IN MOTION

A Learning Resource for Students

Don Metz, Ph.D.

Manitoba Public Insurance

Manitoba

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This module is intended to assist students in achieving the learning outcomes for the Manitoba Senior 2 Science 20F "In Motion" content cluster. It provides for a road safety context to topics in kinematics and dynamics.

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Chapter 1

Introduction

At times, life can be a blur, everything moves by quickly, and people and machines are constantly on the go. Our understanding of motion is important in our everyday lives, especially as our modes of transportation become increasingly more sophisticated.

FIGURE 1

CLASS ACTIVITY:

Tapping into Prior Knowledge

What do YOU know about motion? Use a rotational graffiti activity and the following questions to express your ideas about motion.

Think About IT!

1. What does it mean to move? How does an object move? Give examples.
2. What skills and abilities do you need to drive a car?
3. What happens in a car crash?
4. Is stunt car driving or NASCAR driving dangerous?

FIGURE 2

Discuss your ideas about motion with your group and with your class. Have you ever been in a car collision? Do you know anyone who has been in a car collision?

Rotational Graffiti

The class is divided into groups of three and each group is given a large piece of newsprint (24" x 36" works nicely and is available in pads from office supply stores). Write each of the questions above on the top of separate pieces of newsprint. Each question is repeated on another newsprint with the word "DRAW" added. Using coloured markers, each group has one minute to put their ideas onto the page. At the end of every minute the teacher calls out "rotate" and the students pass their newsprint onto the next group. When the groups have addressed each question twice (one written response and one drawing response), they post their results on the wall for discussion.

Car Crash – Who is to Blame?

Car collisions have serious consequences. People are injured, families lose their loved ones, and vehicles, property, and the environment are damaged. In some cases, irresponsible persons are sued or charged with dangerous driving, or even vehicular manslaughter. The responsibility belongs to everyone.

However, it is not always easy to determine responsibility for a car collision. The collision often happens extremely rapidly and individual observations and memories of the collision can vary.

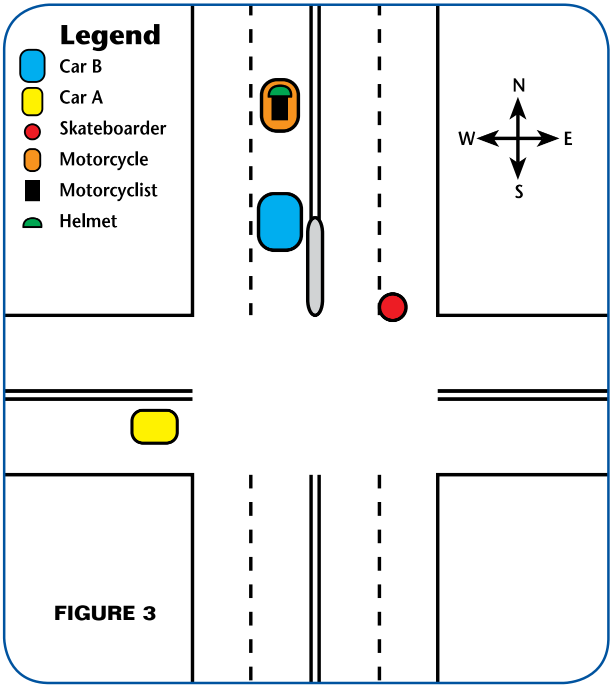
CLASS ACTIVITY:

What do you think of the following car crash scenario? In your group, discuss events that might have led to the collision. Review the evidence and see if you can reconstruct the crash. Each group should present their findings to the class.

Car Crash Scene

Figure 3 shows a traffic scene moments before an accident is about to occur. Car A is travelling east at a constant velocity and is just about to enter the intersection. Car B is moving south with its right turn signal on and a motorcycle is close behind Car B. A skateboarder is crossing the intersection in the easterly direction. All of the individuals involved agreed that these were their positions before the collision. However, they could not remember any specifics about markings on the road.

Figure 4 shows the traffic scene moments after the accident. Each individual told their story in the accident reports that they filed at the police station.



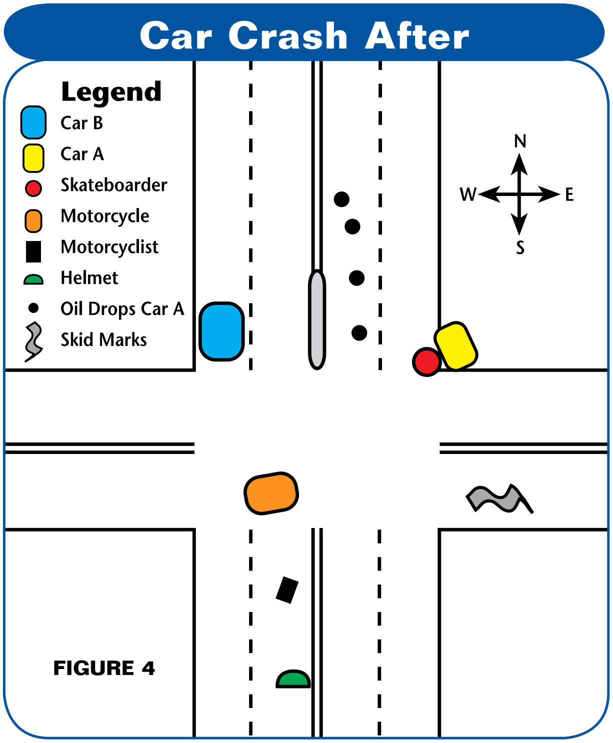
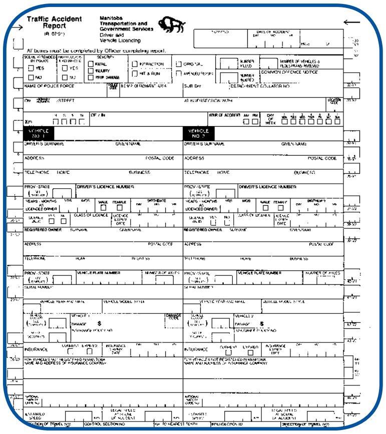


FIGURE 5



Accident Report – Driver of Car A

"My car was travelling east at a constant velocity. As I approached the intersection the light turned green so I kept going through the intersection at the same speed. Then, I heard a loud bang and my car spun to the left carrying it into the pedestrian walkway on the perpendicular street past the skateboarder. My car ended up jumping the curb on the far side of the corner. I wasn't injured but everything took place so quickly I'm not entirely sure what happened."

Accident Report – Driver of Car B

"I was driving south on Main Street when I wanted to check the name of the next street. So I signalled and moved from the median lane to the curb lane. I don't know whether the signal lights were red or green or yellow as I was trying to read the street sign."

Accident Report – Skateboarder

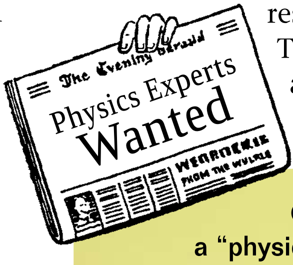
"I was boarding east along the pedestrian walkway with my walkman on so I didn't hear any sounds. I wasn't paying much attention to the traffic when suddenly Car A spun into the walkway. I bailed and my board collided with the rear portion of Car A. I wasn't hurt but I don't listen to the walkman anymore when I'm riding."

