

Newton's 2nd Law Lab

Equipment SWS, motion sensor, meter stick, force sensor, clamp and rod for force sensor, weights with hooks, 18.7 cm glider, 28.7 cm glider, air track, smart pulley, string for gliders, photo gate, large picket fence.

Reading (How to Use SWS) - Pages 225 through 228.

Photogate An SWS digital sensor shaped in the form of a U. An infrared beam (peak at 880 nm) is passed between the legs of the U. With the beam unblocked the output of the sensor is high. With the beam blocked the output is low and a light on the sensor is on. Usually SWS starts timing with a 10 kHz clock when the beam is blocked and stops timing when the beam is unblocked. This sequence is repeated if the beam is alternately blocked and unblocked. When used with various accessories such as picket fences and pulleys SWS can calculate position, velocity, acceleration, rotation, etc.

Force Sensor A SWS analogue sensor that measures force in newtons (N) by means of a strain gauge. This sensor has a hook that if pushed records as a positive force and if pulled records as a negative force. The maximum force is ± 50 N. (1 N=0.2248 lb.) The force sensor can be calibrated. As usual, double click the force sensor icon to show the calibration window. There is a tare button which zeros the force sensor even if there is a force on it. This is a very useful feature that allows you to cancel out a given force and have the sensor give only changes from that force.

Smart Pulley A digital sensor that combines a photogate sensor with a pulley that has spokes. As the pulley turns the photogate is successively blocked by the spokes. If a string is passed over the smart pulley a display can be programmed to give position, velocity, acceleration, etc.

Picket Fence A sheet of clear plastic with opaque bands on it. When a picket fence is passed through a photogate the photogate beam is alternately blocked and transmitted. A display can be programmed to give the position, velocity, acceleration, etc. , of the picket fence. It is necessary to program the display for the band distance. This is the distance from the beginning of one opaque band to the beginning of the next opaque band.

1 Purpose

To verify Newton's 2nd law and some applications of this law.

2 Theory

Let \vec{F} be the force in newtons (N), m the mass in kilograms (kg), and \vec{a} the acceleration in $m \cdot s^{-2}$. Newton's 2nd law states that

$$\vec{F} = m\vec{a}.$$

This is a vector equation but in this lab the motions are in one linear dimension and the vector notation can be dropped. This law can be applied to an entire system or to any part of the system. Here we assume that the system is a rigid body and that the forces are applied in such a way that the body does not rotate. The force \vec{F} is the sum of all the forces acting on the chosen body or system. This can also be called the net force or the total force.

Let m be the mass of an object on or near the surface of the earth, M the mass of the earth, R the radius of the earth, and G Newton's gravitational constant. The gravitational force F_G between m and M is given by Newton's gravitational law as

$$F_G = \frac{GmM}{R^2} = mg,$$

where g is called the acceleration due to gravity (on the surface of the earth) and is given by

$$g = \frac{GM}{R^2} = 9.81 \text{ m} \cdot \text{s}^{-2}.$$

F_G is more popularly known as the weight. The above has 2 important applications.

1. The weight of an object in N is equal to the mass in kg times $g=9.81 \text{ m} \cdot \text{s}^{-2}$.
2. If the only force on a dropped object is F_G , then Newton's 2nd law gives $mg = ma$, or $a = g$. Hence the name for g .

3 Does $F = ma$?

3.1 Description

The force sensor will be used to measure the net force (F) on a mass (m) and the position sensor will be used to measure the acceleration (a). The measured acceleration should be equal to F/m if Newton's 2nd law holds.

3.2 Programming

Check that the motion sensor and the force sensor are plugged in and note the channels used. Program SWS for the digital motion sensor and the analogue force sensor. You may use the default speed of sound and trigger rate for the motion sensor. In the experimental setup window, drag the graph display icon to the motion sensor icon and choose position, velocity, and acceleration. On the graph display click the add plot button and on the menu for analogue sensors click the force sensor. Your graph display will have 4 graphs labeled position, velocity, acceleration, and force.

3.3 Calibrating the Force Sensor

Suspend the force sensor from a horizontal rod. Hang a 0.5 kg mass on the hook of the sensor. Double click on the force sensor icon to open up the calibration window.

- Press the tare button on the force sensor to zero the sensor.
- Click the Read button in the Low Value row and then enter 0 in the left Low Value box.

- Hang two 0.2 kg masses from the 0.5 kg mass already on the force sensor.
- Click Read in the High Value row and then enter the weight of your two 0.2 kg masses in the High Value row. The weight in newtons will be $0.400 \times 9.81 = 3.92$. Strictly speaking you should enter a negative number here as the hook on the sensor is being pulled. For comparison with the acceleration, it is more convenient to change the sign and enter the weight as a positive quantity.
- Click OK.

