NEWTON’S SECOND LAW OF MOTION

The acceleration of an object is defined as the rate of change of velocity. If the velocity changes by an amount \( \Delta v \) in a time \( \Delta t \), then the average acceleration during this time is

\[
a = \frac{\Delta v}{\Delta t}.
\] (1)

Newton’s 2nd law of motion states that if a net force acts on an object, then the object accelerates and its acceleration is proportional to the net force applied:

\[
F_{\text{NET}} = m a
\] (2)

The proportionality constant \( m \) is the inertia of the object and its numerical value is called the mass.

**Equipment:** Track, motion sensor, force sensor + hooks, cart, rubber band, fan, masses, stopper

**PART I: Predictions**

Imagine that you have cart at one end of a level track. There is no friction.

1) Suppose the cart is initially at rest at one end of the track. You push it with a constant force until it reaches the middle of the track and then let it roll freely until it reaches the other end. Sketch the expected velocity versus time curve to the right.

2) Next give it a short tap with your finger to set it into motion. Then when the cart has reached the center of the track you give it another short tap in the same direction and let it roll to the end of the track. Make a sketch of the expected velocity of the cart as a function time in the left graph below. Next, repeat the above but when the cart reaches the middle of the track you tap it in a direction opposite to its motion. Make a sketch of the expected velocity as a function of time in the right graph.
3) Describe why you draw the curves as you did

4) Draw below three free body diagrams of the cart. One when is at rest on the track. Two, while it is moving (and no tapping). Three, at the instant you tap it.

Now for a final prediction. Suppose you raise one end of the track to form an incline. You shove the cart up the incline and record its motion as it goes up and then returns to the bottom of the incline. First, assume that friction can be neglected.

5) Sketch the expected position and velocity of the cart as a function of time.

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<th>x</th>
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6) Now, assume that friction cannot be neglected. Again, sketch the expected position and velocity as a function of time.

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7) Are your predicted curves the same with and without friction? Explain.

**PART II: Push on the cart**

Connect the motion sensor to the Pasco interface box, open Datastudio and set the data rate of the motion sensor to 50 Hz. Place the motion sensor at one end of the track and the cart 15-20 cm from the sensor.

![Diagram of sensor and cart setup]
Tap the cart with one finger to set it moving away from the sensor and then tap it again in the same direction when it reaches the middle of the track. (Note: Try to keep most of your hand away from the cart since it will interfere with the measurements.)

8) Record the velocity as a function of time and make a rough sketch of the curve to the right.

9) Is the curve qualitatively like you predicted?

10) Is the velocity constant between taps? If not, why?

11) Now try to push the cart away from the sensor with a constant force for an extended period of time while recording the velocity. Sketch your measured curve to the right.

12) Does the shape of the velocity versus time curve during the push suggest that you were indeed pushing with a constant force? Explain.

Pushing the cart with your hand with a constant force is difficult to do. In order to maintain a more nearly constant force, you can try to pull the cart with a rubber band while keeping the stretch of the rubber band constant during the pull. (Use thin rubber bands and tie two or three end-to-end.). Add a mass on top of the cart.

Starting with the cart 15 – 20 cm from the sensor, record the velocity while pulling with a constant stretch of the rubber band in a direction away from the sensor.

13) Does the velocity versus time curve suggest that the force is approximately constant?

14) Now add some mass to the cart and repeat with the same stretch of the rubber band. Is your acceleration larger or smaller?

Is this what you expect?

15) For each of the two cases above, calculate the mass times \( \text{acceleration} \). Be sure to include the mass of the cart.

16) We now want to check numerically Newton 2nd law. Use the force sensor to measure the force acting on the cart (pull the rubber band with the hook attached to the force sensor). Again keep the rubber band at constant stretch and use three different masses. Close Datastudio (if still open) and open the file: “Newtonlaw.ds” contained in the T:\Datastudio folder. You see a window with the force \( vs \) time and velocity \( vs \) time so you can compare the values of the force with the acceleration during the same time interval. Tare the force sensor before each measurement (press the tare button on the side of the sensor). The force might not appear to be constant and smooth, so take the mean value of it. Get the measure of the acceleration from the velocity \( vs \) time graph.

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<th>( a ) (m/s(^2))</th>
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On the last column (Check) draw a check mark if the Newton second’s law is satisfied from your data.
PART III: Incline plane

Now, place something under the end of the track opposite to the sensor to raise it by 2-3 cm. Shove the cart so that it rolls up the incline and comes back down. Draw two free body diagrams: as the cart moves up and as it moves back down. Indicate on the diagrams also the net force acting on the cart.

17) Compare the magnitudes of the net forces. Should they be the same? If not, which one is greater?

18) Record the position and velocity during this time. Now compare these graphs with your earlier predictions. From the velocity vs time graph, is the magnitude of the acceleration greater when the cart is moving up or down the incline?

19) How can you tell the two accelerations are different by looking at the position vs time graph?

20) Would you say that friction has a noticeable effect on the shapes of the curves? Explain.

It can be shown that the friction force is given by:

$$F_{FRICITION} = \frac{m}{2} \left| (a_{up} - a_{down}) \right|$$

(3)

21) Find the accelerations by taking the slope of the velocity versus time curve and calculate the friction force using the equation above:

Put together on the same computer screen both the position vs time and the velocity vs time graph. Turn in a printed copy of it.

PART IV: Fan Cart

Another way to maintain an approximately constant force is to use a fan cart. Level the track and place the fan cart near the sensor. Use the fan, set with three AA batteries + one metal cylinders, and record the velocity as it moves away from the sensor. Sketch both position and velocity as a function of time.
22) Are the shapes of the curves what you expect?

23) Does the shape of the velocity vs time curve suggest that the acceleration is approximately constant? Explain.

24) Find the acceleration by taking the slope of the velocity versus time curve.

25) Calculate the force acting on the cart (mass of the cart = 490 g, mass of the fan = 260 g)

26) Now add a mass $m$ to the fan cart, look and the graph and calculate the acceleration from the slope.

27) Calculate the force acting on the cart in this case

28) Compare the results found in 24 and 26 and discuss any difference.

Finally, turn the cart so that the fan blows away from the sensor (and so it would make the cart moving towards the sensor). With the cart near the sensor, shove it away from the sensor so that it goes towards the end of the track and returns, and record the velocity during this time. Sketch your velocity versus time and position versus time curves below.

29) Are they what you expect? Is the effect of friction apparent?

30) Find the accelerations by taking the slope of the velocity vs time curve and calculate the friction force using the equation (3).

Put together on the same computer screen both the position vs time and the velocity vs time graphs. Turn in a printed copy of it.

31) Compare the ways you have found the friction force in Part III and Part IV. Which method do you think is more accurate and why?