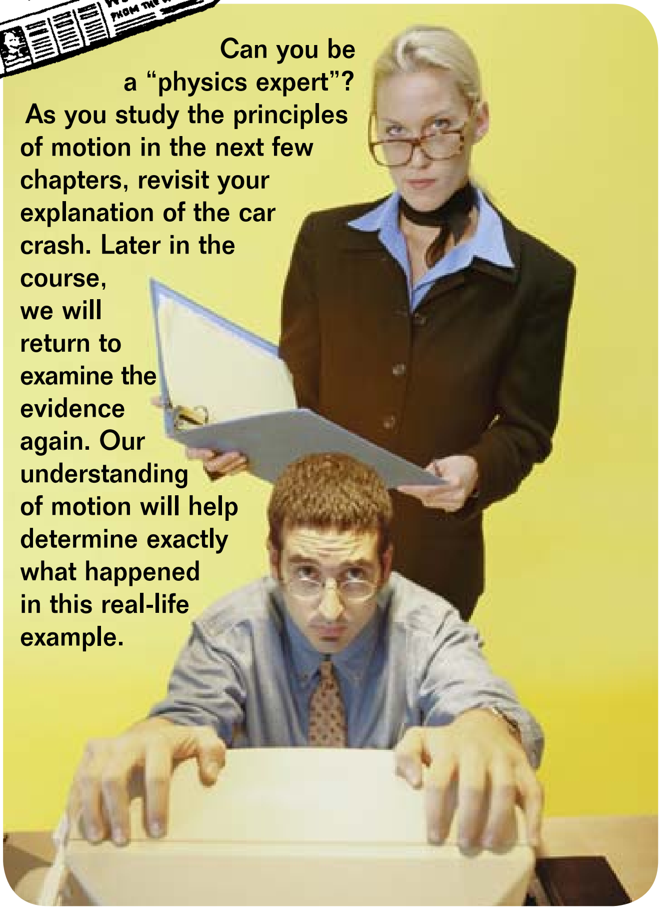
Accident Report – Motorcyclist

"I was travelling south and had the green light. As Car B took the curb lane I signalled for a left turn then proceeded cautiously into the intersection to complete my turn. Car A ran a red light and was making a left turn when I collided with the front end of her car. I was thrown over the hood of the car and landed in the street. My helmet was not securely tied and it flew off my head on impact. I suffered a concussion and remained in the hospital for several days."

Police Report

Front end damage was extensive to the motorcycle. Car A had damage on the front and back fenders. The driver of Car A claimed that the damage on the front end of the car was from a previous fender bender. The motorcyclist claimed that he made the damage on the front end of Car A and that the skateboard damaged the rear of Car A. Oil drops, skid marks, and the motorcyclist's helmet were found in the locations marked in Figure 4. The driver of Car A and the motorcyclist have conflicting stories concerning who was responsible for the accident. Therefore, we recommend that a "physics expert" be approached to investigate each driver's claim.





Chapter 2

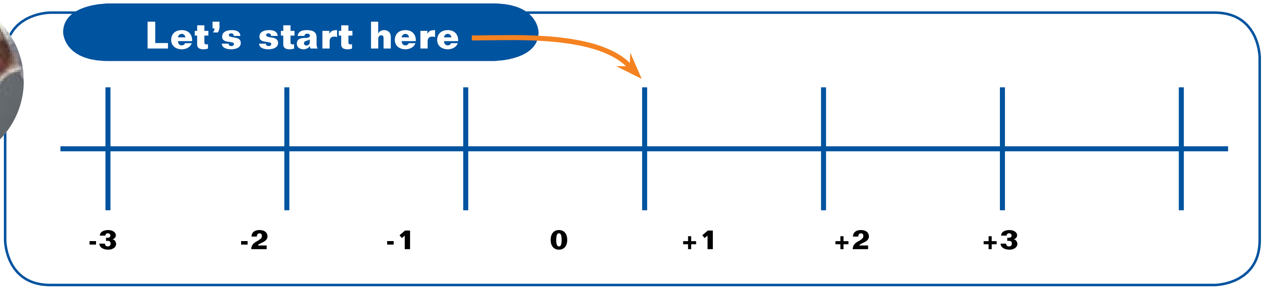
Analyzing Motion

Position and Displacement

What does it mean to move? First of all, if you stay in one place without changing your position, we would say you are standing still. You're not moving!

In order to move, you must change your position. So, get off the couch and move!

If you want to describe the movement of an object (for example, a person running or a vehicle in motion), you must be able to describe its position. In order to communicate our information to other persons, everyone must agree on a reference point, called the origin, from which we begin to take measurements. Position is the distance and direction an object is located from an origin.

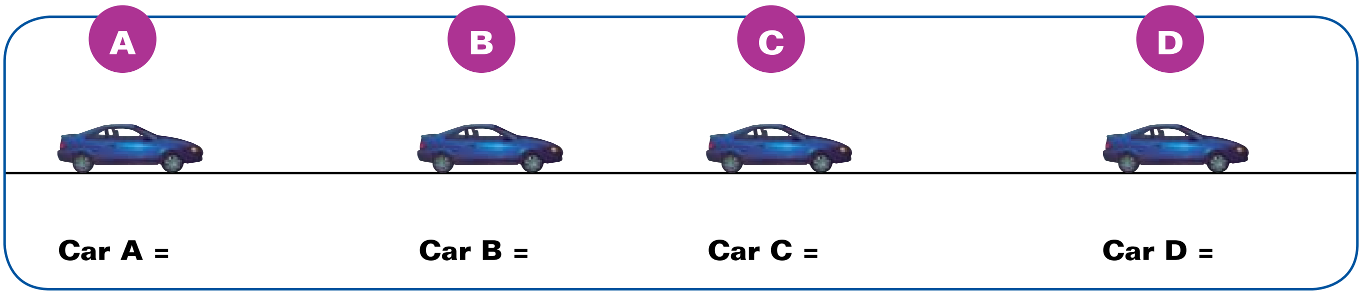


We can easily describe distance by measuring from the origin with a ruler. Direction can be reported in many ways. It is common to use a coordinate line, that is, a line labelled -3, -2, -1, 0, +1, +2, +3 with the origin at 0, as shown in the diagram above. In this case, we use the plus sign (+) to indicate a position to the right of the origin and a minus sign (-) to indicate a position left of the origin. There are other ways to describe direction. For instance, we could use a compass or a direction finder (north, south, east, west).

In this course, we will make describing direction very easy by restricting our motion along a single straight line. In this way, you can describe motion using a coordinate line or by using common terms like right and left, forward and backward, or, if your line is vertical, up and down. Any quantity that is described using magnitude and direction is called a vector quantity. In this text, when vector quantities are represented in symbolic form, they will be **bolded**.

PRACTICE

1. In the following diagram, use the front bumper of Car B as your origin. Then, using a ruler, record in your notebook the position in cm of Cars A, C and D.



Displacement

Remember that in order to move an object, we must change the object's position. Any change in position is called a displacement. Along a straight line, the displacement is found by the final position minus the initial position. We can write this expression as:

$$\text{displacement} = \text{position 2} - \text{position 1}$$

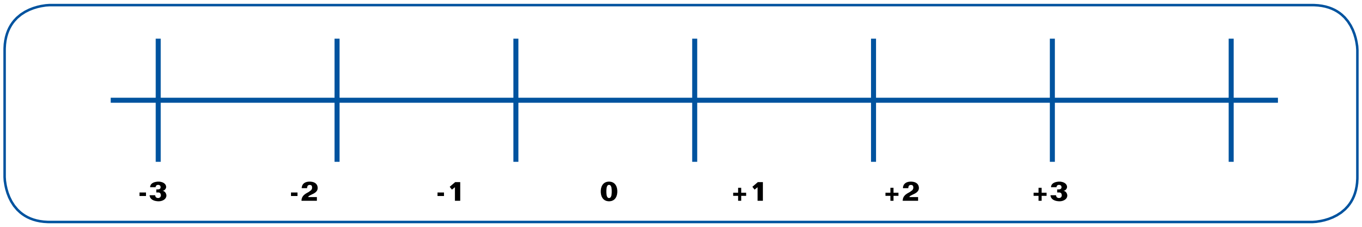
or in SYMBOLIC FORM

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

where d stands for the position and Δ (delta) means "change in". Therefore Δd reads "change in position" or simply displacement. The **bold** font designates a vector quantity, which means a direction must be reported.

Example:

A toy car moves across a table in a straight line. A number line is marked on the table and the initial position of the car is -1 cm. If the car stops at the +3 cm mark, calculate the displacement of the car.



$\mathbf{d}_1 = -1$ cm
and
$\mathbf{d}_2 = +3$

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

$\Delta\mathbf{d} = (+3) - (-1)$

$\Delta\mathbf{d} = \mathbf{+4\ cm}$ (verify by counting spaces on the number line)

PRACTICE

1. The following data represent the initial (d_1) and final (d_2) positions of a car, bicycle, pedestrian, and skateboarder.

	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) Draw a number line and label an origin as point "0". Mark the initial position of each object above the line.

b) Mark the final position of each object below the number line.

c) Calculate the displacement of each object.

d) What is happening? If each displacement takes place in the same period of time, write a paragraph to describe the motion of each object.

