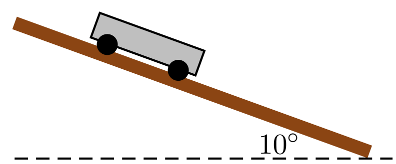
Laboratory 6: Newton's Second Law for a Single Object – Prelab

1 Cart sliding along a ramp.

The illustrated cart can slide along a frictionless inclined surface. The cart is released from rest.



a) Starting with a free body diagram and Newton's second law determine the acceleration of the cart if its mass is 0.500 kg.

b) Suppose that a block with mass 0.250 kg is placed on the cart. Will this change its acceleration? If so, what will the acceleration be? Explain your answer.

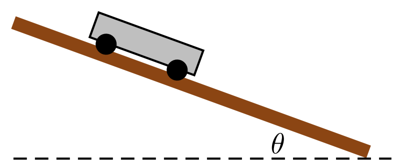
Laboratory 6: Newton's Second Law for a Single Object – Activity

Newton's laws provide a framework for determining the acceleration of any object. The framework requires that all the forces, $\vec{\mathbf{F}}_1, \vec{\mathbf{F}}_2, \vec{\mathbf{F}}_3, \ldots,$ that act on the object are known. The acceleration, $\vec{\mathbf{a}}$, of the object is given indirectly by Newton's second law,

$$\vec{\mathbf{F}}_{\text{net}} = m\vec{\mathbf{a}}$$

where m is the mass of the object and the net force is given by

$$\vec{\mathbf{F}}_{\text{net}} = \sum_i \vec{\mathbf{F}}_i = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \vec{\mathbf{F}}_3 + \ldots.$$



You will observe a cart sliding along an inclined ramp. A motion sensor will record the velocity of the cart as time passes and you can use this data to determine the cart's acceleration, which can be compared against a value determined by applying Newton's laws to the cart.

1 Cart sliding along a ramp: theory

The first aim of the laboratory is to determine a general equation for the acceleration of the cart that applies for various ramp angles and cart masses. Consider a cart, of mass m, that slides up or down a frictionless ramp, whose surface is at an angle θ from the horizontal.

a) Draw a free body diagram for the cart.

b) Will the acceleration of the cart will be different when the cart is sliding up the ramp versus down the ramp? Explain your answer by using the free body diagram for the cart.

In terms of components, Newton's second law states that

$$\boxed{\begin{aligned} \Sigma F_x &= ma_x \quad \text{and} \\ \Sigma F_y &= ma_y. \end{aligned}}$$

(1), (2)

c) Using "tilted axes" with the x-axis along the ramp determine expressions for the components of all the forces. Then use Eqs. (1) and (2) to determine an expression for the magnitude of the cart's acceleration, a. This should have the form

$$a = \text{formula where the only symbols allowed are } g, \theta \text{ and } m.$$

d) Does your formula predict that the mass of the cart will affect the acceleration? Explain your answer.

e) Does your formula predict that the acceleration of the cart as it ascends the ramp will be different from that when it descends? Explain your answer.

2 Cart descending a ramp: experiment

This part of the laboratory will investigate whether predicted acceleration matches the measured acceleration for motion down the ramp. The laboratory is equipped with a cart and a track that can be tilted at various angles. A motion sensor connected to the top of the ramp will be used to record position and velocity data for the moving cart.

a) Start CapStone and connect the motion sensor. Set the sample rate to 25 Hz. Configure CapStone to display a graph of velocity versus time.

b) Prop the track up so that the motion sensor is at the top of the resulting ramp.

c) Describe how to determine the angle that the track makes with respect to the horizontal by using various measurements of lengths and heights (measuring the angle directly using a protractor will be much less accurate).

d) Use the technique from part 2 c) to determine the angle that the track makes with respect to the horizontal.

e) Hold the cart at rest at a distance a little more than 50 cm from the motion sensor. Start data acquisition and release the cart. Save the data. *Note: If the cart collides with the bumper at the end of the track, it can exert a force on the track that moves the track slightly and this will change the angle at which the track tilts. If you plan to redo the experiment you will need to check whether this angle has changed or not.*

f) Explain whether the graph of velocity versus time suggests that the acceleration is constant or not. Determine the acceleration of the cart from the graph of velocity versus time. Print the graph of velocity versus time, with the ramp angle and measured acceleration written on it, and attach this to your package.

g) Predict the acceleration using the formula developed in part 1 c). Determine the percentage difference between the measured and predicted acceleration.

h) Repeat parts 2 d) to 2 g) for the same slope angle but with additional mass added to the cart. Does the additional mass change the cart's acceleration? Does it make the experiment more or less accurate?

i) Repeat parts 2 d) to 2 g) for two other slope angles. Ensure that you save the data from each good run.

3 Cart ascending and descending a ramp: experiment

In section 1 you applied Newton's second law to the cart for the cases where it **ascends or descends** the ramp and you predicted whether the acceleration would differ between these cases, given that the ramp angle is the same. This part of the laboratory will investigate whether your prediction is correct for motion in either direction along the ramp.

a) Ensure that CapStone is still configured as before. Hold the cart at the bottom of the ramp. Start data acquisition and give the cart a gentle push up the slope. CapStone should produce a graph of velocity versus time.
Important: *the older versions of the* motion sensor *do not record position of an object that is closer to the sensor than* 50 *cm accurately. An example of this is illustrated in Fig. 1. Discard any run in which this or worse happens.*

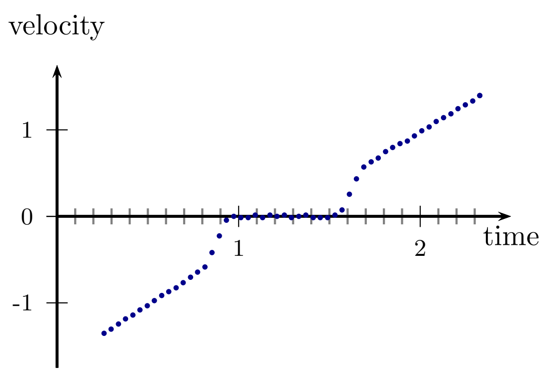


Figure 1: *Data recorded when the cart approached too close to the motion sensor. During the time interval from about* 0.8 *s to* 1.6 *s, the motion sensor did not record the cart's position or velocity correctly.* ***This is bad data!***

b) Print out the graph. Identify the period on the graph during which the cart ascends the ramp. Identify the period during which the cart descends.

c) Does the graph suggest that the acceleration while the cart ascends differs from that while it descends? Explain your answer.

d) Using the graph, determine and record (on the graph) the acceleration of the cart while it ascends.

e) Using the graph, determine and record the acceleration of the cart while it descends.

f) How does the acceleration of the cart when ascending compare (same as, close to, larger, smaller, . . .) to that when it is descending?

g) Repeat parts 3 a) to 3 f) for a different ramp angle. You should observe that there is always a discrepancy between the acceleration of the cart as it ascends the ramp compared to that as it descends. Is the acceleration as the cart ascends always larger than that as it descends or always smaller?

h) The forces that appear on your original free body diagram cannot explain this discrepancy; there must be an additional force present. This force is either friction or air resistance and it points directly opposite to the direction of motion.
Draw a corrected free body diagram that includes this force for the ascending cart. Repeat this for the descending cart. Are the free body diagrams the same or not? For which case (ascending/descending) will the net force be larger? Use this to describe for which case the acceleration will be larger. Does this agree with your observations?

4 Conclusion

What does this experiment establish or verify regarding Newton's second law?