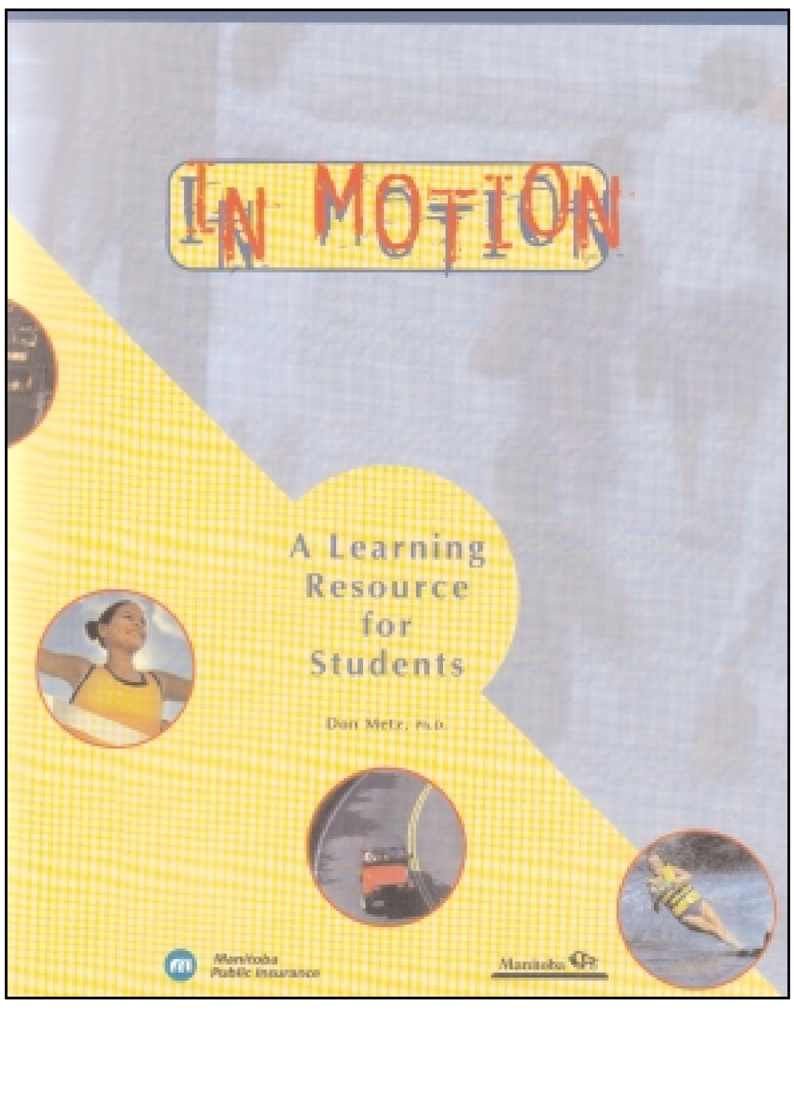
Senior 2

Appendix 7:
In Motion—Teacher Resource Guide



Preface

This resource material is based on actual teacher experiences in Senior 2 Science (20F) classrooms. Therefore, the results of the student learning activities act as summaries of students' results. In many cases, the student-generated inquiry results do not coincide in a precise manner with predicted or theoretical results. This is positive insofar as it brings to light the difficulties in attempting to understand ideal situations from less than ideal (or controlled) circumstances. In a very real sense, this acts as a preliminary view through a window that looks at the nature of scientific inquiry. Inquiry in science, including high-grade research, is often less than tidy. In the cases presented here with students, sources of systematic or procedural error were actively sought, and suggestions were made for correcting or accounting for these errors.

Students are not required to do all the suggested activities and/or respond to all questions presented in the module. The most important consideration is recognizing that achievement of the specific learning outcomes for the *In Motion* thematic cluster is possible through in-depth use of this resource in the classroom. Moreover, it is estimated that approximately 30 to 40 hours would be required to complete the *In Motion* booklet if every student activity were to be addressed. Since time allotments suggest approximately 25 hours to complete this cluster, teachers are encouraged to be strategic in their selection of which activities to do with their students. Again, the primary focus in using this classroom-based resource rests in achieving the specific learning outcomes as outlined in *Senior 2 Science: A Foundation for Implementation*.

The mathematical connections to the content are an important component of the instructional design process that underpins *In Motion — A Student Learning Resource*. Teachers may wish to consult details of appropriate mathematical treatment for students at this grade level as contained in the Modes of Representation section of *Senior 2 Science: A Foundation for Implementation*. The gathering and subsequent analysis of the data is generally done manually by the students, through hand-drawn graphing techniques, calculation of slopes, and discussion of the results. If the opportunity exists, and equipment is available, some time could be saved through the use of Calculator-Based Laboratory (CBL) tools and probe connections to graphing calculators. Another alternative is for the students to perform some activities "virtually" in an Internet browser, using Java applets, which are readily available on the web. This teacher resource has selected a number of effective examples of these applets, and includes them in the Webquest chapter.

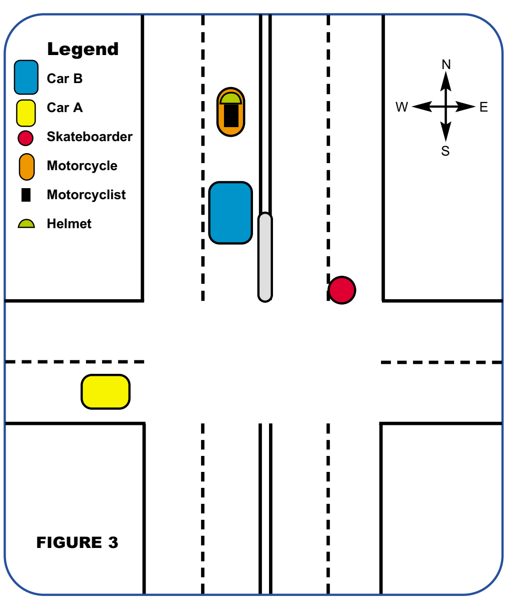
Most of the sections of *In Motion* can be taught as presented in the student learning resource. The booklet closely reflects the specific learning outcomes of the In Motion cluster of Senior 2 Science (20F), with virtually complete coverage of the student activities that are recommended in the *Foundation for Implementation*. In the case of Chapter 2: Analyzing Motion, considerable work has been provided as alternate material for the development of the relationships among position, displacement, velocity, acceleration, and time. These alternate materials are not prescriptive, but are examples of one instructional design approach, starting with concrete experiences of the student, then building toward the more abstract concepts. In a sense, this approach is a *scaffolding* for students, taking them in identifiable steps towards increased sophistication of treatment. These motion concepts could be applied in a variety of situations, and consequently a variety of student activity sheets, along with the answers, have been supplied.

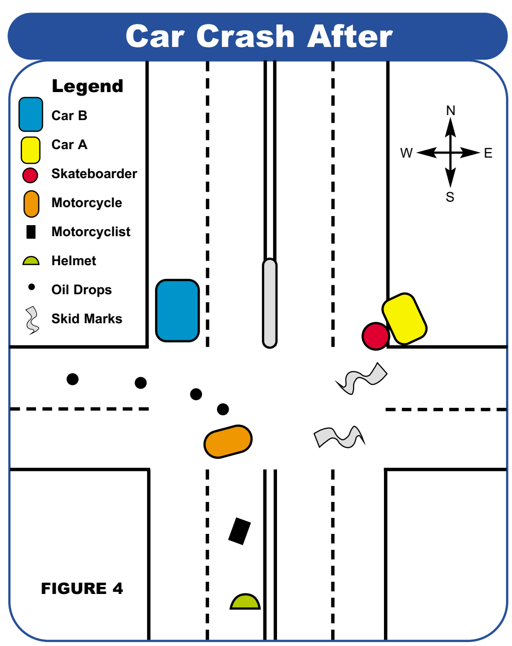
Students often struggle somewhat with the concepts related to Newton's Laws, momentum, impulse, and energy. These are treated more conceptually at Senior 2 than in an exclusively symbolic (mathematical) treatment common at advanced levels of the study of physics. Students may have some difficulty in applying the motion ideas conceptually to actual problems requiring explanations. Some differentiation of instruction is recommended for these topics, and suggestions and strategies are included.

Generally, the students will enjoy doing the activities. The Great Egg Drop Competition and the Rocket Car activities are often very well received. Most of the activities can be completed with equipment found in high school physics laboratories. Very little in the way of new equipment is required. CBL units and graphing calculators should be available from the mathematics department in your school, as these are used regularly in Senior 2 Applied Mathematics (20S).

Overall, *In Motion — A Student Learning Resource* was conceived to address the specific learning outcomes across all levels of student ability. It can be modified and enriched with ease to stimulate the gifted student, and it can also be adapted to meet the needs of those who may be struggling. Teachers are encouraged during the first years of implementation, as with any new course, to find out what works, what does not work, what needs to be changed, and how to adapt to the needs of those students in the local environment. Readily available science and physics textbooks, together with many resources on the Internet, can provide a wealth of supplementary aids for the Senior 2 classroom teacher.

Note: There are some errors in the reference. These have been acknowledged as errata in the appropriate chapter and section.





Chapter 1

Introduction

CLASS ACTIVITY:

Tapping into Prior Knowledge

The rotational graffiti activity will stimulate discussion about the concepts of motion that the students have already acquired. The context of vehicles and traffic provides an avenue for students to relate motion to their everyday personal experience.

Car Crash – Who Is to Blame?

This class activity provides a problem to which the students will return as their knowledge of motion increases. Terms such as speed, acceleration, force, friction, momentum, and energy will be discussed. At this time, there is no need to clarify the terms, as this will be done all in good time.

SUGGESTED ACTIVITY:

From their everyday experience, students should have some understanding of speed, distance, and time interval. Before vector quantities like velocity and displacement are studied, a class activity relating speed, distance, and time interval can be performed.

A battery-operated toy truck or tractor is allowed to move across the floor. In small groups, students are asked to describe the motion. Then they are to share their descriptions with the class. They are encouraged to use whatever words they can that are related to motion.

The students are asked how they would measure this motion. The procedure should involve measuring the time required for the toy to travel a certain distance. This information can be used to calculate speed using the speed-equals-distance-traveled-over-time interval.

This is a good place to introduce some symbolism. The relationship for speed is:
speed = distance traveled/time interval **or** $v = \Delta d/\Delta t$.

The fact that the speed remains constant indicates that the speed is uniform and we call this uniform motion.

Once speed has been measured, the speed equation can be used to predict the distance traveled in a given time. Also, the speed equation can be used to calculate the time required for the toy to travel a certain distance. Students should realize that equations are very useful tools that allow us to make predictions for the outcome of events based on the given information.

While the emphasis for the *In Motion* cluster is not mathematical calculations, it is useful to lay the groundwork for problem solving. Using the speed relationship, students can be instructed in a systematic method of problem solving. Links should be made to the students' mathematics knowledge. If a pattern is developed that the students can follow, it will ensure success in their endeavours.

Speed, Distance Traveled, Time

1. Jose rides his bicycle from his home to school. He travels 6.25 km in 0.550 hour. What is his average speed for the trip?

2. Kevin is warming up for the basketball game. He does three laps around the gym. Each lap is 75.0 metres. It takes Kevin 42.8 seconds to run the three laps.

a. What distance did Kevin run?

b. What was his average speed?

3. April and Ashleigh run a 100-m race. April finishes the race in 13.25 s and Ashleigh takes 13.50 s. What is the average speed with which April and Ashleigh each run the 100 m?

4. Matt skateboards at 3.25 m/s for 55.0 s. How far did he travel?

5. Edward rollerblades around Kildonan Park. He skates at 7.75 m/s for 12.5 minutes.

a. How many seconds was he skating?

b. How far did he skate?

6. Edgar travels to the mall at an average speed of 28.0 km/h. The mall is located 8.00 km from Edgar's home. How long in hours does it take Edgar to travel from his home to the mall?

7. A ladybug is crawling across the floor in a straight line at 1.25 cm/s. The ladybug crawls 3.25 m.

a. What distance in cm does the ladybug crawl?

b. How long does the ladybug take to crawl this distance?

8. You and your family are traveling from Winnipeg to Brandon. The distance from Winnipeg to Brandon is 200 km. If you travel at a speed of 105 km/h, how long will it take to travel from Winnipeg to Brandon?

9. When you get to Brandon, you stop for lunch. This takes one hour. You then travel from Brandon to Regina, a distance of 385 km, in 3.75 hours. What was your average speed?

10. a. How far is it from Winnipeg to Regina?

b. How long did it take you and your family to travel from Winnipeg to Regina? (Hint: state the total time, including while you were eating.)

c. What was your average speed for this whole trip from Winnipeg to Regina?

In Motion Worksheet—Speed, Distance, Time

Note: Three significant digits are used in the final answer.

1. $\Delta d = 6.25$ km

$\Delta t = 0.550$ hours

v = ___________

$v = \Delta d/\Delta t$

$v = 6.25$ km / 0.550 h

$v = 11.36 = 11.4$ km/h

2. 1 lap = 75.0 m

Kevin runs 3 laps

$\Delta t = 42.8$ s

a. Δd = _________

Kevin runs 3 laps x 75.0 m/lap = 225 m

b. v = _________

$v = \Delta d / \Delta t = 225$ m / 42.8 s

$v = 5.2570 = 5.26$ m/s

3. $\Delta d = 100$ m

April's time = $\Delta t_{April} = 13.25$ s

Ashleigh's time = $\Delta t_{Ashleigh}$ 13.50 s

v_{April} = __________

$v_{Ashleigh}$ = __________

$v_{April} = \Delta d / \Delta t_{April} = 100$m / 13.25 s

$v_{April} = 7.547 = 7.55$ m/s

$v_{Ashleigh} = \Delta d / \Delta t_{Ashleigh} = 100$m / 13.50 s

$v_{Ashleigh} = 7.4074 = 7.41$ m/s

4. $v = 3.25$ m/s

$\Delta t = 55.0$ s

Δd = ___________

$v = \Delta d / \Delta t$

3.25 m/s = Δd / 55.0s

3.25 m/s x 55.0 s = Δd

$\Delta d = 178.75 = 179$ m

5. $v = 7.75$ m/s

$\Delta t = 12.5$ minutes

Δd = ___________

a. 1 minute = 60 s

12.5 minutes = 12.5 min x 60s/min = 750 s

b. $v = \Delta d / \Delta t$

7.75 m/s = Δd / 750 s

7.75 m/s x 750 s = Δd

$\Delta d = 5812.5 = 5810$ m

6. $v = 28.0$ km/h
$\Delta d = 8.00$ km
$\Delta t =$ __________

$v = \Delta d / \Delta t$
$28.0 \text{ km/h} = 8.00 \text{ km} / \Delta t$
$28.0 \text{ km/h} \times \Delta t = 8.00 \text{ km}$
$\Delta t = 8.00 \text{ km} / 28.0 \text{ km/h}$
$\Delta t = 0.28571 = 0.286 \text{ h}$

7. $v = 1.25$ cm/s
$\Delta d = 3.25$ m
$\Delta t =$ __________

a. Δd in metres
1 m = 100 cm
$3.25 \text{ m} = 3.25 \text{ m} \times 100 \text{ cm/m} = 325 \text{ cm}$

b. $v = \Delta d / \Delta t$
$1.25 \text{ cm/s} = 325 \text{ cm} / \Delta t$
$1.25 \text{ cm/s} \times \Delta t = 325 \text{ cm}$
$\Delta t = 325 \text{ cm} / 1.25 \text{ cm/s} = 260 \text{ s}$

8. $\Delta d_{W\text{–}B} = 200$ km
$v_{W\text{–}B} = 105$ km/h
$\Delta t_{W\text{–}B} =$ __________

$v_{W\text{–}B} = \Delta d_{W\text{–}B} / \Delta t_{W\text{–}B}$
$105 \text{ km/h} = 200 \text{ km} / \Delta t_{W\text{–}B}$
$105 \text{ km} \times \Delta t_{W\text{–}B} = 200 \text{ km}$
$\Delta t_{W\text{–}B} = 200 \text{ km} / 105 \text{ km/h}$
$\Delta t_{W\text{–}B} = 1.90476 = 1.90 \text{ h}$

9. $\Delta d_{B\text{–}R} = 385$ km
$\Delta t_{B\text{–}R} = 3.75$ h
$v_{B\text{–}R} =$ __________

$v_{B\text{–}R} = \Delta d_{B\text{–}R} / \Delta t_{B\text{–}R}$
$v_{B\text{–}R} = 385 \text{ km} / 3.75 \text{ h} = 102.666 = 103 \text{ km/h}$

10. **a.** $\Delta d_{W\text{–}B} = 200$ km
$\Delta d_{B\text{–}R} = 385$ km
$\Delta d_{W\text{–}R} =$ __________

$\Delta d_{W\text{–}R} = \Delta d_{W\text{–}B} + \Delta d_{B\text{–}R}$
$\Delta d_{W\text{–}R} = 200 \text{ km} + 385 \text{ km} = 585 \text{ km}$

b. $\Delta t_{W\text{–}B} = 1.90$ h
$\Delta t_{lunch} = 1.00$ h
$\Delta t_{B\text{–}R} = 3.75$ h

$\Delta t_{total} = \Delta t_{W\text{–}B} + \Delta t_{lunch} + \Delta t_{B\text{–}R}$
$\Delta t_{total} = 1.90 \text{ h} + 1.00 \text{ h} + 3.75 \text{ h} = 6.65 \text{ h}$

c. $v_{ave} = \Delta d_{W\text{–}R} / \Delta t_{total} = 585 \text{ km} / 6.65 \text{ h} = 87.9699$
$v_{ave} = 88.0 \text{ km/h}$

Chapter 2

Analyzing Motion

Position and Displacement

Answers to Questions

The calculations will be done using significant digit rules. If changes are made to the number of significant digits, they will be noted.

PRACTICE—PAGE 8

1. The positions of the cars are as follows:

Car A = –5.10 cm or 5.10 cm to the left of the origin.

Car B = 0 cm. Car B is at the origin.

Car C = +4.05 cm or 4.05 cm to the right of the origin.

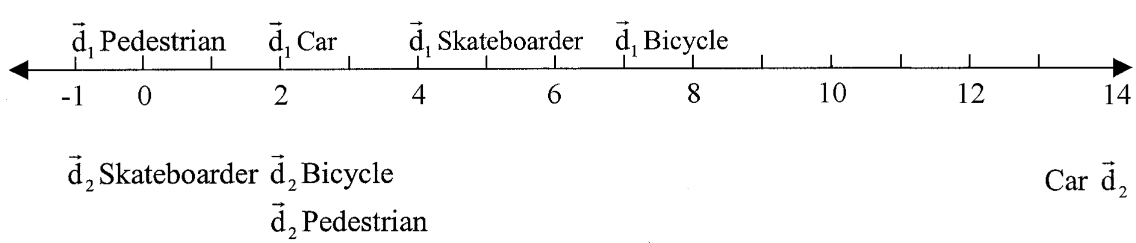
Car D = +9.62 cm or 9.62 cm to the right of the origin.

PRACTICE—PAGE 9

1.

	Car	Bicycle	Pedestrian	Skateboarder
d_1	+2 m	+7 m	-1 m	+4 m
d_2	+14 m	+2 m	+2 m	-1 m

a. and b.



c. Displacement = final position – initial position

$D\vec{d} = \vec{d}_2 - \vec{d}_1$

For the car, $D\vec{d}$ = +14 m – +2 m = +12 m

For the bicycle, $D\vec{d}$ = +2 m – +7 m = –5 m

For the pedestrian, $D\vec{d}$ = +2m – –1 m = +3 m

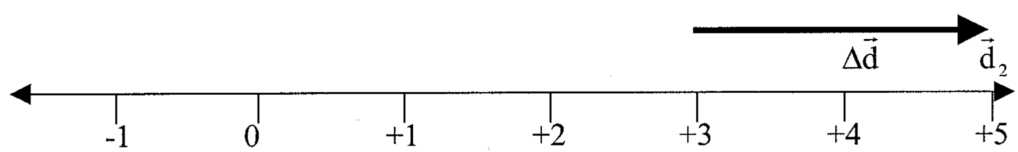
For the skateboarder, $D\vec{d}$ = –1 m – +4 m = –5 m

d. If the displacements all occur in the same time period, the motion can be described. The car traveled a distance of 12 m to the right. The bicycle traveled 5 m to the left. The pedestrian traveled 3 m to the right. The skateboarder also traveled 5 m to the left.

The bicycle and the skateboarder traveled at the same rate and kept the same distance apart. The car passed by the skateboarder first, then the bicycle. The pedestrian passed the skateboarder and ended up at the same position as the bicycle.

The car was traveling the fastest. The pedestrian was traveling the slowest. The bicycle and the skateboarder traveled at the same speed in the same direction.

2.



The truck had a final position of +5 after a displacement of +2. The arrow on the diagram shows the displacement of +2 had to start at +3 so that the final position was +5.

$D\vec{d} = +2$ and $\vec{d}_2 = +5$

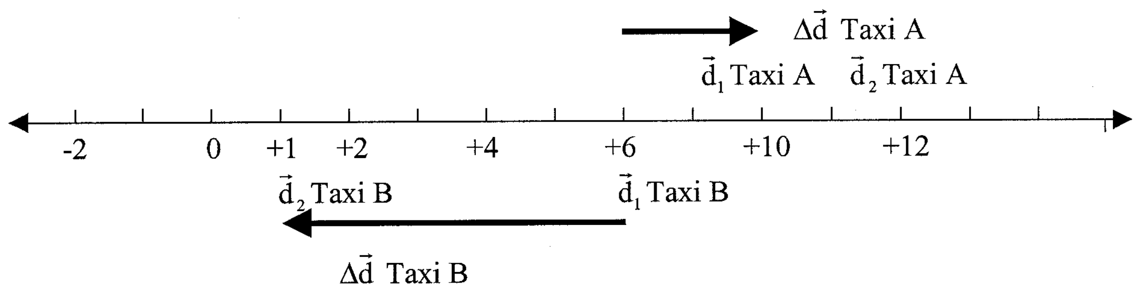
Using $D\vec{d} = \vec{d}_2 - \vec{d}_1$

$+2 = +5 - \vec{d}_1$

$\vec{d}_1 = +5 - +2 = +3$

The initial position was +3.

3.



4. Taxi A $\vec{d}_1 = +6$ and $\vec{d}_2 = +10$

$D\vec{d} = \vec{d}_2 - \vec{d}_1$

$= +10 - +6 = +4$

Taxi B $\vec{d}_1 = +6$ and $\vec{d}_2 = +1$

$D\vec{d} = \vec{d}_2 - \vec{d}_1$

$= +1 - +6 = -5$

5. The displacement of Taxi A is +4 and the displacement of Taxi B is –5. Since the time of travel for both taxis was the same, the taxi that traveled farther had the larger speed.

6. If the origin was moved, the positions of the taxis would be different. However, even though the positions may have been different, the displacements would still be the same.

Instants and Intervals of Time

Think About IT!

Think About IT!—Page 10

1. Examples of an interval of time include one year to measure age, one class of 55 minutes, one school year, et cetera.

2. To convert seconds to hours, divide the number of seconds by the number of seconds per hour.

   10 s/3600 s/h = 10 s x 1 h/3600 s = 1/360 s

   The difficulty in this calculation was the odd conversion factor.

Investigation #1 VEHICLES IN MOTION

Think About IT!

Think About IT!—Page 11

1. The car is moving slowest when it is at the top of the ramp. The car has just begun to speed up from rest and is traveling very slowly. Also, in the results, one can see that the dots marking the positions of the car are closest together at the top of the ramp.

2. The car is moving fastest on the level surface. This is shown by the fact the dots are spaced farthest apart on the level surface. The car traveled the farthest in equal time intervals.

3. The spaces do not change across the table because the car is not speeding up or slowing down, since it is traveling on a level surface.

4. On the ramp, the car speeds up as it rolls down the ramp. On the table, the car moves with the same speed.

Uniform Motion

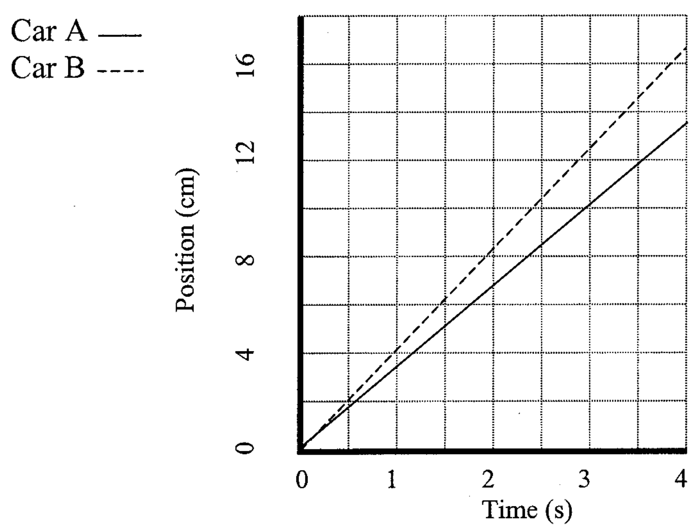
Since students are using rulers with millimetre calibration, an estimated digit in the 0.1 mm or 0.01 cm is used in the measurements. The distance is measured from the front tip of one car to the front tip of the next car.

Table A

Position (cm)	Time (s)
0	0
3.36	1
6.63	2
9.95	3
13.27	4

Table B

Position (cm)	Time (s)
0	0
4.10	1
8.20	2
12.30	3
16.40	4



Think About IT!—Page 12

1. The slope of the line for Car B is steeper than the slope of the line for Car A.

2. Car A has a smaller space between successive images of the car. The points on the Position-Time graph do not rise as rapidly as those for Car B.

   Car B has a larger space between successive images of the car. The points on the Position-Time graph rise more rapidly than those for Car A.

Think About IT!—Page 13

1. Concept map: The list of terms can also include direction, vector, and scalar.

Calculating Slope

PRACTICE—PAGE 14

1. The positive direction will be to the right for all diagrams.

   a. Origin

   $\vec{d}_1 = 0$ km $\qquad t = 1.2$ h $\qquad \vec{v}_{avg} = ?$ $\qquad \vec{d}_2 = +36$ km

   $$\vec{v}_{avg} = \frac{\mathrm{D}\vec{d}}{\mathrm{D}t} = \frac{+36 \text{ km} - 0 \text{ km}}{1.2 \text{ h}} = +30 \text{ km/h}$$

   The average velocity of the bicycle is +30 km/h.

   b. Origin

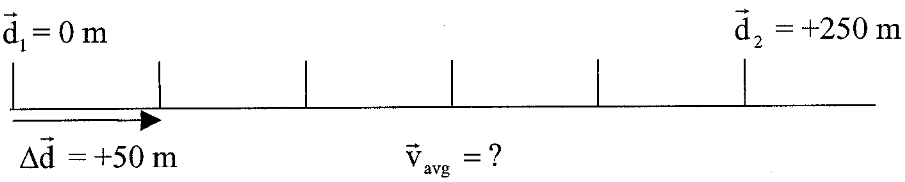
   $\vec{d}_1 = 0$ m $\qquad t = 2$ s $\qquad \vec{v}_{avg} = ?$ $\qquad \vec{d}_2$ +17 m

   $$\vec{v}_{avg} = \frac{\mathrm{D}\vec{d}}{\mathrm{D}t} = \frac{+17 \text{ m} - 0 \text{ m}}{2 \text{ s}} = +8.5 \text{ m/s}$$

   The average velocity of the person is +8.5 m/s.

   Using significant digits, the answer is +8 m/s.

c.

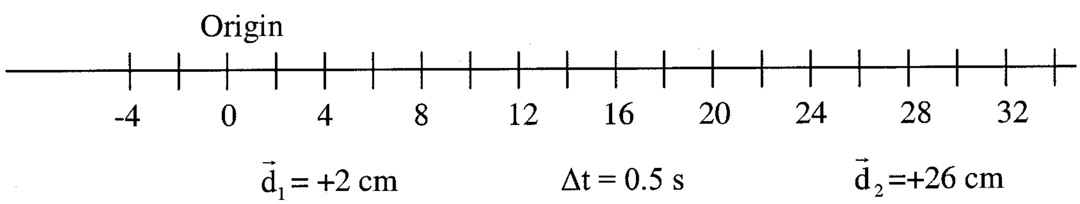


$$\vec{v}_{avg} = \frac{D\vec{d}}{Dt} = \frac{+250\text{ m} - 0\text{ m}}{18\text{ s}} = +13.9\text{ m/s}$$

The average velocity of the car is +13.9 m/s.

Using significant digits, the answer rounds to +14 m/s.

d.



$\vec{v}_{avg} =$

$$\vec{v}_{avg} = \frac{D\vec{d}}{Dt} = \frac{+26\text{ cm} - +2\text{ cm}}{0.5\text{ s}} = +48\text{ cm/s}$$

The average velocity of the mini-V is +48 cm/s. With significant digits, use +50 m/s.

2. a. For a bicycle, 30 km/h would be fast.

b. Running at 8.5 m/s is fast, bordering on unrealistic for the average person. Olympic calibre sprinters run at 10 m/s.

c. The car is traveling at 13.9 m/s x 3.6 = 50 km/h. This would be a medium speed for a car.

d. For a mini-V, 48 cm/s is a medium speed.

3. Assume that the skateboarder is coasting east, to the right or in the positive direction.

Corner = Origin

$\vec{v}_{avg} = +2$ m/s; $t = 3.5$ s

$$\vec{v}_{avg} = \frac{\Delta \vec{d}}{\Delta t}$$

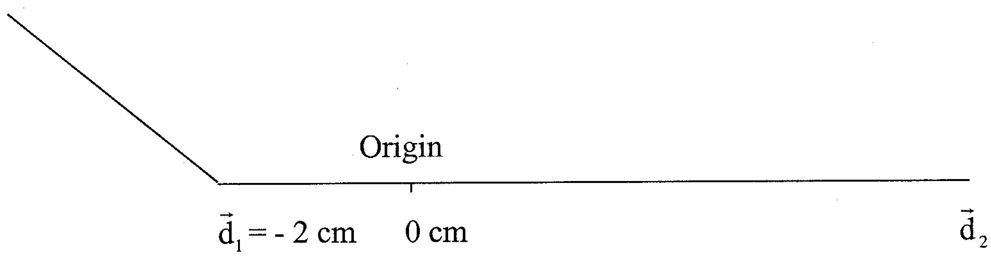
$+2 \text{ m/s} = \Delta \vec{d} / 3.5 \text{ s}$

$\Delta \vec{d} = (+2 \text{ m/s})(3.5 \text{ s}) = +7 \text{ m}$

The displacement is +7 m or 7 m to the right.

4. When speeding, the displacement of a car in one unit of time is greater than that allowed by law. For example, a car traveling 35 km in one hour is speeding if the speed limit is 30 km in one hour.

5.



Since the positions are marked in cm, $\vec{v}_{avg}$ should be expressed in cm/s.

$\vec{v}_{avg} = +1.5 \text{ m/s} = +150 \text{ cm/s}$; $t = 0.4$ s

The unknown is the length of the track, $\Delta \vec{d}$.

$$\vec{v}_{avg} = \frac{\Delta \vec{d}}{\Delta t}$$

$+150 \text{ cm/s} = \Delta \vec{d} / 0.4 \text{ s}$

$\Delta \vec{d} = (+150 \text{ cm/s})(0.4 \text{ s}) = +60 \text{ cm}$

The track is 60 cm long. This answer has only one significant digit.

Uniform Motion

PRACTICE—PAGE 17

1. Since the object only traveled a distance of 70 m or so during a time of one hour, this Position-Time graph could represent the motion of an insect, such as a ladybug, along a straight-line path. The story might go like this.

The ladybug started at a position of 0 m at time 0 h. The ladybug moved in the positive direction, traveling at a constant low velocity. It reached a position of +3 m after 0.15 h. At 0.15 h, it began to move with a larger constant positive velocity, reaching a position of +20 m at 0.35 h. Then around 0.35 h, the ladybug began to crawl still more quickly in the positive direction at a constant velocity, reaching a position of +30 m shortly before 0.4 h. Around 0.4 h the ladybug slowed down, then traveled to a position of + 40 m, reaching it at 0.5 h. At 0.5 h, it slowed down again, traveling with a low constant positive velocity until 0.8 h, reaching a position of +50 m at that time.

At 0.8 h, the ladybug stopped, turned around, sped up, and traveled with a large negative constant velocity to a position of +35 m at 0.93 h. At that time the ladybug sped up once more and traveled at a still larger constant negative velocity, reaching a position of +20 at 1.0 h.

2. The average velocity is found by taking the slope of the line on the Position-Time graph for that time interval.

The instantaneous velocity is found by locating the position on the curve of the Position-Time graph for the instant in question. Draw a line on the graph that runs in the same direction as the curve at that point in time. The slope of this line segment represents the instantaneous velocity. Note that since this line is estimated to run in the same direction as the curve, this can lead to wide variations in the slope.

In Question 2, the times have an additional 0 added on, giving each reading two significant digits.

a. $t_1 = 0 \text{ h}, \ \vec{d}_1 = 0 \text{ m}$

$t_2 = 0.10 \text{ h}, \ d_2 = +15 \text{ m}$

$\vec{v}_{avg} = ?$

$$\vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t} = \frac{+15 \text{ m} - 0 \text{ m}}{0.10 \text{ h} - 0 \text{ h}} = \frac{+15 \text{ m}}{0.10 \text{ h}} = +150 \text{ m/h}$$

Instantaneous velocity: From the line drawn on the graph at 0.05 h, the following points are taken.

$t_1 = 0 \text{ h},\ \vec{d}_1 = 0 \text{ m}$

$t_2 = 0.40 \text{ h},\ d_2 = +60 \text{ m}$

$\vec{v}_{0.05} = ?$

$$\vec{v}_{0.05} = \frac{\Delta \vec{d}}{\Delta t} = \frac{+60 \text{ m} - 0 \text{ m}}{0.40 \text{ h} - 0 \text{ h}} = \frac{+60 \text{ m}}{0.40 \text{ h}} = +150 \text{ m/h}$$

The two velocities are equal.

b. $t_1 = 0.20 \text{ h},\ \vec{d}_1 = +20 \text{ m}$

$t_2 = 0.40 \text{ h},\ d_2 = +26 \text{ m}$

$\vec{v}_{avg} = ?$

$$\vec{v}_{avg} = \frac{\Delta \vec{d}}{\Delta t} = \frac{+26 \text{ m} - +20 \text{ m}}{0.40 \text{ h} - 0.20 \text{ h}} = \frac{+6 \text{ m}}{0.20 \text{ h}} = +30 \text{ m/h}$$

Instantaneous velocity: From the line drawn on the graph at 0.3 h, the following points are taken.

