1.4 Uniform Acceleration

This important section presents the defining equation, graphing, and experimentation related to uniform acceleration. Because of the activities, investigation, and large amount of information, this section likely requires two full class periods. However, students have studied many of these concepts in grade 10 science, so they may be able to go through the material more quickly.

<table>
<thead>
<tr>
<th>Achievement Chart Categories</th>
<th>Assessment Opportunities/Specific Expectation Addressed</th>
<th>Assessment Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge/Understanding</td>
<td>Practice Questions</td>
<td>Rubric 1: Knowledge/Understanding</td>
</tr>
<tr>
<td></td>
<td>Understanding Concepts, q. 1–8, 10–13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FM1.01, FM1.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Section 1.4 Questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Understanding Concepts, q. 1–8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FM1.01, FM1.02</td>
<td></td>
</tr>
<tr>
<td>Inquiry</td>
<td>Try This Activity (page 26)</td>
<td>Rubric 2: Inquiry Skills</td>
</tr>
<tr>
<td></td>
<td>FM2.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Practice Questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Applying Inquiry Skills, q. 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FM2.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Try This Activity (page 29)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FM2.03</td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>Investigation 1.4.1</td>
<td>Rubric 3: Communication</td>
</tr>
<tr>
<td></td>
<td>Analysis b–g, Evaluation h–k, Synthesis 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FM2.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Section 1.4 Questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflecting q. 10–11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FM2.03</td>
<td></td>
</tr>
<tr>
<td>Making Connections</td>
<td>Section 1.4 Questions</td>
<td>Rubric 4: Making Connections</td>
</tr>
<tr>
<td></td>
<td>Making Connections, q. 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FM3.02</td>
<td></td>
</tr>
</tbody>
</table>

Expectations Addressed

Overall Expectations—FMV.01

Overall Skills Expectations—SIS.01, SIS.02, SIS.03, SIS.05, SIS.08, SIS.09, SIS.10, SIS.11

Specific Expectations:

- FM1.01 define and describe concepts and units related to force and motion (e.g., vectors, scalars, displacement, uniform motion, instantaneous and average velocity, uniform acceleration, instantaneous and average acceleration, applied force, net force, static friction, kinetic friction, coefficients of friction)
- FM1.02 describe and explain different kinds of motion, and apply quantitatively the relationships among displacement, velocity, and acceleration in specific contexts
- FM2.03 interpret patterns and trends in data by means of graphs drawn by hand or by computer, and infer or calculate linear and nonlinear relationships among variables (e.g., analyze and explain the motion of objects, using position-time graphs, velocity-time graphs, and acceleration-time graphs)
- FM3.02 evaluate the design of technological solutions to transportation needs and, using scientific principles, explain the way they function (e.g., evaluate the design, and explain the operation of, airbags in cars, tread patterns on car tires, or braking systems)
**BACKGROUND INFORMATION**

Uniformly accelerated motion is motion in a straight line in which the speed changes uniformly with time. It is the easiest type of acceleration to study, both conceptually and mathematically. The speed can be increasing, yielding a positive slope on a velocity-time graph, or it can be decreasing, yielding a negative slope.

The defining equation for average acceleration is 

$$\vec{a}_{av} = \frac{\Delta \vec{v}}{\Delta t}$$, which is commonly applied in the form 

$$\vec{a}_{av} = \frac{v_f - v_i}{\Delta t}$$.

Typical units for acceleration are \((\text{km/h})/\text{s}\) and \((\text{m/s})/\text{s}\) (which is mathematically equivalent to \(\text{m/s}^2\)).

It is important that students develop the skill of interpreting graphs and relating them to observed motion. A good opportunity to see how position, velocity, and acceleration graphs relate to accelerated motion is found in the Try This Activity on page 26.

For uniformly accelerated motion, the position-time graph yields a smooth curve with a constantly changing slope. The tangent technique for finding the slope at different instants (pages 31 and 32) yields instantaneous velocities that can be plotted on a velocity-time graph. The slope of the straight line on this graph yields the average acceleration. The tangent technique may seem tedious and inaccurate, but the skill in using it and the understanding of why it works are advantageous. For example, many of the students who study physics eventually study calculus. There, they can relate finding slopes on position-time graphs to finding the first and second derivatives, and they can relate finding areas on velocity-time and acceleration-time graphs to the process of integration. After the students have mastered the understanding of slopes and areas, using a calculator or computer will save time and be highly accurate.

