

AP Physics Lab #4: Newton's Second Law (Big Idea 3 & 4)

3.B.1.2: The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces.

4.A.3.1: The student is able to apply Newton's second law to systems to calculate the change in the center-of mass velocity when an external force is exerted on the system.

In your discussion of Newton's first law, you learned that when the sum of the forces acting on an object is zero, its velocity does not change. However, when a net force acts on the object, it accelerates. In this experiment, you will determine the relationship between the net force acting on an object and its acceleration. In this experiment, you will identify the forces acting on an object both when its change in velocity, Δv , is zero and when it is accelerating. Collect force, velocity, and time data as a cart is accelerated on a track. Use graphical methods to determine the acceleration of the cart. Determine the relationship between the cart's acceleration and the net force applied to it. Determine the effect of the mass on the relationship between acceleration and force.

Newton's Second Law Pre-Lab:

P1. Your instructor will show you the apparatus for this experiment. It is called a "modified Atwood's machine." A weight is connected to a cart by a string over a pulley. When the weight is allowed to fall, observe the motion of the cart. A force sensor mounted on the cart enables you to measure the force acting on the cart when it is moving. Discuss how you could determine the acceleration of the cart. Sum the forces for both objects in the cart-hanging mass system. Sketch a graph of the acceleration vs. time based on your observations and class discussion.

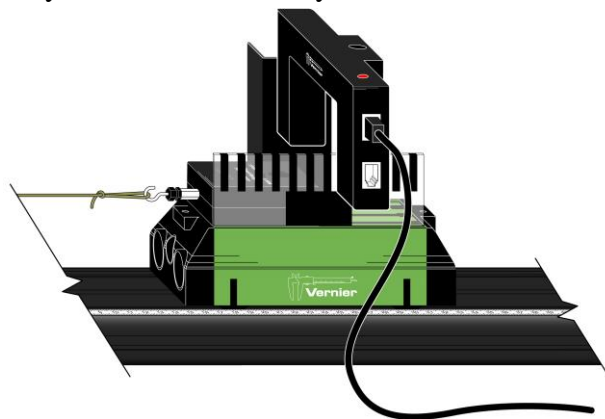
Newton's Second Law Lab- Data Collection:

Materials: LabQuest 2, Logger Pro (optional), Lab Quest App (optional), dual-range force probe, photogate, motion detector, dynamics track system, ultra-pulley, pulley bracket, hanging masses

There are three methods one can use to collect velocity vs. time data and determine the acceleration of the cart. Choose the one method that interests you the most.

Method 1: Timing with a Photogate and Picket Fence

1. Attach an Ultra Pulley to the Pulley Bracket; attach this assembly to one end of the Dynamics Track. Make sure that you have adjusted the track to make frictional forces negligible.
2. Connect the Dual-Range Force Sensor (DFS) and a Photogate to the interface; then start the data-collection program. You will need only graphs of force vs. time and velocity vs. time, so you can delete others and then re-size graphs to make them easier to see. LabQuest App users can do this in the Graph Options menu.
3. Place the Cart Picket Fence in the slot on the cart so that the alternating dark and clear bands are on the top. Now place the force sensor on the cart.
4. Position the photogate (using a support rod and clamp) so that the alternating dark and clear bands on the picket fence will interrupt the beam, as shown in the figure above and to the right.



- Choose an appropriate range of masses to use to apply the force that will accelerate the cart. Determine the total mass of your cart, force sensor, and any additional mass you may be instructed to use.
- Set up data collection. Most of you will use the instructions for the LabQuest device and not Logger *Pro*.

Using Logger *Pro* (on the computer)

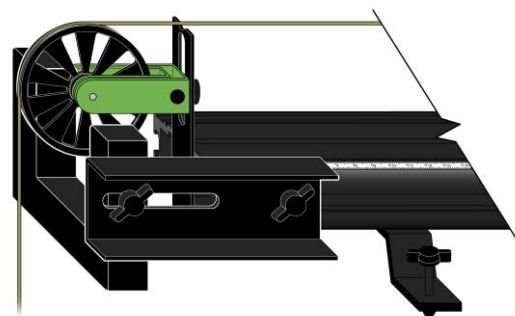
- Choose Experiment ► Set Up Sensors ► Show All Interfaces from the Experiment menu.
- Click the image of the Photogate, select Set Distance or Length, then select Cart Picket Fence from the list of devices.
- Choose Data Collection from the Experiment menu. In the Mode list, click Digital Events. End collection after 20 Events.

Using LabQuest as a standalone device

- Data collection defaults to Photogate Timing (Motion) mode. Select Cart Picket Fence (not Vernier Picket Fence). The length should automatically switch to 0.01 m and be set to record 26 events. This corresponds with the width and number of lines on the cart picket fence.
- Disconnect the hanging mass from the force sensor, then zero the sensor by tapping the screen.
 - Re-connect the hanging mass to the Force Sensor. Position the Photogate so that the cart and picket fence pass through the photogate while the cart is accelerating (before the hanging mass stops moving). Use something to cushion the hanging weight when it strikes the floor.
 - Start data collection, then release the cart.
 - To determine the force acting on the cart, select the portion of the force *vs.* time graph corresponding to the interval during which the cart's velocity was changing smoothly. Find the statistics for this interval. Manual scaling of your graph is more helpful for doing this than Autoscaling.
 - To determine the acceleration of the cart, perform a linear fit on the velocity *vs.* time graph. Be sure to record the values of force and acceleration for this hanging mass in your lab notebook.
 - Repeat Steps 9–11 until you have force *vs.* acceleration data that are reasonably consistent for that mass.
 - Increase the hanging mass and continue until you have acceleration *vs.* force data for at least five different hanging masses.