$t_1 = 0 \text{ h},\ \vec{d}_1 = +14 \text{ m}$

$t_2 = 1.0 \text{ h},\ d_2 = +48 \text{ m}$

$\vec{v}_{0.3} = ?$

$$\vec{v}_{0.3} = \frac{\Delta \vec{d}}{\Delta t} = \frac{+46 \text{ m} - +14 \text{ m}}{1.0 \text{ h} - 0 \text{ h}} = \frac{+32 \text{ m}}{1.0 \text{ h}} = +32 \text{ m/h}$$

The two velocities are almost equal.

c. $t_1 = 0.60 \text{ h},\ \vec{d}_1 = +32 \text{ m}$

$t_2 = 0.08 \text{ h},\ d_2 = +60 \text{ m}$

$\vec{v}_{avg} = ?$

$$\vec{v}_{avg} = \frac{\Delta \vec{d}}{\Delta t} = \frac{+60 \text{ m} - +32 \text{ m}}{0.08 \text{ h} - 0.60 \text{ h}} = \frac{+28 \text{ m}}{0.20 \text{ h}} = +140 \text{ m/h}$$

Instantaneous velocity: From the line drawn on the graph at 0.05 h, the following points are taken.

$$t_1 = 0\text{ h},\ \vec{d}_1 = 0\text{ m}$$
$$t_2 = 1.0\text{ h},\ d_2 = +54\text{ m}$$
$$\vec{v}_{0.7} = ?$$
$$\vec{v}_{0.7} = \frac{D\vec{d}}{Dt} = \frac{+54\text{ m} - 0\text{ m}}{1.0\text{ h} - 0\text{ h}} = \frac{+54\text{ m}}{1.0\text{ h}} = +54\text{ m/h}$$

The two velocities are not equal.

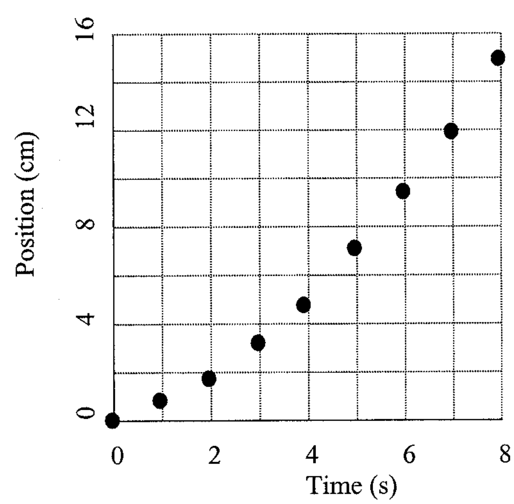
Accelerated Motion

Note to Teacher: The instructions on page 18 indicate students are to measure the displacement between successive dots, but Table C asks for the **position** of the dots.

Have the students measure the position of each dot from the origin and record these in Table C. Also, since the dots are so large, students should pick one edge of the dot as the origin and measure the positions to the same edge of each of the remaining dots.

Table C

Position (cm)	Time (s)
0	0
0.8	1
1.9	2
3.3	3
5.0	4
7.1	5
9.4	6
12.0	7
14.9	8



The points on the graph should be joined with a smooth curve.

Erratum: The units for Column 1 in Table C should read as "cm" only.

Think About IT!—Page 18

1. The Position-Time graph for uniform motion would be a straight line. The slope of this line would yield the average velocity. The slope is constant; therefore, the velocity is constant or uniform.

   In this case, the slope of the line on the Position-Time graph is not constant, but is always changing. Therefore, the velocity cannot be constant and the motion is non-uniform.

2. As the car's velocity increases, the spacing of the dots becomes greater. The car will travel a farther distance in the same time when the velocity is greater.
3. The spacing of the dots increases uniformly. This indicates that the velocity of the car is increasing uniformly also. The acceleration must be uniform.

Table D—Page 19

A better format for this table would include a displacement column.

Table D

Time (s)	Position (cm)	Displacement During Time Interval (cm)	Average Velocity (cm/s)
0	0		
1	0.8	0.8 – 0 = 0.8	0.8/1 = 0.8
2	1.9	1.9 – 0.8 = 1.1	1.1
3	3.3	3.3 – 1.9 = 1.4	1.4
4	5.0	5.0 – 3.3 = 1.7	1.7
5	7.1	7.1 – 5.5 = 2.1	2.1
6	9.4	9.4 – 7.1 = 2.3	2.3
7	12.0	12.0 – 9.4 = 2.6	2.6
8	14.9	14.9 – 12.0 = 2.9	2.9

The average velocity for a time interval closely represents instantaneous velocity at the midpoint of each time interval. This leads us to Table E.

Erratum: The units for Column 2 in Table D should read as "cm" only.

Think About IT!—Page 20

1. The velocity changes at a regular rate, about 0.3 cm/s.
2. As time increases, so does the velocity. They are directly related.
3. The acceleration was uniform or constant at +0.3 cm/s/s.

Table E

Velocity (cm/s)	Time (s)
0.8	0.5
1.1	1.5
1.4	2.5
1.7	3.5
2.1	4.5
2.3	5.5
2.6	6.5
2.9	7.5

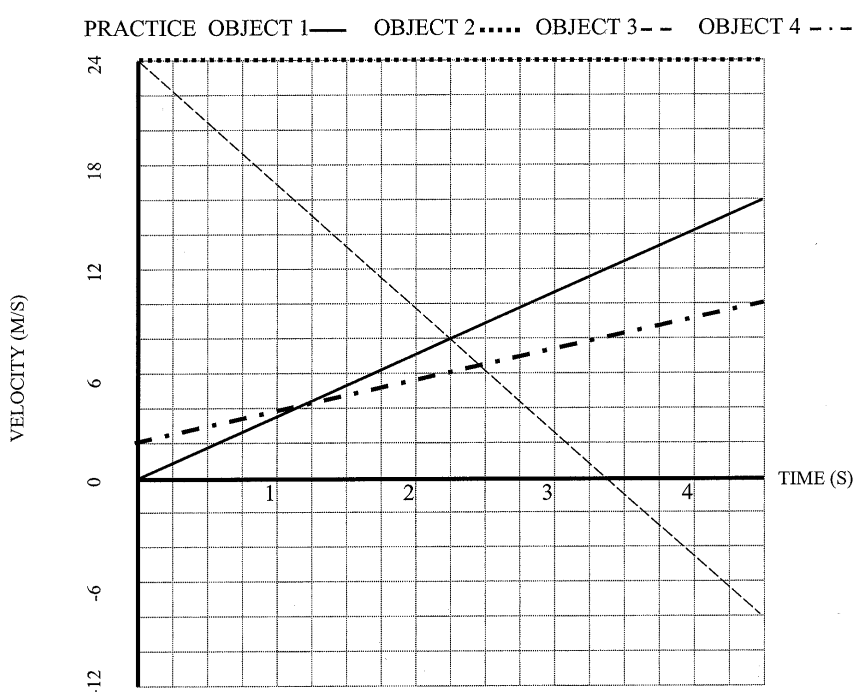
PRACTICE—PAGE 21

1. The first object is accelerating in the positive direction at +16.0 m/s / 4 s = +4.0 m/s. It is traveling in the positive direction and speeding up.

   The second object has a constant velocity of +24.0 m/s. The acceleration is 0 m/s/s. It is traveling in the positive direction.

   The third object is moving initially with a large positive velocity of +24 m/s. The velocity decreases from 0 s to 3 s. The object is slowing down. At 3 s the object momentarily stops and begins to move in the negative direction, speeding up until 4 s. The acceleration is always a negative acceleration. The acceleration is constant at –8m/s/s.

   The fourth object is initially moving at +2 m/s and speeds up in the positive direction. The object is always moving in the positive direction with a constant acceleration of + 2.0 m/s/s.



2. Uniform motion and non-uniform motion:

Compare:

Both can be described using a Position-Time graph to indicate the position of the object at given points in time.

The slope of the Position-Time graph in both cases yields the velocity of the object.

Both can be described using a Velocity-Time graph to indicate the velocity of the object at given points in time.

The slope of the Velocity-Time graph in both cases yields the acceleration of the object.

Contrast:

The Position-Time graph for uniform motion is a straight line, a line of constant slope. The velocity of the object is uniform or constant. The Velocity-Time graph will be a straight, horizontal line. The acceleration is 0 m/s/s.

The Position-Time graph for non-uniform motion is a curved line, a line of changing slope. The velocity is always changing in time from instant to instant.

If the Velocity-Time graph is a straight line of constant slope (non-zero), then the acceleration is constant.

If the Velocity-Time graph is a curved line, then the acceleration is non-uniform, changing in time from instant to instant.

3. All the calculations of acceleration will use the following equation:

$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = \frac{\vec{v}_{final} - \vec{v}_{initial}}{t_{initial} - t_{initial}}$$

The units used will be those given in the question.

a. $\vec{v}_1 = 0 \text{ km/h};\ \vec{v}_2 = +20 \text{ km/h};\ \ t = 6 \text{ s};\ \vec{a}_{avg} = ?$

$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = \frac{\vec{v}_{final} - \vec{v}_{initial}}{t_{initial} - t_{initial}} = \frac{+20 \text{ km/h} - 0 \text{ km/h}}{6 \text{ s}} = +3.3 \text{ km/h/s}$$

Use one significant digit in the answer: +3 km/h/s.

b. $\vec{v}_1 = +10 \text{ km/h};\ \vec{v}_2 = +60 \text{ km/h};\ \ t = 30 \text{ min};\ \vec{a}_{avg} = ?$

$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = \frac{\vec{v}_{final} - \vec{v}_{initial}}{t_{initial} - t_{initial}} = \frac{+60 \text{ km/h} - +10 \text{ km/h}}{30 \text{ min}} = +1.67 \text{ km/h/min}$$

Using significant digits, round off to +2 km/h/min.

c. $\vec{v}_1 = +50$ km/h; $\vec{v}_2 = +60$ km/h; $t = 6$ s; $\vec{a}_{avg} = ?$

$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = \frac{\vec{v}_{final} - \vec{v}_{initial}}{t_{initial} - t_{initial}} = \frac{+60 \text{ km/h} - +50 \text{ km/h}}{6 \text{ s}} = +1.67 \text{ km/h/s}$$

Using significant digits, round off to +2 km/h/s.

d. $\vec{v}_1 = 0$ m/s; $\vec{v}_2 = +7$ m/s; $t = 3$ s; $\vec{a}_{avg} = ?$

$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = \frac{\vec{v}_{final} - \vec{v}_{initial}}{t_{initial} - t_{initial}} = \frac{+7 \text{ m/s} - 0 \text{ m/s}}{3 \text{ s}} = +2.33 \text{ m/s/s}$$

Using significant digits, round off to +2 m/s/s.

Note to Teacher: Question 4 requires students to determine the displacement by taking the area beneath the curve of a Velocity-Time graph. This is beyond the scope of Senior 2 Science (20F). These concepts should be used only with the most capable students and should be considered as **enrichment material**.

4. In all cases, the origin will be the position of the initial velocity. Because the motion is non-uniform velocity with constant acceleration, all the Velocity-Time graphs will be straight-line graphs. However, the Position-Time graphs will all be curves. Since, in all cases, the acceleration is positive, the curves on the Position-Time will have an increasing slope, upwards to the right.

The displacement can be found by rearranging $\vec{v}_{avg} = \frac{D\vec{d}}{Dt}$ to solve for $D\vec{d}$. The rearranged equation is $D\vec{d} = \vec{v}_{avg}Dt$. On a Velocity-Time graph, this represents the area beneath the line on the graph.

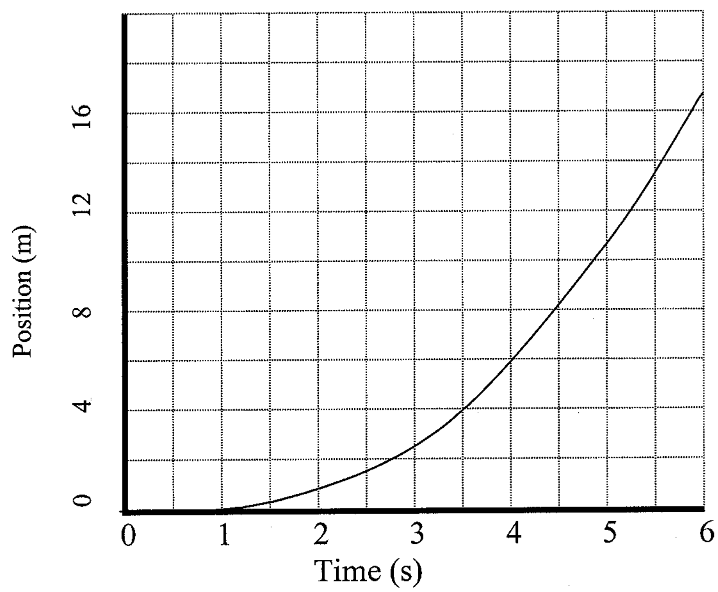
In our cases here, the average velocity can be found from the two given velocities as a simple average—add them up and divide by 2. So we use $\vec{v}_{avg} = \frac{\vec{v}_1 + \vec{v}_2}{2}$ and the final equation becomes $D\vec{d} = \frac{\vec{v}_1 + \vec{v}_2}{2}Dt$. The displacement will give the final position of the object for all the graphs. The line on the Position-Time graph will be a curve joining the initial position to the final position.

Finally, in some cases, the velocities will be changed to m/s from km/h to facilitate the comprehension of the displacement.

4. a. $\vec{v}_1 = 0 \text{ km/h} = 0 \text{ m/s}; \ \vec{v}_2 = +20 \text{ km/h} / 3.6 = +5.5 \text{ m/s}; \ t = 6 \text{ s}; \ \Delta\vec{d} = ?$

$$\Delta\vec{d} = \frac{\vec{v}_1 + \vec{v}_2}{2}\Delta t = \frac{(0 \text{ m/s} + 5.5 \text{ m/s})}{2}(6 \text{ s}) = +16.5 \text{ m}$$

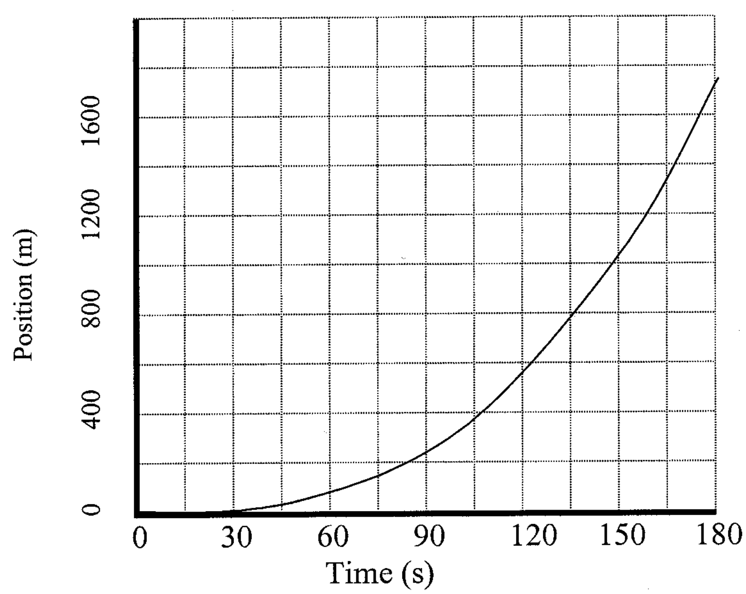
Therefore, $\vec{d}_2$ is +16.5 m. A curved line is drawn on the Position-Time graph starting at 0 m and ending at +16.5 m. The remaining questions are done in a similar fashion.



b. $\vec{v}_1 = +10 \text{ km/h} / 3.6 = +2.8 \text{ m/s}; \ \vec{v}_2 = +60 \text{ km/h} / 3.6 = +16.7 \text{ m/s};$

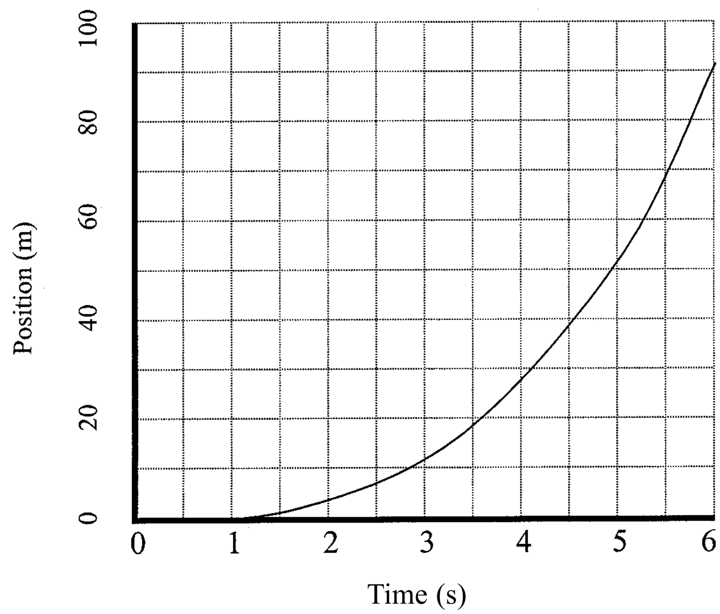
$t = 30 \text{ min} = 180 \text{ s}; \ \Delta\vec{d} = ?$

$$\Delta\vec{d} = \frac{\vec{v}_1 + \vec{v}_2}{2}\Delta t = \frac{(+2.8 \text{ m/s} + 16.7 \text{ m/s})}{2}(180 \text{ s}) = +1750 \text{ m}$$



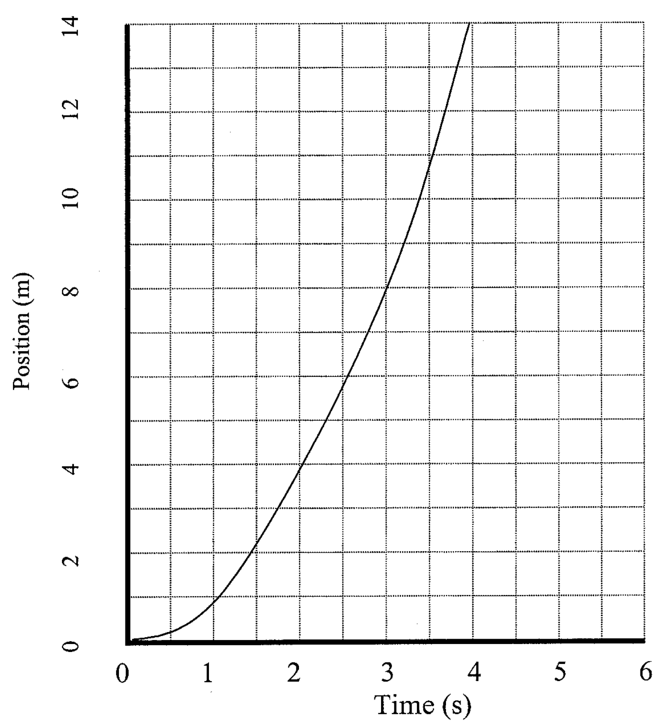
c. $\vec{v}_1 = +50\text{ km/h}/3.6 = +13.9\text{ m/s};\ \vec{v}_2 = +60\text{ km/h}/3.6 = +16.7\text{ m/s};\ t = 6\text{ s};\ D\vec{d} = ?$

$$D\vec{d} = \frac{\vec{v}_1 + \vec{v}_2}{2} Dt = \frac{(+13.9\text{ m/s} + 16.7\text{ m/s})}{2}(6\text{ s}) = +91.8\text{ m}$$



d. $\vec{v}_1 = 0\text{ m/s};\ \vec{v}_2 = +7\text{ m/s};\ t = 4\text{ s};\ D\vec{d} = ?$

$$D\vec{d} = \frac{\vec{v}_1 + \vec{v}_2}{2} Dt = \frac{(0\text{ m/s} + 7\text{ m/s})}{2}(4\text{ s}) = +14\text{ m}$$



Think About IT!—Page 22

It appears that there are two sets of footprints: those of a wolf and those of a rabbit.

In the diagram, to the right represents the east or an easterly direction.

The wolf is traveling in a direction slightly south of east. By the spacing of the tracks, the wolf appears to be walking or running slowly. The rabbit is hopping along slowly in a direction slightly north of east. The paths of the wolf and the rabbit intersect. At this point, there are many wolf tracks in the same area. This indicates that the wolf remained there for a time while it killed and ate the rabbit. Once the meal was finished, the wolf moved away more slowly in a southeasterly direction.

Chapter 2

Analyzing Motion: Enrichment

Note to Teachers:

The concepts involved in motion—position, velocity, acceleration, and time—should be developed using the four modes of representation: visual, numeric, graphical, and symbolic. Students need concrete experiences with these concepts. Some additional activities are provided, along with typical results.

To reinforce the concepts of motion, some extended student activities are supplied, along with answers. Many of these activities can be done by students working collaboratively in groups. Students helping other students has benefit for all involved.

Students are required to perform calculations. At this time, you may wish to introduce the concept of significant digits and the rules for significant digits in calculations. Some information is provided, with a very simple mnemonic device to aid students in determining which digits are significant.

Position and Displacement

SUGGESTED ACTIVITY:

Mark off a reference system on the board or on the wall. The origin is clearly marked as 0 m. The positions of +1 m, –1 m, +2 m, –2 m, et cetera, are marked off. A student stands at one of these positions, marked as $\vec{d}_1$. The student then moves to a second position, marked as $\vec{d}_2$.

Ask students to determine the distance traveled.

Ask students to determine the displacement.

The displacement, $\Delta\vec{d} = \vec{d}_2 - \vec{d}_1$, can be calculated. Here, displacement can be seen as distance traveled with a direction.

The importance of direction can be illustrated as follows. If a student starts at +1 m and has a displacement of +2 m, the final position is +3 m. However, if the student starts at +1 m and the displacement is –2 m, the final position is –1 m. The direction is important because the student, while starting at the same spot, has different final positions.

Ask students to start at a given position and to predict the final position, given the displacement. Students can determine the initial position, given the final position and the displacement. The use of the number line is very helpful for the students to visualize the situation.

Vectors and Scalars

Once students are introduced to the concepts of vectors and scalars, they should include direction with all vector quantities.

Instruct students in recognizing quantities from the units attached. For example, 5 m indicates distance. A value such as +5 m or 5 m east or 5 m [E] indicates displacement. Students also need to practise using the name that accompanies a symbol. Many times an equation is memorized without any understanding of the meaning of the symbols.

As students encounter new quantities, they should be encouraged to keep track of them—name, symbol, unit, vector, or scalar.

When measuring quantities in science, it is necessary to specify the direction for some quantities. Most quantities we measure are scalars. These are measured with a size or magnitude but without regard to direction. For example, temperature is a scalar. While it can be positive or negative, it does not have a direction like right or left, or east or west associated with it.

Other quantities require that a direction be given along with the size or magnitude. Force is a vector. You can pull on a door handle with a force of 25 newtons east or you can push on the door handle with a force of 25 newtons west. Although these two forces have the same magnitude, they act in different directions. One force will open the door; the other force will not.

In the study of motion, two similar quantities, speed and velocity, are often confused. Speed describes how fast an object is moving, regardless of direction. The speedometer of a car measures speed. It indicates how fast the car is moving, but does not include the direction. For example, 100 km/h is a typical speed for a car on the highway.

Velocity, though, is a vector. If we start at a point and travel at 100 km/h east for one hour, we will end up 100 km east of our starting point. If we travel at 100 km/h west, starting from the same point, we will end up 100 km west of the starting point. These two velocities, 100 km/h east and 100 km/h west, are definitely different velocities. It is the direction that makes them different.

In summary, **scalars are quantities with size or magnitude only.** We give the value of such a quantity with a number for its size and a unit to tell us the type of quantity.

A vector is a quantity with both magnitude and direction. We describe the value of a vector with a number for its size, a unit to tell us the type of quantity, and a direction.

For each quantity, give the unit and state whether it is a vector or scalar quantity.

Table 1

Quantity	Symbol of the Quantity	Unit	Vector or Scalar
Time Instant			
Time Interval			
Distance Traveled			
Displacement			
Mass			
Length			
Speed			
Acceleration			
Velocity			
Force			
Energy			

Significant Digits

The Purpose of Significant Digits

Systems of measurement were invented in order to compare quantities. Only the size of the object used to define a unit of measure is known exactly. The metre was once defined as the distance between two scratches on a bar of platinum-iridium alloy at 0°C. All other measurements of distance are estimated. Not all measurements, however, are known to the same accuracy, which refers to how close the measurement is to the true value. A micrometer, for example, will yield a more accurate measurement of a hair's diameter than will a metrestick.

Recording a Measurement Using Significant Digits

When recording a measurement, include every digit that is absolutely certain plus the first digit that must be estimated. This is the definition of a significant digit. Significant digits are part of the measurement.

For example, suppose the length of a table is measured with a ruler calibrated to 10 centimetres. A proper measurement would be recorded as 2.64 metres. This indicates the table has a length of 2 metres plus 60 centimetres plus a little bit more. The table is definitely less than 2.7 metres but greater than 2.6 metres. The first two digits are known exactly and the third digit is estimated (a guess). The measurement has three significant digits. A measurement of the same table with a ruler calibrated to centimetres could yield 2.642 metres.

The final significant digit will always be one unit smaller than the calibration of the measuring instrument. For example, the first measurement above was recorded to the nearest centimetre, and the ruler was calibrated to only the nearest 10 centimetres. The second measurement was recorded to the nearest tenth of a centimetre, and the ruler was calibrated to the nearest centimetre.

Zeros are to be recorded if they are significant. If a table was measured and the end of the table coincided with a mark on the ruler (e.g., 2.6 metres), a zero must be recorded. If the ruler is calibrated in 10 centimetres, record zeros until the next smaller unit, one centimetre, is recorded. In this case, the measurement would be 2.60 metres. If the metrestick was calibrated in centimetre units, then zeros are recorded until one millimetre is recorded. Here, the measurement would be 2.600 metres.

Rules for Significant Digits

The following rules are used to determine the number of significant digits in a given measurement.

1. All non-zero digits are significant.

   E.g., 374 (3 sig digs), 8.1 (2 sig digs)

2. All zeros between non-zero digits are significant.

   E.g., 50407 (5 sig digs), 8.001 (4 sig digs)

3. Leading zeros in a decimal are not significant.

   E.g., 0.54 (2 sig digs), 0.0098 (2 sig digs)

4. Trailing zeros are significant if they are to the right of a decimal point.

   E.g., 2370 (3 sig digs), 16000 (2 sig digs), 160.0 (4 sig digs)

5. In numbers greater than 1, trailing zeros are not significant unless stated so.

   E.g., 37000 (2 sig digs)

The last three zeros may or may not be part of the measurement. To show that they are, we use scientific notation. All the zeros written in the number in scientific notation are significant.

37000 with 3 sig. digits would be 3.70×10^4

37000 with 4 sig. digits would be 3.700×10^4

37000 with 5 sig. digits would be 3.7000×10^4

37000.0 has 6 sig. digits

ACTIVITY 1

Determine the number of significant digits in each of the following numbers

1) 5.897	2) 8.000	3) 10001
4) 0.333	5) 8.001	6) 0.008000
7) 7	8) 0.009	9) 947.000
10) 10000	11) 12000	12) 10000.0
13) 10321	14) 55040	15) 375000

ACTIVITY 2

State the number of significant digits in each measurement.

1) 2509 m	2) 7.62 km	3) 0.00055 m
4) 0.0670 m	5) 5.060×10^5 m	6) 9.0000×10^{-5} m
7) 240 m	8) 2.4 m	9) 2400 m
10) 2400.0 m	11) 0.005050 m	12) 50 m

ANSWERS—ACTIVITY 1

1) 4	2) 4	3) 5
4) 3	5) 4	6) 4
7) 1	8) 1	9) 6
10) 1	11) 2	12) 6
13) 5	14) 4	15) 3

ANSWERS—ACTIVITY 2

1) 4	2) 3	3) 2
4) 3	5) 4	6) 5
7) 2	8) 2	9) 2
10) 5	11) 4	12) 1

Alternate Rule for Significant Digits

Here is an alternate rule for determining significant digits. The rule is really a mnemonic device. Students are easily confused about the number of significant digits, especially if zeros are present. This rule will allow students to achieve success in working with significant digits, which should, in turn, encourage them to keep using them.

This method is called the "Atlantic-Pacific" method.

If the number in question does not contain a decimal, think "A" for Absent. If the number in question does contain a decimal, think "P" for Present.

Next, imagine a map of North America with north pointing to the top of the page. The "A" now stands for Atlantic and the "P" now stands for Pacific. Imagine an arrow starting from the correct coast being drawn towards the number. Once the arrow hits a non-zero digit, that digit and all digits after it are significant.

EXAMPLE 1

How many significant digits are shown in the number 37 500?

There is no decimal, so we think of "A" for "Absent." Therefore, an arrow must come in from the Atlantic Ocean (i.e., the right side), as shown below.

37 500 ‹

The first non-zero digit that the arrow hits would be the 5. The 5 and all digits after it, in this case to the left of the 5, are significant.

ANSWER—EXAMPLE 1

There are three significant digits in the number 37 500, the 3, 7, and the 5.

EXAMPLE 2

How many significant digits are shown in the number 0.040500?

There is a decimal, so we think of "P" for "Present." Therefore, an arrow must come in from the Pacific Ocean (i.e., the right side), as shown below.

fi 0.040500

The first non-zero digit that the arrow hits would be the 4. The 4 and all digits after it, in this case to the right of the 4, are significant.

ANSWER—EXAMPLE 2

There are five significant digits in the number 0.040500: the 4, 0, 5, 0, and 0.

Example 2 employs three separate rules for significant digits and zeros.

Uniform Motion

The following activity is an alternative to the activity with the toy vehicle pulling the ticker tape to record its position. This activity involves the participation of the whole class and produces velocities of various sizes and directions. It also provides the students with an opportunity to describe motion in a variety of ways.

The activity is intended to establish two important types of information that can be obtained from a Position-Time graph. The first type of information is found by reading the Position-Time graph directly. This provides the position of a moving object at a given instant in time, or the instant in time at which the object is at a given position.

The second type of information is found indirectly from the graph: it involves a calculation or interpretation. This indirect information is the slope of the line on the Position-Time graph. The slope gives the velocity of the object. The steepness of the slope gives the speed or magnitude of the velocity, while the sign of the slope gives the direction of the velocity.

Students can work collaboratively on the analysis of the results of the following activity.

Introducing Motion: Position, Time, Distance and Speed, Displacement, and Velocity

Purpose:

To determine the position of a person moving in a straight line at different instants in time.

To interpret a Position-Time graph to obtain distance traveled, speed, displacement, and velocity.

Apparatus:

50 metres of hallway or field, stopwatches, measuring tape

Procedure:

PART A

- Using the measuring tape, mark off 5-m intervals along a crack in the floor tiles. Place a piece of masking tape at each 5-m mark. Mark these positions using small signs, like yardage markers along the sidelines of a football field.
- Have students with stopwatches stand at each of the markers.
- Have one student begin at the 0-m mark. When the student begins to move, all timers start timing with the stopwatches.
- The student walks the full length of the course at a constant rate. As the walking student passes each timer, the timer will stop the stopwatch.
- The timers then share their times and positions with the group.

Observations:

Description of motion:

Draw a picture of the motion:

Table 2A

Time (Sec)											
Position (Metres)											

On the following graph, label time on the horizontal axis and position on the vertical axis and plot the points from the data table. Draw in the line of best fit.

Procedure:

PART B

The student starts from the 0-m mark this time and walks more quickly than before, but at a constant rate over the whole course. Again the timers start timing when the student begins to move and stop timing when the student passes the timers' position.

Observations:

Description of motion:

Draw a picture of the motion:

Table 2B

Time (Sec)										
Position (Metres)										

Plot this information on the previous graph, using a different colour for these points. Draw in the line of best fit.

Procedure:

PART C

The student starts from the 0-m mark this time and runs at a constant rate over the whole course. Again the timers start timing when the student begins to move and stop timing when the student passes the timers' position.

Observations:

Description of motion:

Draw a picture of the motion:

Table 2C

Time (Sec)											
Position (Metres)											

Plot this information on the previous graph, using a third different colour for these points. Draw in the line of best fit.

1. Using the descriptions of the motion, how do the starting points compare for the three trials?

2. From the graph, determine the starting point for each of the three trials. Compare these to the answers in part (b).

3. From the description of the motions, what is the same about all three motions?

4. From the description of the motions, what is different about the three motions?

5. On the graph, what is different about the three lines?

Procedure:

PART D

The student starts from the last mark this time and walks quickly but at a constant rate over the whole course, ending up at 0 m. Again the timers start timing when the student begins to move and stop timing when the student passes the timers' position.

Observations:

Description of motion:

Draw a picture of the motion:

Table 2D

Time (Sec)											
Position (Metres)											

Plot this information on the graph, using a fourth different colour for these points. Draw in the line of best fit.

Analysis:

1. How does this fourth line differ from the other three lines on the graph?

2. From the description of the motions, can you relate something about the line to the motion it represents?

   Line 1:

   Line 2:

   Line 3:

   Line 4:

Procedure:

PART E

At the 10-m mark, station two timers. The student starts from the 0-m mark this time and walks quickly to the 10-m mark. The first timer stops the stopwatch. The student stays at the 10-m mark for a slow count of 5. At the count of 5, the second timer stops her stopwatch and the student resumes her journey, covering the whole course at a slower pace than before. Again the timers start timing when the student begins to move and stop timing when the student passes the timers' position.

Observations:

Description of motion:

Draw a picture of the motion:

Table 2E

Time (Sec)											
Position (Metres)											

Plot this information on the graph below. Plot position on the vertical axis and plot time on the horizontal axis. **Do not draw a line of best fit.** Instead, draw a line of best fit for each section.

Analysis:

1. What is different about each section of the graph?

2. Go back to the description of the motion. What does the graph look like when the student was moving quickly? Not moving? Moving slowly?

Conclusion:

Describe the information one is able to obtain **directly** from a Position-Time graph.

We can obtain more indirect information from a Position-Time graph by looking at the line. Describe the information we can obtain **indirectly** from a Position-Time graph.

