Chapter 10.8 - Review

10.8

Analyzing Distance–Time Evidence

There are many experimental designs that will provide distance and time evidence for an object that is accelerating. You used a simple design with a ruler and stopwatch in Investigation 9.6 (page 360), and a more sophisticated design with a ticker-tape timer in Investigation 9.10 (page 372). How do you get a value for acceleration from a record of distances travelled at different times?

The following example illustrates how to answer the question, "What is the acceleration of an air puck sliding down an inclined air table?" An air puck slides down a tilted air table and leaves a series of dots (**Figure 1**). In this example the timer is set at 100 ms. This means that the space between any adjacent two dots represents a 100-ms time interval. (Remember to count spaces, not dots.) After identifying the first clear and distinct dot, place the "0" of your ruler at the centre of this first dot and align your ruler along all of the dots. You then read, to the nearest 0.5 mm, the distances shown on your ruler to the centre of each of the dots (**Table 1**, column C). Sometimes you may be asked to measure distances at a multiple of the set time interval, such as every 4 spaces or 10 spaces. This may occur if there are more dots than you need or they are very closely spaced.

To begin analyzing the evidence, find the difference between each consecutive pair of distances. This gives the distance travelled, Δd, (**Table 1**, column E) in each successive 100-ms time interval, Δt, (**Table 1**, column D). You can now calculate the average speed during that interval (**Table 1**, column F). For example, for the time interval from 200 ms to 300 ms:

$$
\begin{aligned}
v_{av} &= \frac{\Delta d}{\Delta t} \\
&= \frac{15.0\ \cancel{m}m}{100\ \cancel{m}s} \\
&= 0.150\ m/s
\end{aligned}
$$

The answer you have is an average speed during the time interval from 200 ms to 300 ms. Assuming that the change in speed is constant (constant acceleration), this average speed will be the instantaneous speed in the middle of the time interval. In other words, this speed of 0.150 m/s occurs at 250 ms (0.250 s), midway between 200 ms and 300 ms (**Table 1**, column G). Finally, convert the mid-interval times from milliseconds into seconds (**Table 1**, column H).

The purpose of an analysis is to answer the question asked at the start of the investigation. In this example the question is "What is the acceleration of an air puck sliding down an inclined air table?" You can obtain the acceleration of the air puck by drawing a graph of speed versus time using the calculations recorded in the shaded columns of **Table 1**, and by finding the slope of the best-fit line (**Figure 2**).

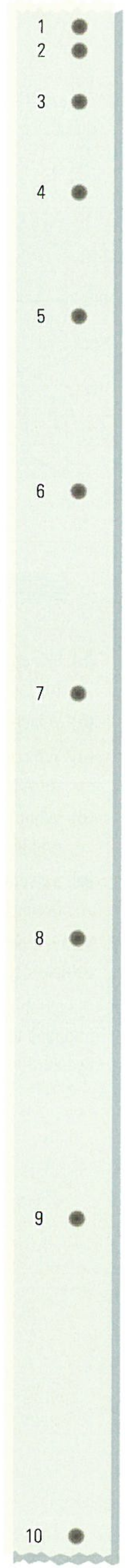


Figure 1
A spark is fired at regular time intervals and leaves a series of dots indicating the position of the air puck after each time interval.

Table 1 **Analysis of Air-Table Evidence**

A Dot #	B Time from start (ms)	C Distance from start (mm)	D Interval time* (ms)	E Interval distance (mm)	F Average speed (m/s)	G Mid-Interval time (ms)	H Mid-Interval time (s)
1	0	0					
			100	4.0	0.040	50	0.050
2	100	4.0					
			100	8.5	0.085	150	0.150
3	200	12.5					
			100	15.0	0.150	250	0.250
4	300	27.5					
			100	20.5	0.205	350	0.350
5	400	48.0					
			100	29.0	0.290	450	0.450
6	500	77.0					
			100	33.5	0.335	550	0.550
7	600	110.5					
			100	40.5	0.405	650	0.650
8	700	151.0					
			100	46.5	0.465	750	0.750
9	800	197.5					
			100	52.5	0.525	850	0.850
10	900	250.0					

*Note that this measurement has three significant digits due to the precision of the timing device.

