UNIT 4
NEWTON'S THIRD LAW, FORCE DIAGRAMS AND FORCES

Objectives

- To understand and be able to apply Newton's Third Law

- To be able to determine the object that is exerting a particular force

- To understand there are different types of forces, and become familiar with normal, gravitational, tensile and frictional forces

- To be able to determine whether a force is a contact or non-contact force

- To be able to draw a force diagram

- To be able to identify Newton's Third Law pairs of forces

- To be able to treat forces as vectors

Equipment:
  Motion Detector
  LoggerPro software
  LabPro computer interface
  2 Force sensors
  Spring scales
  2 Low friction dynamics carts
  Low friction dynamics track
  2 Kinesthetic carts
  Aluminum can
  Base of a rod stand

1.1

a. In each of the following situations, determine which person pulls with a greater force or if both people pull with the same force.

With both people standing on the floor,
  (i) person A pulls on person B
  (ii) person B pulls on person A
  (iii) both person A and B pull on each other

One person is on a kinesthetic cart:
  (iv) person A pulls on person B
  (v) person B pulls on person A
  (vi) both person A and B pull on each other

b. Perform the experiments in part **a**, using spring scales or force sensors to measure the forces.

c. When two objects are in contact with each other, and one object pushes or pulls on the other, how do the forces applied by each object on the other compare? Explain.

d. A person standing on a skateboard, pushes on a wall. Does the person move? Does the wall move? Does the person exert a force on the wall? Does the wall exert a force on the person? If the wall exerts a force on the person, how do the forces exerted by the wall on the person and the person on the wall compare? Why does only the person move?

e. In a collision, two objects are pushing on each other. How does the magnitude of the force of each object compare to the magnitude of the force on the other object? Explain.

f. Carry out the experiment in part **e** with two low friction carts on a dynamics track. Use the force sensors attached to each of the carts to measure the magnitude of the force on each cart. With the force sensors connected to channels 1 and 2, the LoggerPro software should come up with the appropriate graph to record the magnitude of the force on each sensor.

Carry this experiment out in each of the three cases below:

> (i) The carts have the same mass.
> (ii) One cart has additional mass.
> (iii) One cart has much more mass than the other cart.

g. Consider the following situation. An aluminum can is taped to the front of a kinesthetic cart and the base of a rod stand is taped to the front of a second kinesthetic cart. The front of the carts collide.

> (i) Predict what would happen to the can and what would happen to the base of the rod stand. Explain.

> (ii) Was the magnitude of the force of the aluminum can on the base of the rod stand greater, less than or equal to the magnitude of the force of the base of the rod stand on the aluminum can?

h. Carry out the experiment in part **g**.

i. Are your answers to part **g** (i) and (ii) consistent with each other and with your experiments in part **f**? Explain.

Discuss your answer with an instructor.

Newton's Third Law in Newton's own words is:

To every action there is always opposed an equal reaction.

This can also be stated:

> *If one object exerts a force on a second object, then the second object exerts a force back on the first object that is equal in magnitude and opposite in direction to that exerted on it by the first object.*

j. Is this consistent with your observations above?

When two objects are in contact with each other, each object exerts a force on the other object. The force exerted is perpendicular to the contact surface. This is called a *normal* force.
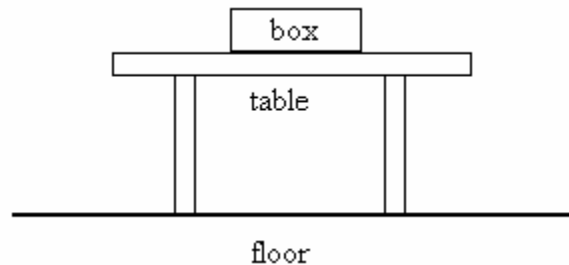
In the following sections we will examine different kinds of forces that can be applied to objects, force as a vector quantity, and applications of Newton's Laws.

We have studied force in one dimension. We will now discuss force as a vector quantity that can be applied to an object in any direction.