Questions:

1. Distinguish between distance traveled and displacement.

2. Distinguish between average speed and average velocity.

3. For each trial (A through E), calculate the total distance traveled. Obtain the information from the graph.

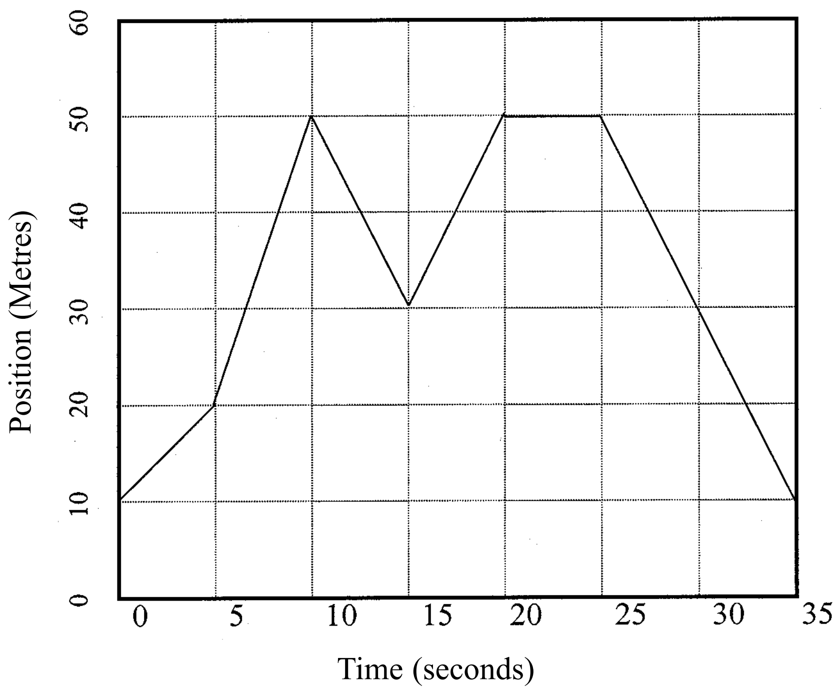
4. For each trial (A through E), calculate the total time for the journey. Obtain the information from the graph

5. For each trial (A through E), calculate the average speed. Show the equation and the work for each calculation.

6. For each trial (A through E), calculate the **displacement** for the whole journey. Obtain the information from the graph.

7. For each trial (A through E), calculate the **average velocity** for the journey. Show the equation and the work for each calculation.

8.



The graph of Position-Time above shows the position of a soccer linesman running along the sideline of a soccer field during a soccer game.

The 0-m mark is located at the goal line at the south end of the field. All the positions are marked north of that starting point.

a. Where does the linesman start his journey?

b. During which time intervals is the linesman moving to the north?

To the south?

Not moving?

c. What is the distance traveled and the displacement for each interval listed below? Include direction with displacement.

Table 3

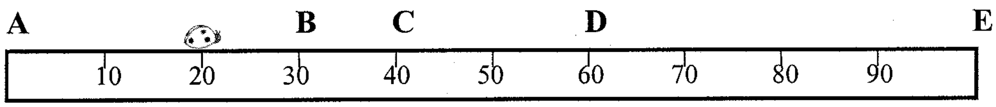
Time Interval	Distance Traveled	Displacement
0–5 seconds		
5–10 seconds		
10–15 seconds		
15–20 seconds		
20–25 seconds		
25–35 seconds		

d. Calculate the average speed and the average velocity of the linesman for each time interval.

Table 4

Time Interval	Average Speed	Average Velocity
0–5 seconds		
5–10 seconds		
10–15 seconds		
15–20 seconds		
20–25 seconds		
25–35 seconds		

Describing Motion in Various Ways



1. A somewhat confused ladybug is moving back and forth along a metrestick. Determine both the displacement and distance traveled by the ladybug as it moves from:

   a. A to B

   b. C to B

   c. C to D

   d. C to E and then to D

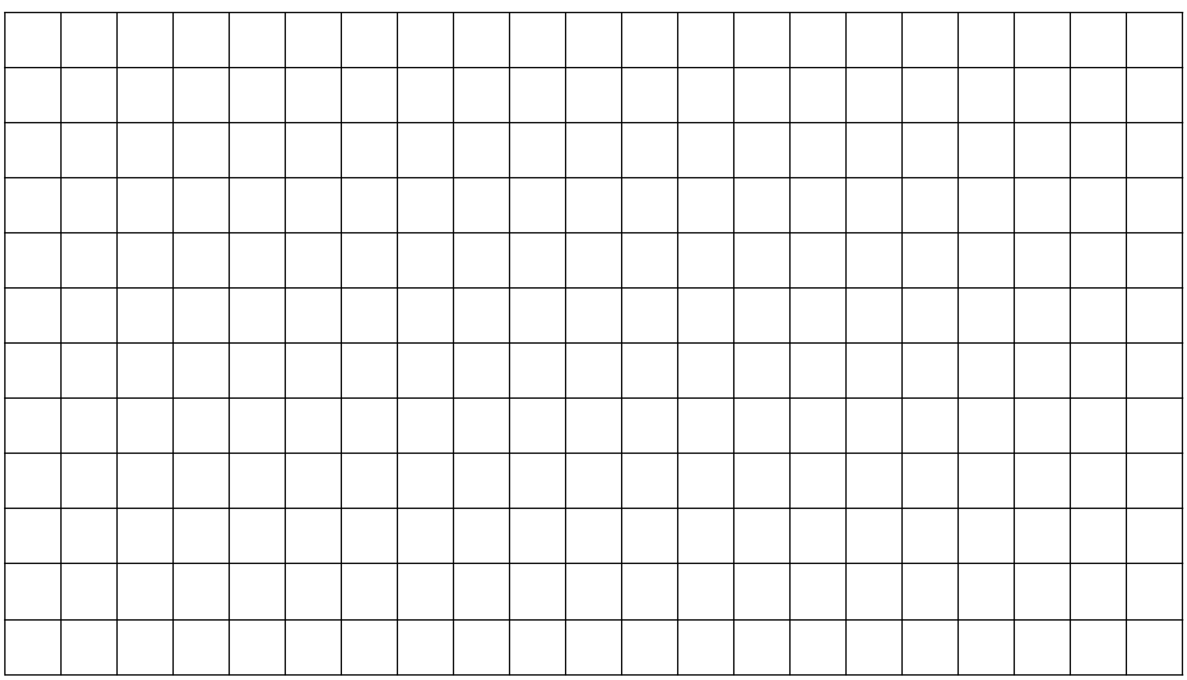
2. In the diagram above, **east** points to the **right**. During which of the intervals in #1 is the ladybug moving in the **easterly** direction?

   In the **westerly** direction?

3. Below is a table showing the position above the ground floor of an elevator at various times. On the graph below the table, plot a graph of Position-Time.

Table 5

Time (Sec)	0	4	20	32	36	60	72
Position above the ground floor (m)	4.0	8.0	8.0	16	20	20	12



4. A troubled student is waiting to see the principal. He paces back and forth in the hallway in front of the principal's office. The hallway runs north and south. The door to the office is our origin, 0 m. Here is a description of the student's motion.

   The student starts at 5.0 m N. He walks to the south for 7.0 m during 10.0 s. He stands still for 5.0 s. He turns around and walks 15.0 m N during 15.0 s. He stops to say "Hello" to a friend and remains still for 10.0 s. Finally, the principal calls him to the office door. It takes the student 10.0 s to reach the door.

   a. What is the total time the student spent in the hallway?

   b. What was the distance traveled by the student during his pacing?

   c. What was the average speed of the student during his pacing?

   d. On the graph below, plot time on the horizontal axis and position on the vertical axis. Use straight-line segments to join the points of Position-Time that you plot.

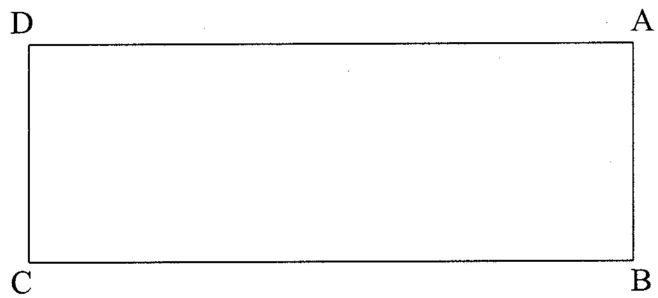
   e. What is the total displacement for the student's journey? Find this from the graph.

   f. What is the average velocity for the whole journey?

Velocity, Displacement, Time Problem Set

Questions 1–4 use the information below.

A city block is laid out in a grid running in the north-south and east-west directions. The blocks measure 135 m in length in the east-west direction, and 45.0 m in width in the north-south direction. A city block is drawn below.



1. On your bicycle, you travel from A to B during 9.00 s.
   a. What is your average speed?
   b. What is your average velocity?
2. If you travel from A to B to C to D, what is your
   a. distance traveled?
   b. displacement?
3. If the journey in #2 took 55.0 s, calculate
   a. your average speed.
   b. your average velocity.
4. You travel around the block in 90.0 s. Calculate your average speed and your average velocity.
5. Fargo is located 375 km south of Winnipeg. If it takes 4.00 h to travel from Winnipeg to Fargo, calculate your average velocity.
6. You make the return trip to Winnipeg from Fargo also in 4.00 h. What was your average velocity?
7. Jim lives on the same street as his school. The front of the school is located 1020 m [E] of Jim's house. If Jim walks at 3.00 m/s [E], calculate the time it takes Jim to walk from his house to the front of the school.
8. An airplane flies at a velocity of 215 km/h [W] for 2.75 hours. What is the displacement for this journey?

Relating Position-Time Graphs to Velocity-Time

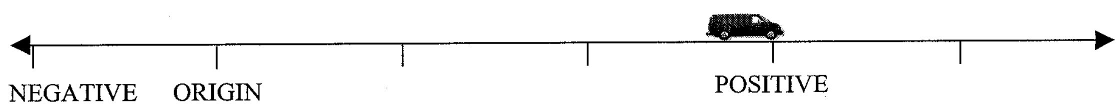
Position-Time graphs can be read directly to give the position of an object at an instant in time. This interpretation of a P-T graph tells us where an object is at a given time. This information generates the Position-Time version of the story of the motion.

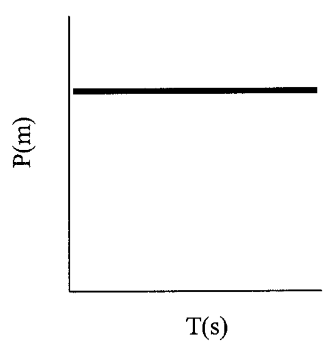
Slopes of P-T Graphs for Uniform Motion

The slope of a P-T graph gives us the velocity of the object $\vec{v}_{average} = D\vec{d} / Dt$. This allows us to tell the Velocity-Time version of the story of the motion. Remember that slope refers to the steepness of a line. Therefore, the steeper the line on a P-T graph, the greater the magnitude or size (speed) of the velocity will be for that time interval or instant in time.

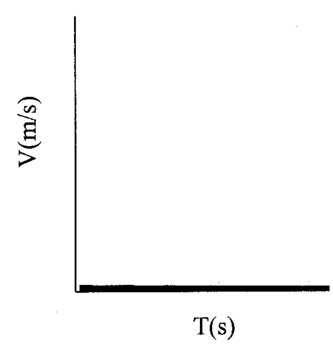
Since velocity is a **vector** quantity, it is important that the direction of the velocity is always included. Think of velocity as **speed with direction**.

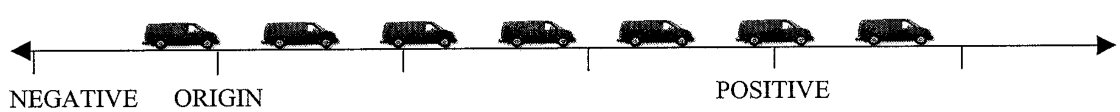
Here are some typical examples of P-T graphs with various slopes. Straight lines on P-T graphs yield constant slopes, and constant velocities (speed and direction remain the same). All the time intervals are equal for the time between the positions of the van.

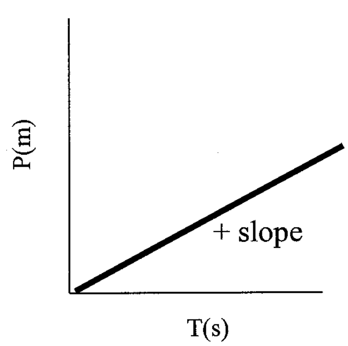




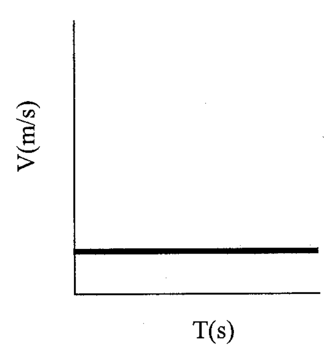
This graph indicates the object stayed at the same position or did not move. The slope is 0m/s. The velocity is 0m/s.

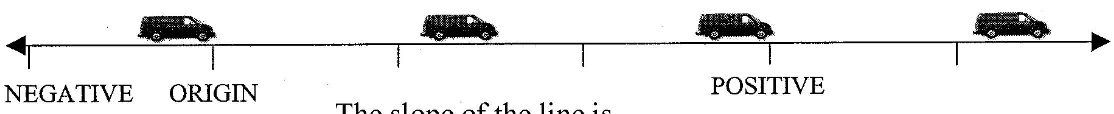


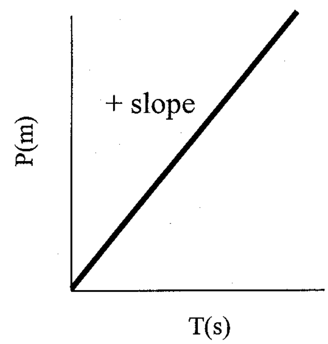




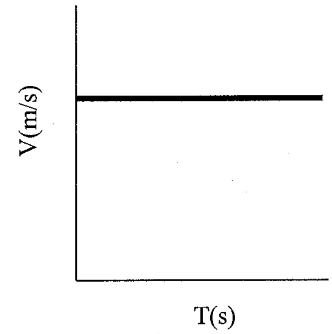
The slope of the line is positive with a low value. The velocity has a low positive value. The speed is low and the direction is positive. The line is straight so the velocity is constant. The object is moving away from the origin to the right.

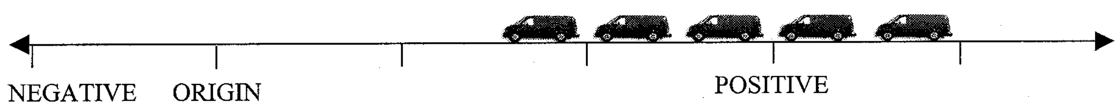


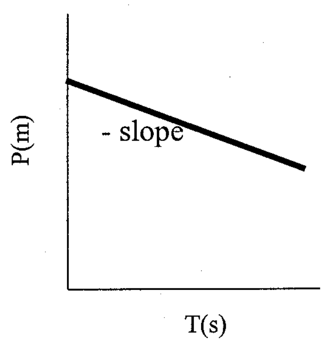




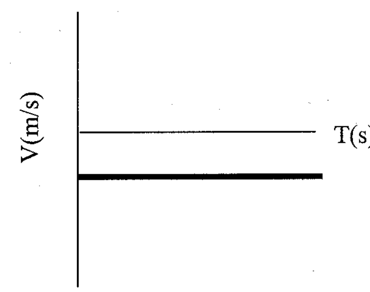
The slope of the line is positive with a higher value than the previous one. The velocity is positive with a larger value (speed) than the previous one. The object is moving away from the origin to the right.

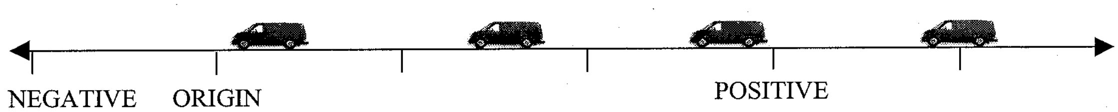


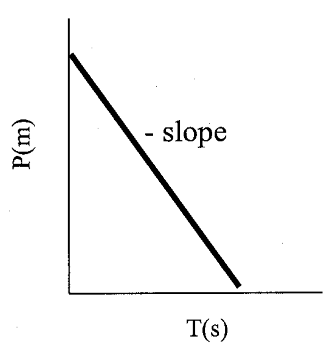




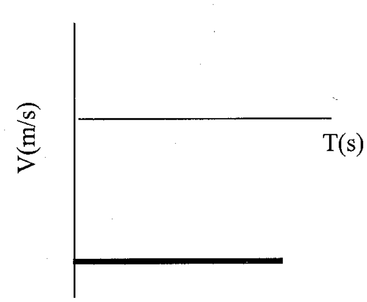
The slope of the line is negative with a low value. The velocity has a low negative value (speed). The line is straight so the velocity is constant. The object is to the right of the origin and moving left towards the origin.

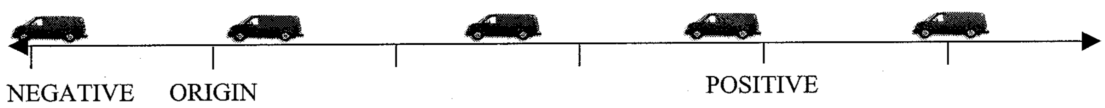


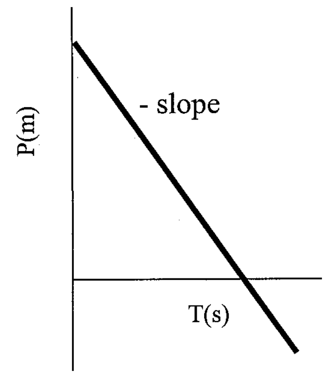




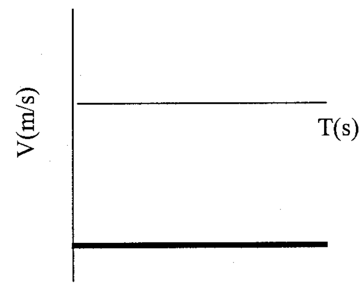
The slope of the line is negative with a larger size than the previous one. The velocity is negative with a larger value (speed) than the previous one. The object is to the right of the origin and moving towards it.







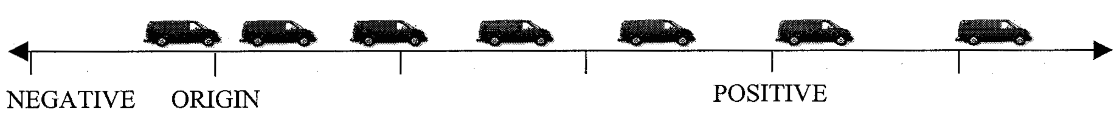
The slope of the line is the same as the previous case. The velocity is negative and has the size (speed). The object is to the right of the origin and moving towards it. The object passes the origin and moves to the left of it.

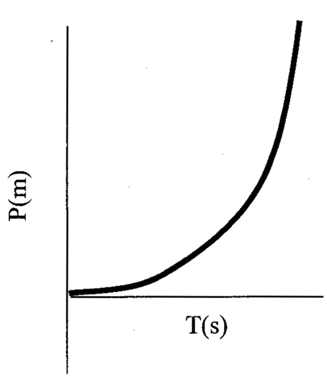


Position-Time Graphs for Non-Uniform Motion

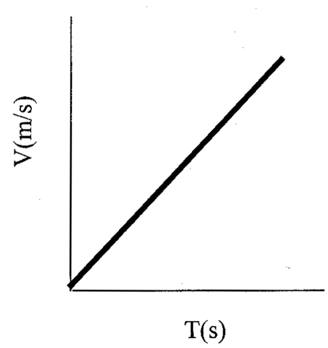
In this type of motion, objects are speeding up or slowing down. Therefore, the velocity is not constant. Since the slope on a P-T graph gives the velocity, a changing velocity will mean that the slope on the P-T graph must also change. A line with a changing slope is a curve. The slope of the curve at a given moment will calculate the velocity at that instant, the instantaneous velocity.

So, if the slope on a P-T graph becomes more positive (the line becomes steeper), the instantaneous velocities are becoming more positive (larger speed in the positive direction).

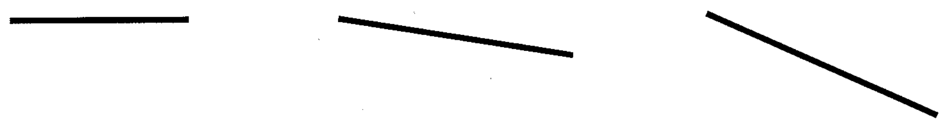




The slope at 0 seconds is 0 m/s. The slope of the graph is becoming more positive, larger in the positive direction. The velocity is increasing in the positive direction (speeding up in the positive direction). This is accelerated motion.

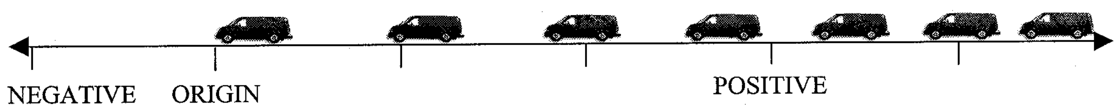


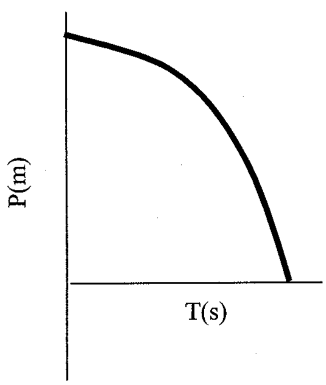
Objects can also speed up traveling in the negative direction. If an object starts from rest (slope on P-T graph = 0 m/s) and speeds up in the negative direction, the slope on the P-T graph will become more and more negative.



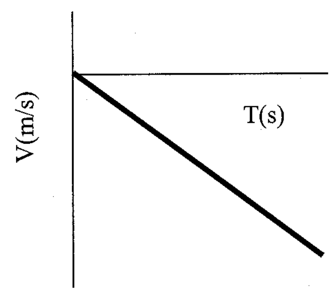
Slope is 0. Slope is small negative. Slope is large negative.

Again, the P-T graph will be a curve for which you calculate the instantaneous velocity, using the slope of the line at that moment in time. Here, the velocity becomes more negative (larger speed in the negative direction).





The object starts at rest to the right of the origin and moves towards the origin. The slope becomes more negative. The velocity becomes more negative (speeding up in the negative direction). The object's last position is at the origin.



Accelerated Motion

For the class activity, students should be reminded to measure the distance between the dots from a position on one dot to the same point on the next dot.

Also, for the class activity, some information in the tables is incorrect.

Table C should have a heading of Position (cm).

Table D has the same unit error for Position as Table C. Also in Table D, the construction of the table does not lend itself to performing the required calculations. Two alternate arrangements are presented below.

Table 6

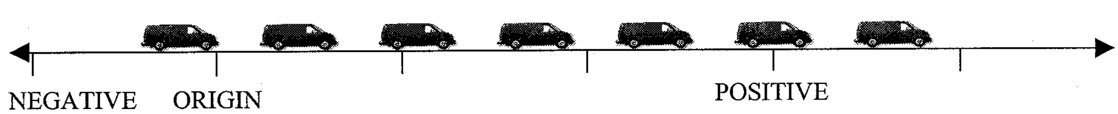
Time (s)	Displacement (cm)	Average Velocity (cm/s)
0–1		
1–2		
2–3		
3–4		
4–5		
5–6		
6–7		
7–8		

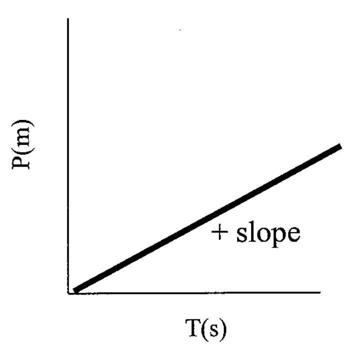
Table 7

Time (s)	Position (cm)	Displacement During Time Interval (cm)	Average Velocity (cm/s)
0			
1			
2			
3			
4			
5			
6			
7			
8			

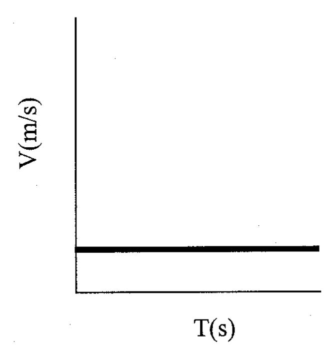
Acceleration—Non-Uniform Velocity

Up until now, most of the graphs of Position-Time have been straight-line graphs. The slope of a Position-Time graph gives the velocity. If the line is straight, the velocity is constant or uniform over that time interval. In these cases, since the velocity was uniform, there was no acceleration.

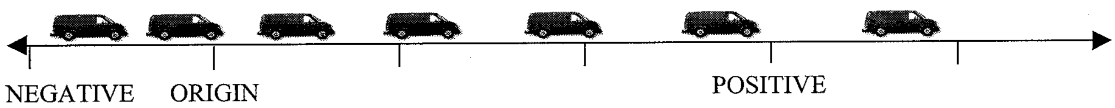


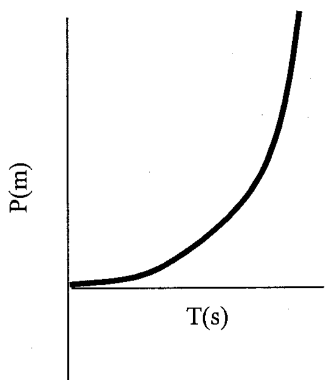


The slope of the line is positive with a low value. The velocity has a low positive value. The speed is low and the direction is positive. The line is straight so the velocity is constant. The object is moving away from the origin to the right.

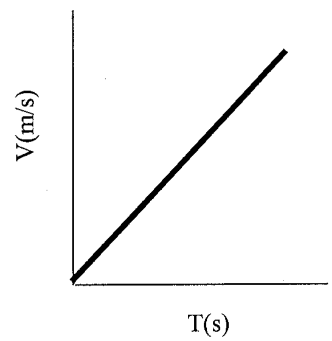


A few graphs of Position-Time were curves. On these graphs, the slope of the line still gave the velocity, but only the velocity at that instant (or instantaneous velocity). Since the slope of the curve on the Position-Time graph was always changing, so too was the instantaneous velocity always changing from one instant to the next. In these cases, the velocity was non-uniform or changing. There was an acceleration.





The slope at 0 seconds is 0 m/s. The slope of the graph is becoming more positive, larger in the positive direction. The velocity is increasing in the positive direction (speeding up in the positive direction). This is accelerated motion.



Acceleration involves an object speeding up or slowing down while moving in a straight-line path. Acceleration illustrates how velocity changes with time.

Acceleration is defined as the rate at which an object changes its velocity. It is a vector quantity, meaning that the direction in which acceleration acts is important.

The chart on the right shows that the velocity of an object is changing with time. For each second, the velocity changes by 3 m/s. The acceleration of this object is 3 m/s/s.

Since the acceleration is always 3 m/s/s, the acceleration is a uniform acceleration.

Table 8

Time (s)	Velocity (m/s)
0	0
1	3
2	6
3	9
4	12

Acceleration is calculated using the following relationship:

$$\text{Average acceleration} = \frac{\text{change in velocity}}{\text{time interval}}$$

$$= \frac{\text{final velocity} - \text{initial velocity}}{\text{time interval}}$$

In symbols, the following equation is used to calculate acceleration:

$$\vec{a}_{ave} = \frac{\vec{v}_{final} - \vec{v}_{initial}}{t_{final} - t_{initial}}$$

$$\vec{a}_{ave} = \frac{D\vec{v}}{Dt}$$

For example, the average acceleration for the time interval from 1 s when the velocity is 3 m/s, to 4 s when the velocity is 12 m/s, would be found as follows:

$\text{Time}_{initial} = 1\text{ s} \quad \text{velocity}_{initial} = 3\text{ m/s}$

$\text{Time}_{final} = 4\text{ s} \quad \text{velocity}_{final} = 12\text{ m/s}$

$$\begin{aligned}\vec{a}_{ave} &= \frac{D\vec{v}}{Dt} \\ &= \frac{12\text{ m/s} - 3\text{ m/s}}{4\text{ s} - 1\text{ s}} \\ &= \frac{+9\text{ m/s}}{3\text{ s}} = +3\text{ m/s/s}\end{aligned}$$

Acceleration is expressed in units of velocity over time. The units of velocity and time determine the units of acceleration.

Typical units of acceleration are:

$$\frac{\text{velocity}}{\text{time}} = \frac{\text{m/s}}{\text{s}} = \text{m/s/s} \quad \text{or} \quad \frac{\text{velocity}}{\text{time}} = \frac{\text{km/h}}{\text{s}} = \text{km/h/s}$$

Remember, acceleration is a vector. Always include a direction with your answer.

The Meaning of the Sign of Acceleration

The sign of the acceleration gives the direction in which the acceleration acts. A positive acceleration acts to the right and a negative acceleration acts to the left. A positive acceleration does not always mean that an object is speeding up. Sometimes an object with a positive acceleration is slowing down.

Making sense of the sign of acceleration (and whether an object is speeding up or slowing down) requires that the sign of velocity also be considered. The following table summarizes the different situations that can occur.

Table 9

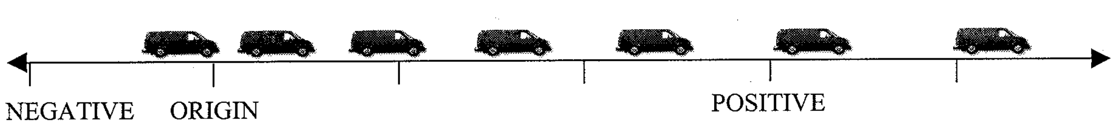
Sign (direction) of velocity	Sign (direction) of acceleration	What you see
+ (right)	+ (right)	Moving right, speeding up
+ (right)	– (left)	Moving right, slowing down
– (left)	– (left)	Moving left, speeding up
– (left)	+ (right)	Moving left, slowing down

The table may look very confusing. It is better to remember a simple rule. You will notice that if the velocity and acceleration have the **same** sign, the object will be **speeding up**. If velocity and acceleration have **opposite** signs, the object will be **slowing down**.

THE MEANING OF THE SIGN OF ACCELERATION—STUDENT ACTIVITY

In the following graphics, the time intervals between successive images of the van are all equal. For the directions, positive is to the right, and negative is to the left.

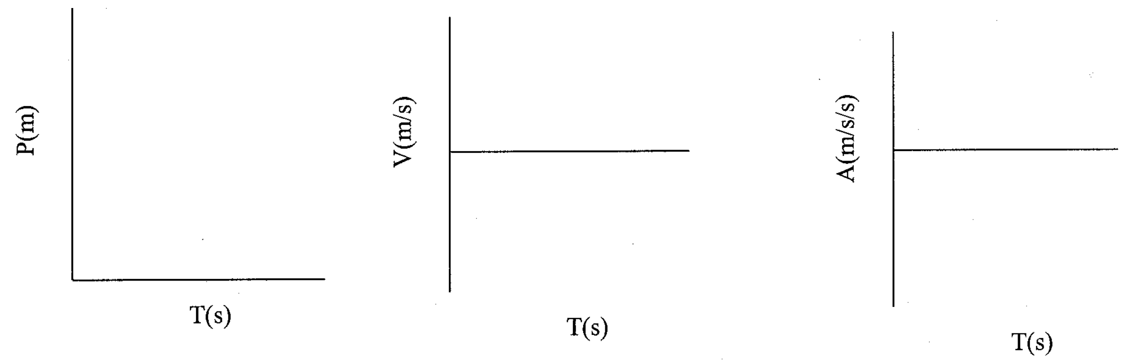
1. For the graphic below, describe the motion of the van.



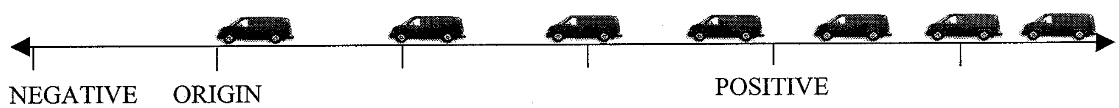
What is the sign of the velocity?

What is the sign of the acceleration?

Sketch the lines for the Position-Time graph, the Velocity-Time graph, and the Acceleration-Time graph that describe this motion.



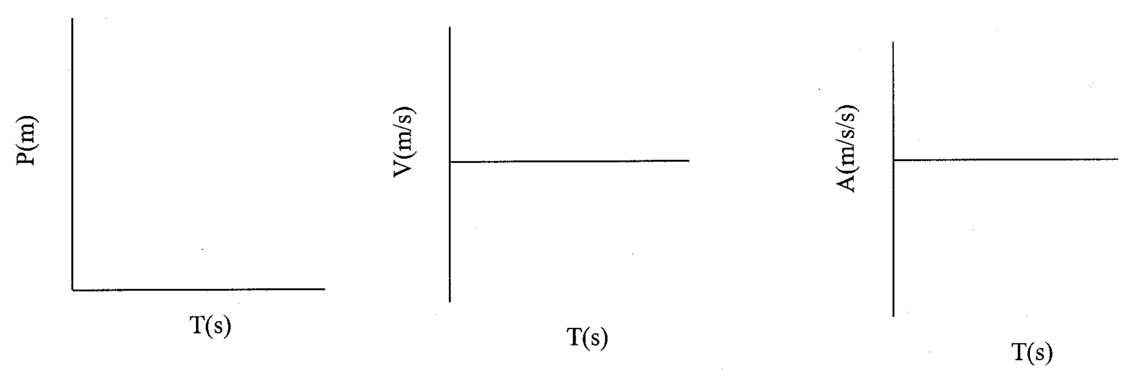
2. For the graphic below, describe the motion of the van.



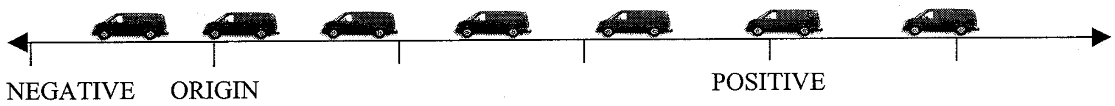
What is the sign of the velocity?

What is the sign of the acceleration?

Sketch the lines for the Position-Time graph, the Velocity-Time graph, and the Acceleration-Time graph that describe this motion.



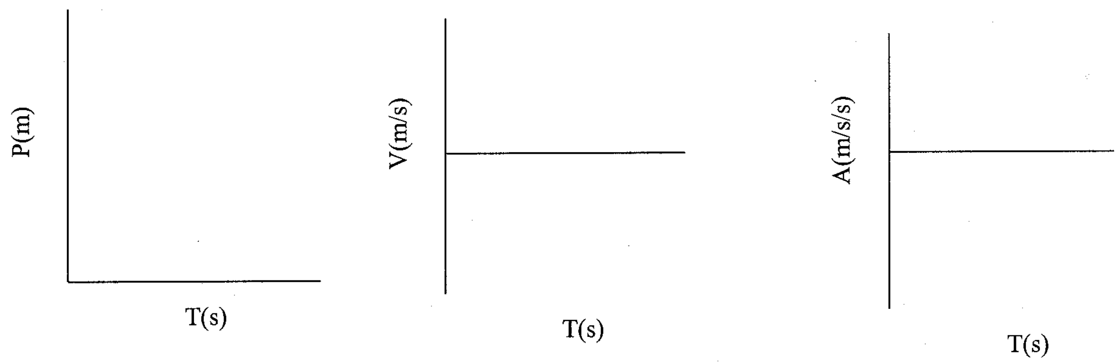
3. For the graphic below, describe the motion of the van.