For the graph shown in **Figure 2**,

$$\text{slope} = \frac{\text{rise}}{\text{run}}$$

$$a = \frac{\Delta v}{\Delta t}$$

$$= \frac{(0.50 - 0.00)\ \text{m/s}}{(0.80 - 0.00)\ \text{s}}$$

$$= 0.63\ \frac{\text{m}}{\text{s}^2}$$

According to the evidence collected in this experiment, the acceleration of the air puck on an inclined air table is 0.63 m/s^2.

Air Puck Sliding Down Inclined Air Table

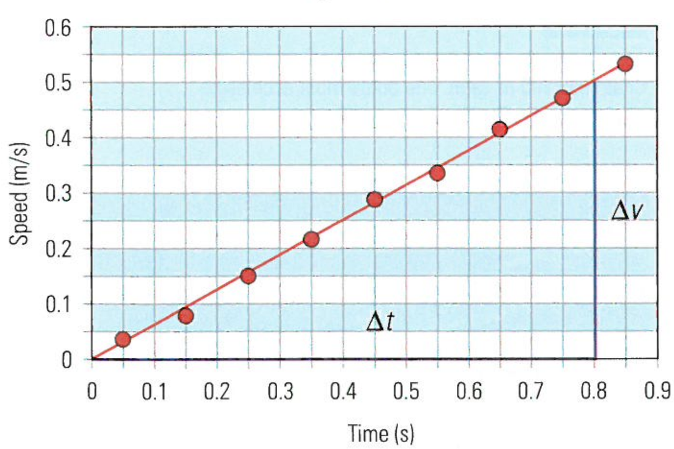


Figure 2
Determining slope of a speed–time graph

Understanding Concepts

1. State three different designs that can be used to obtain distance and time evidence in an experiment.
2. Does it matter which two points on a best-fit line are used to calculate the slope? To test your answer, calculate the slope between these two points: 0.80 s, 0.50 m/s and 0.40 s, 0.25 m/s. Compare your answer to 0.63 m/s^2, as calculated at left.
3. (a) In almost every experiment, there are uncertainties in the measurements that are made. In the example discussed in this section, what measurements were made?
   (b) It is not possible for you to estimate the uncertainty for the timer unless you consulted the manufacturer's specifications. However, you also made measurements with your ruler. What would you guess is the maximum error that you might have in a distance measurement, assuming you didn't misread the ruler?
   (c) Other than the time and the distance measurements, (02) what are some other sources of uncertainty in an experiment like the one described in this section?

Challenge

1 How does the timing device used here compare to the device you are creating for your Challenge?

SKILLS HANDBOOK: (02) Evaluating the Evidence

10.9 Investigation

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

Constant Acceleration

Accelerated motion is common in both natural and technological systems (**Figures 1** and **2**). An understanding of all kinds of motion, including accelerated motion, is necessary before we can begin to ask questions about why objects move or change their motion.

The starting point for studying motion is to determine how far an object travels in measured periods of time. From this basic information the acceleration can be obtained. The purpose of this laboratory investigation is to determine the acceleration of an object sliding or rolling down a ramp.

Figure 1
The apple is stationary when in the tree, but moving just before it hits the ground, so it must be accelerating during its fall.

Question

What is the acceleration of a cart rolling down a ramp?

Design

You will be using a ticker-tape timer with a known frequency to record the distance travelled by a cart on a ramp (**Figure 3**). Time is the independent variable and distance is the dependent variable. Controlled variables include the cart and the slope of the ramp. (It is possible to use other technologies, for example photogates and a computer, to determine acceleration. If you use other technologies, adjust the procedure accordingly.)

(a) Create a table in which to record your observations and analysis. Refer to Section 10.8, Table 1, for a sample table. (K7)

Figure 2
This Canadian boat competed at the Super Boat World Championship in 1999. The boats must accelerate after they round each marker in the race.