Remove the two 0.2 kg masses from the force sensor but leave the 0.5 kg mass.

The force sensor has been calibrated to read zero when the mass (0.5 kg) is at rest. The net force when the mass is accelerated will now be given by the output of the force sensor.

3.4 Taking Data

Place the motion sensor on the floor with the grill pointing up. Be sure that it is far enough away from the edge of the bench so that it does not measure the height of the bench. Carefully remove the force sensor with the 0.5 kg mass attached and hold it over the motion sensor. Have your partner click Rec and move the force sensor up and down 3 times in a vertical line above the motion sensor. Click Stop. Examine your data. You should take several runs to determine how to get the best data. You will probably do better if you move the sensor fairly quickly up and down, but you should not move so quickly that the mass disengages from the sensor.

3.5 Analysis

Compare the graph for force with the graph for acceleration. Does the curve for force pretty much duplicate the shape of the curve for acceleration? Are the magnitudes what they should be? What about the zero crossings? If you made exactly the same motion with the force sensor but at a different distance from the motion sensor, which of your 4 graphs would differ from the ones you actually took?

4 Newton's 2nd Law Applied To A System.

4.1 Description

Newton's laws are tested for a system of 2 masses connected by a string. Mass M_1 is hanging from a vertical string. The string goes over a smart pulley and is attached to a mass M_2 . This second mass is a glider that lies on a horizontal air track, and the string attached to this glider is also horizontal. The glider on the air track is held stationary and then let go. The motion of the string and hence of the gliders is measured by the smart pulley.

4.2 Theory

Let the tension in the string be T and the common acceleration of the masses be a . If the positive directions are taken as down for M_1 and toward the pulley for M_2 the 2nd law applied to each of the masses gives

$$M_1g - T = M_1a \text{ and}$$

$$T = M_2 a.$$

Eliminating T results in

$$a = \frac{M_1 g}{M_1 + M_2}.$$

The above analysis assumes that the pulley is massless and frictionless. If either of these assumptions is not true the tension in the string is not the same on each side of the pulley.

4.3 Programming

Check that the smart pulley is plugged in and note the channel. Program SWS for a digital sensor and choose smart pulley. Open the graph display, choosing position, velocity, and acceleration.

4.4 Set Up

Remove the rod from the clamp that was used in part one. Position the clamp at the end of the air track with the screw on top of the bench. Insert the smart pulley into the clamp. First use the 18.7 cm long glider and level the air track. The string has two loops. Attach one end of the string to the glider, pass the string over the pulley, and attach a 10 g mass to the other end of the string. Adjust the smart pulley so that the string next to the glider is horizontal and passes through the groove in the end of the air track. Check that when the glider is a few inches from the end of the air track the mass hits the floor.

4.5 Data Taking

Draw the glider back from the end of the track as far as you can without having the mass hit the clamp holding the smart pulley. Let go of the glider and click Rec at the same time. Click Stop just before the glider hits the end of the air track. Click the statistics and auto scale buttons and determine the slope of the velocity curve. (Box in your data if necessary to remove bad points.) Determine the acceleration a . Repeat for masses of 20 g and 30 g.

Use the 28.7 cm long glider. Accelerate it with masses of 30, 40, and 50 grams.

4.6 Analysis

Compare your results to the theoretical values. How well do they agree? What are possible reasons for any disagreement?

5 The Acceleration of Gravity, g

5.1 Description

A picket fence is dropped through a digital photogate sensor. The acceleration of the picket fence is measured and compared to g .

5.2 Programming

Check if the photogate sensor is plugged in and note the channel. Program SWS for the photogate & picket fence. Double click the sensor icon and note the opaque band spacing is 0.05 m. This is the correct value for the picket fence used in this experiment. Verify this by using the meter stick. Click OK. Open the graph display, choosing position, velocity, and acceleration.

5.3 Taking Data

Place the photogate stand near the edge of the bench and have the photogate itself extend over the edge of the bench. Put a few coats on the floor directly beneath the photogate to act as a cushion for when the picket fence hits the floor. Hold the picket just above the photogate, click the Rec button, and let go of the picket fence. Click Stop. (SWS does not actually take data until the photogate beam is first blocked, so there is no need to drop the picket fence immediately after the Rec button is clicked.) Determine the acceleration of the picket fence. Take a few runs to have some statistics.

5.4 Analysis

Compare your results to g . What contributes to errors? Please do not do this (you might damage the picket fence by hitting the photogate) but if you were able to release the picket a considerable distance above the photogate and still have it go through the photogate would your results be as accurate? Explain.

6 Finishing

Please return the bench to the condition in which you found it. Remove the smart pulley from the bench clamp and use the bench clamp to mount the rod and force sensor. Thank you.