7. A communication satellite has small engines aboard that are used to keep the satellite within its proper space. Use at least one of Newton's laws to explain the use of the engines.
8. Find out about the asteroid impact in the Yucatan Peninsula in Mexico about 65 million years ago, which is believed to have caused the extinction of dinosaurs and numerous other species. Also find out about the chances that an asteroid or a huge meteor could crash into Earth in the future. Follow the links for Nelson Physics 11, 3.2.
   (a) How does an asteroid impact relate to gravitational forces?
   (b) What might possibly be done to prevent an asteroid impact in the future?
   (c) How do the research scientists apply their knowledge of local gravitational fields to determine the shape of the impact crater?

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Figure 1
To reduce the friction between skis and the snow, skiers choose a wax that is designed for use within a specific temperature range. At temperatures of, say, −10°C, the ski wax is more slippery than the wax used at higher temperatures.

3.3 The Effects of Friction

Friction is part of everyday life. Removing a fried egg from a frying pan is easier if the pan has a non-stick surface. You find running easier on a dry sidewalk than on a skating rink. Skiers can choose different waxes for their skis, depending on the air temperature and characteristics of the snow (**Figure 1**). Cars need friction to speed up, slow down, and go around corners.

Static and Kinetic Friction

Friction resists motion and acts in a direction opposite to the direction of motion. It occurs because of the electrical forces between the surfaces where two objects are in contact. No one would put on a pair of ice skates to try to glide along a concrete sidewalk. The friction between the sidewalk and the skate blades would prevent any skating.

One type of friction, called **static friction**, is the force that tends to prevent a stationary object from starting to move. ("Static" comes from the Greek word *statikos*, which means "causing to stand.") The maximum static friction is called the **starting friction**. It is the amount of force that must be overcome to start a stationary object moving. See **Figure 2(a)**.

static friction: the force that tends to prevent a stationary object from starting to move

starting friction: the amount of force that must be overcome to start a stationary object moving

kinetic friction: the force that acts against an object's motion in a direction opposite to the direction of motion

In certain circumstances static friction is useful; in others, it is not. A person trying to turn a stubborn lid on a jam jar appreciates the extra friction that comes with using a rubberized cloth between the lid and the hand. However, someone attempting to move a heavy filing cabinet across a floor does not appreciate static friction.

Once the force applied to an object overcomes the starting friction, the object begins moving. Then, moving or kinetic friction replaces static friction. **Kinetic friction** is the force that acts against an object's motion in a direction opposite to the direction of motion. For horizontal motion, if the applied force has the same magnitude as the kinetic friction, the moving object will maintain uniform velocity. See **Figure 2(b)**.

Different types of kinetic friction have different names, depending on the situation. *Sliding friction* affects a toboggan; *rolling friction* affects a bicycle; and *fluid friction* affects a boat moving through water and an airplane flying through air.

Practice

Understanding Concepts

1. Compare and contrast starting friction and kinetic friction, giving an example of each.
2. Give examples of friction you have experienced, besides the ones already given, that are
   (a) sliding (b) rolling (c) fluid
3. What type of friction is air resistance? Give two examples of it.

Controlling Friction

About 4500 years ago, the Egyptians built enormous pyramids using huge stone blocks that were difficult to move by sliding. The Egyptians placed logs beneath the blocks to push them and move them. By doing this, people were taking advantage of the fact that rolling friction is much less than sliding friction. Modern technology uses the same principles as the Egyptians did, though in a more sophisticated way. We try to reduce undesirable friction for many reasons. For instance, all machines have moving parts that experience friction during operation. Friction can wear out the machines, reduce efficiency, and cause unwanted heat. (If you rub your hands together vigorously, you can feel the heat produced by friction.) Excess friction in machines can be overcome by making surfaces smooth, using materials with little friction, lubricating with grease or oil, and using bearings.

Bearings function on the principle of the rolling logs used by the Egyptians to move stones. A *bearing* is a device containing many rollers or balls that reduce friction while supporting a load (**Figure 3**). Bearings change sliding friction into rolling friction, reducing friction by up to 100 times.

Ways of reducing undesirable friction in other situations are also common. The wax applied to skis mentioned earlier reduces sliding friction. A layer of air between a hovercraft and the water reduces fluid friction in a manner similar to the use of air pucks and the linear air track in a physics laboratory (**Figure 4**(**a**)). A human joint is lubricated by *synovial fluid* between the layers of cartilage lining the joint. The amount of lubrication provided by synovial fluid increases when a person moves, giving an excellent example of the efficiency of the human body (**Figure 4**(**b**)). In fact, our lubrication systems work so well that it is difficult for technologists to design artificial joints that function to the same standard.