Materials

- smooth board (0.5 to 1.0 m long)
- books or blocks
- low-friction cart
- ticker-tape timer
- clamp and stand
- about 50 cm of ticker tape
- small piece of masking tape
- metre stick

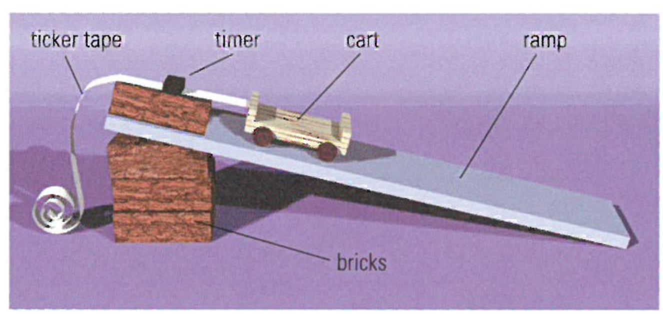


Figure 3
The cart with a timer tape attached is ready to be released down the ramp.

SKILLS HANDBOOK: (K7) Creating Tables of Evidence

Procedure

1 Raise one end of the board with the books or blocks.

2 Clamp the timer near the top end of the board or to a stand placed near the board (**Figure 3**).

3 Set and hold the cart near the ticker-tape timer.

4 Insert the ticker tape through the timer and attach the end of the tape to the cart with a piece of masking tape.

5 Start the timer. Then immediately release the cart, being careful not to push the cart. (Note that the timer should start just before the cart is released.)

6 Turn off the timer when the cart nears the bottom of the ramp or the tape has passed completely through the timer.

7 Catch the cart at the bottom of the ramp.

8 Check the tape to make sure that the dots are clear and that there are no missing dots.

9 Identify the first clear and distinct dot and label it "dot 1." This is the starting point for your time and distance measurements.

10 Number some or all of the other dots as instructed by your teacher. (The number of dots used depends on the particular timer used.)

11 Using the time interval provided by your teacher, record the time from the start beside each labelled dot.

12 Using the first dot as a reference, measure the distance from the start to each labelled dot. Record these distances on your tape.

Analysis and Evaluation

(b) Calculate the distance travelled and the speed for each time interval.

(c) Construct a speed–time graph and determine (U2) the slope to answer the initial Question.

(d) Evaluate the design, materials, and procedure, (O) including possible flaws, suggested improvements, and sources of experimental uncertainty.

(e) Prepare a formal lab report for this experiment. (Q)

Understanding Concepts

1. What is the difference between constant speed and changing speed (accelerated motion) when looking at the evidence on a ticker tape?

Making Connections

2. How does the equipment that is available for measuring distance and time affect values obtained for speed and acceleration?

Exploring

3. **(a)** Enter your evidence from this investigation into a (V4) spreadsheet.

(b) Generate the speed in each interval, and enter the mid-interval times.

(c) Graph the speed–time information using the graphing function of the spreadsheet.

(d) Generate a best-fit (linear regression) line and have the program determine the slope. Compare this slope with the one you obtained in the Analysis and Evaluation section above.

Work the Web

An accelerometer is an instrument used to measure acceleration. There are simple, commercial, and research accelerometers. Find out how each type works by visiting www.science.nelson.com and following the links through Science 10 and 10.9. Using diagrams, report on how one accelerometer works.

Challenge

2 This is a classic investigation. How is it similar to the investigation you have chosen to test a law? How is it different?

(U2) Graphing (O) Evaluating (Q) Lab Reports (V4) Using Computers for Graphing

10.10 Investigation

INQUIRY SKILLS MENU

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

Acceleration of Different Vehicles

When purchasing a vehicle, several perspectives are used to help make a final decision. Cost is important to most people, as well as aesthetic and technical considerations (**Figure 1**). Designers and engineers for all major automobile manufacturers try to produce a series of vehicles of different types to attract as many potential buyers as possible. One factor important to some people is the acceleration characteristic of the vehicle. Some characteristics of a variety of vehicles are shown in **Table 1**.