Observing an accelerometer attached to an accelerating object is another good way to enhance the understanding of uniformly accelerated motion. The accelerometers shown in Figure 6 on page 29 are typical of the devices that students can use in the classroom or on a field trip to an amusement park, such as Paramount Canada’s Wonderland. Most students can predict what will happen to the accelerometers when speeding up or slowing down occurs. However, the explanation is an application of Newton’s first law of motion, which is not presented until Chapter 2.

Investigation 1.4.1 (pages 33–5) involves attempted uniform acceleration. In planning which possible method students should use to perform this investigation, consider also the acceleration due to gravity investigation (page 39) to ensure that the students gain the broadest possible experience.

**ADDRESSING ALTERNATIVE CONCEPTIONS**

The graphs shown in the text tend to be idealized. For example, the velocity-time graphs in Figure 5 on page 26, and in Figures 8 and 9 on page 30, have sharp changes in the slope. Such instantaneous changes in velocity are unlikely in real life. The peaks should be curved lines, but that would make analysis, such as finding the slopes of lines, more complex.

Students may be fooled by an accelerometer that differs from those shown on page 29. For example, if a helium balloon is tethered by string to the floor of a bus, the balloon moves forward rather than backward as the bus accelerates forward. (The solids and liquids in the accelerometers on page 29 would all move backward relative to the bus’s frame of reference.) The air in the bus piles up toward the rear of the bus, pushing the less dense helium-filled balloon toward the front.

**Related Background Resources**

The instructions for using graphing software or a graphing calculator would benefit both students and teachers.

In science supply catalogues, the device in Figure 6(b), page 29, is called an accelerometer (about $70), and the device in (c) is called a pocket accelerometer (about $30). The device in (c) is found in amusement park physics kits, such as the one made by Pasco and distributed in Canada by Merlan Scientific, www.merlan.ca.

Another type of accelerometer, not shown in Figure 6, is called the fishing bobber accelerometer and is available in science supply catalogues.

The manual for “physics day” at an amusement park is available to every teacher who takes students to Physics/Math Day at Paramount Canada’s Wonderland. The manual describes experiments that students can carry out at the park and is updated annually.

Nelson Web site: www.science.nelson.com for specific Web links
PLANNING

Suggested Time
Narrative/Practice Questions—50 to 60 minutes, plus at least 10 minutes for Practice Question 9 on page 28
Try This Activity (page 26)—5 to 10 minutes
Try This Activity (page 29)—5 to 10 minutes
Investigation 1.4.1—50 to 60 minutes
Section Questions—25 to 35 minutes

Core Instructional Resources
• Solutions Manual
• Colour Transparencies
• Reference to the Appendixes: Appendix A4 has lab report suggestions and Appendix A5 has information on errors.

Supplemental Resources
• Lab and Study Blackline Masters

TEACHING SUGGESTIONS
• This is a lengthy section that requires much advanced planning. Since students have studied uniform acceleration in the motion unit in grade 10 science, it is a good idea to determine how much they remember (or are confused about!) from that course. To find out what they know, brainstorm concepts such as definitions, equations, graphs, and methods of determining acceleration experimentally. Building on what the students already know may save time in this section.
• Try to combine observed motion with numerical values, the three types of graphs (position, velocity, and acceleration), equations, units, and the use of accelerometers. For example, get the students to imagine uniformly accelerated motion in a bus, giving typical values of position, velocity, and acceleration, drawing related graphs, and predicting how an accelerometer (page 29) would act.
• Emphasize the importance of units, both in applying the equation for average acceleration and in finding slopes and areas on graphs. It is easy to see that (m/s)/s is a velocity unit divided by a time unit, yielding an acceleration unit. The equivalent unit, m/s², is more abstract, so allow students to use (m/s)/s if they wish.
• Plan the best time to perform Investigation 1.4.1. The actual motion in the investigation takes only a few seconds, but the setup and analysis take much longer.
• Question 13 on page 33 is important because it gives the students practice in applying the tangent technique. If your students need more practice, it is easy for you to make up a table of data by using the following uniform acceleration equation: \( \frac{\Delta d}{\Delta t} = \frac{a_{ov} (\Delta t)^2}{2} \). (This equation, derived in section 1.6, applies to situations in which the initial velocity is zero.)