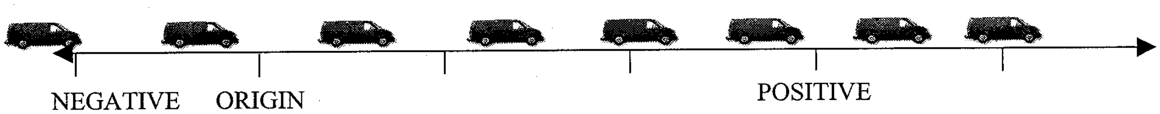
What is the sign of the velocity?

What is the sign of the acceleration?

Sketch the lines for the Position-Time graph, the Velocity-Time graph, and the Acceleration-Time graph that describe this motion.



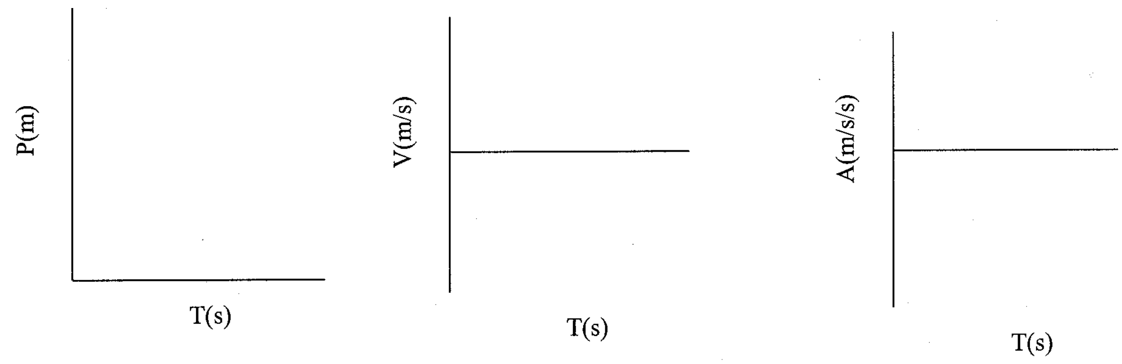
4. For the graphic below, describe the motion of the van.



What is the sign of the velocity?

What is the sign of the acceleration?

Sketch the lines for the Position-Time graph, the Velocity-Time graph, and the Acceleration-Time graph that describe this motion.



5. From the data in the table below, describe the motion of the object.

Table 10

Time (s)	Velocity (m/s)
0	10
1	9
2	8
3	7
4	6
5	5

What is the sign of the velocity?

What is the sign of the acceleration?

6. From the data in the table below, describe the motion of the object.

Table 11

Time (s)	Velocity (m/s)
0	–4
1	–8
2	–12
3	–16
4	–20
5	–24

What is the sign of the velocity?

What is the sign of the acceleration?

7. From the data in the table below, describe the motion of the object.

Table 12

Time (s)	Velocity (m/s)
0	–11
1	–9
2	–7
3	–5
4	–3
5	–1

What is the sign of the velocity?

What is the sign of the acceleration?

8. From the data in the table below, describe the motion of the object.

Table 13

Time (s)	Velocity (m/s)
0	0.25
1	0.50
2	0.75
3	1.00
4	1.25
5	1.50

What is the sign of the velocity?

What is the sign of the acceleration?

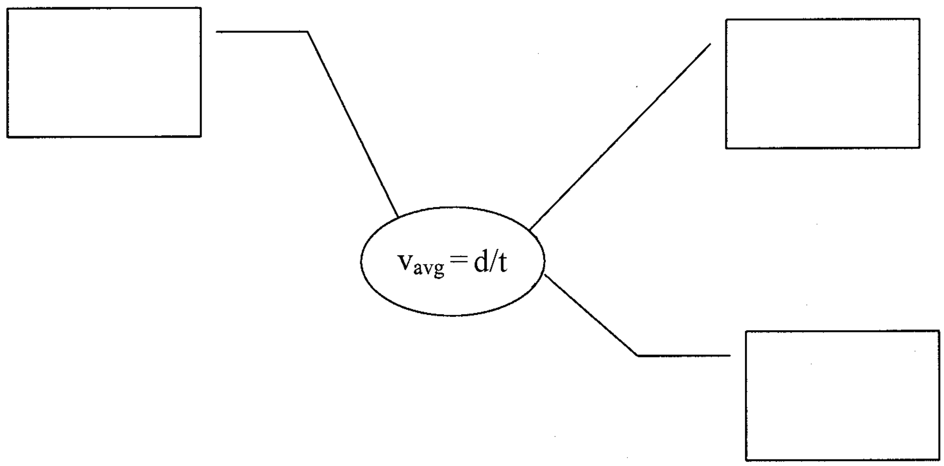
Acceleration, Velocity, Time Problem Set

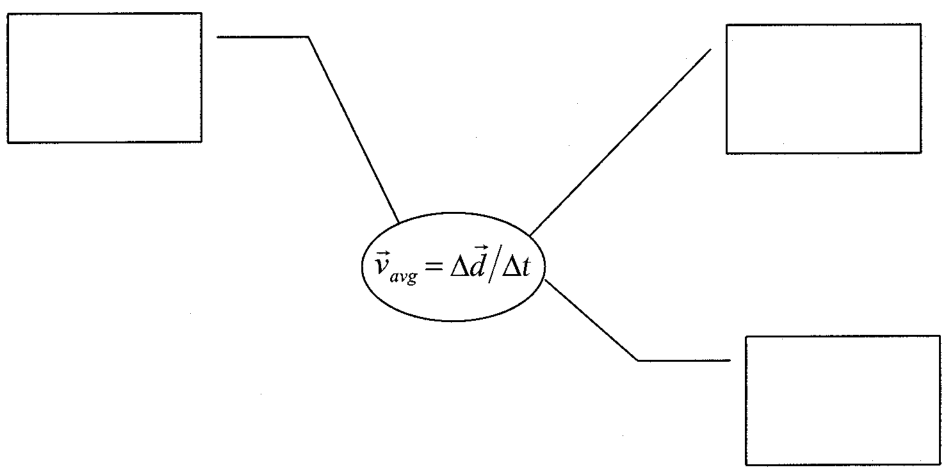
1. A car can accelerate from a standstill to 100 km/h [E] in 9.60 s. Calculate the average acceleration.
2. An object is falling at –4.20 m/s. A downward motion has a negative direction. At a time 2.50 s later, the object is falling at –28.7 m/s. What was the average acceleration?
3. A curling stone is sliding at +1.72 m/s. After 2.25 s, the curling stone is sliding at +1.00 m/s. What was the average acceleration?
4. Albertine rides her bicycle on a hill with a downward slope. If Albertine coasts down the hill with an average acceleration of 1.68 m/s/s, what is her change in velocity during 5.25 s?
5. Albertine reaches the bottom of the hill coasting along at 9.25 m/s. She begins to coast up a second hill where the average acceleration is –1.20 m/s/s. What is the change in Albertine's velocity during 3.00 s of coasting up this hill? What is her final velocity?
6. A car traveling at 18.0 m/s [E] brakes for a red light and comes to a stop. The car accelerates at an average rate of –3.60 m/s/s. What is the length of the time interval over which the car is braking?
7. A dragster racing on a quarter-mile track (about 400 m) has an average acceleration of 11.2 m/s/s [E] reaching a velocity of 72.0 m/s [E]. What was the time needed to race this distance?

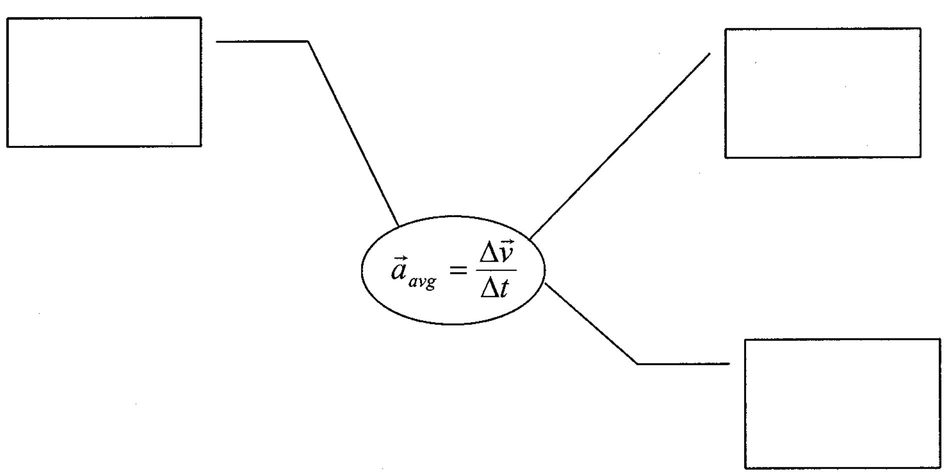
Concept Map: Speed, Velocity, and Acceleration

Give the name of each of the following equations.

For each symbol in the following equations, give the name the quantity, a definition, its unit, and whether it is a vector or scalar. Write the information around each rectangle.







Chapter 2

Analyzing Motion: Enrichment Solutions

Vectors and Scalars

When measuring quantities in science, it is necessary to specify the direction for some quantities. Most quantities we measure are scalars. These are measured with a size or magnitude but without regard to direction. For example, temperature is a scalar. While it can be positive or negative, it does not have a direction like right or left, or east or west, associated with it.

Other quantities require that a direction be given along with the size or magnitude. Force is a vector. You can pull on a door handle with a force of 25 newtons east, or you can push on the door handle with a force of 25 newtons west. While these two forces have the same magnitude, they act in different directions. One force will open the door; the other force will not.

In the study of motion, two similar quantities, speed and velocity, are often confused. Speed describes how fast an object is moving, regardless of direction. The speedometer of a car measures speed. It indicates how fast the car is moving, but does not include the direction. For example, 100 km/h is a typical speed for a car on the highway.

Velocity, though, is a vector. If we start at a point and travel at 100 km/h east for one hour, we will end up 100 km east of our starting point. If we travel at 100 km/h west, starting from the same point, we will end up 100 km west of the starting point. These two velocities, 100 km/h east and 100 km/h west, are definitely different velocities. It is the direction that makes them different.

In summary, **scalars are quantities with size or magnitude only.** We give the value of such a quantity with a number for its size and a unit to tell us the type of quantity.

A vector is a quantity with both magnitude and direction. We give the value of a vector using a number for its size, a unit to tell us the type of quantity, and a direction.

For each quantity, give the unit and state whether it is a vector or scalar quantity.

Table 1

Quantity	Symbol of the Quantity	Unit	Vector or Scalar
Time Instant	t	second (s)	scalar
Time Interval	t	second (s)	scalar
Distance Traveled	d	metre (m)	scalar
Displacement	D$\vec{d}$	metre (m)	vector
Mass	m	kilogram (kg)	scalar
Length	l	metre (m)	scalar
Speed	v	metres/second (m/s)	scalar
Acceleration	$\vec{a}$	metres/second/second (m/s/s or m/s^2)	vector
Velocity	$\vec{v}$	metres/second (m/s)	vector
Force	$\vec{F}$	newtons (N)	vector
Energy	E	joules (J)	scalar

Introducing Motion: Position, Time, Distance and Speed, Displacement, and Velocity

Purpose:

To determine the position of a person moving in a straight line at different instants in time.

To interpret a Position-Time graph to obtain distance traveled, speed, displacement, and velocity.

Apparatus:

50 metres of hallway or field, stopwatches, measuring tape

Procedure:

PART A

- Using the measuring tape, mark off 5-m intervals along a crack in the floor tiles. Place a piece of masking tape at each 5-m mark. Mark these positions using small signs, like yardage markers along the sidelines of a football field.
- A student stands at each of the markers with a stopwatch.
- Have one student begin at the 0-m mark. When the student begins to move, all timers start timing with the stopwatches.
- The student walks, at a constant rate, the full length of the course. As the walking student passes each timer, the timer stops the stopwatch.
- The timers then share their times and positions with the group.

Observations:

Description of motion:

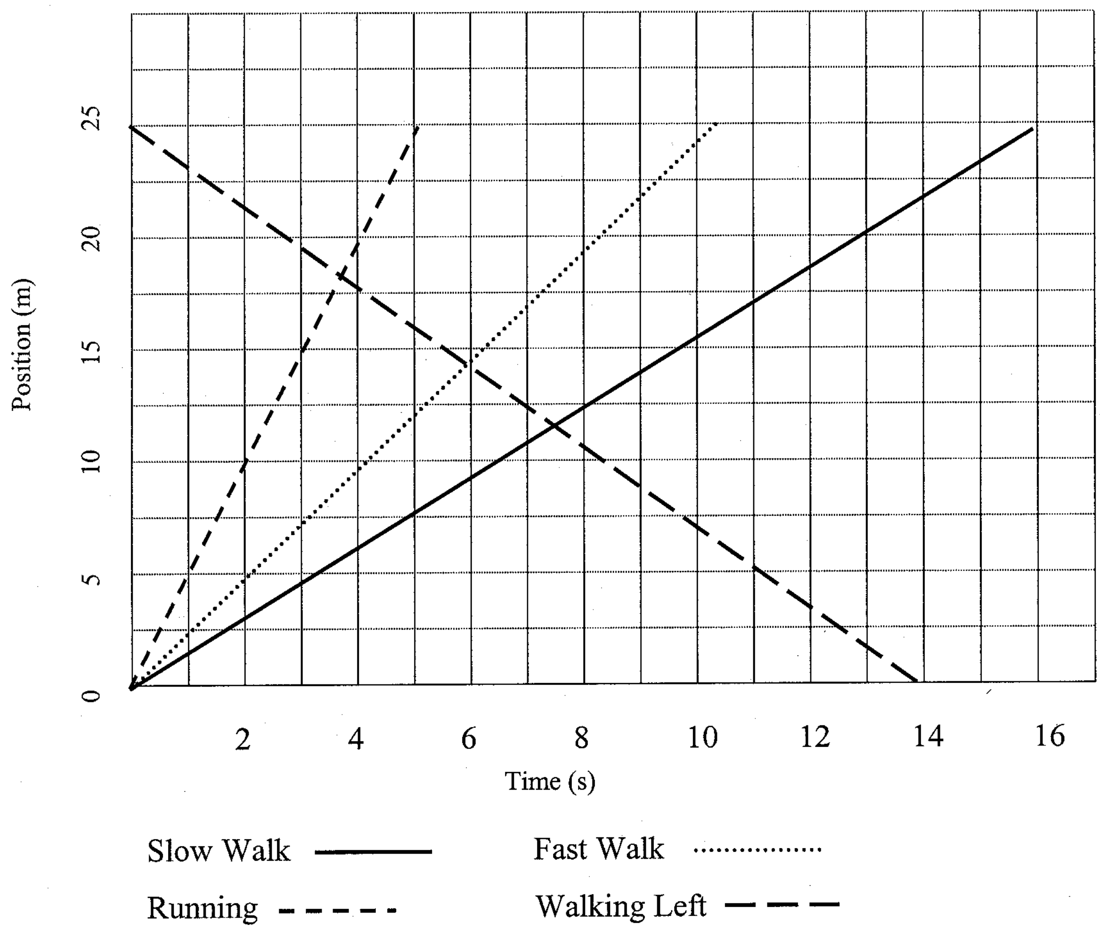
The student walks at a constant pace starting at the origin and ending at a position of 25 m to the right of the origin.

Draw a picture of the motion:

Table 2A

Time (Sec)	0	3	6	9	13	16					
Position (Metres)	0	5	10	15	20	25					

On the following graph, label time on the horizontal axis and position on the vertical axis and plot the points from the data table. Draw in the line of best fit.



Procedure:

PART B

The student will start from 0-m mark this time and walk more quickly than before but at a constant rate over the whole course. Again the timers will start timing when the student begins to move and stop timing when the student passes the timers' position.

Observations:

Description of motion:

The student started at the origin and walked at a faster but steady pace to the right, ending up at a point 25 m right of the origin.

Draw a picture of the motion:

Table 2B

Time (Sec)	0	2.0	4.0	6.5	8.3	10.4				
Position (Metres)	0	5	10	15	20	25				

Plot this information on the previous graph, using a different colour for these points. Draw in the line of best fit.

Procedure:

PART C

The student starts from 0-m mark this time and runs at a constant rate over the whole course. Again the timers start timing when the student begins to move and stop timing when the student passes the timers' position.

Observations:

Description of motion:

The student started at the origin and ran at a steady pace to the right, ending up at a point 25 m right of the origin.

Draw a picture of the motion:

Table 2C

Time (Sec)	0	1.0	2.0	2.8	4.0	5.1				
Position (Metres)	0	5	10	15	20	25				

Plot this information on the previous graph, using a third different colour for these points. Draw in the line of best fit.

1. Using the descriptions of the motion, how do the starting points compare for the three trials?

   The starting points are all the same, at 0 m.

2. From the graph, determine the starting point for each of the three trials. Compare these to the answers in part (b).

   All the lines start at 0 m at 0 s. The starting points are all the same as in #1.

3. From the description of the motions, what is the same about all three motions?

   All the motions start at the origin and end at 25 m to the right of the origin. The person moves to the right.

4. From the description of the motion, what is different about the three motions?

   The speed is different in each case. In A, it is a walk. In B, it is a faster walk. In C, it is running.

5. On the graph, what is different about the three lines?

   The slopes or steepness of the lines are all different.

Procedure:

PART D

The student will start from the last mark this time and walk quickly but at a constant rate over the whole course, ending up at 0 m. Again the timers will start timing when the student begins to move and stop timing when the student passes the timers' position.

Observations:

Description of motion:

The student begins at the 25 m mark and walks to the left, ending up at 0 m, the origin.

Draw a picture of the motion:

Table 2D

Time (Sec)	0	3	5	8	11	14					
Position (Metres)	25	20	15	10	5	0					

Plot this information on the graph, using a fourth different colour for these points. Draw in the line of best fit.

Analysis:

1. How does this fourth line differ from the other three lines on the graph?

   The fourth line begins at +25 m instead of at the origin. The line slopes to the right and down (negative slope) instead of to the right and up (positive slope) like the others.

2. From the description of the motions, can you relate something about the line to the motion it represents?

   Line 1: *The student moves steadily but slowly to the right. The slope of the line is small and positive.*

   Line 2: *The student moves steadily but more quickly to the right. The slope of the line is larger and positive.*

   Line 3: *The student moves steadily but very quickly (running) to the right. The slope of the line is still larger and positive.*

   Line 4: *The student moves steadily but slowly to the left. The slope of the line is small and negative.*

Procedure:

PART E

At the 10-m mark, station two timers. The student starts from the 0-m mark this time and walks quickly to the 10-m mark. The first timer stops the stopwatch. The student stays at the 10-m mark for a slow count of 5. At the count of 5, the second timer stops his stopwatch and the student resumes her journey, covering the whole course at a slower pace than before. Again the timers start timing when the student begins to move and stop timing when the student passes the timers' position.

Observations:

Description of motion:

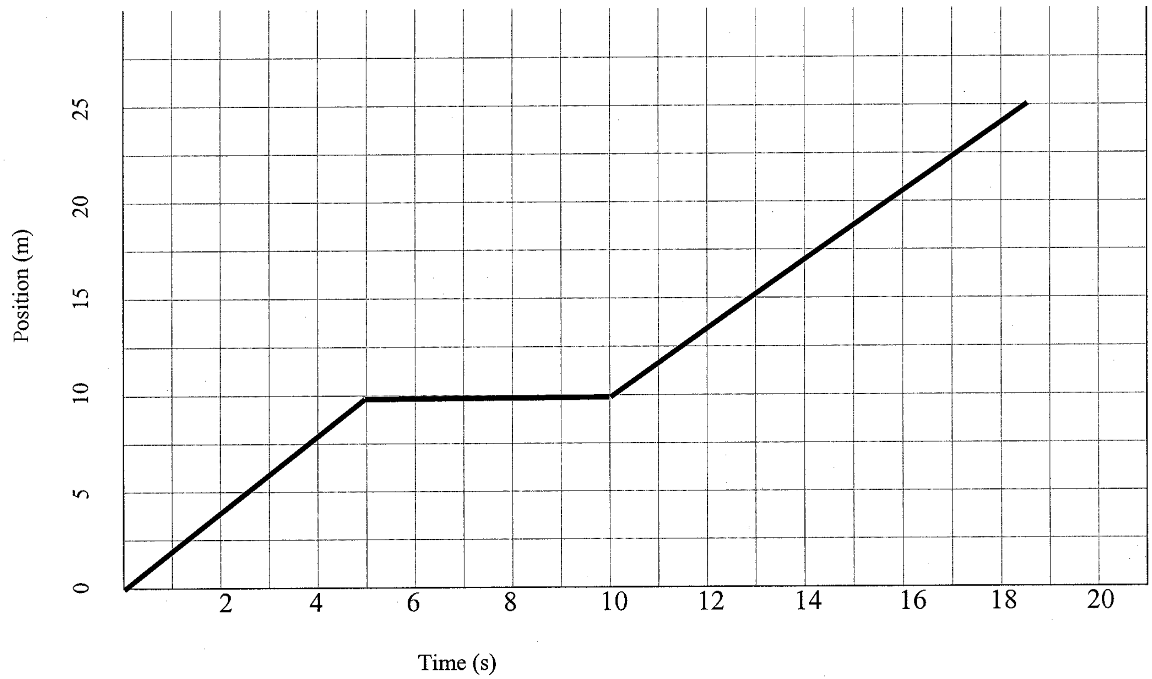
The student started at the origin, 0 m. She walked quickly to the right to the 10-m mark and stopped. She remained at the 10-m mark for a while, then walked more slowly, finishing at the 25-m mark.

Draw a picture of the motion:

Table 2E

Time (Sec)	0	2	4	10	13	16	19				
Position (Metres)	0	5	10	10	15	20	25				

Plot this information on the graph below. Plot position on the vertical axis and plot time on the horizontal axis. **Do not draw a line of best fit.** Instead, draw a line of best fit for each section.



Analysis:

1. What is different about each section of the graph drawn on page 5?

   In each section, the slope of the line is different.

2. Go back to the description of the motion. What does the graph look like when the student was moving quickly? Not moving? Moving slowly?

   In part 1, the student walked quickly. The graph is a straight line with a positive slope.

   In part 2, the student stood still. The graph is a straight line with a slope of 0.

   In part 3, the student walked more slowly than in part 1. The graph is a straight line with a positive slope, but not as steep as in part 1.

Conclusion:

Describe the information one is able to obtain **directly** from a Position-Time graph.

At a given time, the position of the object can be found directly from the graph.

We can obtain more indirect information from a Position-Time graph by looking at the line. Describe the information we can obtain **indirectly** from a Position-Time graph.

Indirectly, it seems that the speed with which the student moves gives a different slope to the line of the Position-Time graph.

When the student moves to the right, the slope is positive; and when she moves to the left, the slope is negative.

When the student moves quickly, the steepness of the line is greater.

Slope on a Position-Time graph determines the velocity of the object. The steepness gives the speed and the sign of the slope gives the direction.

Questions:

1. Distinguish between distance traveled and displacement.

   Distance traveled refers to how far an object moves regardless of its direction of motion. For example, the student walked 10 m. It is a scalar.

   Displacement refers to a change in position of an object. Displacement includes how far an object travels plus the direction of the motion. For example, the student walks 10 m to the right. Displacement is a vector.

2. Distinguish between average speed and average velocity.

   Average speed indicates how fast an object is traveling. It is found by distance traveled over time. It is a scalar.

   Average velocity is the rate of change of position with time. It is found by displacement over time interval. It is a vector.

3. For each trial (A through E), calculate the total distance traveled. Obtain the information from the graph.

   In all trials except D, the student started at the origin and ended up at +25 m from the origin, traveling a distance of 25 m.

   In trial D the student started at +25 m and finished at the origin, traveling a distance of 25 m.

4. For each trial (A through E), calculate the total time for the journey. Obtain the information from the graph

   A: $\Delta t = 16$ *s* *D:* $\Delta t = 14$ *s*

   B: $\Delta t = 10.4$ *s* *E:* $\Delta t = 19$ *s*

   C: $\Delta t = 5.1$ *s*

5. For each trial (A through E), calculate the average speed. Show the equation and the work for each calculation.

   The equation used is $v_{avg} = \Delta d / \Delta t$

   A: $v_{avg} = 25\ m / 16\ s = 1.6\ m/s$

   B: $v_{avg} = 25\ m / 10.4\ s = 2.4\ m/s$

   C: $v_{avg} = 25\ m / 5.1\ s = 4.9\ m/s$

   D: $v_{avg} = 25\ m / 14\ s = 1.8\ m/s$

   E: $v_{avg} = 25\ m / 19\ s = 1.3\ m/s$

6. For each trial (A through E), calculate the displacement for the whole journey. Obtain the information from the graph.

   $$\Delta\vec{d} = \vec{d}_2 - \vec{d}_1$$

   This equation is used for all calculations. For A, B, C, and E, the work is the same.

   $$\Delta\vec{d} = \vec{d}_2 - \vec{d}_1 = +25\text{ m} - 0\text{ m} = +25\text{ m}$$

   For D, the calculation is

   $$\Delta\vec{d} = \vec{d}_2 - \vec{d}_1 = 0\text{ m} - +25\text{ m} = -25\text{ m}$$

7. For each trial (A through E), calculate the **average velocity** for the journey. Show the equation and the work for each calculation.

   $$\vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t}$$

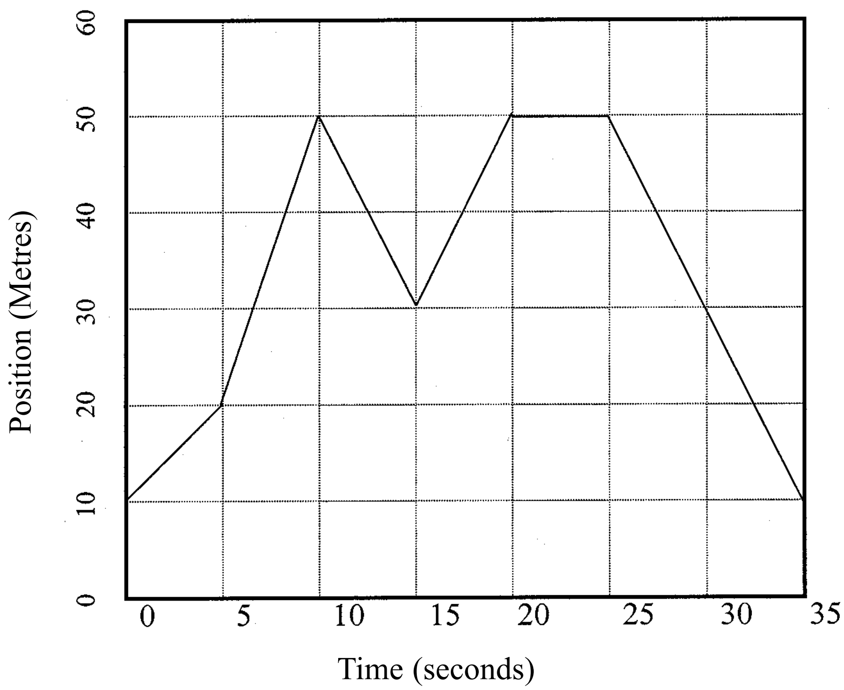
   This equation is used for all calculations.

   $$\text{A: } \vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t} = +25\text{ m}/16\text{ s} = +1.6\text{ m/s} \qquad \text{B: } \vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t} = +25\text{ m}/10.4\text{ s} = +2.4\text{ m/s}$$

   $$\text{C: } \vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t} = +25\text{ m}/5.1\text{ s} = +4.9\text{ m/s} \qquad \text{D: } \vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t} = -25\text{ m}/14\text{ s} = -1.8\text{ m/s}$$

   $$\text{E: } \vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t} = +25\text{ m}/19\text{ s} = +1.3\text{ m/s}$$

8.



The graph of Position-Time above shows the position of a soccer linesman running along the sideline of a soccer field during a soccer game.

The 0-m mark is located at the goal line at the south end of the field. All the positions are marked north of that starting point.

a. Where does the linesman start his journey?

10 m north of the south goal line.

b. During which time intervals is the linesman moving to the north?

0–10 s and 15–20 s

To the south?

10–15 s and 25–35 s

Not moving?

20–25 s

c. What is the distance traveled and the displacement for each interval listed below? Include direction with displacement.

Table 3

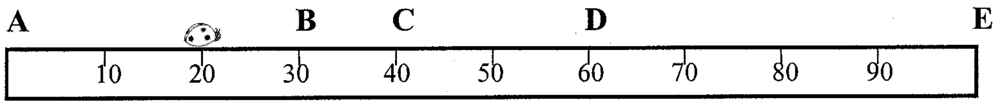
Time Interval	Distance Traveled d (m)	Displacement $D\vec{d} = \vec{d}_2 - \vec{d}_1$ (m)
0–5 seconds	10	+20 m – +10 m = +10 m =10 m [N]
5–10 seconds	30	+50 m – +20 m = +30 m = 30 m [N]
10–15 seconds	20	+30 m – +50 m = –20 m = 20 m [S]
15–20 seconds	20	+50 m – +30 m = +20 m = 20 m [N]
20–25 seconds	0	+50 m – +50 m = 0 m
25–35 seconds	40	+10 m – +50 m = –40 m = 40 m [S]

d. Calculate the average speed and the average velocity of the linesman for each time interval.

Table 4

Time Interval	Average Speed $v_{avg} = d/t$ (m/s)	Average Velocity $\vec{v}_{avg} = \frac{D\vec{d}}{Dt}$ (m/s)
0–5 seconds	10m / 5 s = 2 m/s	10m [N] / 5s = 2 m/s [N]
5–10 seconds	30m / 5 s = 6 m/s	30m [N] / 5s = 6 m/s [N]
10–15 seconds	20m / 5 s = 4 m/s	20m [S] / 5s = 4 m/s [S]
15–20 seconds	20m / 5 s = 4 m/s	20m [N] / 5s = 4 m/s [N]
20–25 seconds	0m / 5 s = 0 m/s	0m / 5s = 0 m/s
25–35 seconds	40m / 10 s = 4 m/s	40m [N] / 10s = 4 m/s [N]

Describing Motion in Various Ways



1. A somewhat confused ladybug is moving back and forth along a metrestick. Determine both the displacement and distance traveled by the ladybug as it moves from:
   a. A to B

   $\Delta\vec{d} = \vec{d}_2 - \vec{d}_1 = +30 \text{ cm} - 0 \text{ cm} = +30 \text{ cm}$

   $d = 30 \text{ cm}$

   b. C to B

   $\Delta\vec{d} = \vec{d}_2 - \vec{d}_1 = +30 \text{ cm} - +40 \text{ cm} = -10 \text{ cm}$

   $d = 10 \text{ cm}$

   c. C to D

   $\Delta\vec{d} = \vec{d}_2 - \vec{d}_1 = +60 \text{ cm} - +40 \text{ cm} = +20 \text{ cm}$

   $d = 20 \text{ cm}$

   d. C to E and then to D

   $\Delta\vec{d} = \vec{d}_2 - \vec{d}_1 = +60 \text{ cm} - +40 \text{ cm} = +20 \text{ cm}$

   $d_{CE} = 60 \text{ cm};\ d_{ED} = 40 \text{ cm};\ d_{total} = 100 \text{ cm}$

2. In the diagram above, **east** points to the **right**. During which of the intervals in #1 is the ladybug moving in the **easterly** direction?

   A to B, C to D, and C to E

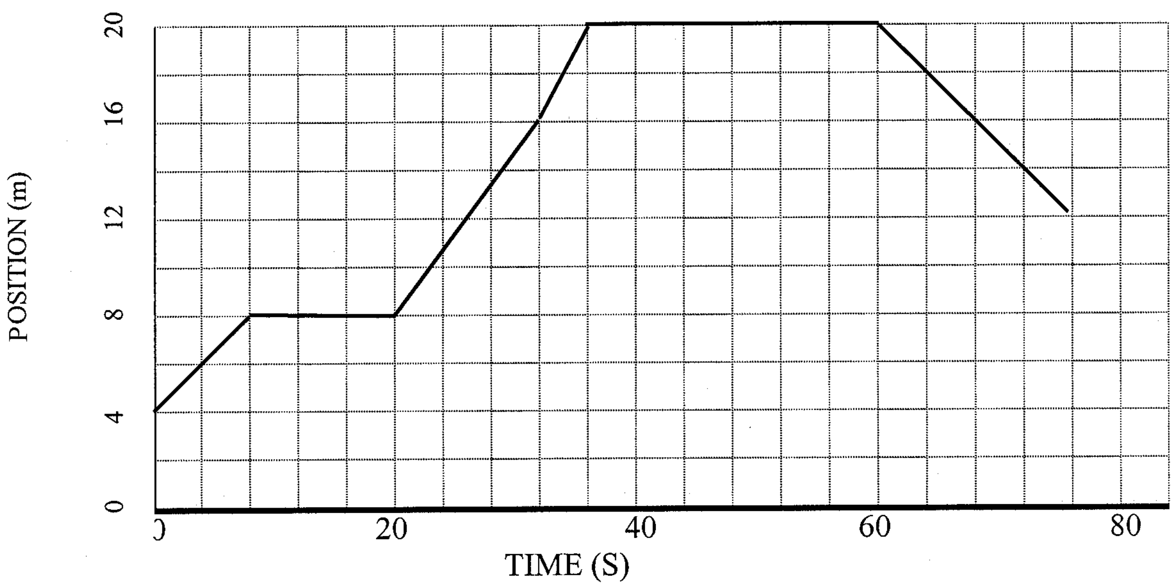
   In the **westerly** direction?

   C to B and E to D

3. Below is a table showing the position above the ground floor of an elevator at various times. On the graph below the table, plot a graph of Position-Time.

Table 5

Time (Sec)	0	4	20	32	36	60	72
Position above the ground floor (m)	4.0	8.0	8.0	16	20	20	12



4. A troubled student is waiting to see the principal. He paces back and forth in the hallway in front of the principal's office. The hallway runs north and south. The door to the office is our origin, 0 m. Here is a description of the student's motion.

   The student starts at 5.0 m N. He walks to the south for 7.0 m during 10.0 s. He stands still for 5.0 seconds. He turns around and walks 15.0 m N during 15.0 s. He stops to say "Hello" to a friend and remains still for 10.0 s. Finally, the principal calls him to the office door. It takes the student 10.0 s to reach the door.

   a. What is the total time the student spent in the hallway?