Table 1 **Characteristics of Various Automatic-Transmission Compact 2-Door Coupe-Style Automobiles**

Car	Cost ($)	Mass (kg)	Type of engine: No. of cylinders	Type of engine: Volume (L)	Type of engine: Power (hp; kW) @ rpm	Est. fuel use (L/100 km) city/highway	Acceleration time 0 to 100 km/h (s)
A	28 500	1340	4	1.80	150; 112 @ 5800	9.4/7.6	7.1
B	26 200	1160	4	1.80	160; 120 @ 7600	9.1/7.6	7.4
C	29 500	1250	4	2.50	165; 123 @ 6500	10.7/8.4	8.0
D	33 900	1190	4	1.80	170; 127 @ 7600	9.4/7.6	7.2
E	34 800	1420	6	2.97	200; 149 @ 5500	11.8/8.4	7.0
F	37 500	1160	4	1.80	180; 134 @ 7600	9.1/5.9	6.8

Key: hp = horsepower
rpm = revolutions per minute

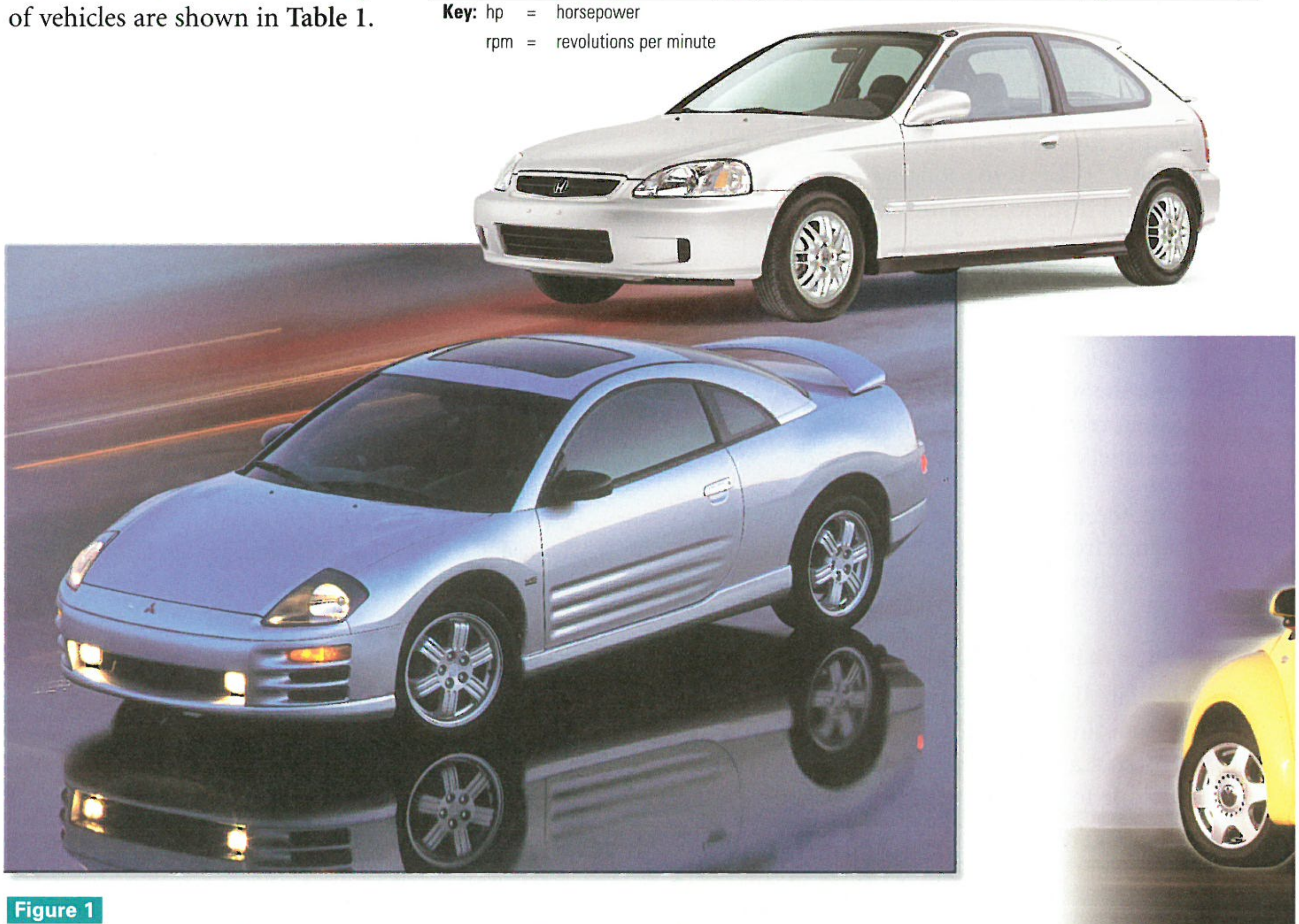


Figure 1
Small, two-door cars are available from many automobile manufacturers.