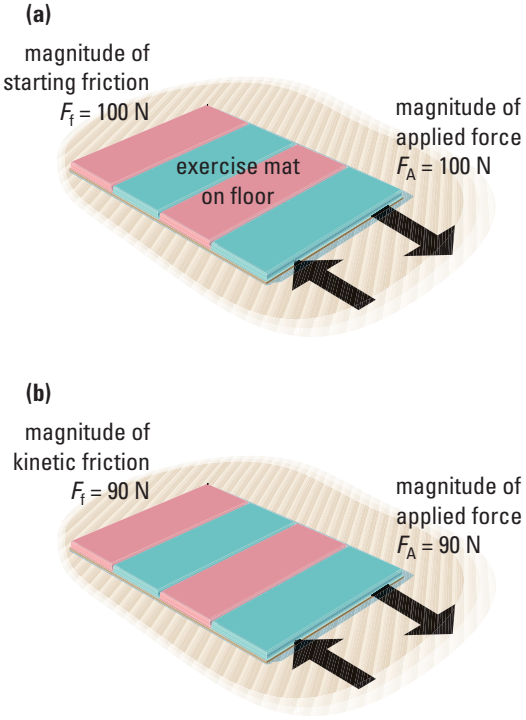

Figure 2
(a) Starting friction must be overcome before an object begins moving.
(b) Kinetic friction occurs with a moving object. In general, kinetic friction between two surfaces is less than starting friction between the same surfaces.

Figure 3
Ball bearings are used to reduce friction in a wheel.

Figure 4
Reducing undesirable friction
(a) This hovercraft carries cars across the English Channel.
(b) A typical joint in the human body

Figure 5
Tight-fitting stones of a large Inca wall near Cuzco, Peru

It has been pointed out that, although friction is often undesirable, it can be useful. Consider, for example, a problem encountered by the Incas, who dominated a large portion of South America before the Europeans arrived in the 16th century. South America has many earthquake zones and, of course, buildings have a tendency to crumble during an earthquake. To help overcome this difficulty, the Inca stonemasons developed great skill in fitting building stones together very tightly so that a great deal of sliding friction would help hold their buildings together, even during an earthquake. **Figure 5** shows an example of the skill of the Incas. Technological applications of useful friction are presented in the next section.

Practice

Making Connections

4. Explain each of the following statements, taking into consideration the force of friction.
   (a) Streamlining is important in the transportation industry.
   (b) Friction is necessary to open a closed door that has a doorknob.
   (c) A highway sign reads, "Reduce speed on wet pavement."
   (d) Screwnails are useful for holding pieces of wood tightly together.

INQUIRY SKILLS

- ○ Questioning
- ● Hypothesizing
- ● Predicting
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

Investigation 3.3.1

Factors That Affect Friction

Since this is the last investigation in Unit 1 and you have had lots of day-to-day experience with friction, you are expected to design, perform, and report on your own friction investigation. To determine the magnitude of the kinetic friction, you can measure the horizontal push or pull required to keep an object moving with uniform velocity on a horizontal surface. (You should be able to explain, using Newton's laws, why a force greater than this push or pull would cause accelerated motion.)

If possible, use a force sensor connected to a computer interface to measure force rather than a spring scale. The force sensor obtains several readings per second and the accompanying software yields an average force, which smooths out the "peaks" and "valleys" of the actual force.

Question

What are the factors that affect the force of friction between two objects or materials?

Hypothesis/Prediction

(a) In your group, discuss your hypothesis and prediction. Then, write them out.

Design

There are several factors to test to determine how they affect friction, and by how much. Use the following questions to decide what variables you want to test.

- To what extent does the type of friction (starting, sliding, rolling) affect its magnitude?
- Does an object's mass influence friction?
- How does the contact area affect sliding friction (**Figure 6**)?
- How do the types of surfaces in contact affect friction?

(b) In your group, decide how you will test, analyze, and report on your variables. Discuss safety precautions, such as how you will control moving objects. Write out your procedural steps and prepare any data tables you will need.

Materials

(c) Create a list of materials available that you intend to use, with quantities.

Procedure

1. When your teacher has approved your procedure and the materials that you will use, carry out the procedure.

Analysis

(d) Answer the Question.
(e) Plot a graph to show the relationship between mass and friction for an object moving horizontally under the influence of an applied horizontal force.
(f) Make a general statement that relates friction to the types of materials in contact. Are there any apparent exceptions? Explain your answer.

Evaluation

Evaluate your investigation by considering the following:

(g) the design of your experiment
(h) the equipment you used to measure force and any other quantities
(i) sources of error in your investigation (other than those already mentioned)
(j) If you were to perform the same investigation again, would you do it differently? Explain.