2. The dispatcher of a courier service receives a message from Truck A that reports a position of +5 after a displacement of +2. What was the initial position of Truck A? First solve the problem using a number line, and then solve the problem using an equation.

3. Two taxis are travelling along Pembina Highway in opposite directions. Taxi A changes its position from +6 to +10 during the same time as Taxi B moves from +6 to +1. Draw a diagram to show the initial and final positions of each taxi.

4. Calculate the displacements of each taxi in question #3.

5. What can you conclude about the speed of the taxis?

6. How would the position of the taxis change if you decided to move your origin? How does the displacement of the taxis change if you decide to move your origin?

Instants and Intervals of Time

We know that cars move at different speeds; they speed up and slow down. In the previous taxi example, we know that Taxi B was moving faster because it travelled a greater distance in the same period of time as Taxi A. However, we still do not know the speed of the taxi. Was traffic moving slowly or quickly?

An instant of time is a reading on a clock, such as 10:15 or 36.2 seconds. In order to know how fast an object is moving, we need to know the time it took for the car to move from one position to another (change in time). An interval of time is the difference between two such clock readings. Thus,

Interval of time = time 2 - time 1

or in SYMBOLIC FORM

$$\Delta t = t_2 - t_1$$

Reminder

"Δ" means "Change in"

Time is a quantity for which direction is not required. Quantities that describe magnitude only are called **scalars**.

In order to answer the question "How fast is the taxi going?", we need to collect information about the position of the taxi at different points in time.

Think About IT!

1. **Describe several real-life examples of an interval of time.**
2. **Determine how many hours is an interval of 10 seconds? What made this calculation a difficult one for you?**

Investigation #1 VEHICLES IN MOTION

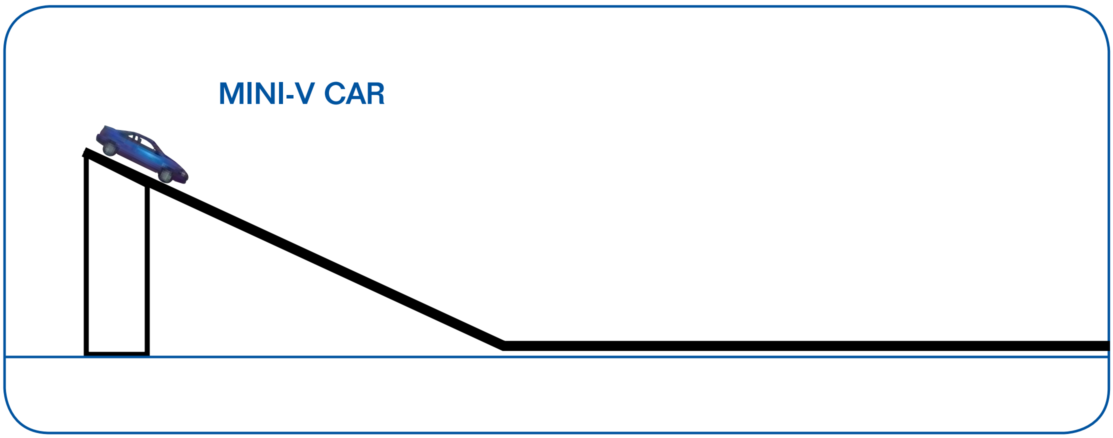
In this activity, you can use a diecast toy car as a miniature vehicle (let's call it a "mini-V"!). Make sure you choose your fastest mini-V car. A marble or steel bearing also works very well.

Procedure

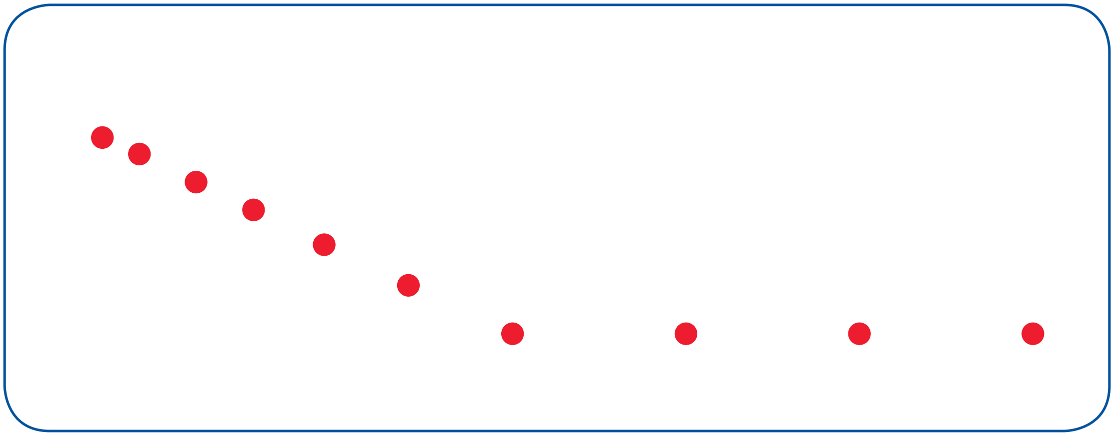
1. Set up a ramp as shown in the diagram. The ramp should be at least 1 m long.

2. Videotape the motion of a mini-V car as it moves down the ramp and across the table. Place the camera about 3 - 4 m away and do not move the camera when you tape the motion.

3. Place an acetate sheet (clear plastic like an overhead sheet) on the television screen and replay the video using the frame by frame advance feature. At each frame or two, mark the position of the mini-V car on the acetate using a marking pen (make a small dot at the same place on the car each time). DO NOT MARK THE TV SCREEN!



Your results should look something like this.



Think About IT!

1. When is the car moving the slowest? Explain.
2. When is the car moving the fastest? Explain.
3. Why do the spaces not change as the car moves across the table?
4. What do you conclude about the motion of the car on the ramp compared to the motion of the car across the table?

Uniform Motion

On most highways there is a posted speed limit. (Do you know what the speed limit is if no sign is posted?) Cars that travel down the highway at this speed are said to be moving in uniform motion. That is, their motion is constant. A picture of Car A travelling down a highway at a constant speed is shown in Diagram A. Each frame represents a picture of the car at one-second intervals. Notice that the spaces are equal for equal time intervals. Measure the distance between each interval and complete Table A. Graph your results with the position on the y axis and the time on the x axis. Repeat the procedure using measurements from Diagram B and answer the questions.

Diagram A

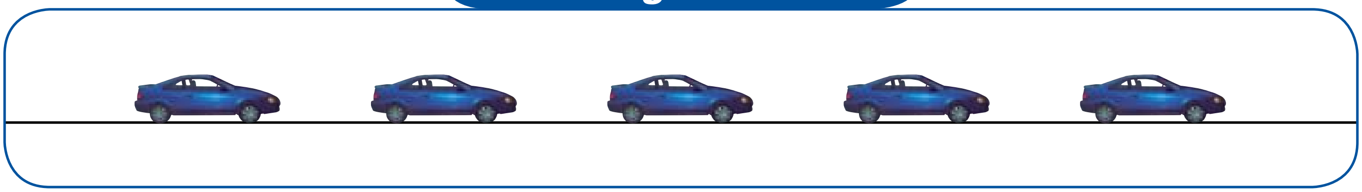


Diagram B

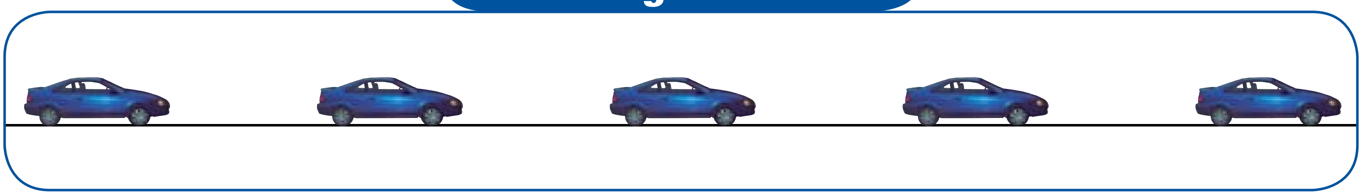


Table A

Position (cm)	Time (s)
	0
	1
	2
	3
	4
	5

Table B

Position (cm)	Time (s)
	0
	1
	2
	3
	4
	5

Think About IT!

