law problems are introduced. Problems involving friction are introduced in Section 2.4. Advanced questions combine problem types (for example, pulleys and ramps with friction), but the solutions are standard once the problems have been appropriately dissected. The Learning Tip on page 90 is particularly helpful.

- Students become more familiar and, thus, more comfortable with every dynamics problem they solve. Teachers should encourage students to do all assigned problems. Students who struggle with dynamics problems may need to be reminded of the proper methodology for solving them. Following the method step-by-step should be stressed for anyone who finds this material difficult. Other students can be challenged with questions that are more difficult from this section of the text, from the Sir Isaac Newton Extension questions on page 119, or from questions provided on the computer test bank and the Fundamentals of Physics question bank.
- Teachers should consider assigning Applying Inquiry Skills question 8 on page 92 as the basis of an activity that illustrates many of the key concepts in this section.

2.4 Exploring Frictional Forces

BACKGROUND INFORMATION

Students were introduced to the concept of friction in grade 11 physics and should be familiar with static friction, kinetic friction, and starting friction. This section provides an extension of these ideas and offers problems that are more complex. Information that is new to students is fluid friction (viscosity) and Bernoulli's principle (pages 102–105).

Related Background Resources

- *Nelson Physics 11* (2002), Section 3.3, pages 96–99

PLANNING

Suggested Time

Narrative/Practice—30 min
Try This Activity, page 101—5 min
Try This Activity, page 102—5 min
Try This Activity, page 105—5 min
Investigation 2.4.1—75 min
Section Questions—30 min

Instructional Resources

- Solutions Manual
- Lab and Study Master: Student Worksheet LSM 2.4-1 Investigation 2.4.1 Measuring Coefficients of Friction
- Appendix A2: Planning an Investigation
- Appendix A5: Lab Reports
- Metre sticks, inclined planes, and various materials (Investigation 2.4.1)
- WintOGreen Lifesavers, pliers, and goggles (Try This Activity, page 101)
- Various grades of motor oil, stoppered test tubes, hot- and cold-water baths, gloves, and goggles (Try This Activity, page 102)
- Empty pop cans and straws (Try This Activity, page 105)
- Computer test bank
- *Fundamentals of Physics: Senior Course Computerized Test Bank*

TEACHING SUGGESTIONS

- The magnitudes of the forces of static friction and kinetic friction that objects experience depend on the nature of the two surfaces in contact with each other and the force with which the surfaces are pressed together. The first factor is quantified by the coefficient of friction, a number without units that varies with factors associated with the surfaces (e.g., the nature of the surfaces, the temperature). This value can be compared to the index of refraction, which students will remember from optics in grade 11 physics. The index of refraction can be related to the amount of refraction that a transparent substance causes when light enters it: the greater the number, the greater the refraction that takes place. Similarly, the greater the coefficient of friction, the more friction the surfaces produce.
- The second factor that determines the magnitude of the frictional force is the magnitude of the normal force that acts on an object. Students will be familiar with the force of friction on objects on horizontal surfaces where the normal force is equivalent to the force of gravity. This is not the case for an object on an inclined plane where the normal force is balanced by the component of gravity perpendicular to the plane. Teachers can illustrate this situation by placing a chalk brush on a metre stick and slowly increasing the angle of inclination of the stick until the brush begins to slide. At this point, the component of gravity along the plane is sufficiently large enough to overcome the static friction, which is reduced as the angle of inclination increases, thereby reducing the component of gravity perpendicular to the plane and the normal force.
- Emphasize that the equation $F_f = \mu F_N$ determines the magnitude of the force of friction and does not involve vectors. The direction of the force of friction is unique to the problem and the sign convention that has been assigned. Kinetic friction always acts in the opposite direction to the object's direction of motion. Static friction always resists any force that would make the object move.
- The Try This Activity, on page 101 is an interesting demonstration. It is effective only when the room is completely dark and the observer is quite close to the event. As an alternative, students could be encouraged to try this at home. Crushing the candy between their teeth while in front of a mirror in a darkened bathroom should provide an adequate demonstration. Teachers are encouraged to try this for themselves.
- The Try This Activity section on page 102 is a short demonstration of the principles of fluid friction and terminal speed. Ask students to predict the outcome before the activity.
- The Try This Activity section on page 105 demonstrates Bernoulli's principle. Students should predict the outcome before performing the activity. As an alternative to this activity, students can attempt Chapter 2 Review question 22 on page 118.
- It is suggested that Investigation 2.4.1 on page 113 be performed the day following the lesson on friction. It provides students with solid evidence about the nature of friction, as well as an opportunity to develop laboratory skills. This investigation is largely self-directed and requires considerable time. To save time, the students can complete LSM 2.4-1.
- If time constraints do not allow for doing Investigation 2.4.1, many of the same concepts can be reached by assigning question 8 on page 101.

Try This Activity

Observing Triboluminescence

- This is a quick activity that provides an interesting application of friction.

Time: 5 min

Teacher Preparation

- Teachers should perform this activity before class to make sure the room is dark enough so that students can observe the effect. Alternatively, encourage students to try this activity at home. Crushing the candy between their teeth while standing in front of a mirror in a darkened bathroom should provide an adequate demonstration.
- There may be other types of candy that produce triboluminescence, although WintOGreen Lifesavers are the most effective.
- It is important to allow time for the students' eyes to adapt to the dark room since the effect is subtle.