      $t_{total} = 10.0\ s + 5.0\ s + 15.0\ s + 10.0\ s + 10.0\ s = 50.0\ s$

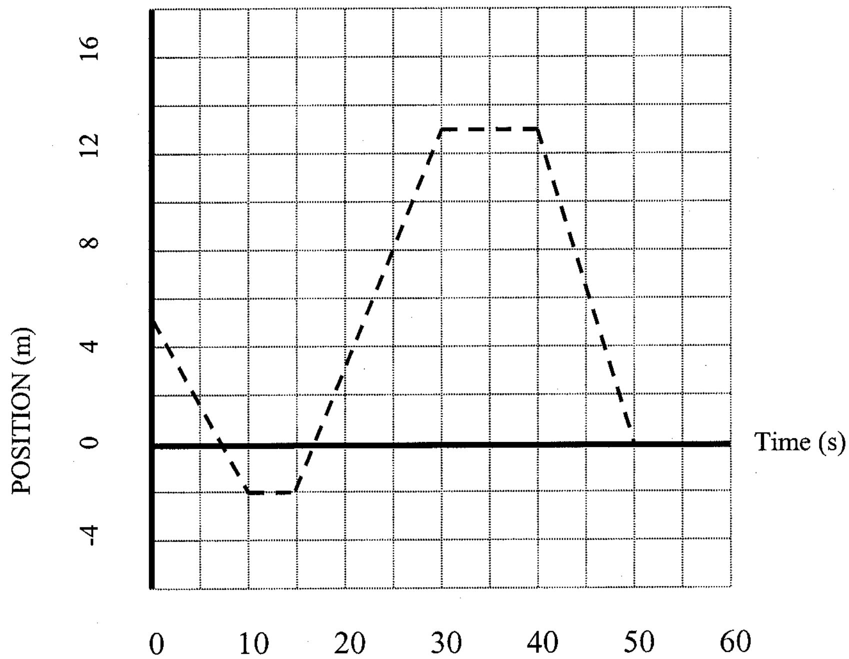
   b. What was the distance traveled by the student during his pacing?

      $d_{total} = d_1 + d_2 + d_3 = 7.0\ m + 15.0\ m + 13.0\ m = 35.0\ m$

   c. What was the average speed of the student during his pacing?

      $v_{avg} = d / t = 35.0\ m / 50.0\ s = 0.700\ m/s$

d. On the graph below, plot time on the horizontal axis and position on the vertical axis. Use straight-line segments to join the points of Position-Time that you plot.



e. What is the total displacement for the student's journey? Find this from the graph.

$$\Delta\vec{d}_{total} = \vec{d}_{50} - \vec{d}_0 = 0\ m - +5.00\ m = -5.00\ m$$

f. What is the average velocity for the whole journey?

$$\vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t} = -5.00\ m / 50.0\ s = -0.100\ m/s$$

Velocity, Displacement, and Time Problem Set

1. On your bicycle, you travel from A to B during 9.00 s.

   $D\vec{d} = 45.0\ \text{m[S]};\ t = 9.00\ \text{s}$

   a. What is your average speed?

   $v_{avg} = ?$
   $v_{avg} = d / t = 45.0\ \text{m} / 9.00\ \text{s} = 5.00\ \text{m/s}$

   b. What is your average velocity?

   $\vec{v}_{avg} = D\vec{d} / Dt = 45.0\ \text{m [S]} / 9.00\ \text{s} = 5.00\ \text{m/s [S]}$

2. If you travel from A to B to C to D, what is your

   a. distance traveled?

   $d_{AB} = 45.0\ \text{m};\ d_{BC} = 135\ \text{m};\ d_{CD} = 45.0\ \text{m}$
   $d_{total} = 45.0\ \text{m} + 135\ \text{m} + 45.0\ \text{m} = 225\ \text{m}$

   b. displacement?

   The displacement from A to B to C to D is the same as going directly from A to D, which is 135 m [W].

3. If the journey in #2 took 55.0 s, calculate

   a. your average speed.

   $d_{total} = 225\ \text{m};\ t = 55.0\ \text{s}$
   $v_{avg} = ?$
   $v_{avg} = d / t = 225\ \text{m} / 55.0\ \text{s} = 4.09\ \text{m/s}$

   b. your average velocity.

   $D\vec{d} = 135\ \text{m [W]};\ t = 55.0\ \text{s}$
   $\vec{v}_{avg} = D\vec{d} / Dt = 135\ \text{m [W]} / 55.0\ \text{s} = 4.09\ \text{m/s [S]}$

4. You travel around the block in 90.0 s. Calculate your average speed and your average velocity.

   a. *d_{total} = distance around the block = 45.0 m + 135 m + 45.0 m + 135 m = 360 m*

   t = 90.0 s

   v_{avg} = d / t = 360 m / 90.0 s = 4.00 m/s

   b. *The displacement for a trip around the block is 0 m. Therefore, the average velocity is 0 m/s.*

5. Fargo is located 375 km south of Winnipeg. If it takes 4.00 h to travel from Winnipeg to Fargo, calculate your average velocity.

$$D\vec{d} = 375 \text{ km [S]};\ t = 4.00 \text{ s}$$

$$\vec{v}_{avg} = D\vec{d} / Dt = 375 \text{ km [S]} / 4.00 \text{ s} = 93.75 = 93.8 \text{ km/h [S]}$$

6. You make the return trip to Winnipeg from Fargo also in 4.00 h. What was your average velocity?

   On the return trip, the velocity is in the opposite direction or 98.3 km/h [N].

7. Jim lives on the same street as his school. The front of the school is located 1020 m [E] of Jim's house. If Jim walks at 3.00 m/s [E], calculate the time it takes Jim to walk from his house to the front of the school.

$$\vec{v}_{avg} = 3.00 \text{ m/s [E]};\ D\vec{d} = 1020 \text{ m [E]}$$

$$t = ?$$

$$\vec{v}_{avg} = D\vec{d} / Dt$$

$$3.00 \text{ m/s [E]} = 1020 \text{ m [E]} / t$$

$$t = 1020 \text{ m [E]} / 3.00 \text{ m/s [E]}$$

$$t = 340 \text{ s}$$

8. An airplane flies at a velocity of 215 km/h [W] for 2.75 hours. What is the displacement for this journey?

$$\vec{v}_{avg} = 215 \text{ km/h [W]};\ t = 2.75 \text{ h}$$

$$D\vec{d} = ?$$

$$\vec{v}_{avg} = D\vec{d} / Dt$$

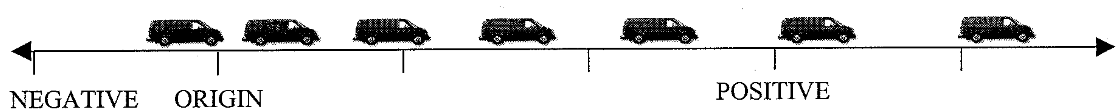
$$215 \text{ km/h [W]} = D\vec{d} / 2.75 \text{ h}$$

$$D\vec{d} = (215 \text{ km/h [W]})(2.75 \text{ h}) = 591.25 = 591 \text{ km [W]}$$

The Meaning of the Sign of Acceleration—Student Activity

In the following graphics, the time intervals between successive images of the van are all equal. For the directions, positive is to the right, and negative is to the left.

1. For the graphic below, describe the motion of the van.



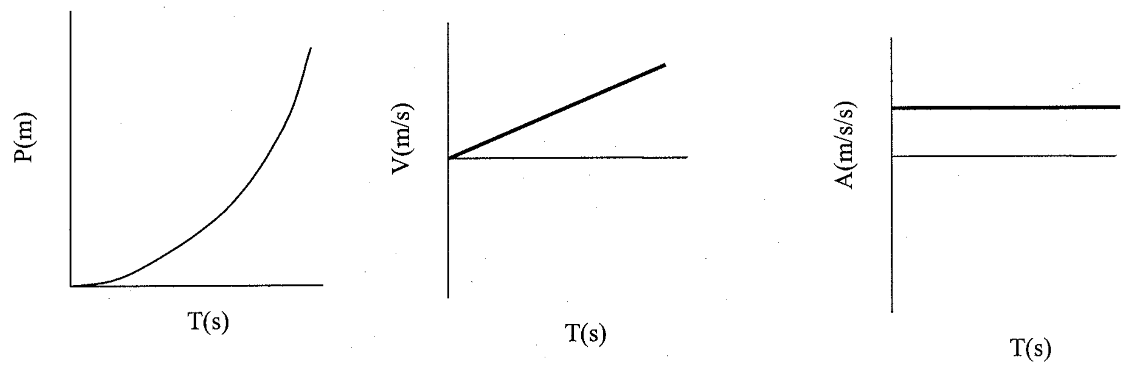
What is the sign of the velocity?

Positive

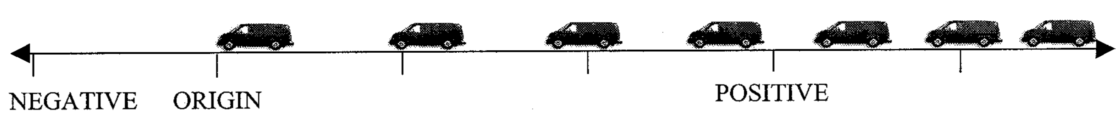
What is the sign of the acceleration?

Positive

Sketch the lines for the Position-Time graph, the Velocity-Time graph, and the Acceleration-Time graph that describe this motion.



2. For the graphic below, describe the motion of the van.



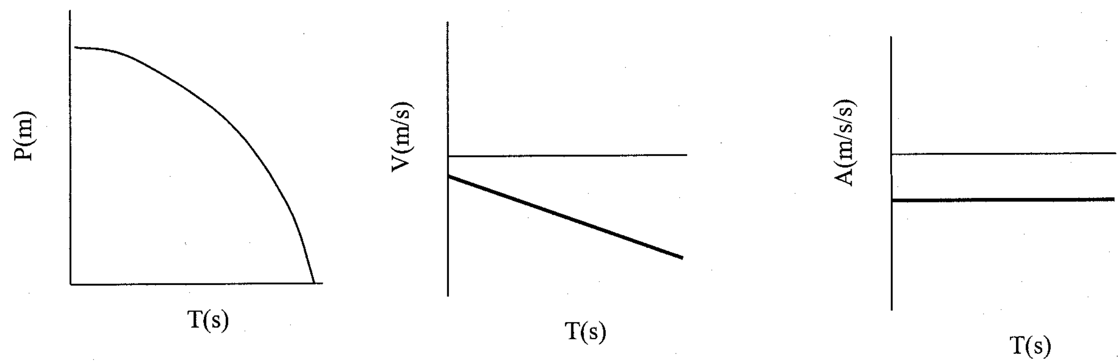
What is the sign of the velocity?

Negative

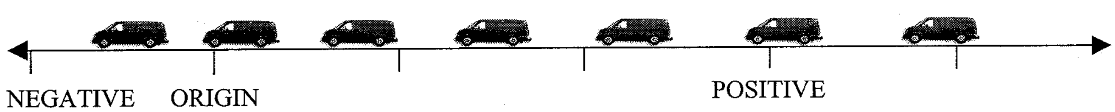
What is the sign of the acceleration?

Negative

Sketch the lines for the Position-Time graph, the Velocity-Time graph, and the Acceleration-Time graph that describe this motion.



3. For the graphic below, describe the motion of the van.



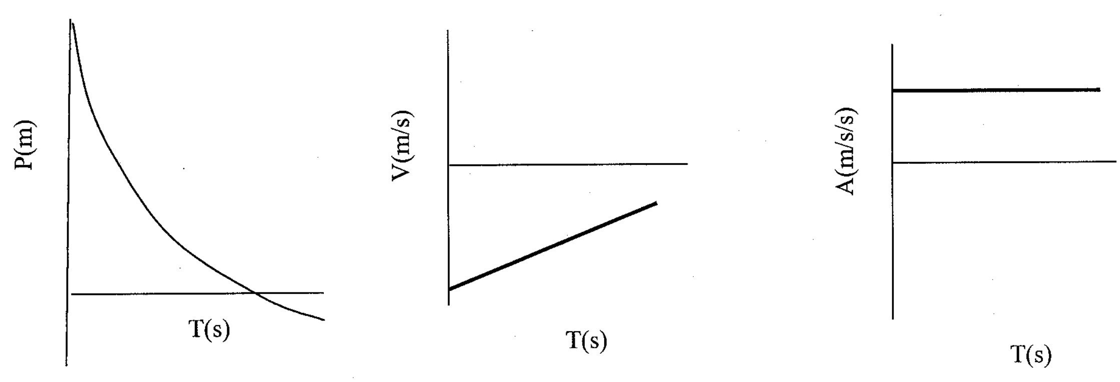
What is the sign of the velocity?

Negative

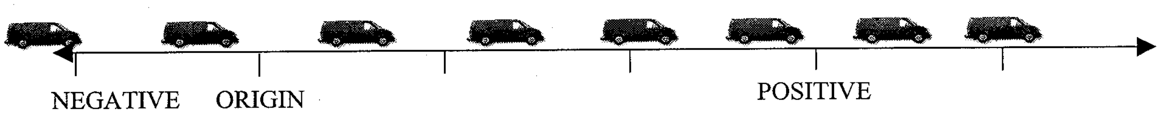
What is the sign of the acceleration?

Positive

Sketch the lines for the Position-Time graph, the Velocity-Time graph, and the Acceleration-Time graph that describe this motion.



4. For the graphic below, describe the motion of the van.



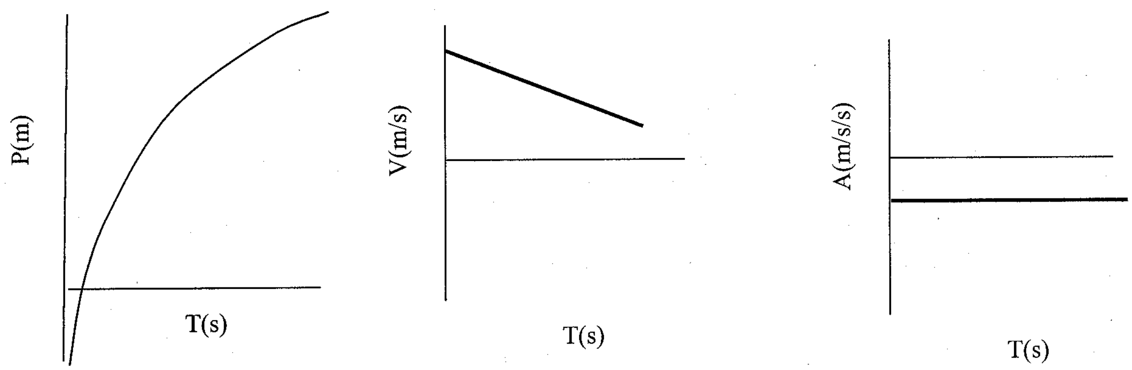
What is the sign of the velocity?

Positive

What is the sign of the acceleration?

Negative

Sketch the lines for the Position-Time graph, the Velocity-Time graph, and the Acceleration-Time graph that describe this motion.



5. From the data in the table below, describe the motion of the object.
The object is moving to the right but slowing down. There is an acceleration opposite to the direction of motion of the object.

Table 10

Time (s)	Velocity (m/s)
0	10
1	9
2	8
3	7
4	6
5	5

What is the sign of the velocity?

Positive

What is the sign of the acceleration?

Negative

6. From the data in the table below, describe the motion of the object.
The object is moving to the left and speeding up. The velocity is increasing in the negative direction, so the acceleration acts in the direction of motion.

Table 11

Time (s)	Velocity (m/s)
0	–4
1	–8
2	–12
3	–16
4	–20
5	–24

What is the sign of the velocity?
Negative
What is the sign of the acceleration?
Negative

7. From the data in the table below, describe the motion of the object.
The object is moving to the left but the velocity is decreasing. The acceleration acts in a direction opposite to the velocity.

Table 12

Time (s)	Velocity (m/s)
0	–11
1	–9
2	–7
3	–5
4	–3
5	–1

What is the sign of the velocity?
Negative
What is the sign of the acceleration?
Positive

8. From the data in the table below, describe the motion of the object.
   The object is moving to the right and the velocity is increasing. The acceleration of the object is in the direction of motion.

Table 13

Time (s)	Velocity (m/s)
0	0.25
1	0.50
2	0.75
3	1.00
4	1.25
5	1.50

What is the sign of the velocity?

Positive

What is the sign of the acceleration?

Negative

Acceleration, Velocity, and Time Problem Set

1. A car can accelerate from a standstill to 100 km/h [E] in 9.60 s. Calculate the average acceleration.

$$\vec{v}_1 = 0 \text{ km/h}; \ \vec{v}_2 = 100 \text{ km/h [E]}; \ t = 9.60 \text{ s}$$
$$\vec{a}_{avg} = ?$$
$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = \frac{100 \text{ km/h [E]} - 0 \text{ km/h}}{9.60 \text{ s}} = 10.4 \text{ km/h/s [E]}$$

2. An object is falling at –4.20 m/s. A downward motion has a negative direction. At a time 2.50 s later, the object is falling at –28.7 m/s. What was the average acceleration?

$$\vec{v}_1 = -4.20 \text{ m/s}; \ \vec{v}_2 = -28.7 \text{ m/s}; \ t = 2.50 \text{ s}$$
$$\vec{a}_{avg} = ?$$
$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = \frac{-28.7 \text{ m/s} - -4.20 \text{ m/s}}{2.50 \text{ s}} = \frac{-24.5 \text{ m/s}}{2.50 \text{ s}} = -9.80 \text{ m/s/s}$$

3. A curling stone is sliding at +1.72 m/s. After 2.25 s, the curling stone is sliding at +1.00 m/s. What was the average acceleration?

$$\vec{v}_1 = +1.72 \text{ m/s}; \ \vec{v}_2 = +1.00 \text{ m/s}; \ t = 2.25 \text{ s}$$
$$\vec{a}_{avg} = ?$$
$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = \frac{+1.00 \text{ m/s} - +1.72 \text{ m/s}}{2.25 \text{ s}} = \frac{-0.72 \text{ m/s}}{2.25 \text{ s}} = -0.32 \text{ m/s/s}$$

4. Alberto rides his bicycle on a hill with a downward slope. If Alberto coasts down the hill with an average acceleration of 1.68 m/s/s, what is his change in velocity during 5.25 s?

$$\vec{a}_{avg} = +1.68 \text{ m/s/s}; \ t = 5.25 \text{ s}$$
$$D\vec{v} = ?$$
$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = +1.68 \text{ m/s/s} = D\vec{v} / 5.25 \text{ s}$$
$$D\vec{v} = (+1.68 \text{ m/s/s})(5.25 \text{ s}) = +8.82 \text{ m/s}$$

5. Alberto reaches the bottom of the hill coasting along at 9.25 m/s. He begins to coast up a second hill where the average acceleration is –1.20 m/s/s. What is the change in Alberto's velocity during 3.00 s of coasting up this hill? What is his final velocity?

$\vec{v}_1 = +9.25 \text{ m/s}; \vec{a}_{avg} = -1.20 \text{ m/s/s}; t = 3.00 \text{ s}$

$D\vec{v} = ? \text{ and } \vec{v}_2 = ?$

$\vec{a}_{avg} = \frac{D\vec{v}}{Dt} = -1.20 \text{ m/s/s} = D\vec{v} / 3.00 \text{ s}$

$D\vec{v} = (-1.20 \text{ m/s/s})(3.00 \text{ s}) = -3.60 \text{ m/s}$

But, $D\vec{v} = \vec{v}_2 - \vec{v}_1$

$-3.60 \text{ m/s} = \vec{v}_2 - +9.25 \text{ m/s}$

$\vec{v}_2 = -3.60 \text{ m/s} + +9.25 \text{ m/s}$

$\vec{v}_2 = +5.65 \text{ m/s}$

6. A car traveling at 18.0 m/s [E] brakes for a red light and comes to a stop. The car accelerates at an average rate of –3.60 m/s/s. What is the length of the time interval over which the car is braking?

$\vec{v}_1 = 18.0 \text{ m/s [E] or } +18.0 \text{ m/s}; \vec{v}_2 = 0 \text{ m/s}; \vec{a}_{avg} = -3.60 \text{ m/s/s}$

$t = ?$

$\vec{a}_{avg} = \frac{D\vec{v}}{Dt}$

$-3.60 \text{ m/s/s} = 0 \text{ m/s} - +18.0 \text{ m/s} \; / t$

$t = -18.0 \text{ m/s} / -3.60 \text{ m/s/s} = 5.00 \text{ s}$

7. A dragster racing on a quarter-mile track (about 400 m) has an average acceleration of 11.2 m/s/s [E] reaching a velocity of 72.0 m/s [E]. What was the time needed to race this distance?

$\vec{v}_1 = 0 \text{ m/s}; \vec{v}_2 = 72.0 \text{ m/s [E] or } +72.0 \text{ m/s}; \vec{a}_{avg} = 11.2 \text{ m/s/s [E] or } +11.2 \text{ m/s/s}$

$t = ?$

$\vec{a}_{avg} = \frac{D\vec{v}}{Dt}$

$+11.2 \text{ m/s/s} = +72.0 \text{ m/s} - 0 \text{ m/s} \; / t$

$t = +72.0 \text{ m/s} / +11.2 \text{ m/s/s} = 6.43 \text{ s}$

Chapter 3

Inertia

Natural Motion – Galileo

CLASS ACTIVITY:

Galileo's Thought Experiment—Page 25

This activity was attempted with three different mini-Vs. The tracks for the mini-Vs were placed along two boards, one forming the downward sloping ramp, and the second forming the upward sloping ramp. The tracks were taped to the boards to limit their motion as the car passed. The cars were released from a point A, 100 cm from the lower end of the down ramp. The vertical height to the point A was 56 cm.

Point B was marked along the upward sloping ramp. It was the point at which the car stopped moving and reversed its direction. The angle of the upward sloping ramp was measured. The distance to point B from the bottom of the upward sloping ramp was measured. The vertical height from the table to point B was also measured.

Theoretically, the car should travel up the upward sloping ramp to point B and reach the same vertical height as the point of release, A. Due to friction and the loss of energy to other forms, the cars never reached the same height as point A (i.e., 56 cm). The best that could be achieved was about 35 cm in height to point B.

The three vehicles being used were slightly different in shape and mass. The lightest (vehicle A), a sports car, performed the worst. The one with the most mass (vehicle C), a van, performed the best.

Typical Results

1. The point of release in all trials was 100 cm from the lower end of the downward sloping ramp and the vertical height was always 56 cm.

Table 1

Angle of upward sloping ramp	Vehicle	Average distance traveled up the upward sloping ramp (cm)	Average vertical distance vehicle to which the vehicle rose (cm)
30°	A	65	28
30°	B	68	30
30°	C	77	35
25°	A	79	30
25°	B	82	32
25°	C	89	34
17°	A	103	28
17°	B	118	31
17°	C	125	34
10°	A	141	25
10°	B	162	31
10°	C	169	33

2. Ideally, the height from which you release the car above the floor and the height to which the car rises above the floor on the other ramp should be the same. However, due to friction and the loss of energy to other forms, the height to which the vehicle will rise is always less than the height from which it was released.

3. Distance from which car is released up the ramp = 90 cm.

Distance car travels up the up ramp will be less than 90 cm if the angles the ramps make with the floor are equal, or if the angle for the upward sloping ramp is greater than for the downward sloping ramp.

If the angle for the downward sloping ramp is less than for the upward sloping ramp, at a certain angle the vehicle will travel farther up the upward sloping ramp than 90 cm.

4. After decreasing the angle of the up ramp:

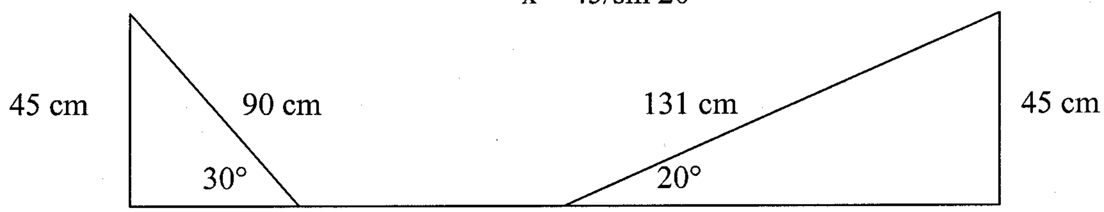
Distance from which car is released up the ramp = 90 cm.

Height above the floor to point of release = 45 cm.

Distance car moves up the up ramp = 131 cm.

$\sin 20° = 45/x$

$x = 45/\sin 20°$



Vertical distance car rises = 45 cm

The distances calculated above are for the ideal case, with no friction. The distances in real life will be less. The car will not rise to a height of 45 cm and will not travel up the slope to 131 cm.

Alternate Activity

If long movable lab tables are available, a similar activity can be done using these tables and a steel ball bearing. Butt the ends of two tables together. Raise the other ends by resting the legs on three or four textbooks. The ball bearing is released on one table from a point 1 m from the end that abuts the second table. Measure the height of the point of release above the floor. The ball then rolls down the first table and up the second table. Record the distance up the ramp the ball bearing rolls and the height it reaches above the floor.

Remove one set of textbooks from below the legs of the upward sloping table. Repeat the procedure. Repeat the procedure a third time. The ball bearing should roll almost to the end of the upward sloping table or completely off the table. If the final set of books is removed, the ball bearing rolls right off the table.

If the ball bearing is released onto a smooth, level floor as in a long hallway, the ball bearing will roll with a fairly constant velocity for a great distance. A ball released down a ramp elevated by 15 cm at one end rolled 40 m across a tiled floor and was still going when it hit the wall.

Typical Results

Table 2

Number of books under legs of upward sloping table	Point of release from end of table (cm)	Height of point of release above lowest point on the table (cm)	Distance ball travels up the upward sloping table (cm)	Height of point ball comes to rest above the lowest point on the table (cm)
3	100	3.5	89	3.0
2	100	3.5	134	3.2
1	100	3.5	>265	76.6
0	100	15 (see above)	>4000	

Think About IT!—Page 25

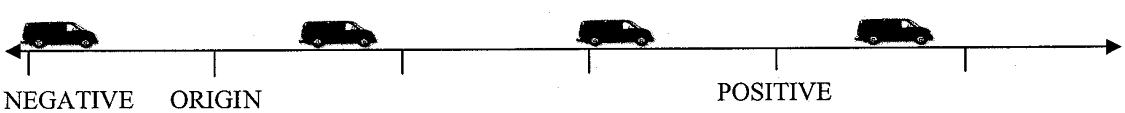
1. As the angle decreases for the up ramp, the car travels a further distance along the up ramp. The car must rise to the same height. Since the angle of the track is less, it takes a longer distance along the track to reach the same height.

2. If the angle of inclination is 0°, the car would roll along forever.

PRACTICE—PAGE 26

1. For initial motion, the object has uniform velocity.

   Van with equal spacing at equal time intervals

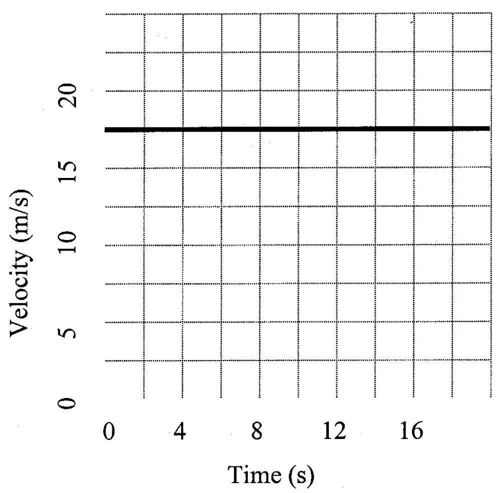


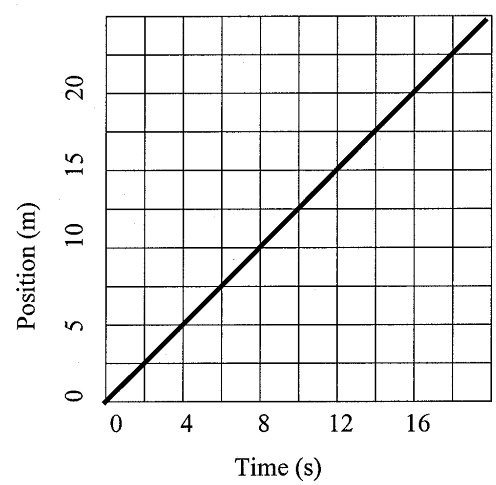
2. This table of data reflects inertial motion.

Table 3

Time (s)	Position (m)
0	0
1	2
2	4
3	6
4	8
5	10

3. This graph reflects inertial motion—motion with constant velocity.





4. An unbalanced force is any force that is acting on an object that is not cancelled out by another force of the same size acting in the opposite direction.

5. Aristotle did not use any kinds of measurements to verify his ideas about motion. He did not account for friction. To overcome friction, objects had to be pushed in order to continue to move.

6. Galileo reasoned things out in "thought experiments." While his reasoning was correct, it was not verified by measurement.

The Velocity of a Car on an Inclined Plane

Think About IT!

Think About IT!—Page 30

1. The calibration ratios should follow the pattern 1, 4, 9, 15, 25.

Sample Data

Table 4

Release point—distance up the ramp (cm)	Horizontal distance object travels before hitting the floor (cm)	Relative velocity	Actual calibration ratio	Ideal calibration ratios
5.0	17.4	1	1	1
18.5	34.8	2	4	4
34.0	52.2	3	7	9
61.5	69.6	4	12	16
100.0	87.0	5	20	25

Calibration ratio = Release point distance / First release point distance

Note to Teacher: The ramp was set at 30° from the horizontal. The track used was a plastic toy-car track nailed to the ramp. The track was quite bumpy. The object used was a marble. Better results could be obtained with a smoother track and a heavier object, such as a steel ball bearing.

The experiment was repeated using a smooth track consisting of a 1.5-m fenceboard with two smaller boards forming a channel wide enough for a Mini-V, and a steel ball bearing.

Table 5

Release point—distance up the ramp (cm)	Horizontal distance object travels before hitting the floor (cm)	Relative velocity	Actual calibration ratio	Ideal calibration ratios
5.0	21	1	1	1
22	42	2	4.4	4
45	63	3	9	9
82	84	4	16.4	16
121	105	5	24.2	25

These results closely match the ideal calibration ratios.

The angle for the calibration of the track does not matter as long as it is kept constant. In later activities, the calibrated track is used again. Be sure the students have the correct angle for the slope. A convenient way to do this is to put a mark at 100 cm from the end of the track and rest the track on three or four identical books.

2. The mathematical significance of the pattern 1, 4, 9, 16, 25 is that these numbers each represent the squares of a number.

$1 = 1^2$

$4 = 2^2$

$9 = 3^2$

$16 = 4^2$

$25 = 5^2$

Investigation #2 INERTIA AND THE UNRESTRAINED OCCUPANT

Note to Teacher: Students using toy cars had difficulty with their passengers. If the passengers were too large or too lifelike (i.e., with arms and legs), they had difficulty remaining on the vehicle as it rode down the ramp. Also, the passengers with arms and legs tended to travel inconsistent distances after leaving the vehicle.

The car tended to skip over the barrier, a metrestick, when the velocity was 4 or 5. A good height for the barrier is about 1 cm. This barrier will stop the car at all speeds and allow the passenger to travel over it.

Typically, the results, when graphed, all followed the curve of an exponential relationship with an exponent of 2.

Distance traveled is proportional to velocity squared.

Some examples can reinforce this idea. For example, if a passenger is thrown a distance of 4 m at 20 km/h, then at 80 km/h, 4x the velocity, the passenger is thrown $4(4)^2 = 4(16) = 64$ m.

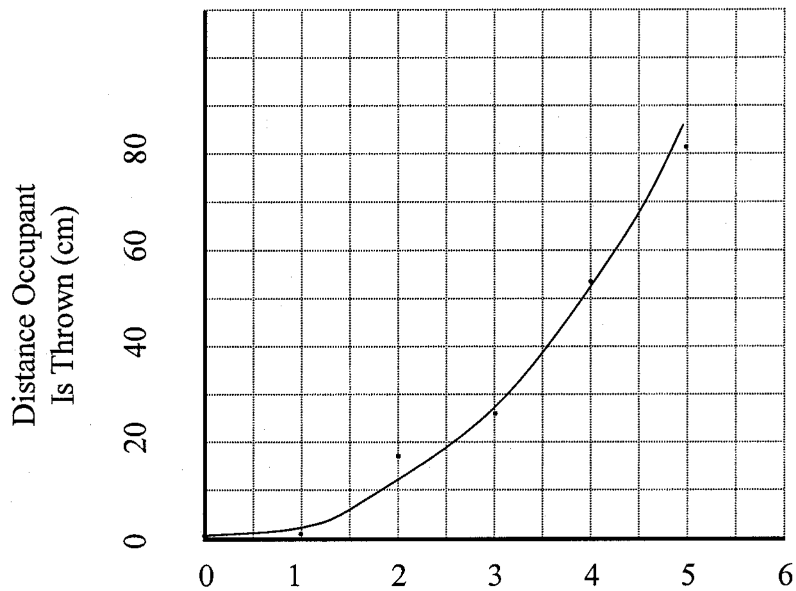
Table 6

Speed	Trial #1	Trial #2	Trial #3	Average distance occupant is thrown (cm)
0	0	0	0	0
1	0	2	0	0.7
2	19	15	18	17.3
3	30	19	29.5	26.2
4	37.5	76.5	46.5	53.5
5	86	63	94	81

Think About IT!

Think About IT!—Page 31

1.



2. As the speed increases, the distance the occupant is thrown also increases.

The distance the occupant is thrown increases more rapidly than the velocity of the vehicle. This is an exponential relationship. The graph is a curve. This curve was mentioned in exponential population growth as a "J" curve.

3. Other factors that affect the distance the occupant is thrown are:

- the shape of the occupant (does it have arms? Legs? Is it round? Flat?)
- how it moves after landing (sliding, rolling)
- size of occupant
- angle of contact with the ground

Challenge—Page 32

"Idealize" the inertia and the unrestricted occupant activity.

1. How will the velocity be controlled?

Students can launch the vehicle at varying velocities, using different means. For example, elastics can be attached to a dynamics cart. The elastic can propel the cart. This would be done by attaching the elastic to the cart and to a fixed point. The cart would be pulled back, stretching the elastic. Once released, the cart would accelerate to a certain velocity before smashing into the barrier.

The elastic can be stretched to double the original distance. This will double the force and should result in a velocity that is twice as great as the original. This can be repeated for other amounts of stretch of the elastic.

2. How can the passenger be modified to come to rest in a regular fashion?

If solid objects are used, these should have a regular shape. The less sharp the corners, the better. A die could be used, but a dodecahedron might be better. Board games come with regularly shaped solid objects with many sides. The more sides the object has, the better.