1. What is the difference between Graph A and Graph B?
2. How do the spacings of the cars in the two diagrams compare to the plotted points on the graphs?

Slope

The spacings between the dots in our frame-by- frame analysis are reflected in the steepness of the line on the graphs. The steeper the line, the larger the spaces. That is, Car B travelled a greater distance in 1 second than Car A. In other words, Car B was going faster than Car A. "How fast" a car moves is called the speed of the car and is displayed on the car's speedometer.

Velocity is the term physicists use to describe how fast and in what direction an object moves. Velocity is defined as:

$$\text{Velocity} = \frac{\text{Change in position}}{\text{Change in time}}$$

This definition is true for objects whose velocities are not changing. In real life, it is very difficult to find objects that move exactly uniformly, so we often assume that an object has a constant velocity even if it does vary somewhat. Consequently, we call this form the average velocity and in symbolic form we write:

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

Velocity is a vector and always has a direction. In your answers, you can use common terms like right, left, forward and backward, or if you use a coordinate line, + or - signs.

The steepness of the line on the graph is called the slope of the line. The slope of any straight line (including the roof on your house!) is always constant. Numerically, this constant is the ratio of the rise (the vertical displacement (Δy)) and the corresponding run (the horizontal displacement (Δx)).

We can calculate slope by using the formula

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}}$$

or

$$\text{Slope} = \frac{\Delta y}{\Delta x}$$

(We will do this in detail on the next page).

In our motion example, the position (**d**) is on the y axis and time (t) is on the x axis. Therefore, the slope is $\Delta\mathbf{d}/\Delta t$. That is, the slope of the line is the velocity of the object.

Think About IT!

1. Make a concept map to link the following terms together:

- **slope,**
- **velocity,**
- **speed,**
- **Δd,**
- **Δt,**
- **steepness,**
- **constant,**
- **displacement,**
- **rise,**
- **run.**

Include some terms of your own.

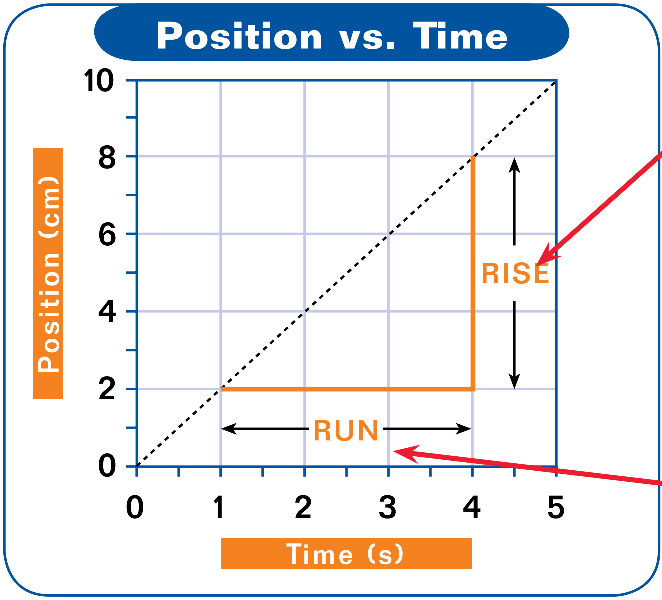
Calculating Slope

In order to calculate the slope, choose any two points on the straight line. Generally, to reduce errors in calculation, we choose two points that are reasonably far apart. Notice also from the position-time graph that:

$$\text{Rise} = \mathbf{d_2} - \mathbf{d_1} = \Delta\mathbf{d}$$

and the

$$\text{Run} = t_2 - t_1 = \Delta t$$



$\text{Rise} = \mathbf{d_2} - \mathbf{d_1}$

$\text{Rise} = 8 - 2$

$\text{Rise} = 6$

$\text{Run} = t_2 - t_1$

$\text{Run} = 4 - 1$

$\text{Run} = 3$

PRACTICE

1. For each of the following cases, sketch a diagram and label an origin and a direction on the diagram. Calculate the average velocity.

a) A bicycle travels 36 km in 1.2 h.

b) A person runs 17 m toward a bus stop in 2 seconds.

c) A car passes 6 telephone poles, each spaced 50 m apart, in 18 seconds.

d) A mini-V car moves along a track from +2 cm to +26 cm in 0.5 seconds.

2. For each example in question #1, comment from your personal experience on whether the object is moving slow, medium, fast, or has an unrealistic velocity.

3. A skateboarder is coasting at a velocity of 2 m/s away from the corner. If we let the corner be the origin, how far will the boarder travel in 3.5 seconds?

4. In terms of the displacement of a vehicle on a highway, what does speeding mean?

5. A mini-V car rolls off a ramp with a constant velocity of 1.5 m/s onto a horizontal track. The end of the ramp is at position -12 cm. If the car reaches the end of the track in 0.4 seconds find the length of the track. Include a diagram and label the origin.

Converting from m/s to km/h

Example: Convert 4.0 m/s to km/h

1 m = 0.001 km   4.0 m = 0.004 km

That is, divide metres by 1 000

1 h = 60 min and 1 min = 60 seconds

1 h = 60 x 60 = 3 600 seconds

$$1 \text{ second} = \frac{1}{3\ 600} \text{ hour}$$

$$4.0 \text{ m/s} = \frac{\frac{4.0m}{1\ 000}}{\frac{1s}{3\ 600}} \text{ km/h}$$

AND

$$4.0 \text{ m/s} = \frac{4.0}{1} \times \frac{3\ 600}{1\ 000} \text{ km/h}$$

$$4.0 \text{ m/s} = \frac{4.0}{1} \times 3.6 \text{ km/h}$$

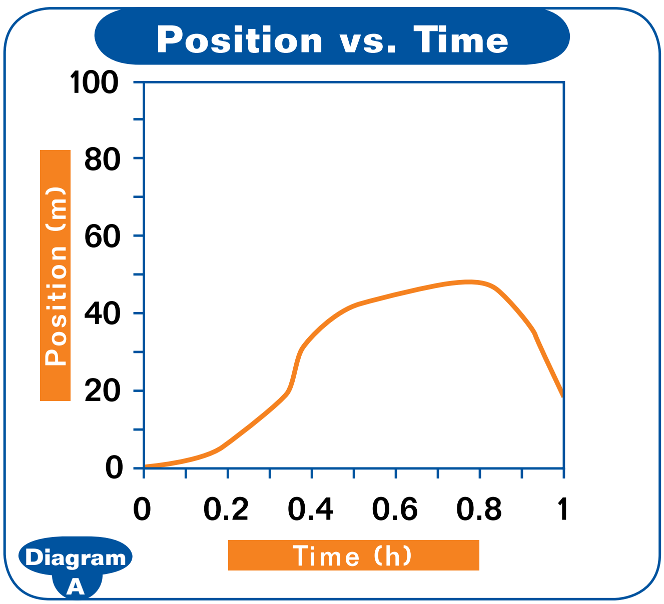
$$4.0 \text{ m/s} = 14.4 \text{ km/h}$$

Conversion Shortcut: To convert m/s to km/h just multiply m/s by 3.6!

Instantaneous Velocity

Average velocity describes the velocity of an object during an interval of time. Instantaneous velocity is the velocity at a specific time. For uniform motion, the instantaneous velocity is always the same as the average velocity, which is why we call it uniform. For uniform motion, the position-time graphs are straight lines. However, the position-time graphs for non-uniform motion are curves.

Diagram A is the position-time graph of object in non-uniform motion. Can you tell from the graph when the object is going slow or going fast?