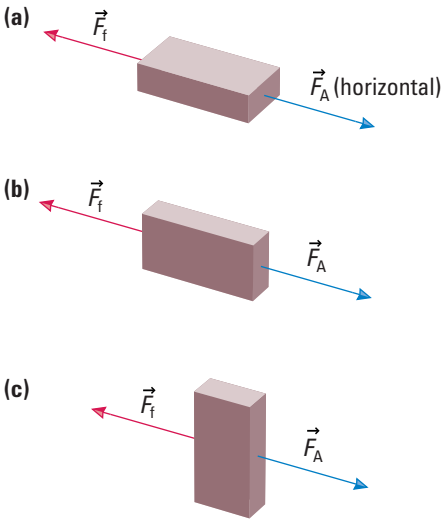

Figure 6
Determining the force needed to cause uniform velocity
(a) Block lying flat
(b) Same block on its edge
(c) Same block on its end

SUMMARY The Effects of Friction

- Friction acts parallel to two surfaces in contact in a direction opposite to the motion or attempted motion of an object.
- Static friction tends to prevent a stationary object from starting to move. Kinetic friction acts against an object's motion; it is usually less than static friction.
- For an object to maintain uniform velocity, the net force acting on it must be zero, so for an object moving at uniform velocity on a horizontal surface, the applied horizontal force must be equal in magnitude to the kinetic friction.
- Unwanted friction can be reduced by changing sliding to rolling, by using bearings, and by using lubrication.
- The extent to which certain factors affect friction, such as the types of surfaces in contact or the mass of the object, can be determined using a controlled experiment.

DID YOU KNOW ?

Teflon: An Amazing Material

The material called Teflon has many uses when low friction is desired, such as in non-stick frying pans. Although two research scientists created this chemical by chance in 1938, its usefulness was not realized until 20 years later. Since Teflon does not stick to any materials, the process used to make it stick onto a frying pan surface is unique: the Teflon is blasted into tiny holes in the surface of the pan where the material sticks well enough for use.

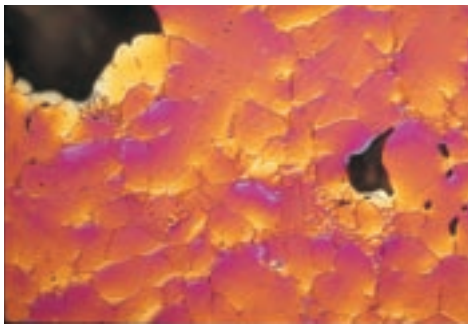

Figure 7
This micrograph of a polished aluminum surface was taken at a magnification of 50×.

Section 3.3 Questions

Understanding Concepts

1. The photograph in **Figure 7** shows a microscopic view of an aluminum surface that appears smooth to the unaided eye. Describe what the photograph reveals about friction.
2. Is friction desirable or undesirable when you tie a knot in a string? Explain.

Applying Inquiry Skills

3. Exercise bikes have a control that allows the rider to adjust the amount of friction in the wheel. Describe how you would perform an experiment to determine the relationship between the setting on the control and the minimum force needed to move the bicycle's pedal.
4. (a) At speeds typical of transportation vehicles (trucks, bikes, boats, airplanes, etc.), how do you think fluid friction depends on the speed?
   (b) Describe a controlled experiment that could be conducted to check your answer in (a).

Making Connections

5. Friction may be a help in some situations and a hindrance in others. Describe two examples for each situation. For those situations where friction is undesirable, what efforts are made to reduce it as much as possible? For those situations where friction is desirable, how is it increased?
6. Explain how you would solve each of the following problems. Relate your answer to friction.
   (a) A refrigerator door squeaks when opened or closed.
   (b) A small throw rug at the front entrance of a home slips easily on the hard floor.
   (c) A picture frame hung on a wall falls down because the nail holding it slips out of its hole.

3.4 Analyzing Motion with Friction

Most frictional forces are complex because they are affected by a number of factors, such as the nature of the materials involved and the size, shape, and speed of the moving object. In this section, we shall focus on the force of friction acting on an object on a horizontal surface experiencing only horizontal forces.

Solving problems involving friction brings together many concepts presented in this unit, including velocity, acceleration, forces, free-body diagrams, Newton's laws of motion, gravitational attraction, and weight. It also relies on different skills you have applied, such as using a calculator, graphing, and analyzing experimental results. Thus, it is fitting that you complete this unit by combining the concepts and skills from all three chapters to solve motion problems involving friction.

Coefficient of Friction

coefficient of friction: ratio of the magnitude of friction to the magnitude of the normal force

The **coefficient of friction** is a number that indicates the ratio of the magnitude of the force of friction, F_f, between two surfaces to the magnitude of the force perpendicular to these surfaces. Recall that the magnitude of the force perpendicular