If plasticine or clay is used, it can be moulded into a cube, then the corners can be flattened. This would make the object roll in a more regular fashion.

Think About IT!—Page 32

1. The real relationship between the distance an unrestrained object is thrown and the speed of the car is an exponential relationship.

distance a velocity squared

d a v^2

If speed doubles, distance increases by 22 or 4 times.

If speed triples, then distance increases by 32 or 9 times.

Chapter 4

Forces and Motion

Think About IT!

Think About IT!—Page 33

1. **A car accelerates:**

   There is a force of friction between the tires and the road. The tires push backwards against the surface of the road. This pushes the car forward.

A car slows down:

Friction acting on the car opposes the motion. The car is slowed by friction.

The driver applies the brakes. Friction between the brake pads and rotors slow the movement of the wheels, slowing the car down.

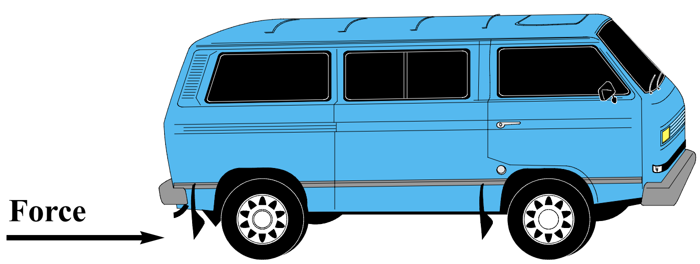
A car turns left:

A change in the direction of velocity is also **acceleration**. Any acceleration requires a force. The force of friction between the tires and the road pushes the car to the left, causing it to change the direction of motion.

A car brakes to stop:

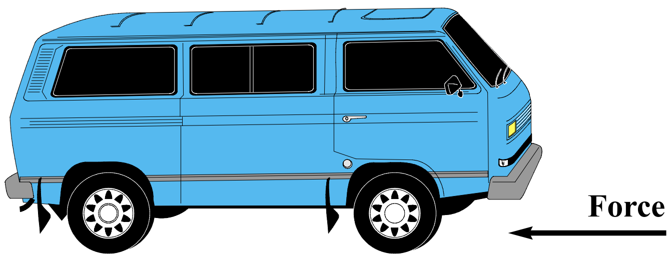
Again the force of friction between the brake pads and the rotors slows the movement of the wheels, slowing the car down.

2. **Accelerates:**



This is the force pushing the car forward as it accelerates.

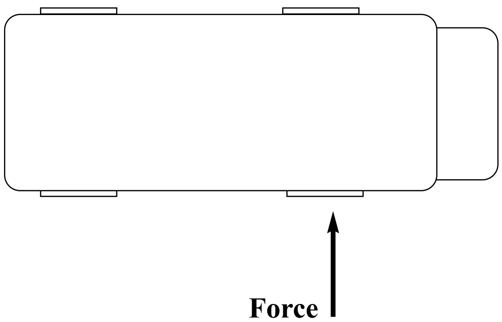
Slows down:



This is the braking force that slows the car down.

Turns left :

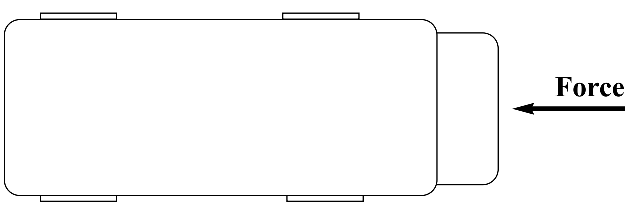
Top view:



This force turns the car left. The force does not speed up the car or slow it down, but changes the direction of the motion. This is also an acceleration.

Brakes:

Top view:



This force brings the vehicle to a stop. This force is due to the brake pads rubbing against the rotors, slowing down the rate of rotation of the wheels.

Investigation #3 FORCE AND ACCELERATION

Object:

How does the unbalanced force acting on an object affect its motion if the mass of the object is kept constant?

Independent variable = unbalanced force (weight of falling mass)

Dependent variable = motion of cart

Controls:

Mass being accelerated. Include both the mass of the cart and the falling mass.

Note to Teacher: Physics labs should have masses that would be convenient to use. An appropriate mass to use would be 100 g or 0.100 kg with a dynamics cart with a mass of about 1.00 kg. Have students label the carts they use. Later on, they must double the mass of their cart.

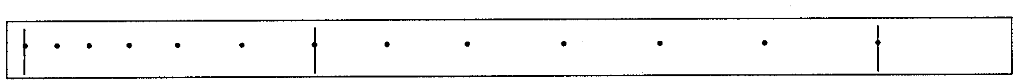
Forces are measured in newtons. Mass is measured in kilograms. The force of gravity on the hanging mass is about is about 1 N (Force of gravity = mass x 9.8 N/kg).

The acceleration of a 1.0-kg cart plus the 0.1-kg hanging mass should be about 1N/1.1 kg = 0.9 m/s/s. Due to friction, expect accelerations to be less than 0.9 m/s/s.

The tables C, D, and E from pp. 18–20 have been combined into one. See the following page for a sample blank table.

Students should analyze the dots on the ticker tape using 6 dots = 0.10 s for a ticker timer with a frequency of 60 vibrations/second.

Be sure students do **not** count the first dot at the start of the time interval as one of the six dots. There should be six spaces visible between dots in a 6 dot = 0.10 s time interval.



Once the table is complete, students graph **time** at the midpoint of the interval and average velocity.

The graph should be a straight line with a positive slope.

The slope of a Velocity-Time graph yields **acceleration**.

Typical Results:

Table A

Unbalanced force due to weight of hanging mass (N)	Mass of cart and hanging mass (kg)	Acceleration (m/s/s)
1		
1		
1		
1		
1		

Conclusion:

A constant unbalanced force exerted on an object causes the object to accelerate at a constant rate.

Table B

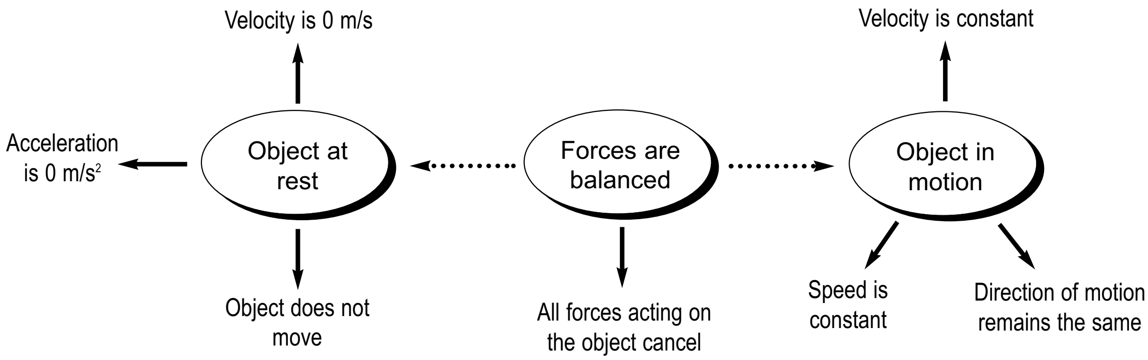
Time (s)	Position (cm)	Time at midpoint of interval(s)	Displacement during time interval (cm)	Average velocity (cm/s)

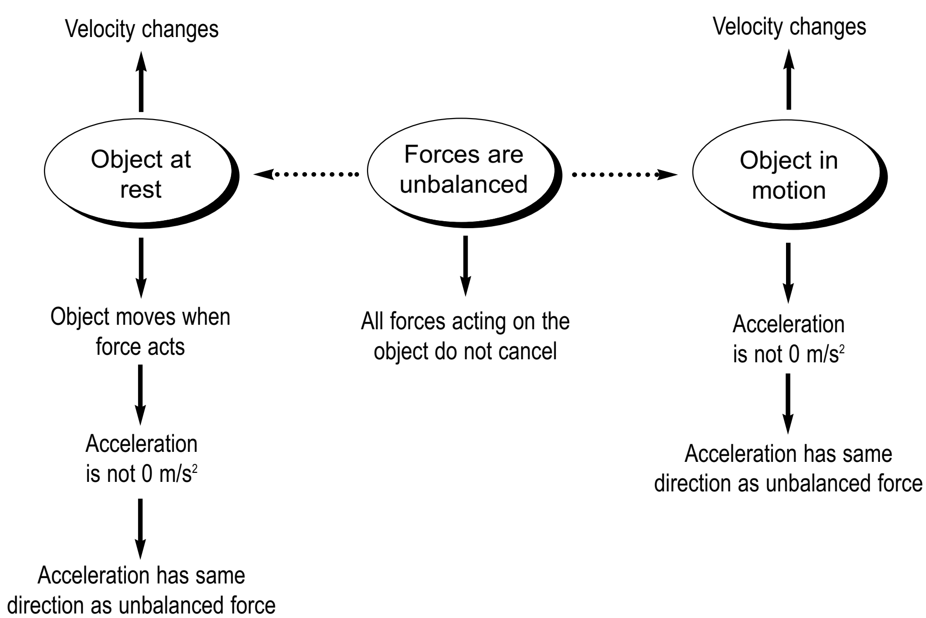
Think About IT!—Page 34

1. The dots on the tape show that the displacement between adjacent dots increases. This indicates that the velocity is increasing (i.e., the object is speeding up). The change in velocity implies there is an acceleration. A constant, unbalanced force acting on an object produces a constant acceleration.

Think About IT!—Page 35

1.





Investigation #4 MASS AND ACCELERATION

Note to Teacher: Using ticker tapes to measure acceleration is a long process that needs reinforcement. Students must perform the necessary calculations many times to become proficient at them.

If the students understand these ideas conceptually without calculations, a good deal of time can be saved.

A suggested alternative to develop the inverse relationship between mass and acceleration for a constant force is to use dynamics carts, bricks for added mass, and scales or elastics to provide the unbalanced force. Students can pull a cart with a constant force measured on a scale. Students must accelerate with the scale and the cart in order to keep the force constant. As the mass increases, students can see and feel that the acceleration required becomes smaller. This develops the concept very effectively.

An elastic attached at one end to the cart and stretched at the other end by a metrestick can also be used to provide the force. The student must keep the elastic stretched a certain amount, say 40 cm, in order to maintain a constant force.

Object:

How does the mass of the cart affect the acceleration if the unbalanced force is kept constant?

Independent variable = mass of cart **plus** falling weight

Dependent variable = acceleration

Control: unbalanced force

Note to Teacher: The mass being accelerated is the mass of the cart **plus** the mass of the falling weight.

Students will already have one set of data for the acceleration of the cart.

Have each group add different masses to its cart and perform this one trial. Each group should keep the same falling weight as the previous trial. Once the group has determined the acceleration, the information can be shared with the other groups.

Weights or bricks or extra dynamics carts can be used to provide the extra mass on the carts.

Sample Data:

These trials used a falling mass of 100 g (force = 1 N). The students used dynamics carts, to which were added weights of 0.500 kg, 1.000 kg, 1.500 kg, and 2.000 kg. The total mass accelerated was the mass of the cart, the added mass, and the hanging mass.

Each group performed a trial for all the above added masses (four trials in all). This gave each member of the group one tape to analyze. The groups then shared their results with the class. Graphs of acceleration and total mass were plotted. The graph clearly shows the inverse relationship between the total mass and its acceleration.

The results given here represent the averages for five sets of data.

Table C

Mass on cart (kg)	Total mass (kg)	Falling mass (kg)	Acceleration (cm/s/s)
0	1.08	0.100	51
0.500	1.58	0.100	35
1.000	2.08	0.100	30
1.500	2.58	0.100	24
2.000	3.08	0.100	21

Conclusion:

If the unbalanced force acting on the cart is kept constant as the mass of the cart increases, the acceleration of the cart decreases.

Alternate Method:

If you have access to the Internet, an applet called Newton's Second Law by Walter Fendt can be used to do this experiment virtually. Students can adjust the masses of the cart and the falling mass, and the applet will calculate the acceleration. Again, remember that the mass being accelerated is not just the mass of the cart, but the combined mass of the cart and the falling mass.

<http://www.walter-fendt.de/ph14e/n2law.htm>

The applet is called Newton's Second Law.

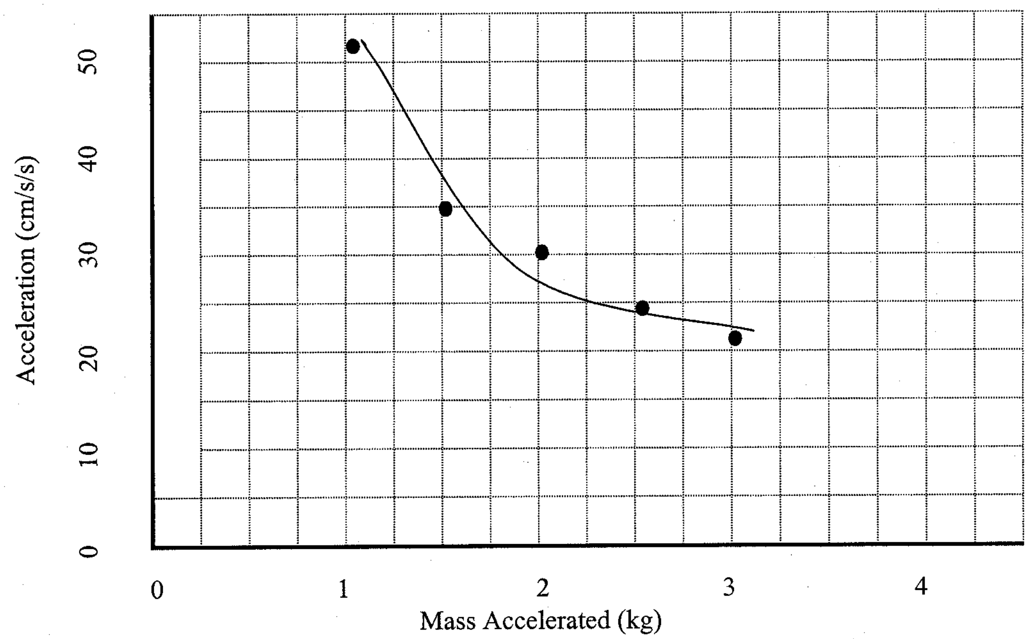
These applets can be downloaded if required, then utilized offline.

Think About IT!—Page 35

1. As the mass of the cart increases, the acceleration decreases if the unbalanced force is kept constant.

Math Connection

The graph of mass accelerated and acceleration should yield a curve. The relationship is an inverse one (i.e., as mass increases), acceleration decreases for the same unbalanced force. A typical graph appears as follows.



Investigation #5 FORCE AND MASS

Object:

How is the unbalanced force acting on the cart related to the mass of the cart if the acceleration is constant?

Independent Variable = mass of cart and hanging mass

Dependent Variable = hanging mass providing the unbalanced force

Controls = acceleration

Note to Teacher: It is expected, based on $\vec{F} = m\vec{a}$, that to maintain a constant acceleration, a doubling of the mass implies a doubling of the force. That is, $\vec{F}$ a m for constant acceleration.

Before the students actually perform the experiment, ask them to hypothesize about the force needed to accelerate double the mass. Then they can experiment to test the hypothesis.

Students can double the mass by accelerating two carts instead of one, provided they have equal masses. The students used 0.5-kg masses for the unbalanced force in previous investigations. This can easily be doubled or tripled.

In this case, doubling the mass of the cart and doubling the falling mass essentially doubles the total mass of the system. This system should show the same acceleration as the original cart and falling mass.

Sample Data:

Table D

Mass measured in carts	Falling mass providing unbalanced force (kg)	Acceleration (cm/s/s)	Average acceleration (cm/s/s)
1	0.100	77, 54, 57, 60, 60, 56, 47, 60	59
2	0.200	77, 63, 34, 37, 52, 62, 58, 58	55
3	0.300	48, 69, 50, 35, 68, 51, 60, 62	55

Analysis:

Students can analyze the ticker tapes to obtain the acceleration from a Velocity-Time graph.

If CBLs are used, the graphing calculators can be used to calculate the acceleration.

Conclusion:

The unbalanced force required to provide a constant acceleration is related directly to the mass that is being accelerated. If the mass doubles, the force needed to provide a constant acceleration also doubles.

If the results do not show that $\vec{F}$ a m, students should critically analyze the experiment to suggest ways to improve the procedure.

Alternate Method:

This activity lends itself nicely to a virtual demonstration using the Newton's Second Law applet by Walter Fendt, which is available on the Internet.

<http://www.walter-fendt.de/ph14e/n2law.htm>

Think About IT!—Page 36 (Top of Page)

1. As the mass increases, the unbalanced force needed to provide a constant acceleration increases directly in proportion to the increase in mass.

Think About IT!—Page 36 (Bottom of Page)

1. The dots for the Car A grow increasingly farther apart. This indicates that the velocity of Car A is increasing (speeding up to the right). Car A is accelerating to the right. This acceleration is caused by a constant, unbalanced force acting to the right.

The dots for Car B also grow increasingly farther apart, but the separation of the dots increases more rapidly than Car A. This indicates that the velocity of Car B is increasing (speeding up to the right). Car B is accelerating to the right. However, the acceleration of Car B, the rate at which velocity changes, is larger than for Car A. This larger acceleration indicates the force acting on Car B is larger than on Car A if their masses are equal.

A ball rolling out into the street can be a warning that a child may dart out to retrieve the ball. At the point where the driver of Car A can see the ball, Car A will have reached a certain velocity. The driver of Car A must brake the car (i.e., give it a negative acceleration to bring it to a stop). The force to cause this braking is the force between the tires and the road.

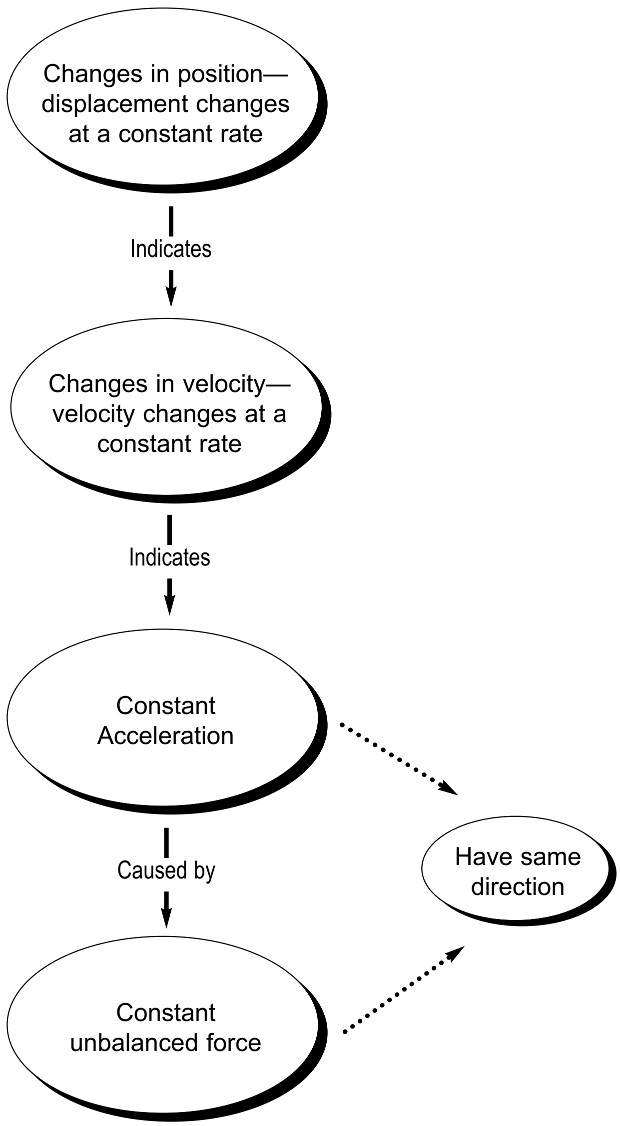
Car B reaches the point where the driver can see the ball, but it has a larger velocity than Car A. The driver of Car B applies the brakes and the force of friction between the tires and the road supply the unbalanced force needed to stop Car B. If the force of friction between the tires and the road is the same for both cars, Car B will take a longer time to brake to a stop and travel a larger distance than Car A. This larger stopping distance may carry Car B past the point where the ball, and a child trying to retrieve it, are located. The result could be a collision between Car B and the child.

Force and Direction

Think About IT!

Think About IT!—Page 38

1.



2. The racetrack is banked to maximize the turning force required to accelerate the object. This acceleration changes the direction of motion of the object, not its speed.

3. **A fi B: Car accelerates**

   Second Law—An unbalanced force acting on an object (the car) causes the object (the car) to accelerate in the direction of the unbalanced force.

   B fi C: Driver removes his foot from the pedal

   First Law—An object in motion remains in motion with a constant velocity unless acted upon by an unbalanced force.

   C: Black ice

   Second Law—An unbalanced force is required to accelerate the car by changing the direction of its motion.

   The force of friction between the tires and the road creates this force.

   The ice reduces the friction between the tires and the road.

   First Law—Since there is no unbalanced force, the rear wheels move in a straight line (skidding) outside the radius of the curvature of the road.

   D: Car moves in a straight line

   First Law—An object in motion, the car, continues in motion with a constant velocity because there is no unbalanced force acting on the object.

   There is no force between the tires and the road to turn the car around the curve.

   E: Car slams into the bank and stops

   Second Law—The bank exerts an unbalanced force on the car, causing it to accelerate. The force acts in the opposite direction to the velocity of the car, so the acceleration is negative.

   F: Windshield is cracked

   First Law—An object in motion (passenger) remains in motion at a constant velocity when acted upon by an unbalanced force. The passenger continues moving when the car stops.

   Second Law—The passenger striking the windshield exerts a force on the windshield, cracking it. The force of the windshield on the passenger accelerated the passenger in the opposite direction compared to the velocity.

4. Water skiers or hockey players lean in order to turn so that the cornering forces (forces that change the direction of velocity) are maximized and properly balanced. Otherwise, they would topple over.

Car Crash

The motorcyclist was heading south. The motorcycle is in the intersection after the accident. This indicates the motorcycle hit an object, which stopped the motion of the motorcycle. A large force was needed to stop the motorcycle quickly. Such a force could be provided by the crash between the motorcycle and the car. This is Newton's Second Law.

The motorcyclist and her helmet are found south of the intersection and the motorcycle. Since the motorcycle was traveling south when it crashed into the car, the motorcyclist and her helmet, which were in motion, continued in motion until an unbalanced force acted on them. This is Newton's First Law.

When the motorcyclist landed on the ground, the force of friction between the road and the motorcyclist brought her to a stop. Again, this is Newton's Second Law.

If the motorcycle struck the front fender of Car A, the force of the collision would have pushed the front of Car A in a southerly direction. Car A would then have traveled in a more southeasterly direction. If the motorcyclist struck the rearmost portion of Car A, this would push the rear of Car A to the south. Car A was already turning north (we could assume), so the rear of Car A would slide to the east, and the direction Car A would take would then be more northerly and somewhat east of north. The skidmarks east of the intersection would be consistent with the rear tires sliding sideways in an easterly direction. Alternatively, the skidmarks may have nothing whatever to do with this particular incident. What about those oil drops?

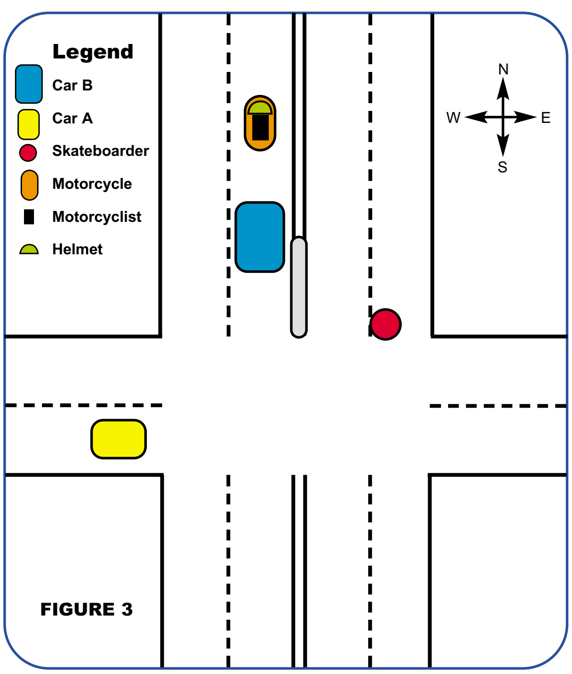


FIGURE 3

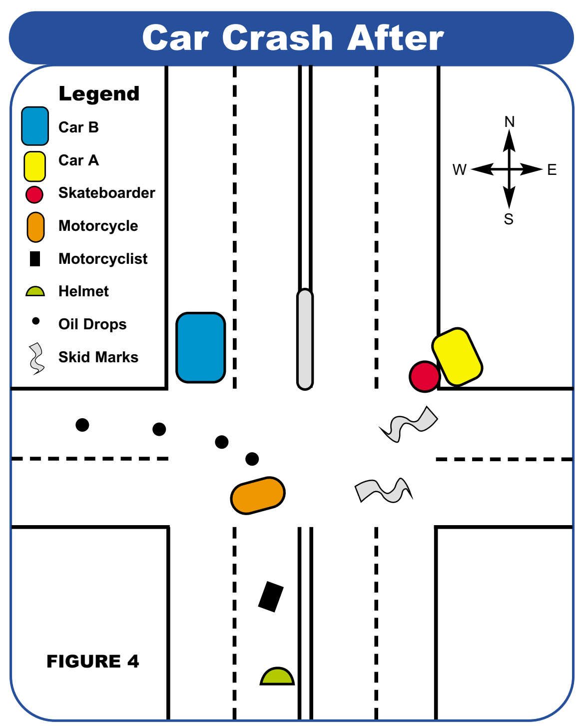


FIGURE 4

Action - Reaction Forces

Think About IT!

Think About IT!—Page 39

The sprinkler head turns because an unbalanced force is exerted on it.

Water is forced out of the nozzle of the sprinkler. The sprinkler must exert a force on the water to cause the water to move (accelerate).

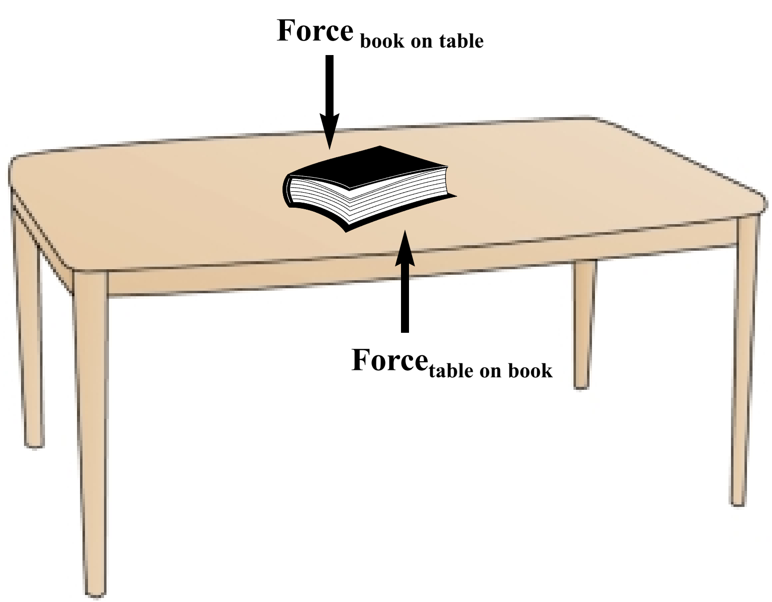
The water exerts an equal but opposite force on the sprinkler. The sprinkler accelerates due to this unbalanced force of the water acting on the sprinkler.

Note to Teacher:

- Action-reaction pairs of forces do not cancel each other out.
- Each force for two objects in contact acts on a different object.
- Therefore, they cannot cancel.

For example, a book rests on the table. The force of gravity pulls the book down, causing it to exert a force on the table. The table pushes the book upwards with the normal force, which is equal but opposite to the force of gravity on the book.

If we isolate the book and the table, we can show exactly the forces that act on each object.



Try IT!—Page 39

The scale reads 16 newtons.

The lighter student and heavier student are exerting forces to keep the spring scale motionless. Therefore, the net force on the scale is 0N.

The lighter student pulling on the scale can be thought of as the scale being attached to a rigid object like the wall. The heavier student must pull on the rope with a force of 16N to make the scale read 16N.

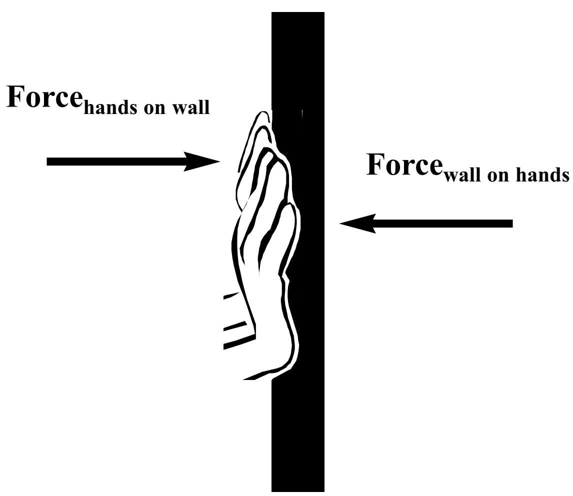
Conversely, the heavier student pulling on the scale can also be thought of as the scale being attached to a rigid object like a wall. The lighter student must pull on the rope with a force of 16N to make the scale read 16N.

Therefore, the students exert the same force. However, one student pulls to the right and the other student pulls to the left.

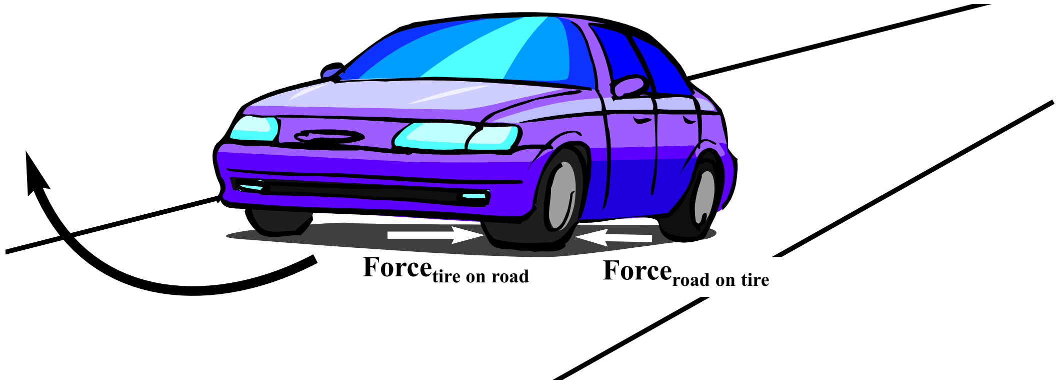
Think About IT!—Page 40

Note to Teacher: Question 3 is difficult. Break the situation down for the students into smaller interactions.

1. a. A person leans against a wall



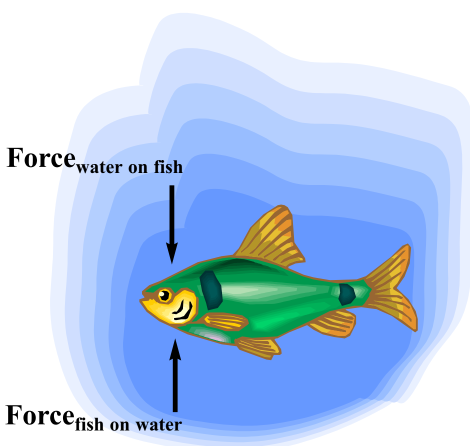
b. A car rounds a corner with constant speed.



This is a top view of the tire in contact with the surface of the road. The car is accelerated in the direction of the unbalanced force acting on the car (i.e., the force the road exerts on the tire). The car turns to the right. This type of force that causes only the direction of velocity to change is called *centripetal force*.

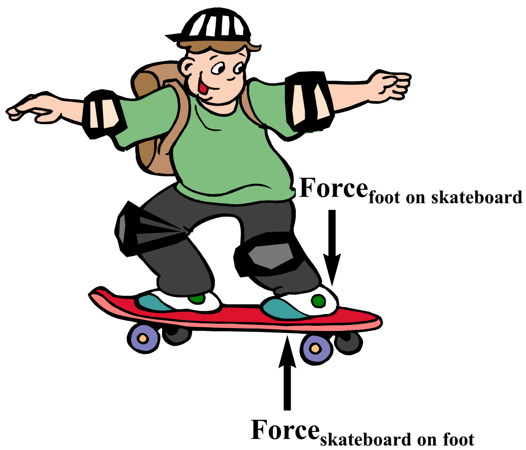
c. Fish swims

The fish pushes water one way and is propelled in the opposite direction.



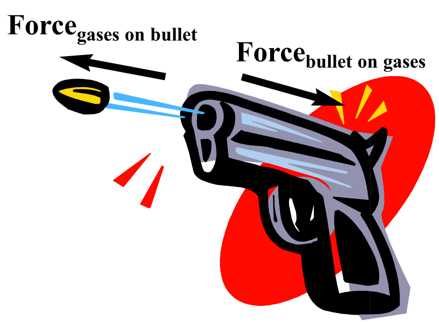
d. Skateboarder jumps

When jumping, the skateboarder pushes down on the skateboard with his foot. The skateboard pushes up on the skateboarder with an equal but opposite force.