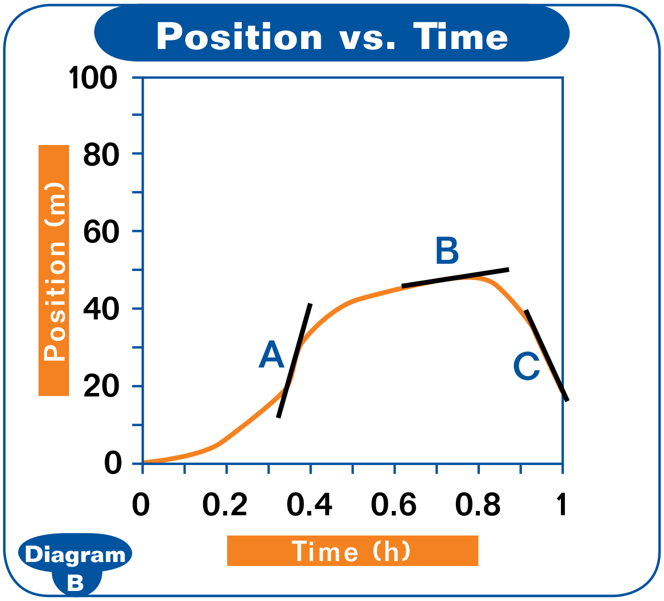


Recall that the velocity is the slope of the position-time graph. So, the object is going fast when the slope is very steep and is going more slowly when the slope is more gradual. (Diagram B)

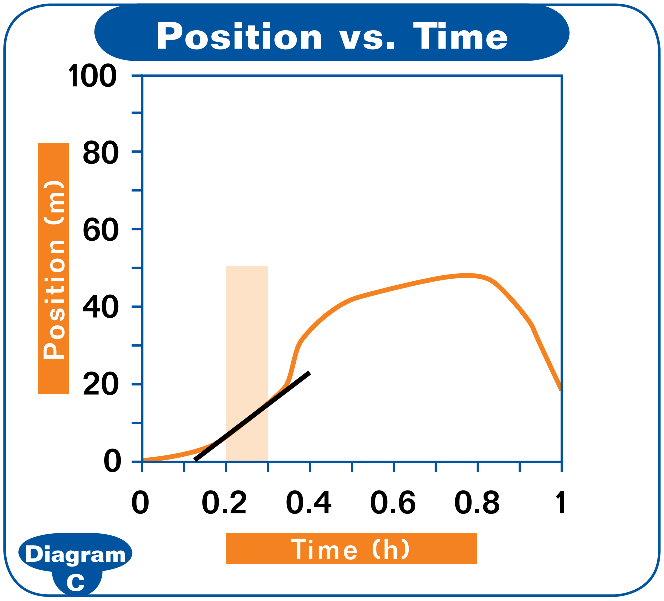
Point A – steep slope, going fast

Point B – gradual slope, going slow

Point C – steep slope, going fast but in the opposite direction.



In most cases we can closely approximate an instantaneous velocity by choosing a small enough interval of time such that the graph is almost a straight line. For example, using the position-time graph, if we choose an interval of time from t = 0.2 h to t = 0.3 h and draw a line between these two points, this straight line closely approximates the curve. (Diagram C)



The average velocity for this interval is:

$$v_{avg} = \frac{\Delta \mathbf{d}}{\Delta t} \qquad v_{avg} = \frac{20 - 10}{0.3 - 0.2}$$

$$v_{avg} = \frac{\mathbf{d_2} - \mathbf{d_1}}{t_2 - t_1} \qquad v_{avg} = +100 \text{ km/h}$$

This average closely approximates the instantaneous velocity at the midpoint of the interval. In this case, the midpoint between t = 0.2 h to t = 0.3 h is 0.25 h. Therefore, the instantaneous velocity at 0.25 h is very nearly 100 km/h. Mathematically, we write $v_{0.25}$ = 100 km/h.

PRACTICE

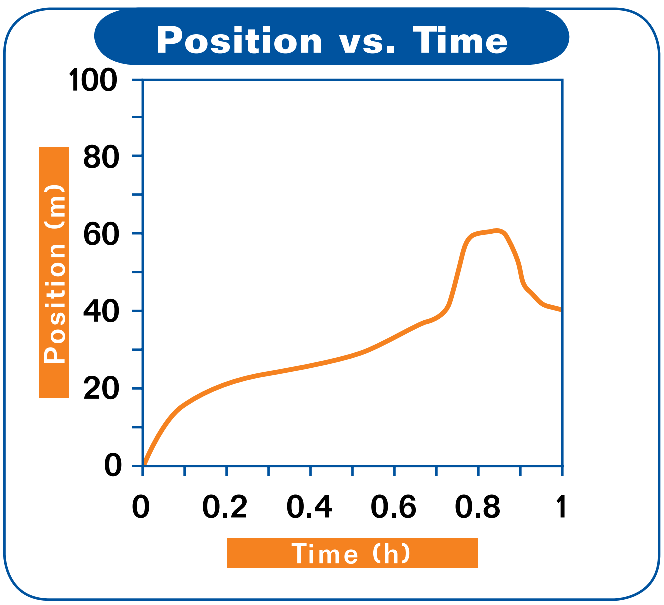
1. Using the position-time graph as your guide, tell a story about an object that might move in this manner.

2. From the graph, calculate the average velocity between the following points and comment whether or not the average velocity closely approximates the instantaneous velocity at the midpoint of the interval.

a) t_1 = 0 h and t_2 = 0.1 h

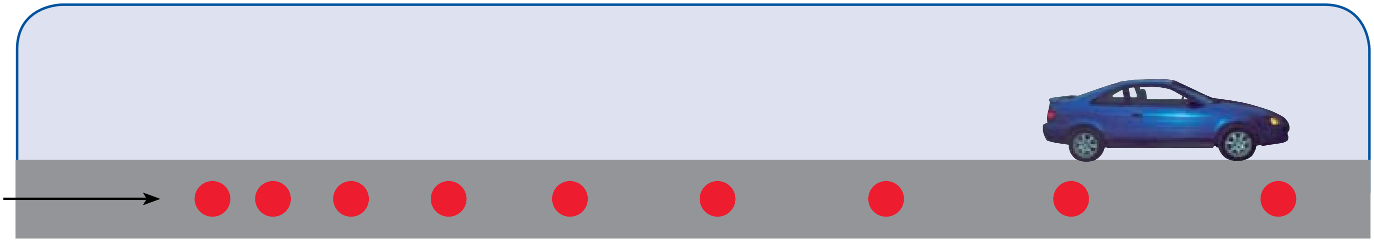
b) t_1 = 0.2 h and t_2 = 0.4 h

c) t_1 = 0.6 h and t_2 = 0.8 h



Accelerated Motion

As you drive your car from a stop light or a parking spot, you must gradually increase your speed from zero to the posted speed limit. When a vehicle speeds up or slows down, we say that it is accelerating.



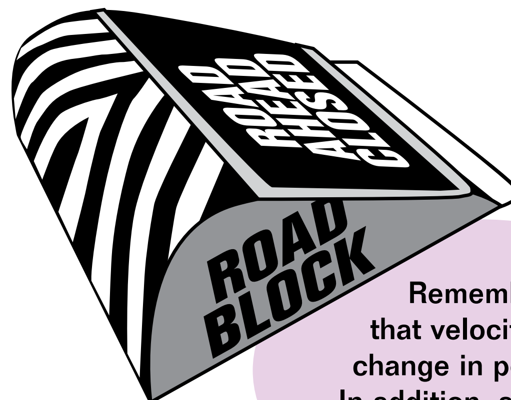
CLASS ACTIVITY:

Remember the dots from the mini-V car as it rolled down the ramp? Did you notice that the spaces were increasing for equal time intervals? As the car moves faster, the distance between the dots increases. Measure the distance between the dots for each interval and complete Table C (you can use your results from page 11 or use the diagram above). Graph your results with the position on the y axis and the time on the x axis.

Table C

Position (cm/s)	Time (s)
	0
	1
	2
	3
	4
	5

It is very easy to mix up the terms velocity and acceleration.



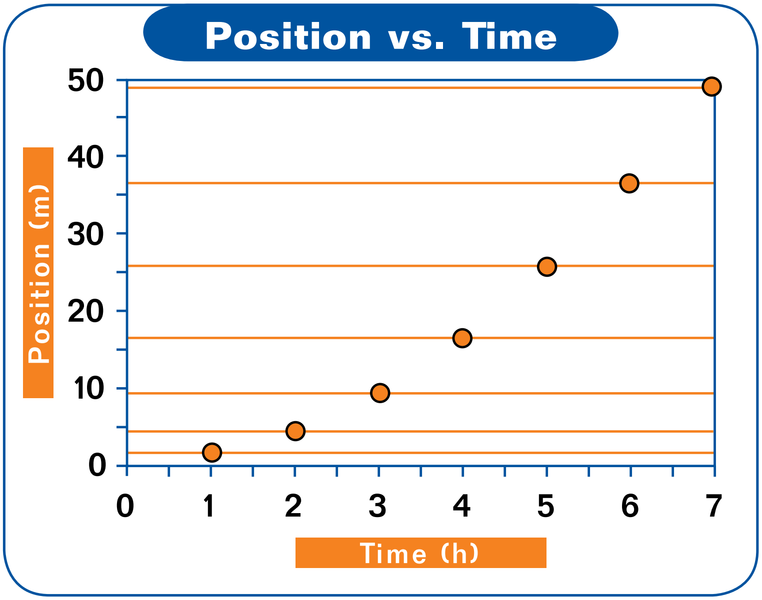
Remember that velocity is a change in position. In addition, an object must change its velocity to accelerate.