TRY THIS ACTIVITY
Analyzing Motion Graphs
• This activity is placed near the start of the section, before students study position-time and acceleration-time graphs. This placement allows you to find out how well the students relate graphing to real-life motion. Also, it allows students to observe how motion is represented on computer-generated graphs.

BEFORE
Teacher Preparation
Time: 5 to 10 minutes

Materials and Equipment:
Each group of three or four students will need
a cart
a ramp
a motion sensor or smart pulley
access to a computer with appropriate software

Safety and Disposal:
• Make sure that one person is responsible for catching the cart as it completes its downward motion.

Assessment:
• Students could be assessed on their inquiry skills.

Student Preparation
• Have some student volunteers sketch their predicted graphs for questions (a) and (b) on the chalkboard, then discuss the predictions with the entire class.

DURING
• Students can check their own predictions as they observe the motion and related graphs.

AFTER
• (a) Using “up the ramp” as positive, the graphs for the motion are shown in Figure 1. Students’ predictions may differ.
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Unit 1 Forces and Motion

TRY THIS ACTIVITY

Student Accelerometers

- In this activity, students predict how they think various designs of horizontal accelerometers will work, and then test their predictions using at least one of the designs shown in Figure 6 on page 29. Although each accelerometer in Figure 6 is attached to a cart, the predictions can be tested by using a simple accelerated motion of the accelerometer in your hand.

**BEFORE**

**Teacher Preparation**

**Time:** 5 to 10 minutes

**Materials and Equipment:**

Here are descriptions of the accelerometers in Figure 6:

- (a) This is a student-made accelerometer consisting of a small rubber stopper attached to the origin of a large plastic, wooden, or cardboard protractor.
- (b) This accelerometer is available commercially and is often found singly for classroom demonstrations.
- (c) This is an expensive and accurate accelerometer. The commercial version has a small metal device that pinches the tubing, allowing the acceleration to be recorded until a reading can be taken (note that the pincher is not shown in the figure).
- (d) This is a common form of horizontal accelerometer found in amusement park physics kits available commercially.

**Safety and Disposal:**
- If a cart is used for demonstrating acceleration, be sure it can be stopped safely.

**Assessment:**
- The students can be assessed on their inquiry skills.

**Student Preparation**

- After giving the students a few minutes to discuss and record their predictions, have them share their predictions and explanations with the rest of the class.

**DURING**

- The easiest way to test the students’ predictions is to hold the accelerometer in your hand and accelerate it briefly to the right (from the students’ frame of reference), and observe the action of the stopper, the liquids, or the beads.

**AFTER**

- (a) Probably most students will be able to predict what will happen to each type of accelerometer. Expect only a brief explanation, since a full explanation is not possible without involving Newton’s first law of motion, presented in Chapter 2.
- (b) As each device accelerates to the right, the indicator will move toward the left relative to the device. Thus, the stopper will be at an angle to the left of the vertical, the liquids will be higher on the left side than the right side, and the beads will move up and to the left.

**Extensions/Modifications:**

- If students want to know why the components move to the left, you can suggest that they wait until they learn about Newton’s first law of motion in Chapter 2, or you can explain how that law relates to the observed action.
- A simple extension of the activity is to ask the students to predict what will happen to the accelerometers held in your moving hand as you bring them to a stop. If you do this, have the students complete their predictions before you start step (b).
- Another trickier and fun extension involves an accelerometer with an air-filled fishing bob attached by string to the inside of a lid on a transparent jar that is filled with water and inverted. The floating bob moves in a direction opposite to what happens with the accelerometers shown in Figure 6. The water moves to the left (relative to the jar) as the accelerometer accelerates to the right, and the water pushes against the less dense fishing bob. (See also description of the helium balloon accelerometer in Addressing Alternative Conceptions.)