Equipment:
    None

2.1 Consider a box on a table as in the diagram below.

a. What forces are acting on the box? List each force, the object that is exerting the force, and the direction of the force.

b. What forces are acting on the table? List each force, the object that is exerting the force, and the direction of the force.

c. What is the net force on the box? Explain your reasoning.
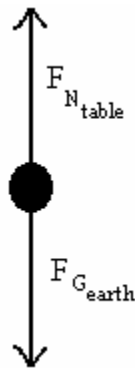
d. Is the box accelerating?

e. Are your answers to parts **c** and **d** consistent and consistent with Newton's Second Law? Explain.

Discuss your answers 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. You should also be able to determine the type of force (normal, gravitational,…), the object exerting the force and if the force is a contact force or non-contact force. (This is described below.)

A force is a contact force if, in order to exert the force, the object exerting the force must be in contact with the object on which the force is exerted. A normal force is an example of a contact force. A force is a non-contact force if, in order to exert the force, the object exerting the force does not have to be in contact with the object on which the force is exerted. The gravitational force is an example of a non-contact force.

The force diagram for the box on the table in part **a** is as follows:

F_N is a normal force. It is the force exerted by the table on the box. It is a contact force. F_G is the gravitational force. It is the force exerted by the Earth on the box. It is a non-contact force.

If the box is not moving, it is not accelerating. The net force on the box must be zero. The vectors for F_N and F_G must be the same length, because this is the only way for the net force on the box to be zero.

f. Draw the force diagram for the table in the diagram in above. For each force indicate the type of force, the object exerting the force and whether it is a contact force or a non-contact force in a sentence below the diagram.

g. If Newton's Third Law is true, for every force that is exerted on an object, there is another force of equal magnitude and opposite in direction exerted by the object. These two forces are called Newton's Third Law pairs.

(i) What is the Newton's Third Law pair force for the normal force of the table on the box? In which diagram does this force appear? Explain.

(ii) What is the Newton's Third Law pair force for the gravitational force of the Earth on the box? In which diagram does this force appear? Explain.

(iii) Can Newton's Third Law pair forces appear in the same diagram? Explain your reasoning.

h. Determine the Newton's Third Law pair force for each of the forces in the table diagram. If the table is not accelerating, how are the forces in the diagram related (mathematically)? Explain.

Discuss Newton's Third Law pair forces and force diagrams with an instructor.

Equipment:
      String
      500g mass

3.1 So far we have discussed two types of forces: (1) the force exerted by one object on another because they are in contact, called a normal force and (2) the gravitational force of the earth on an object. A third type of force is the force exerted along a string, rope, cable, etc. when it is taut.

Consider a box being pulled by a rope as in the diagram below.
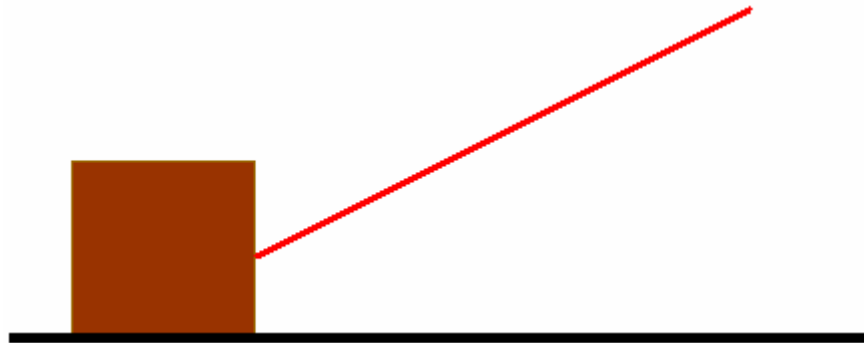
Each part of the rope exerts a force on the part of the rope next to it. This type of force is called a tensile force. If the mass of the rope is negligible, the tensile forces on each little piece of rope are equal. This will be shown in Unit 4 Reading A. The rope also exerts a normal force on the box. If the mass of the rope is negligible, it can be shown that the tensile force along the rope is equal to the normal force on the box. The normal force on the box is often referred to as a tensile force for this reason. In this class, we will consider strings and ropes to have negligible mass.