Think About IT!

1. Does your graph describe uniform or non-uniform motion?
2. What can you say about the spacing of the dots and the velocity of the car?
3. What can you say about the acceleration of the car?

From your position versus time graph, the line curves upwards because the spacing between the dots is increasing. We can draw reference lines on the graph to show how the points on the curve correspond to the spacing of the dots.

In order to investigate the changes in velocity we must graph the instantaneous velocities for several different times. First, complete Table D to find the average velocity for each interval of time.



In order to find how velocity changes, we must graph instantaneous velocity versus time.

Graphing Instructions

1. First, calculate the average velocity for each interval to complete Table D.
2. Remember that the average velocity of an interval closely approximates the instantaneous velocity at the midpoint of the interval. Use Table D to complete Table E and then graph velocity versus time.

Table D

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

Table E

Velocity (cm/s)	Time (s)
	0.5
	1.5
	2.5
	3.5
	4.5
	5.5
	6.5

Think About IT!

1. How does the velocity change in this example?
2. What can you say about the relationship between velocity and time in this case?
3. What do you conclude about the acceleration?

Analysis of Accelerated Motion

Since the velocity changes at a constant rate, the graph of velocity versus time is a straight line. The slope of this line is the rate of change of velocity with respect to time and is called acceleration. Therefore, we can say:

$$\text{Acceleration} = \frac{\text{Change in Velocity}}{\text{Change in time}}$$

or in SYMBOLIC FORM

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

Acceleration is a vector quantity and always has the same direction as the change in velocity.

PRACTICE

1. Table F shows the velocity in m/s of different objects at regular intervals of time. Sketch the velocity-time graph for each case and describe the motion.

Table F

Time	0.0 s	1.0 s	2.0 s	3.0 s	4.0 s
Case 1	0.0	+ 4.0	+ 8.0	+ 12.0	+ 16.0
Case 2	+ 24.0	+ 24.0	+ 24.0	+ 24.0	+ 24.0
Case 3	+ 24.0	+ 16.0	+ 8.0	0.0	-8.0
Case 4	+ 2.0	+ 4.0	+ 6.0	+ 8.0	+ 10.0

2. Compare and contrast uniform and non-uniform motion. Include reference to position, velocity, and acceleration.

3. Find the acceleration in each case.

a) A car increases its velocity from 0 km/h to 20 km/h in 6 seconds.

b) A train crosses a boulevard at 10 km/h and begins accelerating as it heads out of the city. Thirty minutes later it crosses another road at 60 km/h. What is the average acceleration of the train during this period of time?

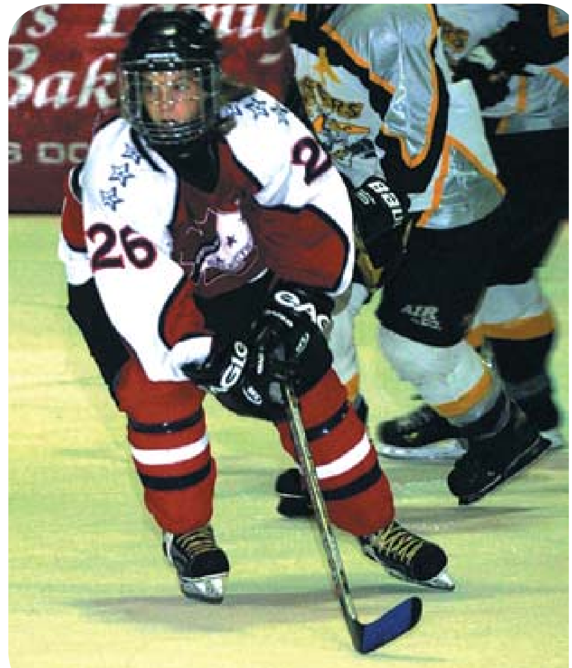
c) A truck travelling west at 50 km/h pulls out to pass another vehicle that is moving at a constant velocity. The truck increases its velocity to 60 km/h in 6 seconds.

d) Estimate your own acceleration when starting from rest to your maximum velocity.

4. In each case from question #3, sketch the corresponding position-time graph. First, choose and label an origin and then choose an appropriate scale.

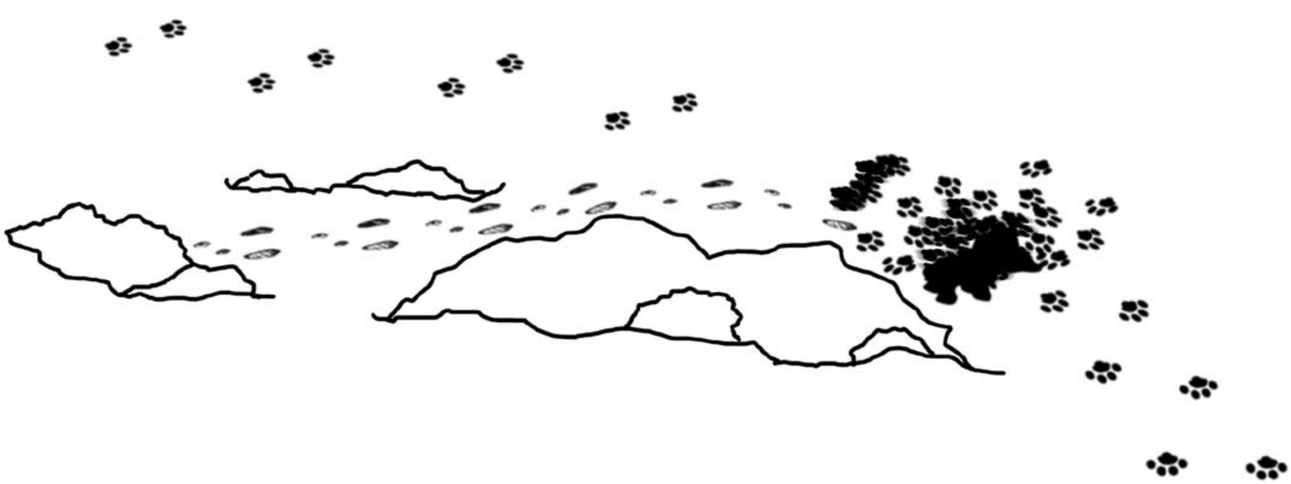
Real-life Motion

Real-life motion is much more complex than the ideal cases that we have just covered. Other factors, such as friction, must be taken into account when we analyse motion. However, we can still apply some of these basic principles to study motion in the real world. Using a camcorder, record some motion in the real world. You can videotape a car driving down the highway, a cyclist, electric toys moving across tables or over ramps, skaters, or any other type of motion you find interesting. You can even use your favourite action video. However, for the segment that you wish to analyse be sure that the camera does not pan. Place an acetate sheet over the TV screen. Then replay the video frame by frame and mark a dot on the object in motion. When you have a series of dots, analyse them and tell a story about the motion in terms of position, displacement, velocity, acceleration and time.



Think About IT!

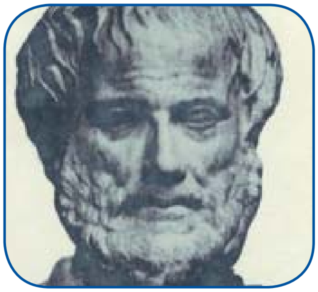
The following diagram illustrates animal footprints left behind in the snow. Reconstruct what happened from the footprints and your knowledge of motion.