**INVESTIGATION 1.4.1**

**Attempting Uniform Acceleration**

- In this investigation, students observe and analyze the motion of a cart that accelerates down an inclined plane.
**BEFORE**

**Teacher Preparation**

**Time:** 50 to 60 minutes

**Materials and Equipment:**

If the investigation is performed as suggested on page 34, each group of three or four students will need

- a ticker-tape timer and ticker tape
- a dynamics cart or smooth-rolling toy truck
- one 2-m board
- bricks or books
- a clamp
- masking tape

Other methods of performing the investigation will require different equipment, such as a motion sensor or a video camera and player.

**Safety and Disposal:**

- Be sure the cart is stopped before it reaches the bottom of the ramp.
- Remind students about typical safety precautions when using electrical equipment.

**Assessment:**

- Students can be assessed on their inquiry skills.

**Student Preparation**

- To analyze the data obtained in the investigation according to the instructions, students must understand how to apply the tangent technique described earlier in the section. Practice Question 13 on page 33 is important.

**DURING**

- Students should be aware of the two major sources of error when using a ticker-tape timer:
  - The ticker tape must be taut, and the cart must be held perfectly still and not released until just after the timer has been turned on. A good way to do this is to hold the cart steady by pulling on the tape from behind the timer.
  - Choosing the initial dot is crucial. Students who are not sure of which dot to choose should consult the teacher.

**AFTER**

- (b) The line is plotted in the first quadrant of the graph and should be a smooth parabola with an ever-increasing slope.
- (c) The velocity graph should be a straight line starting at the origin and having a positive slope. The value of the slope depends mainly on the angle at which the ramp was set up.
- (d) As stated in (c), the velocity graph should be a straight line, though not necessarily perfectly straight. A perfectly straight line with a positive slope would indicate uniform positive acceleration. Calculating the slope of the line yields the acceleration of the cart.
- (e) Students can use the equation for the area of a triangle to determine the area under the line on the velocity-time graph. Unit analysis verifies that the area represents the change of position (or displacement) for the time interval calculated. The area should be equal to the actual measured value within typical experimental error (about 10%).
  - (f) The slope of the line on the velocity-time graph yields the average acceleration, which should be a straight horizontal line on an acceleration-time graph assuming the acceleration was constant.
  - (g) The results should show constant positive acceleration. The value of the (constant) acceleration depends mainly on the angle of the ramp; for example, at an angle of $12^\circ$, the magnitude of the acceleration is 2.0 m/s$^2$ (assuming friction is negligible).
  - (h) Evidence for uniform acceleration comes from a smooth parabolic curve of the position-time graph, a straight line with a constant slope on the velocity-time graph, or a straight horizontal line on the acceleration-time graph.
  - (i) Students can refer to the graphs, as in (h), or they can refer to the numerical data they gathered in the investigation.
  - (j) The sources of error depend on the apparatus and equipment used. When using the setup shown in Figure 12 on page 34, typical sources of error are
    - determining which dot on the ticker tape to use as the starting dot (which could be either a systematic error or a random error)
    - any random motion of the cart and tape after the timer is activated but before the cart is released (random error)
    - difficulties with the timer, such as double dotting or skipping dots (likely random errors)
    - friction in the cart’s motion (friction within the wheels and friction on the ramp); friction between the tape and the timer (which may be random if the timer tends to “grab” the tape going through it)
    - improper calibration of the ticker-tape timer (systematic error)
    - using tangents to determine the slopes of the curved line on the position-time graph (random source of error)
  - (k) Answers will depend on the difficulties students may have encountered. One obvious choice is to use a motion sensor to gather data.
  - (l) The last two dots on the tape can be used to determine the approximate value of the velocity that occurred at the middle of the time interval between the two dots. Thus, the magnitude of the final velocity required for the equation is the displacement between these two final dots divided by the time interval for a single cycle of the timer. Assuming that the initial velocity of the motion is zero and the acceleration is uniform, if we divide the final velocity by the time interval from 0.0 s to the middle of the time between the dots, we get the average acceleration.

**Extensions/Modifications:**

- Refer to the subsection “Analysis for Other Methods of Data Gathering” on page 35