Method 2: Timing with a Photogate and Ultra Pulley

- Attach an Ultra Pulley to the Pulley Bracket; attach this assembly to one end of the Dynamics Track. Make sure that you have adjusted the track to make frictional forces negligible.
- Connect the Dual-Range Force Sensor (DFS) and a Photogate to the interface; then start the data-collection program. You will need only graphs of force *vs.* time and velocity *vs.* time, so you can delete others and then re-size graphs to make them easier to see. LabQuest App users can do this in the Graph Options menu.
- Attach the force sensor to the cart.
- Attach the photogate to the track using a bracket so that the spokes on the pulley interrupt the beam, as shown to the right.
- Discuss with your instructor what range of masses to use to apply the force that will accelerate the cart. Determine the total mass of your cart, force sensor, and any additional mass you may be instructed to use.



6. Set up data collection.

Using *Logger Pro* (on the computer)


- Choose Set Up Sensors ► Show All Interfaces from the Experiment menu.
- Click the image of the Photogate, select Set Distance or Length, then select Ultra Pulley (10 Spoke) Inside from the list of devices.

Using LabQuest as a standalone device

- Data collection defaults to Photogate Timing mode. Tap Mode and select Pulley (10 spoke) ► inside edge.

- Disconnect the hanging mass from the force sensor, then zero the sensor.
- Re-connect the hanging mass to the force sensor. Position the cart so that the hanger has about 30 cm to fall. Use something to cushion the hanging weight when it strikes the floor.
- Begin collecting data, then release the cart. Stop data collection after the weight hits the cushion on the floor.
- To determine the force acting on the cart, select the portion of the force *vs.* time graph corresponding to the interval during which the cart's velocity was changing smoothly. Find the statistics for this interval. Manual scaling of your graph is more helpful for doing this than Autoscaling.
- To determine the acceleration of the cart, perform a linear fit on the portion of the velocity-time graph during which the velocity is changing smoothly. Be sure to record the values of force and acceleration for this hanging mass in your lab notebook.
- Repeat Steps 9–11 until you have force *vs.* acceleration data that are reasonably consistent for that mass
- Increase the hanging mass and continue until you have acceleration-force data for at least five different hanging masses.

Method 3: Timing with a Motion Detector

- Attach an Ultra Pulley to the Pulley Bracket; attach this assembly to one end of the Dynamics Track. Make sure that you have adjusted the track to make frictional forces negligible.
- Connect the Dual-Range Force Sensor (DFS) and a Motion Detector to the interface; then start the data-collection program. You will need only graphs of force *vs.* time and velocity *vs.* time, so you can delete others and then re-size graphs to make them easier to see. LabQuest App users can do this in the Graph Options menu.
- Attach the force sensor to the cart. Mount the motion detector at the end of the track opposite the pulley. If your motion detector has a switch, set it to Track. 
- Discuss with your instructor what range of masses to use to apply the force that will accelerate the cart. Determine the total mass of your cart, force sensor, and any additional mass you may be instructed to use.
- Set up data collection.

Using *Logger Pro* (on the computer)

- Choose Data Collection from the Experiment menu.
- Reduce the length of time to 3 seconds.

Using LabQuest as a standalone device (next page)

- a. Tap Length and change the length of data collection to 3 seconds.
 - b. Change the time to 3 seconds on the x-axis column using Graph Options in the graph tab.
6. Position the cart so that the hanging mass is approximately 30 cm from the floor, disconnect the hanging mass from the force sensor, then zero both sensors. Make sure the starting position of the cart is at least 20 cm from the motion detector.
 7. Re-connect the hanging mass, begin collecting data, then release the cart. Catch the hanging mass before it strikes the floor.
 8. To determine the force acting on the cart, select the portion of the force *vs.* time graph corresponding to the interval during which the cart's velocity was changing smoothly. Find the statistics for this interval. Manual scaling of your graph is more helpful for doing this than Autoscaling.
 9. To determine the acceleration of the cart, perform a linear fit on the portion of the velocity *vs.* time graph during which the velocity is changing smoothly.
- Be sure to record the values of force and acceleration for this hanging mass in your lab notebook.
10. Repeat Steps 7–9 until you have force *vs.* acceleration data that are reasonably consistent for that mass
 11. Increase the hanging mass and continue until you have acceleration *vs.* force data for at least five different hanging masses.

Newton's Second Law Lab- Data Analysis:

1. To evaluate the relationship between acceleration and force, disconnect the sensors and choose New from the File menu.
2. Even though you investigated how acceleration responded to changes in the force, in order to facilitate your analysis of data, plot a graph of force *vs.* acceleration.
3. If the relationship between force and acceleration appears to be linear, fit a straight line to your data. If possible, print a copy of your data table and graph.
4. Write the equation that represents the relationship between the force, F , acting on the cart and the cart's acceleration, a . Be sure to record the value of the mass of the cart, sensor, and any additional masses you used.
5. Write a statement that describes the relationship between the force acting on the cart and the cart's acceleration.
6. Compare your results to those obtained by others in class. What relationship appears to exist between the slope of the graph of F *vs.* a and the mass that was accelerated?
7. Assuming that the conclusion you reached in Step 6 is correct, express the SI unit of force, N, in terms of the fundamental units of mass, length, and time.
8. Write a general equation that expresses the relationship between the force, mass, and acceleration.
9. Examine the force *vs.* time graph for one of your trials. Explain why the force reading decreases as the cart is released and accelerates. Suppose that you had kept the net force acting on the cart the same, but varied the mass instead. Predict the shape of the graph of acceleration *vs.* mass. Your answer to this question should suggest why it would be very difficult to perform an experiment to test your prediction. Explain.