Chapter 3

Inertia

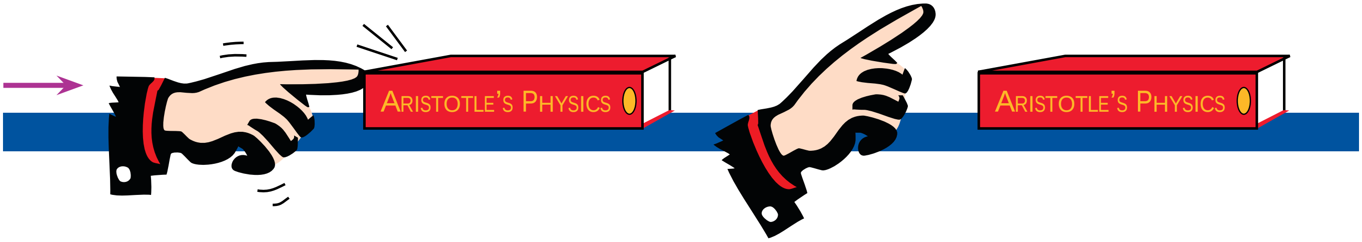
Natural Motion – Aristotle



One of the most fundamental questions about motion that we can ask concerns the natural motion of an object. That is, how would an object behave if it were free of any constraints or forces acting on it? The great Aristotle pondered this question more than 2500 years ago.

Aristotle, a Greek philosopher, offered the first coherent description of the natural world. The first thing he did was separate the celestial and terrestrial worlds into two realms of experience. In the celestial world of the stars and planets, everything naturally moved in perfect circles with a constant velocity. In the terrestrial world, the natural tendency of objects was to move toward the centre of the universe, that is, toward the centre of the earth. Remember, the Greeks believed in a geocentric model of the universe with the earth at its centre.

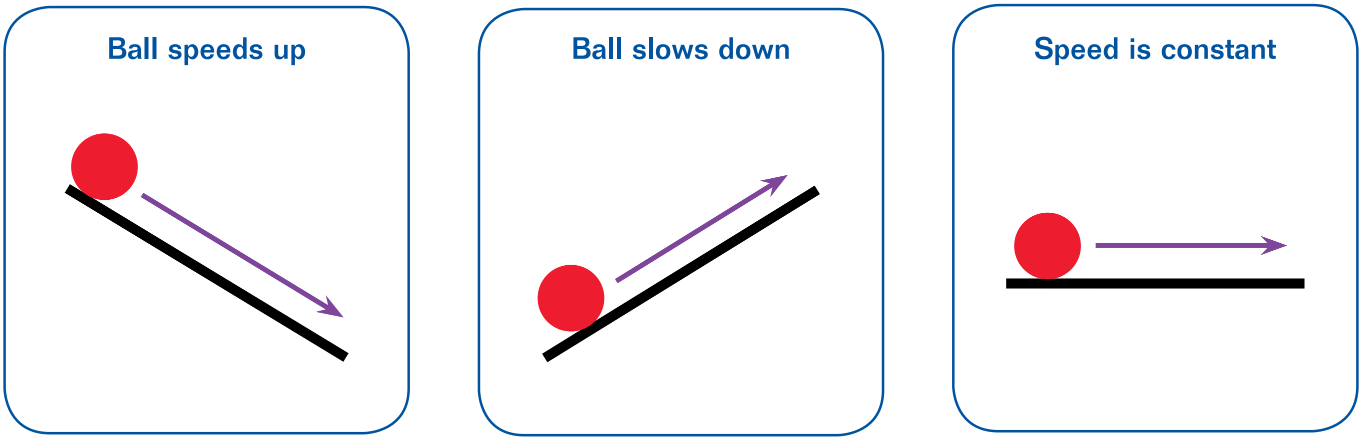
Aristotle's physics adequately explained one of the most basic laws of motion: "what goes up, must come down". According to Aristotle, any motion that was not up or down could only be attained if a force acted on the object. Aristotle called this violent motion. In Aristotle's physics, you must apply a force to move an object and continue to apply this force to keep the object in motion. Try it yourself. Push a book along a table and then remove your hand from the book. The book very quickly comes to a stop.

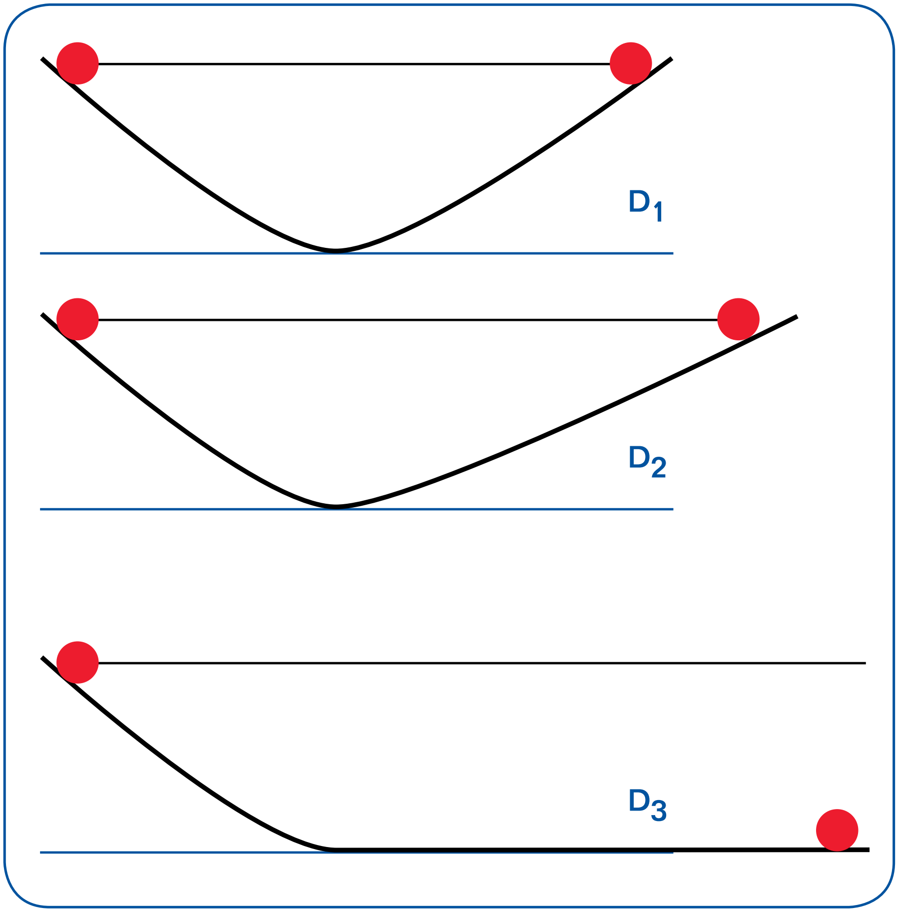


Natural Motion – Galileo

Galileo questioned Aristotle's physics. He knew that motion in the real world was much more complex. The reason the book comes to a stop in the real world is that when you remove your hand there is still friction between the book and the table. That is, another force is acting on the object. One of Galileo's great contributions to science was his ability to think of an "ideal" world without friction. Galileo experimented in his ideal world using thought experiments. He reasoned how the world would behave and then extended these principles to the real world.

For example, Galileo argued that if a ball was released on an inclined plane it would speed up as it rolled down the plane. If a ball was rolled up the plane it would slow down as it moved up the plane. Consequently, Galileo surmised that if the plane were not inclined at all, the ball would neither speed up nor slow down. This meant that the ball would continue its motion with a constant velocity forever.