SKILLS HANDBOOK: (K2) Asking the Question (K3) Developing the Prediction and Hypothesis

Question

(a) Write a scientific question about the acceleration characteristics of different vehicles. Be specific about the variables from Table 1 that you will investigate.

Prediction/Hypothesis

(b) Write a prediction, including your reasoning.

Design

(c) Outline a plan to use information from Table 1 about the characteristics that you have chosen that may be related to acceleration. Identify independent, dependent, and controlled variables in this study.

Analysis and Evaluation

(d) Prepare a graph, placing the chosen variables on the appropriate axes.
(e) What interpretation(s) can be made about the relationship, if any, between your independent and dependent variables?
(f) Write a statement to answer your Question.
(g) Evaluate this experiment, including any flaws in the design, any assumptions that may not be correct, and any biases that may be present.

Understanding Concepts

1. List the cars in **Table 1** in order of increasing acceleration ability.
2. List four different factors that people may consider when purchasing a vehicle.
3. Give some reasons why it is difficult to compare different vehicles.

Making Connections

4. All major automobile manufacturers are designing and building electric cars. What are the most important advantages and disadvantages of electric cars?
5. **(a)** If you could design a car of your own, what acceleration characteristics would you want it to have?
   (b) Give reasons for your decision.
   (c) From whose perspective are you considering your decision?
   (d) Design an advertisement for your vehicle and present it to your class. You can use any medium, such as radio, print, or TV.

Exploring

6. Research hybrid electric vehicles and compare them with both gasoline and electric cars.

Work the Web

Visit www.science.nelson.com and follow the links from Science 10, 10.10 to access **Table 1**. Import the data into a spreadsheet program. Create graphs using several pairs of variables. Briefly explain, as best you can, the relationships that appear.

Challenge

3 The performance of a vehicle is assessed, in part, by how quickly it accelerates. How might high positive acceleration result in breaking the law? How could this be shown on a graph?

K4 Creating the Design V Graphing O Evaluating

Volker Nolte

Coaching Educator

Volker Nolte has found a career that allows him to promote his interests in world-class rowing and in coaching education.

Since 1992, Volker has been a rowing coach with the Canadian National team. He is responsible for talent identification, training, counselling, and preparation of boats for world championships and the Olympic Games.

Every fourth year, Volker moves to training facilities in Victoria, British Columbia, to work with Olympic rowers. Says Volker, "You learn technique only when you row. So we go to one of the few place in Canada where you can row all year round—Victoria, B.C."

For the remainder of the time, he teaches coaching and biomechanics at the University of Western Ontario in London, Ontario.

Volker knows his rowing well, having successfully competed at the junior and senior world-championship levels in his native Germany. It was from his experiences as a high-level rowing competitor that he began considering ways to improve coaching. "When I was an athlete, I found that my coaches were often lacking in education themselves. I thought if they had received better training, perhaps they could have given me better advice, counselling, and feedback. When I finished my rowing career, I thought I'd try to put something back into the sport and educate coaches and athletes."

Although he holds a Ph.D. in biomechanics, to be a good coach requires taking "a little from every kind of education I've had," Volker says.

As a scientist, Volker is highly interested in the technological side of the sport, which can involve using cameras, electronics, and computers to collect and analyze information about a boat's speed and acceleration. But, "Good coaching is part science and part art. On the science side, the coach has to learn how the body functions, body mechanics, how to apply forces to achieve the fastest and strongest movement. Then, there's the art side, where a coach has to understand how to motivate and lead people."

As a coach, his goals—like those of his athletes—are high and, especially leading up to Olympic years, clearly focused. "On the national rowing team we obviously want to be the best in the world."

Making Connections

1. Make a concept map that summarizes the personal qualities needed to be a good coach. Tick off your own personal qualities. Write a few sentences explaining if and how you could develop qualities you don't already possess.
2. Make a two-column chart in which you identify the scientific and human dimensions of good sports coaching. First list information from the profile, then record ideas from your own sports experiences.

