UNIT 2
ONE-DIMENSIONAL FORCES AND MOTION

Objectives

- To devise a method for applying a constant force to an object.

- To devise a scale for measuring force.

- To understand the relationship between force and acceleration based on observations of the motions of objects to which forces are applied in one dimension, particularly in the case of very little friction.

- To understand the concept of net force.

- To understand the concept of Newton's First Law.

- To operationally define mass.

- To understand the mathematical relationship between force and acceleration; the concept of Newton's Second Law.

Watch this video produced by the Insurance Institute for Highway Safety. This clip is an example of one-dimensional forces and motion. It depicts a split screen view of a 35 MPH car crash into a fixed barrier. In the top window the car is equipped with a working air bag but in the bottom window the car has no air bag. In both views, the crash test dummy is using both the lap and shoulder seat belts. This clip is in slow motion. The total actual running time of the crash depicted in the clip is less than a second.

Equipment:

Motion Detector
LoggerPro software
LabPro computer interface
Kinesthetic cart
Cloth

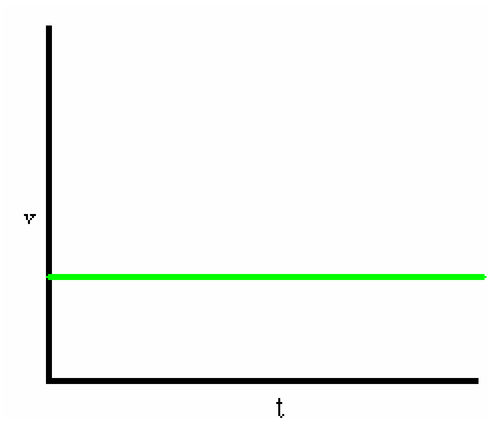
You may need the following:

Rubber bands
Springs
Bungee cords
Rolling chair
Your choice of objects

1.1

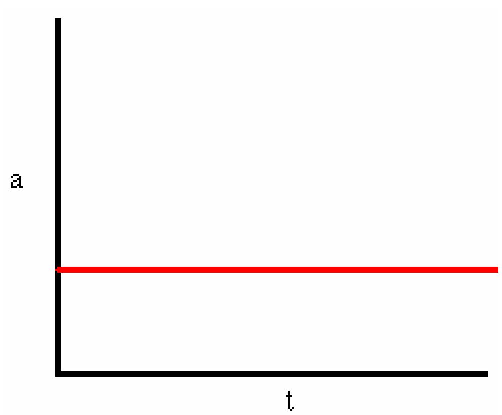
a. Give a definition of force. It does not have to be formal. Discuss in your own words what a force is.

b. Consider the velocity versus time graph for an object moving on a low friction track below.



Could you apply a force to produce this type of motion? If so, describe the force. Would the force be constant or changing? Explain.

c. Consider the acceleration versus time graph for an object moving on a low friction track below.



Could you apply a force to produce this type of motion? If so, describe the force. Would the force be constant or changing? Explain.

d. How would you apply a constant force to an object? How would you know the force is constant?

Devise a method for pulling on an object with a constant force. Explain your method and also explain why you believe that the force is constant.

Discuss your method with an instructor.

1.2

a. Pull a person with a constant force in each of the cases below:

(i) person sitting on a kinesthetic cart

(ii) person sitting on a cloth.

In each case use the motion detector to make graphs of velocity vs. time and acceleration vs. time.

b. Examine the velocity vs. time and acceleration vs. time for each of the cases in part **a** above. Ignore the smaller bumps associated with the wobbling spring or rubber band. Is the velocity zero, constant, or changing? Is the acceleration zero, constant, or changing? Explain what characteristic of the graph shape supports your description.

c. In which of the two cases in part **a** is there a lot of friction? In which of the two cases is there very little friction? Explain.

d. Is there a relationship between a constant applied force and velocity when friction is significant? Is there a relationship between a constant applied force and acceleration when friction is significant?

e. Is there a relationship between a constant applied force and velocity when friction is not significant? Is there a relationship between a constant applied force and acceleration when friction is not significant?

Discuss with an instructor.