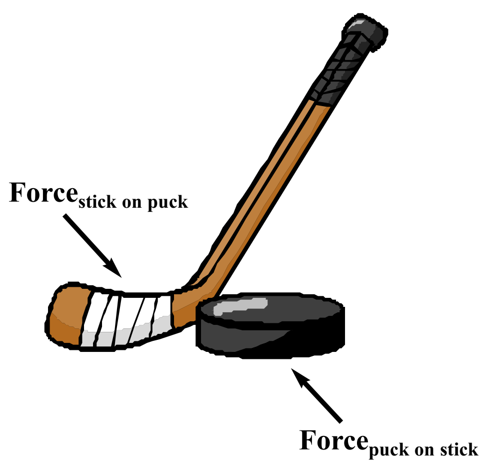


e. A gun recoils

The expanding gases inside the barrel of the gun push on the bullet, propelling it in one direction. The gases also push on the end of the barrel of the gun in the opposite direction.



f. A hockey player's slapshot



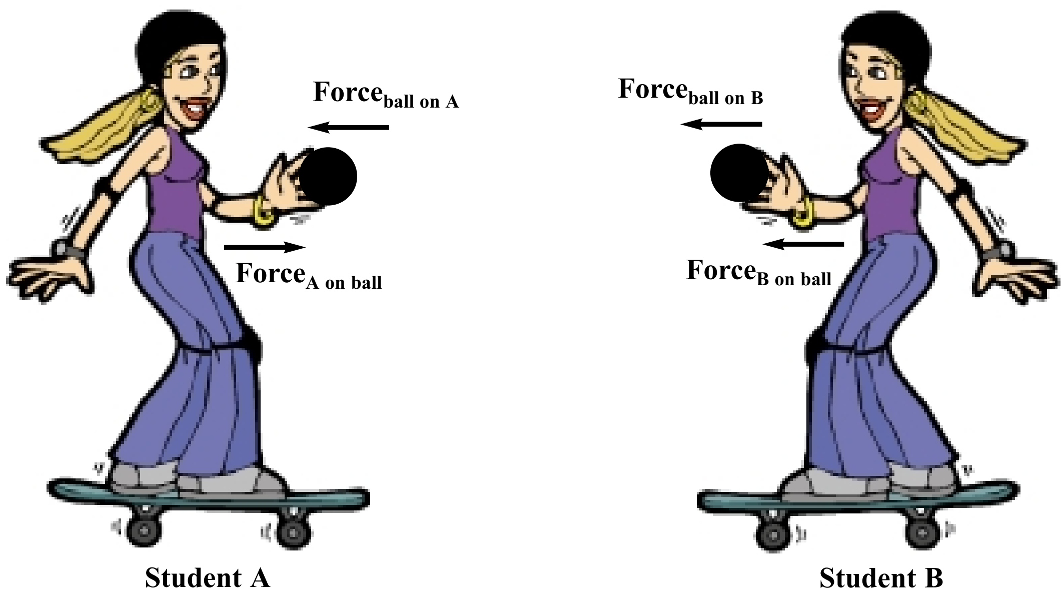
2. The two forces are equal, but opposite.

$\text{Force}_{\text{car on mosquito}} = \text{Force}_{\text{mosquito on car}}$

3. Separate this problem into parts: Student A throwing the ball; the ball flying through the air; Student B catching the ball; after Student B catches the ball.

Student A pushes the ball to the right (**action force**). This force accelerates the ball to the right. The student is pushed by the ball to the left (**action-reaction pair of forces**). This reaction force accelerates Student A to the left.

After the ball is released, the student rolls along at constant velocity to the left (no unbalanced force). The ball flies along to the right with constant velocity towards student B (no unbalanced force—Newton's First Law).



Student B catches the ball. The ball is moving to the right. The ball exerts a force on the student to the right as the student catches the ball (**action force**). This action force accelerates the student to the right. The student exerts a force to the left on the ball (**reaction force**). This causes the ball to accelerate to the left (slows down).

After the ball is caught, the ball and Student B roll along to the right at a constant velocity (no unbalanced force acting).

4. Whenever a part of your body collides with another object, like the surface of the road, your body part exerts a force on the road (**action force**).

By Newton's Third Law, the road must exert an equal but opposite force on your body part. This is the force that can damage you.

The protective equipment provides a cushion for these action-reaction forces so that the forces are decreased.

The smaller forces reduce the damage done to you.

Chapter 5

Momentum and Energy

Momentum

Think About IT!

Think About IT!—Page 42

Order is small momentum to large momentum.

Table A

Object	Amount of Momentum (describe in your own words)	Comments
Statue	It has mass, but no velocity, momentum is 0.	
Building	It has mass, but no velocity, momentum is 0.	This has a larger mass than a statue, but momentum is still 0.
Football	It has a larger velocity, but little mass.	
Slapshot	The puck has mass and a larger velocity than the football.	The puck is moving faster than the football.
Marathon runner	It has both mass and velocity.	The velocity is smallest of sprinter, runner, and skateboarder.
Skateboarder	It has about the same mass as runner, but has a larger velocity.	
Sprinter	It has same mass as runner and skateboarder, but travels with a larger velocity.	
Transit bus	It has a large mass and small velocity.	
NASCAR stock car	It has a smaller mass than the bus, but a much larger velocity.	The car is moving much faster than the bus. This makes up for the smaller mass of the car.

Math Connection

The velocities used are realistic velocities.

Table B

Object	Mass (kg)	Velocity (km/h)	Momentum (kg-km/h)	Comments
Transit bus	8 000	50	400 000	
Football (thrown)	0.5	35	17.5	
Sprinter	75	35	2700	
Golden Boy statue	1 650	0	0	
NASCAR stock car	1 545	300	463 500	
Marathon runner	65	12	780	
Slapshot	0.15	150	22.5	
Building	1 000 000	0	0	
Skateboarder	68	20	1360	

The ranking of the smallest to largest momentum is:

- Statue
- Building
- Football
- Puck (slapshot)
- Marathon runner
- Skateboarder
- Sprinter
- Transit bus
- NASCAR stock car

Impulse and Momentum

Note to Teacher:

Impulse and momentum can be related through Newton's Second Law.

In symbolic form, the equation for Newton's Second Law is: $\vec{F}_{net} = m\vec{a}$

Where:

$\vec{F}$ is the unbalanced force.

m is the mass of the object.

$\vec{a}$ is the acceleration of the object.

Acceleration is found using the equation:

$$\vec{a}_{avg} = \frac{D\vec{v}}{Dt}$$

If we substitute for $\vec{a}$ in Newton's Second Law, it becomes:

$$\vec{F} = m \cdot \frac{D\vec{v}}{Dt}$$

Cross-multiply with Dt and:

$$\vec{F}Dt = mD\vec{v}$$

The $\vec{F}$ Dt part is called *impulse*. It can be thought of as the **cause** of motion changes.

Impulse $= \vec{F}Dt$ Units: N $*$ s

The m is **change in momentum** not just momentum.

This is the **effect** or change in motion caused by applying an impulse to the object. If an impulse is applied, an object undergoes a change in velocity and, hence, a change in momentum.

Change in momentum = m $D\vec{v}$ (has units of kg-m/s)

Both quantities are **vectors**.

DEMONSTRATION:

A piece of paper is placed under a beaker at the edge of a table. The paper is quickly pulled out from under the beaker. The beaker does not move. Here, the force of friction between the beaker and the paper acts for a short time. The impulse applied and, hence, the change in momentum of the beaker, are small.

If the paper is pulled gently along the table, the beaker will move with the paper, acquiring a large velocity. Here, the same force of friction acts, but over a long time, allowing the beaker to acquire a large velocity.

Think About IT!—Page 44

1. a. large force—short time

- hitting a baseball with a bat, hitting a golf ball
- two cars crashing together

b. small force for a long time

- coasting to a stop while riding a bicycle
- a sliding curling rock coming to a stop

c. large force for a long time

- a train speeding up or slowing down
- a large boat or ship speeding up or slowing down

d. small force over a short time

- moving a pen or pencil while writing

2. a. Driving the golf ball

The large impulse can be obtained by swinging harder to increase the force, or using proper technique to increase the time of contact (i.e., follow-through). Both provide a large momentum to the ball.

Putting the golf ball

The small impulse can be obtained by exerting a small force with the putter on the ball. This decreases the momentum change the ball undergoes. Again, following through is important to maintain the correct direction.

b. Gymnast and reverse somersault

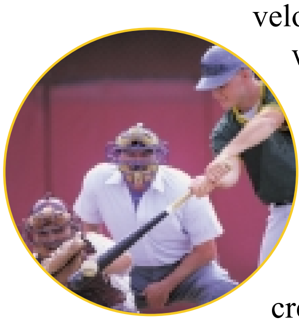
Before the dismount, the gymnast swings around the bar. As she falls, the force of gravity applies an impulse to her, increasing her speed and momentum, especially in the legs. The gymnast rises upwards on the other side. Once her hands release from the bar, the momentum is in the gymnast's body as she flies through the air.

c. Volleyball players "set up" a spike shot

The setter must apply a force to the ball for a given length of time. If the setter can lengthen the time of contact with the ball, the force that must be applied to the ball can be reduced. This also allows for more control. The ball will have a momentum that will carry it in the correct direction and to the correct spot to be spiked. Good setters have "soft" hands. They can cushion the ball while it is in their hands and guide it with the right force in the right direction.

d. Baseball players hitting a grand slam

The player must swing the bat with a large force. This accelerates the bat to a high velocity. This requires strength on the batter's part. Baseball players are seen warming up with weights on the bat. This strengthens the muscles needed to exert a large force on the bat and makes the bat feel very light once the rings are removed.



During the swing, the batter follows through, which lengthens the time of contact between the bat and the ball.

Both the large force and longer contact time increase the impulse applied and create a larger change in momentum. The ball is propelled with a larger velocity and travels farther, right out of the park.

e. Car brakes for a yellow light

The car must slow down and stop, decreasing its momentum to zero.

The braking force acting on the wheels can be small if the time to stop is large. This is the preferred method of stopping.

If the braking time must be small, then large braking forces are needed. The stop will be very abrupt and passengers and objects in the car will continue to move forward.

Drivers should "drive ahead." As they approach an intersection, check the "Walk/Don't walk" pedestrian signs. If the "Don't walk" sign has been on for a long time, the green light is "stale" and the driver should be prepared to stop.

f. A catcher catches a fastball

The ball must undergo a change in momentum to bring it to zero. The catcher would attempt to catch the ball in the webbing of the catcher's mitt.

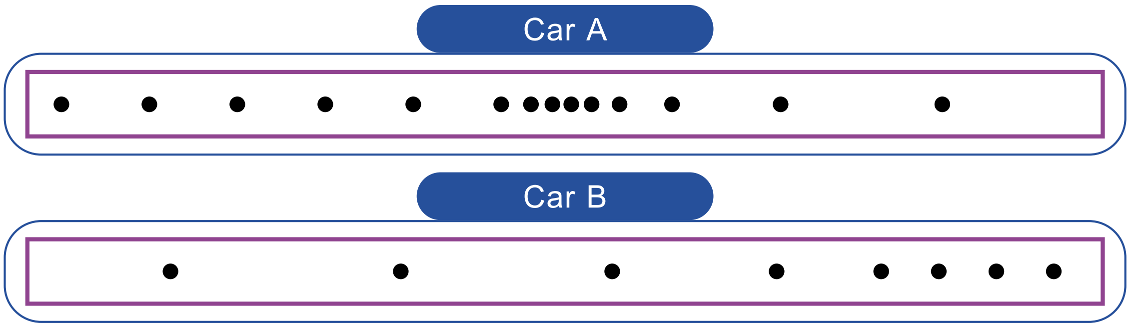
If the ball is caught flush on the palm of the hand, the ball stops in a very short time. To achieve the necessary change in momentum, a large force to stop the ball is required. The reaction force of the ball on the hand can damage the catcher's hand.

If the ball is caught in the webbing, the length of time to stop the ball is increased, in turn decreasing the stopping force on the ball. Damage to the catcher's hand is avoided.

The catcher can also lengthen the time of the catch by allowing her glove to move in the direction of motion of the ball as the catch is being made. This also decreases the stopping force and reduces the chances of injury to the catcher's hand.

3. **a.** Car A experiences an impulse after six dots.

   Car B experiences an impulse after one dot.



   b. Car A slowed to 1/3 of its original velocity.

   The change in momentum is a loss of 2/3 of the original velocity.

   Car B slowed to ¼ of its original velocity.

   The change in momentum is a loss of ¾ of the original velocity.

   Car B experiences the larger momentum change.

   c. Since Car B experienced the larger momentum change, it experienced the greater impulse.

   d. Car A experiences two impulses: one between six dots to seven dots; and after 10 dots, between 10 and 14 dots.

4. Mass halfback = 60 kg

   Velocity of halfback = +3.2 m/s

   Momentum of halfback = $m\vec{v}$ = 60 kg * 3.2 m/s = +192 kg-m/s

   Mass of lineman = 120 kg

   Velocity of lineman = –1.8 m/s

   Momentum of lineman = $m\vec{v}$ = –216 kg-m/s

   Since the lineman has the larger momentum, he will push the halfback backwards.

5. If the boulder and the boy have the same momentum, and we assume the boulder has a larger mass, the boy is currently running faster than the boulder is rolling down the hill.

   We can assume the boy cannot run any faster. However, the force of gravity will apply an impulse to the boulder. As time goes on, the boulder will gain momentum and roll more quickly. The boulder will roll faster than the boy can run and catch up to him.

   Eventually, the boy could be crushed.

   or

   The boy could simply step to the side, out of the boulder's path.

6. The person can throw the gold brick in one direction (e.g., east). This action force causes a reaction force of the brick on the fool pointing west.

   So the fool applies an impulse to the brick in the easterly direction and the brick applies an impulse on the fool in the westerly direction.

   The impulse applied to the fool appears as a change in momentum of the fool. The fool slides across the ice to the shore with constant velocity, as there are no unbalanced forces acting on him.

   He is not a fool. What good is gold when you are dead?

7. A spacecraft has a rocket, which is basically a chamber where fuel and oxygen are mixed and burn, producing heat and waste gases. The waste gases are forced out of a small opening at one end of the chamber. This rocket is at the side of the spacecraft.

   The chamber walls exert a force (action force) on the gases, pushing them out the opening. The force of the chamber walls on the gases over a time interval gives an impulse to the gases.

   By Newton's Third Law, the gases exert a reaction force on the chamber walls for the same length of time. This applies an impulse to the chamber walls, which are attached to the rocket. The rocket experiences a change in momentum. In this case, the resulting velocity change is due to the change in the direction of the velocity.

Challenge

Students may suggest cushioning devices, such as pillows, padded chairs/sofas, bubble wrap.

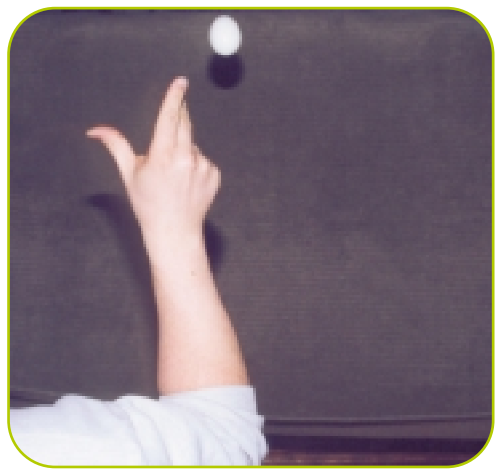
Try IT!

Try IT!—Page 45

Be sure to try this activity. Students will be very impressed.

The principle behind it is to have the egg undergo its change in momentum over a long period of time. This reduces the stopping force required.

This is a natural lead-in to start discussing how passengers in vehicles can be protected when they must suddenly come to a stop (i.e., undergo a large momentum change).



Cushioning Devices

Think About IT!—Page 46

Fifty years ago, cars were built with very strong, rigid bumpers. In car crashes, the rigid bumpers would stop the car quickly, as they would not collapse. This caused passengers in the vehicle to be stopped with a large stopping force, causing injuries to the passengers.

Over the years, cars were redesigned to have shock-absorbing bumpers. In collisions at low speeds, the shock absorbers would collapse, lengthening the stopping time and distance, and reducing the damage to vehicles and the injuries to passengers.

Think About IT!—Page 49

1. **Research Projects—Safety Devices**
2. **Design a car using modern safety features**

The car should include a system to fasten the passengers in the car to prevent second collisions. This should include a shoulder harness/lap belt seat system. This keeps the passenger in place, including preventing the upper body from striking the steering wheel or dashboard. This also prevents a passenger from being thrown from the car and being injured by a second collision with the ground or some other object.

Objects inside the car, like the dashboard, should be padded so that body parts striking the padded surface will stop over a longer time and distance, reducing the stopping force. Objects like door handles should be recessed into the door. Knobs on the dashboard should be recessed and as flat as possible with a large radius so that the force of impact is spread out over a large area should a body part collide with the knob.

The car should include proper support of the back and head in case of a rear-end collision. The headrest should be high enough to be positioned properly behind the head.

The car should have crumple zones in the front and the rear of the car. In a collision, the crumple zones allow the car to stop over a longer period of time and a longer distance, decreasing the stopping force.

The car should have an impact-absorbing bumper. The bumper could be plastic, in which case it crumples during a collision. The bumper could also be attached to a shock absorber, which compresses and absorbs some of the energy of a collision.

The passenger compartment of the car should be strong enough not to flatten during a rollover. The cage of the car should remain intact, preventing the passengers from being crushed.

The passenger car should have air bags in the steering wheel and dashboard to cushion passengers as they continue to move forward when a car is stopped in a head-on collision. The air bags should be designed so that they do not injure the passengers. Injuries can result from the rapidly expanding air bag striking a passenger. The air bags should be designed to accommodate passengers of all sizes. Cars can also have side air bags built into the doors to cushion the passenger during side collisions.

Since children are often the passengers in a car, provisions for a child safety seat should be built into the seating in the car.

Windows should be laminated. This will prevent the glass from breaking up into shards that could then act as knives to cut the passengers. Laminating the glass (i.e., putting two layers of glass held together by a layer of adhesive) allows the glass to break into tiny pieces that are held in place by the adhesive. The windshield must be strong enough to prevent the passenger's head from poking through the windshield. If this happens, the hole in the glass closes and, as the passenger's momentum is reversed, the passenger could be decapitated.

3. Investigate NASCAR Regulations Online

Seat Belts:

<http://www.evergreenspeedway.com/03brules.htm>

<http://www.speedbowl.com/speedpages/2002GeneralRules.html>

<http://www.phy6.org/stargaze/Sfall.htm>

Roll Bar:

<http://www.google.ca/search?q=cache:r6H7FGQPDp4C:www.iceracingthunderbay.com/images/Rules_Regulations.pdf+NASCAR+safety+regulations+rollover+cages&hl=en&ie=UTF-8>

<http://cc4w.org/favorite.htm>

<http://www.evergreenspeedway.com/03brules.htm>

<http://www.stockton99speedway.com/Division%20rules/WLM2003Rules.html>

Head Restraints—HANS (Head and Neck Support):

<http://auto.howstuffworks.com/nascar-safety4.htm>

<http://drive.fairfax.com.au/content/20000412/motorsport/motor3.html>

<http://www.usatoday.com/sports/motor/nascar/2002-12-12-hans-side_x.htm>

Head Restraints—Hutchens Device:

<http://www.stockcarproducts.com/safety9.htm>

<http://www.mascosafety.com/hutchens.html>

Crumple Zones:

<http://www.tennessean.com/sii/00/07/08/safety08.shtml>
A good general information source on NASCAR safety.

<http://www.autoracing1.com/MarkC/2001/0226CrumpleZones.htm>
One Stop Site: This site provides links to a variety of physics sites dealing with "Moving About."

<http://www.phy.ntnu.edu.tw/java/carDistance/carAccident.html>

4. Crumple Zone

The packaging of objects, such as TVs, computer monitors, et cetera, includes rigid foam to keep the object in place in the centre of a box. There is a space between the object and the box so that the box can crumple to absorb some of the energy in a collision without damaging the contents.

Padded Cushions:

Padded cushions spread out the force of contact between objects, lessening the force acting on one unit area. A smaller force results in less damage being done to the part of the body in that unit area. For example, padding in chairs, couches, and seats of all kinds function in this way. These are static situations where there is no motion.

For objects in motion, the same principle applies. Examples would be found in amusement-park rides. Here, the parts of the ride with which the riders come in contact, often violent contact, are padded. In the home, small children are constantly falling. Bumpers placed on corners and sharp edges can greatly reduce the injuries suffered by children. In industry, padded cushions are used where objects contact each other at low speed. For example, if a trailer is being backed into a loading dock, the padded cushion lengthens the stopping distance and prevents damage to the trailer and the dock.

Air Bags:

Hollywood stunt performers use large air bags to cushion their falls from a great height.

Air bags are used in packaging as bubble wrap.

Roll Bars:

Farm tractors use roll bars above the driver. Tractors tend to flip over backwards (i.e., the front end lifts up and swings up over the driver). The roll bar protects the driver from being crushed.

Tractors that are used on hillsides also use roll bars, as they may topple over on their sides.

Recreational vehicles, which are used in all sorts of uneven terrain, have roll bars to protect the driver.

Bumpers:

Bumpers are used on industrial equipment, such as moving platforms, conveyers, et cetera. The bumpers prevent damage to other equipment and to humans in case of collisions.

5. a. **Dr. Claire Straith**

He was a plastic surgeon. In the 1930s, he met many patients who were disfigured from car accidents. The disfigurements were caused by the second collision of the patient's face with the dashboard or the knobs on the dashboard in the car. Dr. Straith campaigned for the automobile makers to install padded dashboards and to redesign the knobs on the dashboard. Today, all cars have padded dashboards, and the knobs on the dashboard are recessed.

b. **Bela Berenyi**

He was an engineer at Mercedes during the 1950s. Until 1959, cars were built to be very strong. They could crash together without crumpling very much. The force of the collision was transmitted through the rigid car body to the passengers. The energy from the crash was dissipated as work was done on the passengers during second collisions, and this resulted in injuries.

Bela Berenyi designed a car body that would dissipate the force exerted on the passengers. The design includes two crumple zones: one at the front of the car and the other at the rear of the car, with a rigid passenger compartment. The crumple zones were designed to distort in a predictable way. The energy of the crash would go into the work done to crumple the crumple zones. During frontal collisions, the structure supporting the engine would slide under the passenger compartment rather than into it. Later, side-impact beams were placed in the side door to help absorb the force of a side collision. This completed the crumple zones on all sides of the car.

c. **Nils Bohlin**

He was an engineer who worked for Volvo. The first seat belts came out in 1949. These were two-point belts that were strapped across the hips. The hips were held in place by the belt during a crash, but the upper torso was not restrained. Drivers especially suffered injuries as the upper torso collided with the steering wheel. Passengers' upper torsos collided with the dashboard and windshield. Spinal injuries occurred as well.

The engineers at Volvo produced a two-point belt that went across the chest. However, in crashes, the hips, where the centre of gravity was found, would fly forward. The rest of the body would follow and the chin would be caught by the chest strap. This resulted in head and neck injuries and, sometimes, decapitation.

Nils Bohlin developed the three-point lap belt/shoulder harness style seat belt. This kept the hips in place and prevented the upper torso from striking the steering wheel, dashboard, or windshield. If properly adjusted, it also prevented the body from sliding under the belt.

d. John Hetrick

In 1952, John Hetrick was granted the patent for the mechanism that has evolved into the modern-day air bag. He noticed that compressed air could very quickly fill up a canvas bag. This is the basic design of an air bag. An air bag has a sensor that sends an electrical signal to an inflator mechanism when the air bag is needed. The inflator mechanism quickly inflates the air bag. The air bag cushions the passenger as he is stopped, spreading out the stopping force and lengthening the stopping time and distance. Once the passenger is stopped, the air bag deflates. This all occurs within about 0.5 seconds.

The advantage of the air bag is that it is user-independent. It works automatically when needed, unlike seat belts which must be done up by the driver and passengers. Around 1970, the National Highway Traffic Safety Administration (NHTSA) in the U.S. found that only 15 percent of people used seat belts. They put pressure on the automobile makers to develop the technology of the air bag. By 1980, Mercedes offered them. By 1988, the NHTSA forced all manufacturers to install them in their new models.

Problems arose where passengers were injured or killed from the force of the air bag as it was inflated. Children and small women who were improperly restrained also suffered injury and death. Late-model cars have two sensors. In low-speed collisions, one sensor fires and the air bag is inflated less and to a smaller size. This lessens the injuries to passengers. In high-speed collisions, both sensors fire and the air bag operates at full inflation and full size.

e. Ralph Nader

Ralph Nader is an American consumer activist fighting for the rights of the consumer against those corporations that build things as cheaply as possible so as to maximize profit.

In 1965, Nader wrote a book called *Unsafe at Any Speed: The Designed-in Dangers of the American Automobile* (Grossman). The book maintained that cars were built for style, cost, and performance, but not for passenger safety. He claimed that the Detroit automobile makers did not place a high priority on safety design in the cars they built. Senate hearings were held in the United States and the resulting publicity made the book a best-seller.

The upshot of all this was that the government of the United States formed the National Highway Traffic Safety Administration. This agency tells the automobile makers what to build into their cars to enhance passenger safety.

Protecting Occupants

Think About IT!—Page 50

1. The package should have a crumple zone to lengthen stopping distance and time.

   If the package does collapse, it must not do so to such an extent that the egg is damaged.

2. The egg can move inside the package. This will lengthen the stopping distance and stopping time, reducing the force.

   The egg should not be allowed to move so freely within the package that it will contact the outer package.

3. Cushioning materials like polystyrene, cotton batting, plastic bubble wraps, and packing chips can be used to absorb the shock.

   Some students have used straws inside the compartment. Others have used straws on the outside of the compartment.

4. Student responses will vary.

Momentum and Energy in a Collision

Note to Teacher: In Newton's Cradle, the total momentum is conserved. If sphere 1 receives some momentum, this momentum is transferred to sphere 6 during the collision. Sphere 1 loses its momentum but sphere 6 gains an equal amount of momentum.

The total momentum in the system is conserved.

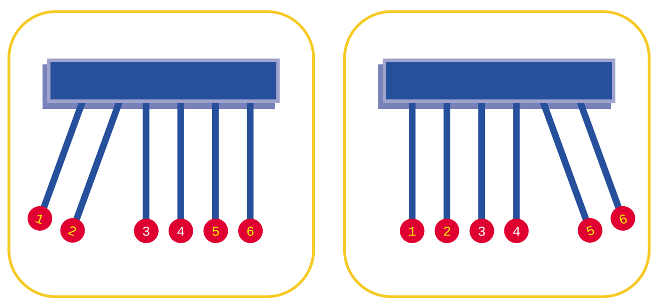
Check with the physics teacher in your school for one of these devices.

Again, Walter Fendt has an applet, appropriately named Newton's Cradle, which will demonstrate how this device works.

<http://www.walter-fendt.de/ph14e/ncradle.htm>

Think About IT!—Page 51

1. Pulling one sphere (sphere 1) and releasing it causes one sphere (sphere 6) to move away from the other end.
2. Pulling two spheres (spheres 1 and 2) away and releasing them causes two spheres (spheres 5 and 6) to move away from the other end.
3. Pulling three spheres (spheres 1, 2, and 3) away and releasing them causes three spheres (4, 5, and 6) to move away from the other end.
4. Pulling one sphere away from each end (spheres 1 and 6) and releasing them at the same time results in these two spheres striking the motionless spheres and rebounding with the same speed but in the opposite direction. The momentum of each sphere is reversed but the total momentum remains the same.



Think About IT!—Page 53

1. If energy were not conserved but destroyed, the world would run out of energy.

   Example: We eat food to supply chemical energy that our body uses to produce energy to keep us warm and to do work such as move other things and ourselves. If this energy was destroyed during conversion, the energy in the food could not be used to keep us warm or to move things.

If energy could be created, the world would be accumulating energy.

Example: A car could work with no fuel. The energy of motion would suddenly appear with no fuel as an energy source and no engine.

2. The kinetic energy that appears where a car accelerates originates in the chemical potential energy stored in the fuel (gasoline) and oxygen, which react during combustion. The combustion reaction releases this energy as heat. The gas molecules move more quickly and push down on the piston, creating kinetic energy. The piston turns the crankshaft in the engine to the transmission, which turns the wheels. The turning wheels exert a force on the road, pushing the car forward. The kinetic energy is transferred along from the piston to the crankshaft to the transmission to the wheels to the car as a whole.

PRACTICE—PAGE 53

1. **Roller Coaster**

   At the top of the ride, the roller coaster has a great deal of potential energy. As the roller coaster falls, it loses potential energy but picks up kinetic energy.

   At the bottom of the ride, the roller coaster has little potential energy but a great deal of kinetic energy.

2. **Bungee Jumper**

   At the top the jump there is a lot of potential energy due to gravity and no kinetic energy. As the jumper falls, she loses gravitational potential energy and gains kinetic energy.

   When the bungee cord starts to stretch, some gravitational potential energy and kinetic energy are converted into elastic potential energy, stored in the cord.

   At the bottom, all the original gravitational potential energy is converted into elastic potential energy. There is no kinetic energy.

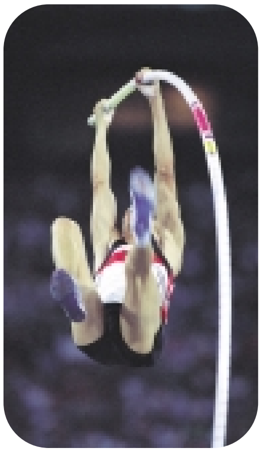
3. **Car Crash**

   As the car accelerates, chemical potential energy is converted into (heat) kinetic energy in the particles of the combustion products of gasoline and oxygen. The kinetic energy is transferred into kinetic energy of the pistons in the engine, which turn the crankshaft, giving it kinetic energy. The transmission transfers this kinetic energy to the wheels. The wheels push the car forward.

   While traveling at a constant speed, the chemical potential energy from the fuel is used to overcome friction. This energy is lost to heat and sound.

   When the car brakes, the kinetic energy is converted into other forms. Heat is produced by the brake shoes rubbing against the rotors. The tires skid on the road, producing heat. Sound is also produced.

   When the car hits the side panel of the truck, more kinetic energy is lost by the car. Some of this kinetic energy is converted into sound. Most of the kinetic energy is lost as the metal bodies of the car and truck are bent out of shape. The metal heats up.



4. Pole Vaulter

A pole vaulter runs. He has kinetic energy.

When the vaulter plants the pole, the pole bends. The kinetic energy of the vaulter is converted into potential energy in the bent pole.

The pole straightens, lifting the vaulter. The pole loses elastic potential energy. The vaulter gains gravitational potential energy.

At the top, the vaulter has gravitational potential energy and a little kinetic energy.

As the vaulter falls, he loses gravitational potential energy and gains kinetic energy.

5. Pogo Stick

At the top of the jump, the child has little kinetic energy. There is no elastic potential energy in the pogo stick. The child has gravitational potential energy.

As the child falls, she gains some kinetic energy, and she loses gravitational potential energy. This energy is used to do work to compress the spring, becoming potential energy as well, coming to a stop at the bottom of the jump.

The spring loses its potential energy as it expands, doing work to raise the child, giving her gravitational potential energy, and to move the child upwards, giving her kinetic energy.

As the child continues to rise, lifting the pogo stick off the ground, the kinetic energy is converted into gravitational potential energy. The child arrives at the top with no kinetic energy.

6. Cars with Spring-Loaded Bumpers

As the cars collide, their kinetic energy is used to do work to compress the springs. The kinetic energy becomes elastic potential energy.

When the cars approach as close as possible, they stop. The original kinetic energy is now all stored in the springs as elastic potential energy.

As the springs expand, the elastic potential energy is converted back into kinetic energy in the cars.

When the cars no longer have the bumpers in contact, the kinetic energy of the cars should be equal to their starting kinetic energy.

The occupants of the cars, if they are fastened to the car, will experience the same transformations as the car.

Chapter 6

Braking

Investigation #6 BRAKING DISTANCE

Table A—Braking Distance

This trial was done using tracks made of old fenceboards, which were propped up by books. The pile of books was 27-cm high and was placed at 1.00 m from the end of the track that touched the floor. The angle of the track was about 15°.

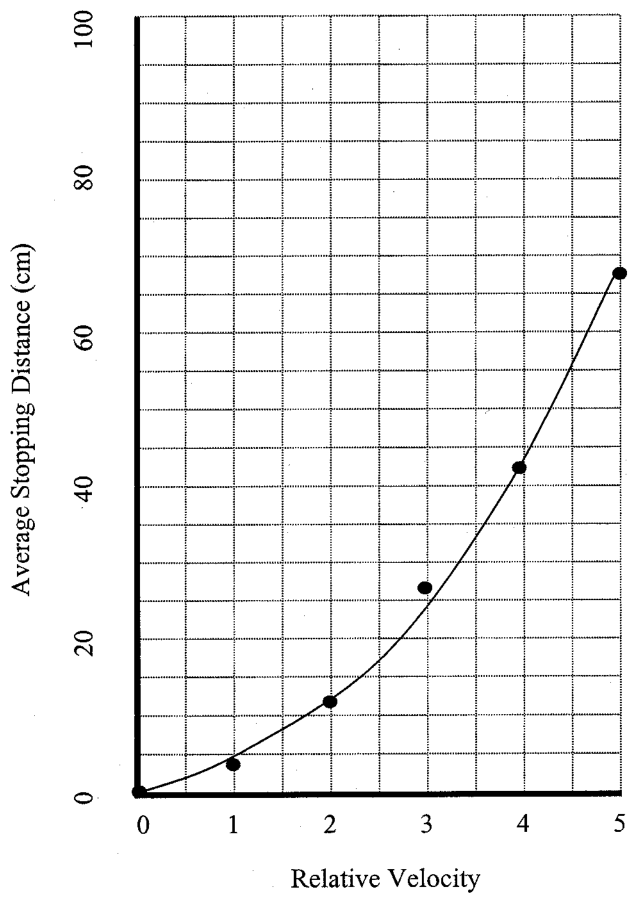
This trial was done with the slider sliding on the surface of a table.

Note: Be sure to position the car so that the middle of the car, the centre of mass, is at the calibrated release point. If the front of the car is used, the first sliding distance will be too large, making the ratios all too small.

Differences between group results can be attributed to the use of different cars.

Table A • Braking Distance

Relative Velocity	Group (cm)						Average Braking Distance (cm)
	#1	#2	#3	#4	#5	#6	
1	3.3	2.4	5.3	2.5	1.5	2.9	2.8
2	13.8	10.9	13.1	9.0	9.2	13.5	11.6
3	29.7	28.3	28.8	20.8	22.9	22.7	25.5
4	50.9	43.7	47.8	30.2	36.9	45.6	42.5
5	81.2	71.9	79.8	51.0	56.7	63.5	67.3



Think About IT!

Think About IT!—Page 55

1. The shape of the graph is a curve, curving upwards to the right.

   The braking distance increases more than the velocity.

   If the velocity doubles, the braking distance is 4X.

   This is an **exponential relation**.

2. In terms of driving, one must realize that the braking distance increases more rapidly than velocity.

   Larger velocities require much larger stopping distances.

Challenge—The effects of friction on braking

Students can adjust the surface on which the slider will be sliding.

To simulate gravel, a thin layer of sand, one grain thick, can be used on the table or floor. The following results were obtained.

Again, the different cars had an effect on the stopping distance.

The effect of stopping on the sand was to increase slightly the stopping distance, as a comparison of the average stopping distances from Tables A and B illustrates.

The results below in table B are for Group #1 from Table A.

Table B • Braking on Sand

Relative Velocity	Trial #1 (cm)	Trial #2 (cm)	Trial #3 (cm)	Average Braking Distance (cm)
1	2.5	3.5	3.5	3.2
2	16.5	16.0	15.0	15.5
3	33.0	36.0	34.0	34.3
4	48.0	58.0	53.0	53.0
5	78.0	89.0	80.0	82.3

Think About IT!

Think About IT!—Page 55

1. The effect of snow, rain, and ice is to lengthen braking distance.

These reduce the force of friction between the tires and the road.

