel. If the motion is linear, it will keep the analysis simple.

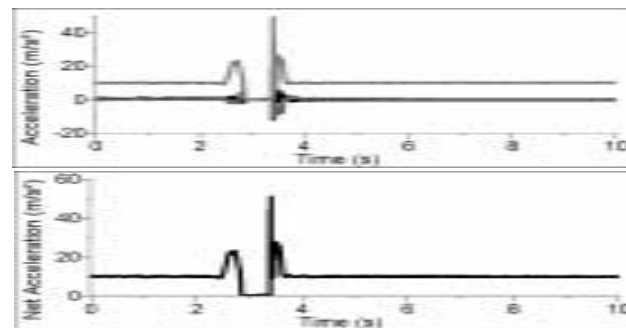
### Suggested Experiments

Since the 3-Axis Accelerometer is equivalent to three Low-g Accelerometers, you can also do any experiment that uses only one or two axes. Examples include:

- Measure the acceleration of dynamics carts as they roll down inclines or have force applied to them.
- Measure acceleration vs. time on elevators, remote-controlled cars, bicycles, or automobiles.
- Use the accelerometer to measure the tilt of an object. Since each channel of the accelerometer senses the vertical component of gravity, its reading will change as its orientation is changed from horizontal to vertical. You can measure angles to the nearest degree.

The 3-Axis Accelerometer can also be used to collect data in more complex experimental settings such as:

- Amusement park rides such as roller coasters, swings, swinging ships, and Tilt-a-Whirl.
- Bungee jumps done by dolls or humans.
- Place the accelerometer and interface in a padded box and toss it in the air. Compare the three individual accelerations to the net acceleration.



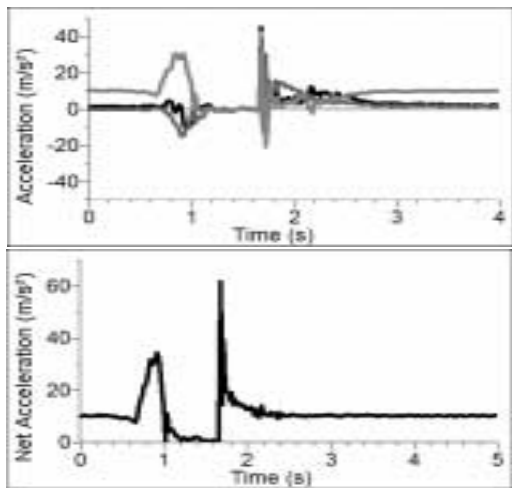
*3-Axis Accelerometer tossed in the air but not rotated*

In the graph above, the box was tossed in the air but not rotated. Notice that the x- and z-axis accelerations before the toss are zero whereas the y-axis acceleration is  $9.8 \text{ m/s}^2$ . During the toss all three accelerations and the net acceleration go to  $0 \text{ m/s}^2$ .

In the graph below, the interface and accelerometer were tossed in the air and spun. During the toss the x-, y-, and z-axis accelerations all change

.Notice that the net acceleration does not quite go to zero due to centripetal acceleration.

3-Axis Accelerometer tossed and rotated in the air.



### Frequent Questions on Accelerometer Measurements

Since the accelerometer is sensitive to both acceleration and the Earth's gravitational field, interpreting accelerometer measurements is complex. A useful model for understanding accelerometer measurements is a spring-based scale with a reference mass (or object) attached to the scale. If the scale is pointing upward (the usual orientation for such a device) the weight of the mass causes the spring to compress, and you get a non-zero reading. If you were to turn the scale upside down, the spring will be extended, instead of compressed, and we get a reading of the opposite sign. If you turn the scale so it points sideways, and keep it motionless, then the spring will just be at its relaxed length, and the reading will be zero. If you accelerated the scale toward the mass, then the spring would compress; away, and the spring would stretch. In each case the scale is reading a value corresponding to the normal force on the mass. This reading can be made relative by dividing out the mass, giving units of N/kg, which is the same as  $m/s^2$ .

The accelerometer measurements can be interpreted in exactly this way.

Q: What does an accelerometer measure?

A: Normal force per unit mass.

Note that it's not the net force per unit mass (which would be acceleration), but it is the normal force per unit mass. This unusual quantity corresponds with what a rider on a roller coaster feels during the turns. This interpretation is useful even for the scalar total acceleration value, which is  $9.8 \text{ N/kg}$  for a three-axis accelerometer at rest, zero for one in free fall, and greater than  $9.8$  for one making a corner.

This normal force interpretation works even for a one-axis accelerometer being accelerated in a horizontal direction. The reading is non-zero as the test mass inside the device has to have a force applied to accelerate it. That's just a normal force that

happens to be horizontal.

When discussing the accelerometer reading, we can call it the Normal Force per Unit Mass, with units of N/kg.

Q: I thought the Accelerometer measured acceleration!

A: Here we are being very careful to not call something an acceleration when it is not a kinematic acceleration. For example, an "acceleration" of  $9.8 \text{ m/s}^2$  for an object that remains at rest is clearly a problematic interpretation, yet that's what the accelerometer reads.

You can correct the Accelerometer reading to get a true acceleration by adding the component of the gravitational acceleration field along the direction of the sensor arrow. For example, if the axis of the accelerometer is pointing upward, then the gravitational component is  $-9.8 \text{ m/s}^2$ . The Accelerometer reads  $9.8 \text{ m/s}^2$  when the arrow is upward and the device is at rest. By adding  $-9.8 \text{ m/s}^2$ , we get zero, which is the correct acceleration. If the arrow is horizontal, then the reading is zero, but the gravitational component is zero, and we still have zero for the true acceleration. If an Accelerometer is zeroed to remove the influence of gravity, the zeroing is later wrong if the Accelerometer is rotated.

Q: What about g-force measurements?

A: We avoid the term g-force because the quantity doesn't have units of force. Instead, g-factor can be used as a simplified label for Normal Force per Unit Mass in axis labels and discussions.

You can see that the g-factor is then 1 for an object sitting at rest on a table, zero in free fall, etc. The g-factor is dimensionless. If the Normal Force is a vector, then so is the g-factor. g-factor is completely optional—it is just a shortcut to avoid a long name.

### Warranty

Vernier warrants this product to be free from defects in materials and workmanship for a period of five years from the date of shipment to the customer. This warranty does not cover damage to the product caused by abuse or improper use.



#### Vernier Software & Technology

13979 S.W. Millikan Way • Beaverton, OR 97005-2886  
Toll Free (888) 837-6437 • (503) 277-2299 • FAX (503) 277-2440  
info@vernier.com • www.vernier.com

Rev. 5/28/07

Logger Pro, Logger Lite, Vernier LabQuest, Vernier LabPro, Go!Link, Vernier EasyLink and other marks shown are our trademarks or registered trademarks in the United States.

CBL 2 and CBL, TI-GRAPH LINK, and TI Connect are trademarks of Texas Instruments.

All other marks not owned by us that appear herein are the property of their respective owners, who may or may not be affiliated with, connected to, or sponsored by us.



Printed on recycled paper.