Equipment:

You may need the following:
Motion Detector
LoggerPro software
LabPro computer interface
Kinesthetic cart
Cloth
Rubber bands
Springs
Bungee cords
Rolling chair
Your choice of objects
Low friction Dynamics Track
Cart
Calibrated spring scale
Force sensor

2.1 In this section, and section **2.2**, we will focus on objects moving with very little friction.

a. Suppose you had a rubber band, spring, or bungee cord, how would you define a unit of force? If you were to give the rubber band, spring, or bungee cord to someone else, how would you explain to them how to pull on something with one unit of force?

Discuss your definition with an instructor.

b. Name your unit of force.

c. If you defined a unit of force by using a rubber band (spring, bungee cord) in part **a** could you pull something with one unit of force using a spring (rubber band, bungee cord)? Explain.

d. Consider the following definition:

> "An equivalent force is a force that accelerates an object in the same way that your unit of force does."

Would it be possible to define an equivalent unit of force (equivalent to the unit of force you defined with a rubber band) with a spring or bungee cord using the above definition?

2.2

a. If your rubber band were extended to twice the length that defines one unit of force, would the rubber band pull with two units of force? You may need to do an experiment to test this. If so, describe your experiment. Explain.

b. If you were to pull an object with two rubber bands that were each extended the length that defines one unit of force, would the rubber bands pull with two units of force? You may need to do an experiment to test this. If so, describe your experiment. Explain.

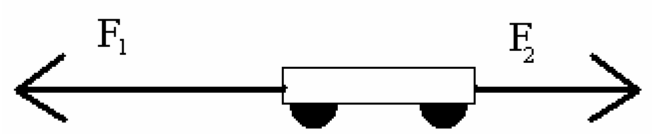
c. Describe how you would pull an object with 3 units of force. 4 units of force? 5 units of force?

The standard unit of force is one Newton (N); $1N = 1kgm/s^2$. A Newton is defined as the amount of force that is needed to give one kilogram an acceleration of $1m/s^2$.

d. It is possible to calibrate a spring to measure in Newtons. There are other instruments that are calibrated to measure in Newtons, one of which is a force sensor that can be attached to the LabPro computer interface. Using one of these instruments, determine how many Newtons it takes to equal one unit of force in your force units?

3.1

a. Suppose you pulled on an object with 3N to the right, 5N to the left, as in the picture below.



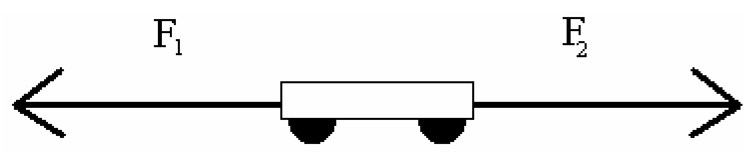
Which direction would the cart move? Explain. Would the cart accelerate? Explain.

b. What equivalent force could you apply to the cart to produce the same acceleration? Explain.

When more than one force is applied to an object, the single equivalent force that could be applied to produce the same acceleration is called the net force.

For example, for the cart in part **3.1.a** the net force is 2N to the left because a single force of 2N would produce the same acceleration as the two forces in the diagram.

c. Suppose you pulled on an object with 10N to the right, 10N to the left, as in the picture below.



If the cart were at rest before the forces were applied, would the cart move? Which direction would the cart move? Explain. Would the cart accelerate? Explain.

d. What is the net force on the cart in part **c**? Explain. What equivalent force could you apply to the cart to produce the same acceleration? Explain.

Equipment:

- Motion Detector
- LoggerPro software
- LabPro computer interface
- Low friction Dynamics Track
- Cart
- Force sensor

4.1

a. Consider a cart on a low friction dynamics track. The cart is given an initial push. After the initial push there is no net force on the cart. Draw the graphs of position vs. time, velocity vs. time, and acceleration vs. time after the initial push.

Discuss your graphs with an instructor.

b. If there were no friction and no other forces (except for the initial push), would the cart in part **a** stop? Explain.

c. Is it possible for an object to move at constant velocity without stopping when there is no net force on the object? Explain.

d. Carry out the experiment in part **a** with the cart on a low friction dynamics track and use the motion detector to record the graphs of position vs. time, velocity vs. time, and acceleration vs. time.

Newton's first law states:

> "A body at rest, will remain at rest and a body in motion at constant velocity will continue in motion at constant velocity, unless acted on by an external force."

e. Is this consistent with the experiment you did in part **d**? Explain.