Work the Web

Visit www.science.nelson.com and follow the links from Science 10, 10.11. List at least five ways in which rowing is related to physics. Share and discuss your lists with a small group of classmates.

Chapter 10 Summary

Expectations

Throughout this chapter, you have had opportunities to do the following:

- Analyze everyday phenomena and technologies in terms of the motions involved. (10.3, 10.6, 10.10)
- Evaluate the costs and benefits, including safety and environmental factors, of transportation technologies which have enabled us to travel at ever-greater speeds and the impact of this on behaviour and injuries. (10.1)
- Distinguish among constant, instantaneous and average speed, and give examples involving uniform and non-uniform motion. (10.2, 10.7)
- Describe quantitatively the relationship among average acceleration a_{av}, change in speed Δv, and elapsed time Δt, and solve simple problems involving these physical quantities;

  $a_{av} = \frac{\Delta v}{\Delta t}$ (10.3)
- Draw distance–time and speed–time graphs for constant acceleration, and calculate the constant acceleration and distance from velocity-time graphs. (10.4, 10.5, 10.9, 10.10)
- Use a broad range of tools and techniques safely, accurately and effectively to obtain, organize and analyze distance and motion. (10.5, 10.8, 10.9)
- Analyze and evaluate evidence to identify some experimental uncertainties or errors. (10.5, 10.8, 10.9, 10.10)
- Draw distance–time graphs and calculate the average speed and instantaneous speed from such graphs. (10.7, 10.8)
- Design, conduct and/or analyze experiments to determine acceleration. (10.8, 10.9)
- Formulate scientific questions about observed relationships, ideas, problems, and issues related to motion. (10.10)
- Demonstrate the skills required to plan an inquiry into motion, controlling variables and adapting procedures. (10.10)
- Select and integrate information from various sources, including electronic and print resources, to answer the questions chosen. (10.10)
- Select and use appropriate vocabulary, SI units, quantity symbols and graphs to communicate scientific and technological concepts, measurements and analyses. (all)

Key Terms

acceleration
area under the line
average acceleration
constant acceleration
instantaneous speed
slope of the line
tangent

Make a Summary

Sketch distance–time and speed–time graphs for constant speed and for constant acceleration. Indicate beside each of these four graphs what the slope and area represents, if anything.

Reflect on your Learning

Revisit your answers to the Reflect on your Learning questions, page 379, in the Getting Started.

- How has your thinking changed?
- What new questions do you have?

Chapter 10 Review

Understanding Concepts

1. In constant acceleration, What is "constant" ?

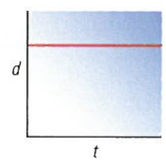
2. Match the type of speed in the first column of **Table 1** with its definition in the second column.

Table 1 **Definitions of Speed**

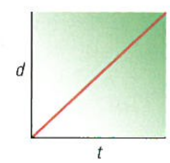
Type	Definition
A. constant speed	1. a speed calculated over the entire trip
B. average speed	2. a speed at a particular moment in time
C. instantaneous speed	3. a speed that does not change over time

3. For each of the following graphs or descriptions of a graph, write a description of the motion represented.

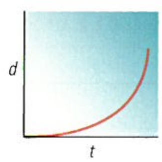
(a)



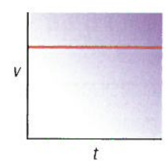
(b)



(c)



(d)



(e) speed–time graph with a positively sloped line
(f) acceleration–time graph with a horizontal line
(g) acceleration–time graph with a curved line

4. Properties of a graph, such as slope and area, usually have some significance. Copy **Table 2**, and state what the slope or area represents, if anything, for the property indicated. If there is no significance, write "none."

Table 2 **Features of Graphs**

Type of Graph	Slope	Area under Line
distance-time		
speed-time		

5. What sources of experimental error or uncertainty have you encountered in your experiments with acceleration?

6. You are a passenger in a car, driving slowly along a road beside a row of hydro towers, each 82.5 m apart. You decide to use your digital watch to measure the time at which you pass each of the towers. The results are shown in **Table 3**.