Consider the following situation. Two objects are hung by a string from the ceiling as shown in the diagram below.
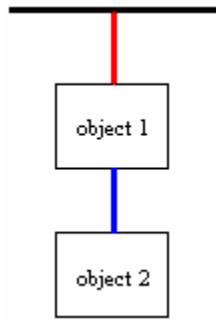
The force diagram for object 1 could be drawn as shown below.
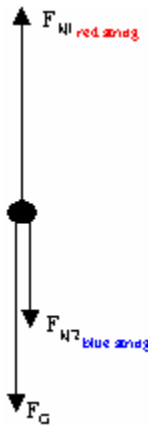
Where F_{N1} is the normal force of the red string on object one, and F_{N2} is the normal force of the blue string on object one, and F_G is the gravitational force of the earth on object one. The forces F_{N1} and F_{N2} are often labeled F_{T1} and F_{T2}, since the normal force of a string on an object is equal to the tensile force in the string, if the mass of the string is negligible. The net force on the box must be zero, since the box is not accelerating. The magnitude of vector F_{N1} must be equal to the sum of the magnitudes of vectors F_{N2} and F_G.

Draw a force diagram for object 2. For each force indicate the type of force, the object exerting the force and whether it is a contact force or a non-contact force in a sentence below the diagram.

Show your diagram to an instructor.

3.2 Consider an object with two strings attached to it, as in the picture below.
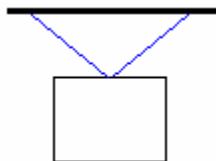
Draw the force diagram for the object. What direction is the force of each string on the object?

Discuss your force diagram with an instructor.

3.3 Consider the diagram shown below. Obtain a string and a 500g mass. Can you hang the mass from the string and straighten the string so that it is parallel to the floor, as shown in the diagram below?
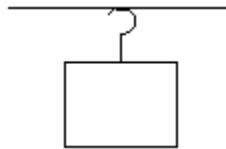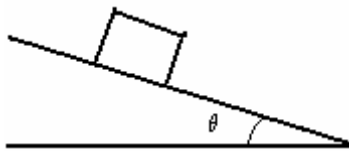
Every member in your group should try to do it. If it is not possible to straighten the string, explain why it is not possible.

Discuss with an instructor.

Equipment:
        None

4.1 Consider an object resting (the object is not moving) on an inclined plane as in the diagram below.

a. Draw the force diagram for the object.

Show your diagram to an instructor.

In order for the block not to slide down the plane, there must be a force, which is not the normal force or the gravitational force, in a direction up the plane. This force is called the frictional force. It is actually an electromagnetic force and has to do with the molecules of the object interacting with the molecules of the inclined plane. Not very much is known about the frictional force. When the object is not moving, it is called the *static* frictional force. It can be found experimentally that the magnitude of the <u>maximal</u> static frictional force is proportional to the magnitude normal force. The constant of proportionality is called *coefficient of static friction*. The symbol for the coefficient of static friction is μ_s. This can be written as

$$F_{\text{static friction}}^{\text{max}} = \mu_s F_N$$

b. For a block on an inclined plane, as in the picture above, determine the normal force and the frictional force for a 35kg block, at rest on the plane. The angle of the incline is θ = 20°. It is useful to choose the x-axis parallel to the incline plane and the y-axis perpendicular to the incline plane. Show your work.

Discuss your results with an instructor.

SUMMARY

You should understand and be able to apply Newton's Third Law. You should be able to determine the object that is exerting a force, classify forces by their type (normal, gravitational, tensile or friction), and by whether or not they are contact or non-contact forces. You should be able to draw a force diagram for an object. You should be able to identify Newton's Third Law pairs of forces. You should be able to treat forces as vectors and to solve problems using Newton's Third Law.