Equipment:

- Motion Detector
- LoggerPro software
- LabPro computer interface
- Low friction Dynamics Track
- Cart
- Force sensor
- Balance
- Masses

5.1

a. In section **1.2.e**, you observed a relationship between force and acceleration with very little friction. When you applied a constant force to an object, you observed a constant acceleration. This implies a mathematical relationship between force and acceleration.

We are going to explore the relationship between force and acceleration in more detail. Attach the force probe to a low friction dynamics cart and to the LabPro computer interface. Also attach the Motion Detector to the LabPro computer interface. Open *Force acceleration*. This will allow you to take acceleration and force data at the same time.

With your hand pull back and forth on the force sensor, moving the cart forwards and backwards on the track, with different accelerations, taking data with both the motion detector and the force probe.

Observe the acceleration vs. time and force vs. time graphs. Is there a relationship between force and acceleration? Predict the mathematical relationship (if you think there is one) between force and acceleration. If you don't think there is a mathematical relationship between the force and the acceleration, explain why. If you do think there is a mathematical relationship between force and acceleration, explain your prediction of the form of the mathematical relationship.

Discuss your answers with an instructor.

b. An operational definition is a concise way to define a term. It is written is such a way so that there is no ambiguity as to the meaning of the term.

An example: Suppose you wanted to define *length*. To define it as "the span or the extent of an object" is not operational. It is not an incorrect definition, but it is not a concise definition.

An operational definition is:

1. Obtain a ruler, or something marked off in standard units.
2. Hold the ruler parallel to the side (the side whose length you would like to determine) of an object.
3. Align the end of the ruler that starts with "0" with one end of the object.
4. Observe what number on the ruler is aligned with the other end of the object.
5. That number is the length of that side of the object.

Write an operational definition for mass.

Discuss your definition with an instructor.

c. Repeat the experiment in part **a**, with *Force vs. acceleration*. This will allow you to also graph force vs. acceleration.

After you have taken the data, choose the graph of force vs. acceleration by clicking on the center of the graph. Choose *Analyze* and choose *Linear fit*. This will give you the slope of the best fit line to the data.

d. Would the graph of force vs. acceleration be different if you changed the mass (added mass to the cart) and pulled the cart in such a way as to produce the same acceleration graph in part **a**? Explain.

e. Repeat the experiment in part **c.** with different masses added to the cart. Take data with three or four different masses added to the cart. Record the amount of mass added to the cart each time. Save the graph each time.

Examine the different graphs. Does the slope of the line change? Does the slope of the line depend on the mass? Explain.

Compare the mass of the cart plus the added mass to the slope of the line for each graph.

f. Newton's second law states:

> "The acceleration of a body is directly proportional to the net applied force and inversely proportional to the mass of the moving body."

A mathematical statement of Newton's second law is:

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

Where $\mathbf{F}_{\mathbf{net}}$ is the net force, or total force, on the object.

g. Is this consistent with your data in part **a** and part **e**? Explain.

Discuss with an instructor.

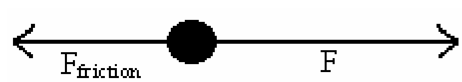
6.1

a. A box is being pulled by a force, **F**, across a table. The force is parallel to the table.The frictional force is not negligible and the box is accelerating in the direction of the force **F**. Draw the forces acting on the box in the horizontal (parallel to the table) direction.

Discuss with an instructor.

It is common to draw force diagrams to indicate the forces acting on an object. When we draw force diagrams, we will represent the object by a large point. The forces will be drawn as arrows pointing in the direction of the force, with the tail of the arrow on the point. Each force should be labeled.

A force diagram for the forces acting on the box in the horizontal direction would look like:



We will discuss force diagrams in more detail in Unit 4.

b. If the box has mass, m, and an acceleration, **a**, write a mathematical statement (in symbols) for the application of Newton's second law to this situation.

Discuss with an instructor.

c. If the box has mass of 4kg, is acceleration of $1.7m/s^2$ and the magnitude of the applied force F is 7N, what is the magnitude of the frictional force? Show your work.

SUMMARY

You should be able to devise a method for applying a constant force to an object and devise a scale to measure force. You should understand qualitatively the relationship between force and acceleration for the case of very little friction (in one-dimension). You should understand the concept of net force. You should understand the Newton's First Law. You should be able to operationally define mass. You should understand the mathematical relationship between force and acceleration; the concept of Newton's Second Law.