Table 3 **Passing Hydro Towers**

Tower	Time on watch (h:min:s)
1	2:27:10
2	2:27:21
3	2:27:31
4	2:27:42
5	2:27:54
6	2:28:05
7	2:28:15
8	2:28:26

(a) Calculate the speed for each "tower interval" and create a speed–time graph for the car.
(b) From your graph, calculate the distance travelled.
(c) Compare your answer in **(b)** to the sum of the distances between the eight poles. Account for any differences.

7. A motorboat accelerates from rest to a final speed of 6.0 m/s in a time of 3.0 s. What is the average acceleration of the motorboat?

8. A car is struck from behind by a large truck. The impact lasts 0.10 s and causes an acceleration of 45 m/s^2 of the car. What is the car's change in speed?

9. A mallard duck, resting on the water, takes off and reaches a speed of 35 km/h in 4.0 min. Calculate the average acceleration of the duck.

10. While pulling a barge, a tugboat accelerates at 0.10 m/s^2 to produce a 5.0 m/s change in speed of the barge. How long did this take?

11. A flea may have the world record for high jumping if relative size is taken into account. A flea can jump an amazing 130 times its own height. This feat is achieved by a phenomenal acceleration of about 1.5 km/s^2, but over a very short time of 1.0 ms. What is the final speed of the flea at the end of 1.0 ms?

Applying Inquiry Skills

12. A bottle-nosed dolphin is cruising along and then accelerates at 0.50 m/s^2 to reach a final speed of 9.7 m/s after 15 s. What was the initial speed of the dolphin?

13. In Donovan Bailey's 1996 Olympic gold medal run (**Figure 1**), his winning time for 100 m was 9.84 s. In the first part of the race his average acceleration was about 1.86 m/s^2 until he reached his maximum speed at 6.5 s, which he maintained until the end of the race.

Figure 1

(a) Calculate Bailey's maximum speed at 6.5 s.
(b) What was his average speed for the whole race?
(c) Sketch a graph to clearly illustrate Bailey's motion.

14. The speed and time record for a high-speed dragster is shown in **Table 4**.

Table 4 Speeds of a Dragster

Time from Start (s)	Instantaneous Speed (m/s)
0.0	0.0
1.0	9.8
2.0	19.8
3.0	29.6
4.0	39.6
5.0	49.5

(a) Plot and label a speed–time graph of this information.
(b) Using your graph, determine the average acceleration of the dragster.
(c) How far did the dragster travel from 0 to 5.0 s?

15. The distance–time graphs shown in **Figure 2** show the motion of two different cars. Using your knowledge about the properties of distance–time graphs, write a qualitative description of the motion of each car indicating how you arrived at your interpretations.

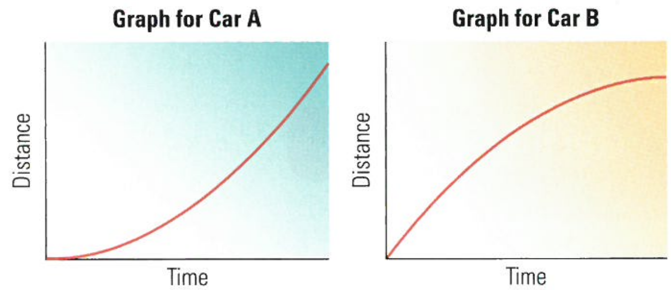


Figure 2

16. What is the acceleration of a world-class ski jumper down the main hill of the ski jump? (**Table 5**)

Experimental Design
The skier is photographed with a rapid-fire flash at dusk. The multiple-exposure picture is analyzed to obtain distances at the fixed time intervals of the flash.

Evidence

Table 5 Acceleration of a Ski Jumper

Time from Start (s)	Distance from Start (m/s)
0.00	0.0
0.50	1.0
1.00	3.9
1.50	8.8
2.00	15.6
2.50	24.4
3.00	35.1
3.50	47.8

Analysis
Construct a speed–time graph, determine the slope, and answer the Question. Record the results of your calculations in a neat, labelled table.

Making Connections

16. How do driving habits affect the fuel economy of a car?

17. Investigate the benefits and risks to the individual and the community of high-speed commuter trains.