Material/Equipment	Quantity per station	Quantity for 16 stations
WintOGreen Lifesavers	4	64
safety goggles	1 pair per student	
pliers	1	16 or 8 shared

Materials and Equipment Notes

- If sufficient pairs of pliers are not available, students can crush the candy in their teeth while their partner observes and then reverse roles.

Safety and Disposal

- Students should be cautioned about crushing the candy in their teeth.
- It is advisable for students to wear eye protection as a precaution.

Student Preparation

- Not applicable

Teacher Suggestions

- Teachers should explain to students that the flashes of light are subtle.

Extensions/Modifications

- Students may want to further investigate triboluminescence. For example, people have reported seeing "balls of light" near seismic events. It is thought that the frictional forces involved with the sudden movement of rock can result in this effect. For more information, see: http://www.geocities.com/RainForest/9911/tribo.htm and http://www.sciencenews.org/sn_arc97/5_17_97/fob2.htm.

Try This Activity

Oil Viscosity

- This is a quick activity that demonstrates that the viscosity of oil decreases with increasing temperature.

Time: 5 min

Teacher Preparation

- Prepare the test tubes and water baths before class. This activity should be done as a teacher demonstration.
- Label the test tubes to avoid confusion.

Material/Equipment	Quantity per station	Quantity for 16 stations
gloves	1 pair per student	
safety goggles	1 pair per student	

prepared test tubes with oil	1 of each type	48 or 16 if sharing
hot and cold water baths	1 of each type	16 or 8 if sharing

Materials and Equipment Notes

- The test tubes should be stoppered securely and taped to prevent spilling.
- To accentuate the effect, the cold-water bath can be an ice-water bath.
- Students should be reminded to use caution around the hot-water bath.

Safety and Disposal

- Disposal of the oil should be done in accordance with local guidelines or stored for pickup with other hazardous materials. It is recommended that a set of test tubes be made up and kept secure to be reused in subsequent courses.
- If students get oil on themselves, use an appropriate solvent to clean up.

Student Preparation

- Students should make predictions before attempting the activity. If the activity is done as a demonstration, provide students with an opportunity for determining the relative viscosity of the various grades of oil.

Teacher Suggestions

- This is a simple activity to provide students with an opportunity to predict and test their hypotheses. Teachers must be particularly vigilant when the students are working with the hot-water bath.

Extensions/Modifications

- Students can further explore the effect of temperature (such as that in an operating engine) on viscosity.
- Students can investigate the efficacy of using synthetic oil in engines and determine if a similar relationship exists between temperature and viscosity.

Try This Activity

How Will the Cans Move?

- This activity demonstrates Bernoulli's principle. Ask students to predict what will happen to the cans and to provide reasons for their predictions.

Time: 5 min

Teacher Preparation

- This activity is best done as a demonstration. Teachers must set up the cans and straws before class.

Material/Equipment	Quantity per station	Quantity for 16 stations
empty cans	2	32
drinking straws	6	96

Materials and Equipment Notes

- Place the drinking straws close enough together so that the cans can move when air is blown between them.
- The teacher should practise this activity/demonstration to determine the correct placement of the cans and the effective volume of air that needs to be blown.

Safety and Disposal

- After this activity, recycle the cans.

Student Preparation

- Ask students to predict what will happen and to give a reason for their predictions. Some knowledge of Bernoulli's principle will help students with their predictions.

Teacher Suggestions

- Teachers may want to do this activity before or after Bernoulli's principle is introduced. Students have more success with their predictions if the principle is understood.

Extensions/Modifications

- Teachers may want to further explore airfoil design and the principles of flight, although time limitations may preclude this. Students can be encouraged to pursue this on their own.

2.5 Inertial and Noninertial Frames of Reference

BACKGROUND INFORMATION

This section provides an opportunity to reinforce Newton's first law of motion, the law of inertia. When an object accelerates, it can display motion that appears to observers in different frames of reference to be contrary to Newton's first law. For example, when a car pulls away from a corner, passengers might argue that their heads move backward in their frame of reference, a contradiction to Newton's first law. However, relative to one another, the passengers are not moving. What force is responsible for a passenger's head moving backward? Fictitious forces are used to explain motion in noninertial frames of reference, and students can draw on their own experiences to illustrate these apparent forces. For example, students riding on a looping roller coaster will have had the sensation of being pushed to the outside of the loop when no such force exists.

Related Background Resources

- Students can share experiences that illustrate the fictitious forces that are apparent in noninertial frames of reference.

PLANNING

Suggested Time

Narrative/Practice—20 min
Section Questions—55 min

Instructional Resources

- Solutions Manual
- Computer test bank
- *Fundamentals of Physics: Senior Course Computerized Test Bank*

TEACHING SUGGESTIONS

- The actual lesson on this material is fairly short. If activities in other sections were not done because of time restraints, teachers can do one or more of them here.
- Chapter 3, Circular Motion; deals with the nature of fictitious forces arising from noninertial frames of reference. Students must understand the nature of the two types of frames of reference.
- Inertial and noninertial frames of reference become increasingly important in Chapter 11.