With friction supplying the stopping power, and with friction decreased, it will take a longer distance to stop the car.

Math Connection

The ratio is calculated by dividing each stopping distance by the first stopping distance.

Ratio = (Stopping distance) / (First stopping distance)

Table C

Ideal Ratio	Ratio: Table	Ratio: Table with Sand
1	2.8 / 2.8 = 1	3.2 / 3.2 = 1
2	11.6 / 2.8 = 4.1	15.5 / 3.2 = 4.8
3	25.5 / 2.8 = 9.1	34.3 / 3.2 = 11
4	42.5 / 2.8 = 15	53.0 / 3.2 = 17
5	67.3 / 2.8 = 24	82.3 / 3.2 = 26

Again, the result for the average stopping distance for the relative velocity of 1 is the critical measurement. If this value is inordinately small or inordinately large, the values of the ratios are skewed.

PRACTICE—PAGE 56

Note to Teacher: Calculation on page 56 should be d = 0.06 x $(13.92 \text{ m/s})^2$.

1. The value of K changes with the surface. It will make the effect of friction on stopping distance evident to the student if stopping distances are computed for all surfaces. (Three significant digits were used in these calculations.)

Table D • Braking Distance (m)

Velocity		Dry Pavement	Wet Concrete	Snow and Ice
km/h	m/s	$d = (.06)v^2$	$d = (.10)v^2$	$d = (.15)v^2$
10	2.78	0.46	0.77	1.15
20	5.56	1.85	3.09	4.63
30	8.33	4.16	6.93	10.4
60	16.7	16.7	27.8	41.7
90	25.0	37.5	62.5	93.8

2. In all cases the braking distance at 60 km/h is 4 times the braking distance at 30 km/h.

Total Stopping Distance

Note To Teacher: To avoid some confusion, convert km/h to m/s first before using the velocity relationship.

It is important to point out to students that units must be the same on each side of the equation.

d = v t

m = ? s

v must have units of m/s in this case.

PRACTICE—PAGE 57

1. Car traveling at 60 km/h on a rain-soaked road. Reaction time is 1.5 s.

Reaction Distance:

t = 1.5 s ; v = 60 km/h ÷ 3.6 = 16.67 m/s = 17 m/s (rounded to 2 significant digits)

d = ?

d = v t

= 17 m/s x 1.5 s = 25 m

Braking Distance:

k = 0.10 for wet concrete.

$d = kv^2$

$= (0.10)(17)^2$

= 29 m

Total stopping distance = Reaction distance + Braking distance

= 25 m + 29 m = 54 m.

Reaction Time

Try IT!

Try IT!—Page 58 and 60

Note to Teacher: Two classes performed this activity to determine their reaction times. The first group did the trials in the order given: no distractions, with impaired visibility, and distracted by talking. The reaction times were basically the same for each case. This can be attributed to the amount of practice the students had before performing each trial.

In the results given below, the students were asked to perform the trials in the reverse order of that given in the *In Motion* booklet. Here, the reaction times for "no distractions" are noticeably better than the times for "with distractions".

Sample Data:

Table E

Student	Average Distance Metrestick Falls (m) **No Distractions**	Reaction Time (s)	Average Distance Metrestick Falls (m) **Distraction—Impaired Visibility**	Reaction Time (s)	Average Distance Metrestick Falls (m) **Distraction—Talking**	Reaction Time (s)
1	0.18	0.19	0.29	0.24	0.51	0.32
2	0.16	0.18	0.39	0.28	0.45	0.30
3	0.06	0.11	0.13	0.16	0.16	0.18
4	0.08	0.13	0.18	0.19	0.29	0.24
5	0.14	0.17	0.24	0.22	0.24	0.22
6	0.10	0.014	0.18	0.19	0.36	0.27
7	0.16	0.018	0.36	0.27	0.34	0.26
8	0.14	0.17	0.20	0.20	0.39	0.28
9	0.51	0.032	0.68	0.37	0.48	0.31
10	0.26	0.023	0.20	0.20	0.45	0.30
11	0.11	0.15	0.24	0.22	0.24	0.22
12	0.13	0.16	0.31	0.25	0.18	0.19
13	0.18	0.19	0.11	0.15	0.65	0.36
14	0.11	0.15	0.11	0.15	0.22	0.21
15	0.13	0.16	0.42	0.29	0.22	0.21
16	0.47	0.47	0.61	0.35	>1.00	>0.45
17	0.13	0.16	0.16	0.18	0.14	0.17
18	0.11	0.15	0.16	0.18	0.14	0.17

Think About IT!—Page 60

1. If a car that is being tail-gated stops suddenly, the tail-gating car crashes into the car. The reason is the reaction distance. The tail-gater's car and the other car should have the same braking distance.

The problem is the distance the tail-gating car travels while the driver is reacting. That extra distance the tail-gating car travels is enough to cover the distance between the two cars. Hence, the two cars crash.

Note to Teacher: Students can test their reaction time and find the reaction distance, braking distance, and total stopping distance using a Java applet found at:

<http://www.phy.ntnu.edu.tw/java/Reaction/reactionTime.html>

This is an excellent activity that clearly demonstrates the factors that affect the total stopping distance of a vehicle. Students can change the speed of the vehicle to demonstrate the effect of increasing or decreasing speed on the total stopping distance.

<http://www.javacommerce.com/cooljava/games-normal/reactiontime.html>

This site allows students to test their reaction time.

PRACTICE—PAGE 60

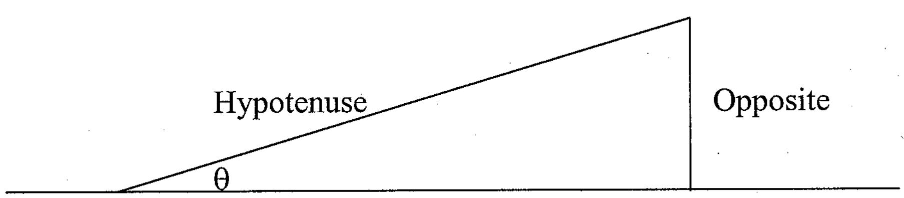
1. For the ideal case with no distractions, the reaction time of a typical student measured by catching a falling ruler is about 0.2 s. Using the applets above, a typical reaction time is about 0.4 s for depressing a mouse button.

The acceleration of the Mini-V down the ramp can be found with the following method. The acceleration of the Mini-V is given by the relationship

a = sin q (980 cm/s/s),

where q = the angle the ramp makes with the horizontal.

Sin q is the ratio of the vertical height to a point on the ramp, divided by the distance that point is up the ramp from the end that touches the table (opposite/hypotenuse).



The formula $v^2 = 2aDd$ can then be used to find the final velocity with which the Mini-V rolls off the ramp.

In this case, v = final velocity and Dd = the distance from the bottom of the ramp to the release point of the car.

Remember, the midpoint of the car should be positioned at each release point.

The trials used a vertical rise of 27 cm for a hypotenuse of 100 cm.

Thus, sin q = 27/100 = 0.27 and the acceleration if the Mini-V was
a = sin q (980 cm/s/s), a = 0.27 (980 cm/s/s) = 265 cm/s/s

The relative velocity for release point 1 (5.0 cm) can be calculated.

a = 265 cm/s/s and Dd = 5.0 cm
v^2 = 2aDd = 2 (265 cm/s/s) (5.0 cm) = 2650
v = 51.5 cm/s

The other velocities are just multiples of 51.5 cm/s.

The reaction distance is calculated using Dd = vDt.

The total braking (stopping) distance is the sum of the reaction distance and the braking distance (measured in the activity on page 55).

Table F

Relative Velocity	Actual Velocity (cm/s)	Braking Distance (cm)	Reaction Time (s)	Distance Traveled During Reaction Time (cm)	Total Braking Distance (cm)
1	51.5	2.83	0.200	(51.5)(0.200) = 10.3	11.1
2	103	11.6	0.200	(103)(0.200) = 20.6	32.2
3	154	25.5	0.200	(154)(0.200) = 30.9	56.4
4	206	42.5	0.200	(206)(0.200) = 41.2	83.7
5	258	67.3	0.200	(258)(0.200) = 51.6	118.9

If a reaction time of 0.400 s is used, the reaction distance will double, which will increase dramatically the total braking distance at high speeds.

Table F

Relative Velocity	Actual Velocity (cm/s)	Braking Distance (cm)	Reaction Time (s)	Distance Traveled During Reaction Time (cm)	Total Braking Distance (cm)
1	51.5	2.83	0.400	(51.5)(0.400) = 20.6	23.4
2	103	11.6	0.400	(103)(0.400) = 41.2	52.8
3	154	25.5	0.400	(154)(0.400) = 61.8	87.3
4	206	42.5	0.400	(206)(0.400) = 82.4	124.9
5	258	67.3	0.400	(258)(0.400) = 103	170

Again, the effect of reaction time and increased velocity can be illustrated by the applets mentioned earlier in this section.

2. When the first car begins to brake, the driver of the second car must perceive this action, process the information, and react by putting his foot on the brake. This reaction time results in the second car traveling the "reaction distance."

If both cars are assumed to stop equally well when braking, the reaction distance will represent the minimum following distance that the second car can safely follow the first car.

<http://www.visualexpert.com/Resources/reactiontime.html>
The website above includes information on the factors that affect reaction time.

The reaction distance is calculated using a typical reaction time of 1.50 s. The speed of the car is 60 km/h, which must be converted to m/s by dividing by 3.6.

v = 60 / 3.6 = 16.7 m/s
Dt = 1.50 s
Dd = vDt
= (16.7 m/s) (1.50 s) = 25.0 m

Again, this is the absolute minimum following distance.

3. At 70 km/h, the speed is 70 / 3.6 = 19.4 m/s.
The reaction distance is (19.4 m/s) (1.50 s) = 29.1 m.
This is about seven car lengths with a bit of a cushion.

At 80 km/h, the speed is 80/3.6 = 22.2 m/s.
The reaction distance is (22.2 m/s) (1.50 s) = 33.3 m/s.
This is about eight car lengths with a bit of a cushion.

At 90 km/h, the speed is 90/3.6 = 25.0 m/s.
The reaction distance is (25.0 m/s) (1.50 s) = 37.5 m.
This is about nine car lengths with a bit of a cushion.

The safe following distance for a car should be about one car length per 10 km/h.

The recommended safe following distance has been replaced with a safe following time. This following time should be 3–4 s.

4. Using the answers to Practice #1, page 56, on dry pavement, the braking distance is 16.7 m at 60 km/h. A speed of 60 km/h would seem to be a good guess to be able to stop in 35 m.

The calculation of stopping distance requires the calculation of reaction distance, using Dd = vDt plus the calculation of braking distance using Dd = kv^2. In both cases, v must be in m/s.

At 60 km/h:

v = 60 / 3.6 = 16.7 m/s and Dt = 1.50 s

Reaction distance: Dd = vDt = (16.7 m/s)(1.50 s) = 25.0 m

Braking distance is 16.7 m.

Total stopping distance is 41.7 m. The pedestrian would be struck by the car.

If we try a speed of 50 km/h, we get the following stopping distance.

V = 50 / 3.6 = 13.9 m/s and Dt = 1.50 s

Reaction distance: Dd = vDt = (13.9 m/s)(1.50 s) = 20.8 m

Braking distance: $d = kv^2 = (0.06)\ (13.9\ \text{m/s})^2 = 11.6$ m

Stopping distance = 32.4 m.

A car would have to be traveling at about 50 km/h in order to stop in time to avoid hitting the pedestrian.

5. The three-second rule for a safe following distance allows the driver of the second car to travel with a reaction time of 1.5 s without braking, then hit the brakes, and still stop in time to avoid a collision with the car ahead.

The braking distance varies with the square of the speed of the car. If the speed doubles, the braking distance increases by a factor of 4. However, since both cars are assumed to brake equally well, the braking distance will be the same for each vehicle.

If cars follow at a certain distance, say 10 m, this may be more than the reaction distance at a low speed. As the speed increases, the reaction distance increases in proportion to the speed of the vehicle. If the speed doubles, the reaction distance doubles. So the 10-m following distance would no longer be a safe following distance.

However, if the following time is used, the car will automatically increase the following distance to keep it safe. In 3 s, the car will travel twice as far if the speed is doubled. Since this is now the following distance, it will be a safe distance. The car will be able to stop in the reaction distance.

In inclement weather, the braking distance increases. The extra second provides a larger following distance, a cushion, which can be used up by the extra braking distance the second car may have.

The Final Challenge—Car Crash

Note to Teacher: This treatment of the crash scene is contingent upon using the revised crash scene map as outlined in the Preface, page A262.

The motorcyclist was heading south. The motorcycle is found in the intersection after the accident. This indicates the motorcycle hit an object, which stopped the motion of the motorcycle. A large force was needed to stop the motorcycle quickly. Such a force could be provided by the crash between the motorcycle and a car. This is an application of Newton's Second Law.

The motorcycle had significant kinetic energy (energy related to motion). This energy was transformed into other forms as the motorcycle came to a stop. Part of the energy was used to do work in damaging the motorcycle and the car's body. Other forms of energy, such as heat and sound, were also produced as a result of the collision event.

The motorcyclist and her helmet are found south of the intersection and the motorcycle itself. Since the motorcyclist was traveling south when the motorcycle crashed into the car, the motorcyclist and her helmet, which were in motion, continued in motion until an unbalanced force acted on them. That unbalanced force was provided by the road. This is an application of Newton's First Law. When the motorcyclist landed on the ground, the force of friction between the road and the motorcyclist brought her to a stop. Again, this is an instance of Newton's Second Law in operation.

Again, the motorcyclist possessed significant kinetic energy. This energy was converted into other forms, like heat as the motorcyclist slid along the road.

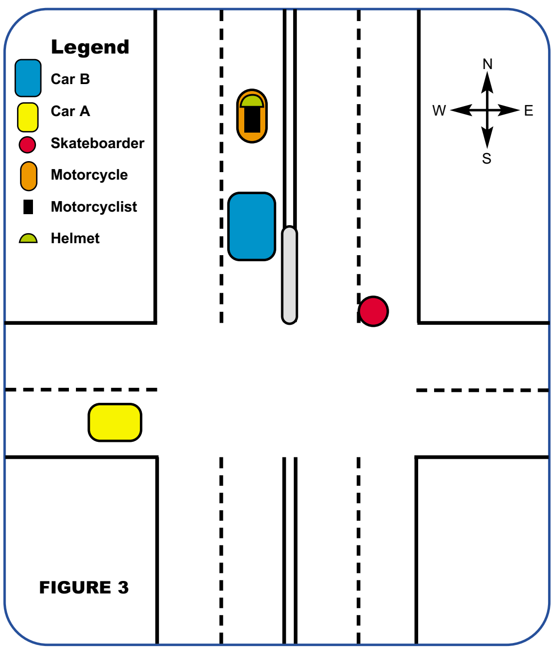
If the motorcycle struck the front fender of Car A, the force of the collision would have pushed the front of Car A in a southerly direction. Car A would then have traveled in a more southeasterly direction. If the motorcyclist struck the rearmost portion of Car A, this would push the rear of Car A to the south. Car A was already turning north (we could assume), so the rear of Car A would slide to the east, and the direction Car A would take would then be more northerly and somewhat east of north. The skidmarks east of the intersection would be consistent with the rear tires sliding sideways in an easterly direction. Alternatively, the skidmarks may have nothing whatever to do with this particular incident.

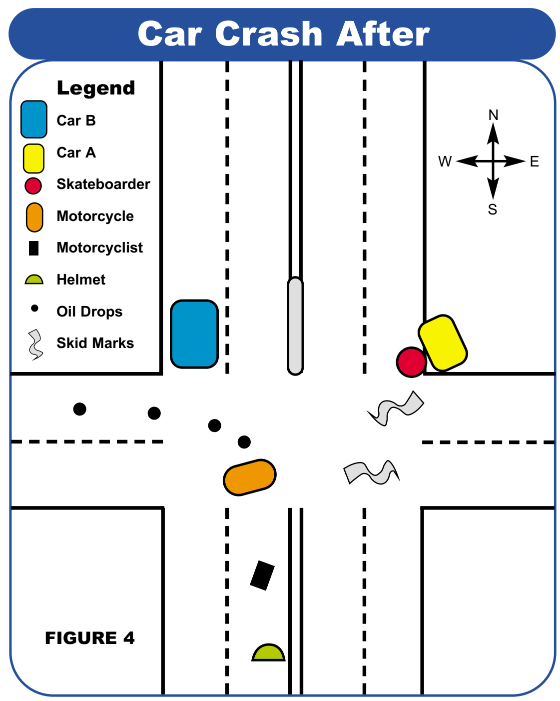
The skidding car would lose kinetic energy. The tires sliding on the road heated up enough to leave marks on the road. After Car A's rear tires stopped sliding, Car A continued in motion forward, ending up on the walkway where the skateboarder was located. When the skateboarder bailed (as we assume occurred), his skateboard, already in motion, stayed in motion until acted upon by an unbalanced force during its collision with the rear fender of Car A.

Oil Drops:

The oil drops are drawn in the incorrect position in the diagram as seen in *In Motion — A Student Resource*. They should be positioned, as indicated, in the intersection near the spot where the motorcycle came to rest. If this was the correct placement of these drops, then the drops act like the dots on a ticker timer. The dots trace out the path of some vehicle that may or may not have been involved in the incident. For instance, the skidmarks could have been from a driver who entered the intersection at the time of the accident, was struck, but then took evasive action and fled the scene altogether. Students should actively speculate on this or similar scenarios.

Another point in favour of the version of the story given by Car A's driver is the fact that the skateboarder was crossing the intersection, moving to the east (or west), which meant that Car A, going east, should have had a green light. This final bit of information should demonstrate that the motorcyclist ran the red light. Or did she…?





Chapter 7

Driving Responsibly

Case Study #1

Note to Teacher: Depending on the time of the school year, students may already have taken Driver Education. Many of the responses reflect the messages of Driver Education. Teachers should be able to draw on the experiences of their students from their Driver Education classes or their in-car driving experience. The responses in this section are representative student samples.

In Case Study #1, students did poorly on the third part of the report: Evaluate available research. The point of this was for students to research the effect of moderate amounts of alcohol and distractions on reaction time and reaction distance. The effects of alcohol and distractions are to increase the reaction time and, hence, stopping distance. The message is that people should not drink and drive, even if their blood alcohol content is below 0.08. Secondly, drivers must give the task of driving their undivided attention.

Challenge—Sample #1

a. Assess and clarify the problem.

In this study, it seems that people are always getting away with irresponsible behaviour. For example, drinking but just slipping by with a lower blood alcohol level. This makes lots of people enraged, especially in this case where the driver hit the woman. It is confusing who caused the problem in this situation. The woman wasn't cautious and safe, and wore dark colours that blended her in with the night. On the other hand Mr. Smith was distracted by a hockey game at night and had drunk a few beers earlier. You don't know who to fault in this.

b. Review the police actions.

The police's actions in this were what they had to act according to the law. It is perfectly legal to drive under 0.08 blood alcohol level so they could not charge him for anything. To lots of people it may not seem right that he drink and drove, never mind hitting someone but the police did what they had to do. They had no other option because of the law.

c. Evaluate the available research.

The police investigated and questioned Mr. Smith in the normal basic way about what happened. They found the main things to lead onto: drinking beer, and not seeing Ms. Martin. They then took a Breathalyzer test and found out his blood alcohol level was only 0.06, below the limit. They didn't need to do any more research because what he did was obviously an accident from the evidence, and he was below the blood alcohol level.

d. Develop a course of action to reduce such incidents.

An extreme may be to just change the law, and lower the blood alcohol level to 0 as it is for some groups of people today. It would most likely be effective in reducing some of the incidents but people will also be angry with this. Another way may be to try and reduce distractions of people, such as banning cell phones in cars, or radios. People should be advised to wear visible bright clothes at night for their own safety. Have streetlights not only at crosswalks but so that the street is lit up everywhere, creating better visibility.

Challenge—Sample #2

1. "Assess and clarify the problem..."

There are several problems with situations like these. First of all, probably the most important, was that Mr. Smith was drinking. Although his blood-alcohol content was below the legal limit, alcohol still affects your alertness and visibility. Another problem is that Mr. Smith was listening to a hockey game on the radio. This would have provided a huge distraction to Mr. Smith. Add that to the fact that he already had a few beers clearly establishes that Mr. Smith was very distracted from assessing the road conditions and taking control of his car. The third problem is that Ms. Martin did not check both ways before crossing the street. Most of us are taught to look both ways before we cross the street but this must have slipped from Ms. Martin's mind. She should have taken extra care before stepping off the boulevard because it was fairly late at night. Finally, another problem is that Mr. Smith applied the brakes too late. If he had been going at a slightly lower speed he probably would have been able to stop in time. The time of day and his mental state are factors that add to the fact that he was driving too fast for his particular situation.

2. "Review the police actions..."

I think the police should have dealt with this situation a little more aggressively. Someone's life was at risk here and it seems that all they did was casually question Mr. Smith. The fact is that Mr. Smith ran over someone. In today's world, it doesn't seem right that you can just run over someone and not suffer any consequences. Mr. Smith had been drinking, and although he did not drink to the limit of 0.08, he did still have a few drinks which most likely affected his judgment. The police should have had a closer look at the situation. There are other options for punishment, such as taking away Mr. Smith's driver's license for a period of time.

3. "Evaluate the available research..."

   The research into this situation is a little vague. Mr. Smith was apparently late to pick his wife up. When we're late and we're driving, our natural tendency is too pick up the pace. So why does the report say that Mr. Smith was running late, but he was driving at the speed limit? It doesn't make a lot of common sense. The report also does not mention the position of the car and if there was any physical evidence in the environment, such as skidmarks on the ground. Maybe Mr. Smith was lying and his judgment was too impaired that he never braked at all. Also, I find it a little strange that he never saw Ms. Martin. It would only make sense that he never saw her if the street corner was very dark, since she was wearing a dark blue coat. The report, overall, was just not thorough enough.

4. "Develop a course of action to reduce such incidents..."

   There are a few things we can do to reduce such incidents. Ms. Martin was wearing a dark coat. Maybe if the street intersection was lit more brightly Mr. Smith would have seen Ms. Martin in time to prevent the accident. The main course of action we can take is to re-assess the legal limit of blood-alcohol content and the penalties for people who have been in an accident but are under the legal limit. In this particular situation, I think Mr. Smith should have been charged with at least some kind of offense. His offense was that he caused the accident. There's only so much authorities can do. The rest is up to the decisions of the public, such as Mr. Smith's decision to have a few beers before driving and Ms. Martin's decision to not look both ways before she crossed the street.

Challenge—Sample #3

The problem is that Mr. Smith hit Ms. Martin when driving at nighttime. Mr. Smith is partly to blame for the accident. Mr. Smith had a few drinks and was listening to the radio while he was looking for the street to turn on. Mr. Smith was being distracted by the radio while driving, and his reaction time is slower because of the alcohol in his body. Old age is also a cause of slow reaction time. He was also driving at the maximum speed limit. He was driving too fast for the conditions he was in. The accident was also Ms. Martin's fault. She was wearing dark colours at nighttime, and it is hard for drivers to see dark colours. Ms. Martin also crossed in the middle of the street without looking both ways for oncoming traffic.

The police didn't charge Mr. Smith with any offences because Mr. Smith's blood-alcohol content was 0.06 mL/L of blood and was below the legal limit of 0.08. He never got charged for hitting Ms. Martin because it was partly her fault that she got hit. She never checked before crossing the street and she was wearing dark clothes. The police couldn't charge anyone because no one was breaking the law. Mr. Smith's blood-alcohol level was below the limit, and he was driving the speed limit.

To reduce such incidents, people could drive a little slower at nighttime because they can't see as good. People could wear bright clothes when walking or biking at nighttime, so that drivers can see them better from a farther distance. Drivers can also put on their high beams when there are no oncoming cars. This will allow them to see farther ahead. People that have been drinking should never drive because even though their blood-alcohol is below the limit, it still affects their driving. Pedestrians can also check both ways before crossing the street.

Case Study #2

Anticipation Guide—Sample #1

1. Drivers who have serious accidents are likely to be the common troublemakers.

   Before: No, I do not agree. People who have serious accidents are not always troublemakers. That is why they are called accidents. The person is not always trying to do it, it is an accident.

   After: No, they are still not said to be "troublemakers."

   Comments: The driver in the newspaper article was said to be a good person, but he still had a serious accident and wasn't labeled a troublemaker.

2. Criminal charges should be laid against young drivers who are involved in accidents.

   Before: It depends on what the accident was, and how it was caused. If it was caused in an illegal way such as drinking, then it is the person's own fault and they should be charged.

   After: Once again, I think it depends on the degree that it happened.

   Comments: In the article, yes, the driver was traveling way over the speed limit, and that is bad enough as it is, but it caused a death. In this case, though, I wouldn't charge him. People make mistakes.

3. The laws of physics suggest cars that are out of control can be brought back into control.

   Before: Yes, it does suggest that. They can be stopped by an unbalanced force and put back into control. Not always, but sometimes.

   After: Yes, I still think it does.

   Comments: It may be hard to get thing back into control, and sometimes impossible, but lots of times it may work. You just have to have the knowledge of how it works.

4. Most serious accidents caused by teenage drivers are the result of illegal narcotics or high blood-alcohol levels.

   Before: Yes, from what I remember, that is the biggest cause of most serious accidents.

   After: No, most serious accidents by teenage drivers are the result of speeding.

   Comments: I think that if more people knew this (because I know I didn't), it may help reduce the chances if the greatest are from speeding.

5. New driving laws, like Graduated Driver Licensing, drafted specifically for novice drivers, are intended to maintain unreasonable control over young adults.

   Before: No, it is intended to help decrease accidents because it is proven that most accidents occur from teenage drivers.

   After: No, they aren't.

   Comments: The new driving laws are to try and get the kids comfortable with driving on the roads and not have to have peer pressure on them at the beginning.

Anticipation Guide—Sample #2

1. Drivers who have serious accidents are likely to be the common troublemakers.

   Before: I think this statement is generally false. Your driving habits don't always reflect what you do outside of the vehicle. I definitely think that your attitude affects your driving, but if you get in a serious accident it may not be your fault and it may be because of other factors, like the weather or having a child in the car, etc.

   After: After reading the article, it seems that the driver of the Mercury was obviously driving way over the speed limit and was out of school. The article didn't mention whether or not the driver was a "troublemaker" before, but I still agree with my BEFORE statement. Although alcohol and other factors affect your driving, I don't think that all people who have serious accidents will become common "troublemakers."

   Comments: The driver of the vehicle will have to live with the guilt of killing a person for the rest of his life. His whole life is changed and if he was a "troublemaker" before the accident, I doubt he would be one after.

2. Criminal charges should be laid against young drivers who are involved in accidents.

   Before: I don't entirely agree with this statement. As young drivers, we are still learning the "rules of the road" and the effects of our actions, such as driving at higher speeds, etc. We have to be given the chance to make mistakes because learning involves making mistakes. Although it's not always the case, I don't think young drivers deserve to be held with criminal charges when they've only grown accustomed to the road for a short time.

   After: I still agree with my above statement. Now that I've read the article, I realize how personal it can get and that a boy my age lost his life because of someone else's actions.

   Comments: Since the driver didn't have a previous record, I don't think he should be charged criminally at this point. He deserves severe consequences though. The biggest consequence is living with his guilt for the rest of his life.

3. The laws of physics suggest cars that are out of control can be brought back into control.

   Before: I agree with this statement. In Driver's Ed they taught us what to do under certain situations where your car does lose control. Let's say that you hit a patch of ice and begin to swerve. If you concentrate and take full control of the wheel without speeding up (accelerating) you can bring your vehicle back under control.

   After: In the article, the driver overcorrected and this resulted in the collision. By maintaining control over the wheel, he probably could have prevented this.

   Comments: Since the driver was driving at such a high speed, the braking distance would be so much longer than if he was going the speed limit. At the higher speed, the driver found himself in a situation where it takes so much longer to brake.

4. Most serious accidents caused by teenage drivers are the result of illegal narcotics or high blood-alcohol levels.

   Before: Right now, I'd say this is probably true although inexperience and speed are two other major causes.

   After: The article mentioned that speed is statistically the greatest threat to young drivers.

   Comments: Although the article's statement is true, illegal narcotics or high blood-alcohol levels also play a large factor in serious accidents with young drivers. Also, teenagers aren't the only ones who speed. Adults also speed and may be under the influence of drugs or alcohol when they drive.

5. New driving laws, like Graduated Driver Licencing, drafted specifically for novice drivers, are intended to maintain unreasonable control over young adults.

   Before: I don't agree with this statement. Honestly, I'm in GDL and completing in-car training with a professional and after about three months with my learners permit, I still need a lot of practice. I think you need control or else a lot of young drivers would be very inexperienced. The rules aren't that harsh and it's not really unreasonable control.

   After: I think the program in the article was a pretty good idea. That's only for about three months with only giving rides to family members. With our GDL program, we have to have nine months with a licenced driver for three years in the car at all times.

   Comments: All the driver had to do was follow the simple law, and his friend would probably be alive today. Breaking the law cost his friend's life.

Anticipation Guide—Sample #3

1. Drivers who have serious accidents are likely to be the common troublemakers.

   Before: I think that serious accidents are not all caused by common "troublemakers." It depends who caused the accident. All people make mistakes while driving, not just troublemakers. The troublemakers are the ones who get into a lot of accidents and cause the accidents.

   After: Young kids usually get into accidents more than mature adults. Young kids are usually the troublemakers on the streets because when they start driving, they drive fast because they think they're superman and won't get hurt in an accident. They think driving fast is cool and they don't think about dying in an accident.

   Comments: Serious accidents aren't all caused by common "troublemakers."

2. Criminal charges should be laid against young drivers who are involved in accidents.

   Before: The accidents could've not been caused by the young drivers and they should not be charged. Young drivers should get charged if they are the ones who caused the accident and if they broke any laws.

   After: I think that if young drivers speed and violate traffic signals/signs, then they should be charged. They should be charged if they caused the accident, especially if someone is killed.

Notes

Online Webquests

<http://www.physicsclassroom.com/Default2.html>

This site is the "motherlode" for this cluster. It has an excellent treatment of 1-D kinematics (distance, displacement, speed, velocity, and acceleration) in terms of conceptual development via a number of modes (descriptions of motion in words, tables, graphs, and symbols). "Newton's Laws" and "Momentum and Its Conservation" are two other pertinent topics.

<http://www.phy.ntnu.edu.tw/java/Reaction/reactionTime.html>

Java applet—Reaction, time, and distance.

<http://www.phy.ntnu.edu.tw/java/carDistance/carAccident.html>

Java applet—Speed, following distance, coefficient of friction, and average reaction time can be adjusted to determine the following distance needed under certain speed and road conditions to stop successfully as the car ahead of you brakes.

<http://www.sdt.com.au/STOPPINGDISTANCE.htm>

Web page on stopping distances varying with speed. It also includes stopping distances of various types of cars. Plus, this site is in metric!

<http://www.pbs.org/wgbh/nova/listseason/26.html>

Escape: Because Accidents Happen: Car Crash—NOVA

Original broadcast date: 02/16/99

Topic: technology/engineering

This program explores the contributions of Dr. Claire Straith, Bel Berenyi, Nils Bohlin, and John Hetrick.

While today's cars are safer than they've ever been, automobile safety has come slowly and at the expense of millions of lives. Car Crash focuses on the unheralded heroes of automobile safety: Dr. Claire Straith, a Detroit plastic surgeon who fought in the 1920s to get padded dashboards and recessed knobs installed in cars to protect motorists' faces in an accident; Bela Berenyi, a Mercedes engineer who completely changed the way cars were designed and built with the invention of crumple zone and rigid cab construction; Nils Bohlin, the Volvo engineer who holds the patent for the single most effective safety device in any car—the seat belt; and John Hetrick, the unsung inventor of the air bag, whose work was 20 years too early.

<http://www.pbs.org/wgbh/nova/transcripts/2605car.html>

This site has the transcript of the program *Escape: Because Accidents Happen: Car Crash.*

<http://www.pbs.org/wgbh/nova/escape/timecar.html>

A great site for a description of the contributions of Dr. Claire Straith, Bela Berenyi, Hans Bohlin, and John Hetrick.

<http://www.pbs.org/wgbh/nova/escape/resourcescar.html>

A host of student resources and activities concerning car safety.

<http://www.riccilegal.com/FSL5CS/articles/articles31.asp>

A history lesson on the evolution of the seat belt and the resistance of the automobile manufacturers to adopt their installation in vehicles.

<http://www.nader.org/history_bollier.html>

This site contains a book outlining a history of Ralph Nader's contributions to the automobile safety and consumer movements in the United States.

<http://www.womanmotorist.com/sfty/index-safety-airbags.shtml>

This site is all about air bags.

<http://www.nhtsa.dot.gov/>

This is the United States government site for traffic safety. Check out the links to videos showing car crashes and the resulting second collisions of anthropometric dummies with the interior of the vehicle. It has videos of all sorts of situations. This site has it all: statistics, ratings of cars, research, and much more.

<http://www.tc.gc.ca/road/menu.htm>

This is the Transport Canada site for road transportation safety.

<http://www.netsoc.dit.ie/~ncolgan/phe/n2law.htm>

Newton's Second Law applet. Students can vary the mass of the car being accelerated or the mass of the hanging mass used to accelerate the cart. The mass under acceleration by the hanging mass is the mass of the cart PLUS the mass of the hanging mass.

<http://www.netsoc.dit.ie/~ncolgan/>

A site with a lot of applets, mostly those by W. Fendt.

<http://www.cs.uleth.ca/students/berdine/>

This site has Newton's Cradle demonstrating a number of different motions, including one sphere released from each side.

<http://www.walter-fendt.de/ph14e/>

This site has the latest updated applets from Walter Fendt. These can be downloaded and run from computers without an Internet connection simply by using the browser.

<http://www.physics.gatech.edu/academics/Classes/summer2002/2211/main/demos/>

This is a compilation of many applets from different sources. There is a particularly good one on distance versus displacement. This also has applets for *In Motion* with constant acceleration, Newton's Second Law, Newton's Cradle, and conservation of momentum with an astronaut tossing a ball in space.

<http://www.visualexpert.com/Resources/reactiontime.html>

This site (www.visualexpert.com) has a host of information on human perception, especially visual, and the factors that affect this. The information is applied to humans as drivers.

<http://www.nhtsa.dot.gov/people/outreach/traftech/pub/tt201.html>

The effect of the combination of alcohol and marijuana on the reaction time of drivers is detailed here. This would be a good site for the Chapter 7 case studies.

<http://www.nsc.org/library/shelf/inincell.htm>

The results of a study "Does Cell Phone Conversation Impair Driving Performance?"

Notes