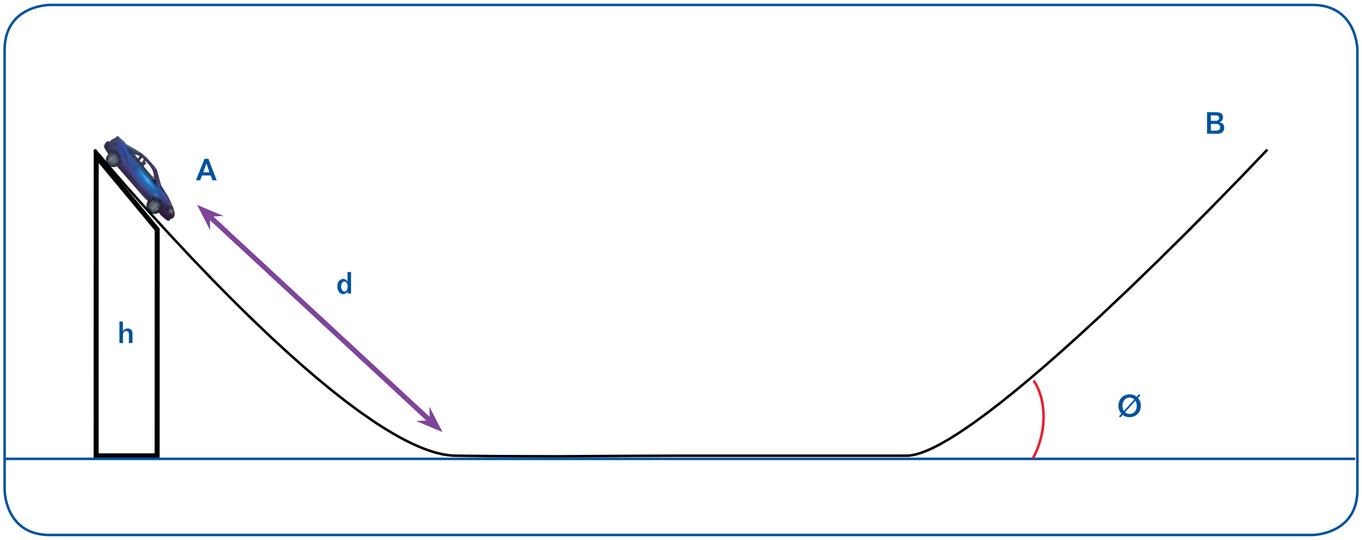


In another thought experiment, Galileo released a sphere down an inclined plane facing another incline. In Galileo's "ideal world", the sphere will rise up the plane on the other side to the same height (D_1). If we decrease the angle of the right plane (D_2), then the mass must travel further in order to achieve the same height from which it is dropped. If we continue to decrease the angle (D_3), it follows that if the second plane has an angle of zero (i.e., horizontal) the sphere will continue forever as it tries to achieve the same height from which it was dropped.

CLASS ACTIVITY:
Galileo's Thought Experiment

We can imitate Galileo's thought experiment using our mini-Vs.

1. Set up a mini-V track as shown and measure the angle of inclination of the ramp (Ø). Choose your best mini-V for this activity.



2. Measure the height from where you release the car at point A and then measure the height the car rises up the other side of the ramp at point B. How do these heights compare?

3. Measure the distance down the ramp and the distance up the ramp. How do these compare?

4. Decrease the angle of the "up" ramp and release the car from the same height. Again, measure and compare the height above ground level and the distance the car moves along the second inclined plane.

Think About IT!

1. **As the angle decreases, what happens to the distance the car travels along the "up" ramp? Why does this distance increase?**
2. **If the angle of inclination is zero, how far would we expect the car to go?**

Remember that Galileo thought about motion in an ideal world. He explained that when you pushed a book across the table and removed your hand, another force, called friction, brought the object to rest. Galileo was a very smart man and thought very carefully about the physics of motion. He knew that the earth was round and what we thought of as a flat piece of the earth was really part of a larger circle. Thus, Galileo concluded that in the absence of any force, an object would continue in motion in a circle around the earth. Although the brilliant Galileo rejected many of Aristotle's ideas, he maintained that the natural motion of an object was circular.

Another great thinker of the time, René Descartes, modified Galileo's idea of natural motion and concluded that the natural tendency of a moving object was really in a straight line.

Although Descartes was the first to propose straight line motion as a natural tendency, it was Isaac Newton who synthesized these ideas about force and motion in his famous book, *Principia*. The property of matter that resists changes in motion is called inertia and is outlined by Newton's First Law of Inertia which states:

An object at rest remains at rest, and an object in motion remains in motion, unless acted upon by an external unbalanced force.

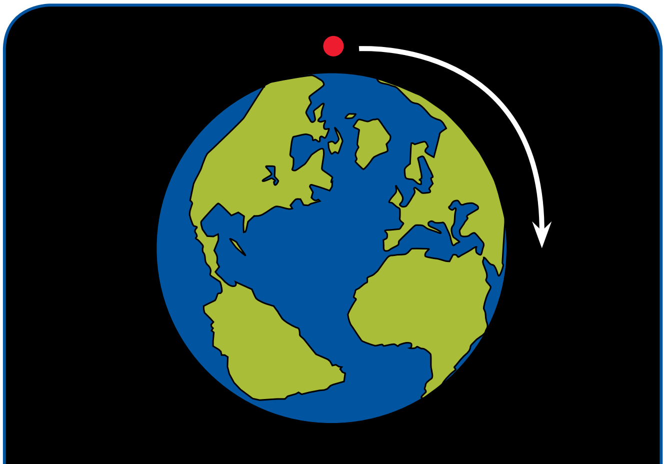


FIGURE 7:
GALILEO'S CIRCULAR INERTIA

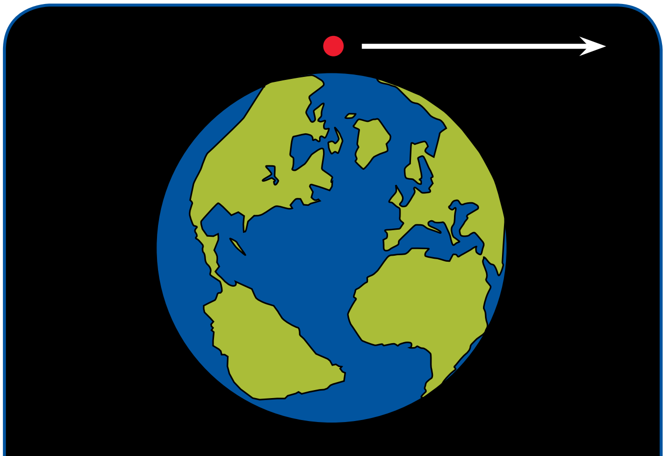


FIGURE 8:
DESCARTES' INERTIA

PRACTICE

1. Make a sketch of the interval spaces for inertial motion.

2. Make up a set of data that reflects inertial motion.

3. Sketch a graph that reflects inertial motion.

4. What is meant by an unbalanced force?

5. What was missing in Aristotle's analysis of natural motion?

6. What was missing in Galileo's analysis of natural motion?

Newton's First Law and the "Second Collision"

Newton's laws apply to all moving objects (and those that don't move, too). Motor vehicles are moving objects that **always** obey the law – Newton's law, that is! According to Newton's first law, a motor vehicle in motion will remain in motion, moving at the same speed and direction, unless acted upon by an unbalanced force. The same principle applies to all occupants and objects in the vehicle. When a moving vehicle suddenly stops in a collision, any unrestrained occupants in the car will continue to move with the same speed and in the same direction until they experience another force. This force is often called the "second collision". Although we say the occupants have been "thrown" from the vehicle, they are really just continuing to move with the same inertia until they experience an unbalanced force in another collision. In the next investigation, we will research some of the factors that might influence how far an unrestrained occupant will be "thrown" from a vehicle. First, we must learn how to control the speed of our mini-Vs.

The Velocity of a Car on an Inclined Plane

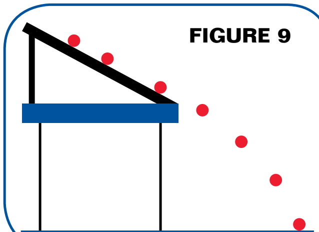
For the following exercises, it is necessary to control the velocity of the mini-V car on an inclined plane. Since the car accelerates down the plane we must determine where to release the car on the plane in order to increase the velocity at a known rate. There are several ways that this may be approached. Two examples are described here: calibrating the inclined plane and historical reasoning.

Calibrating the Inclined Plane

Set up a ramp at the edge of a table and carefully measure the angle of inclination (Figure 9). The end of the ramp should bend slightly so that is matches the horizontal surface of the table.

If we release a ball from some point on the ramp, it accelerates down the ramp to velocity v1 and then is horizontally projected into the air with this velocity. Once the ball leaves the inclined plane, gravity accelerates the ball in the vertical direction. There are no forces acting on the ball in the horizontal direction (ignoring air resistance).

FIGURE 9



Consequently, the ball moves away from the table with a constant velocity.

We can confirm this type of projectile motion by recording the motion using a camcorder. If you play back the motion frame by frame and measure the horizontal displacement of the projectile, you will find that it is constant. We know that:

$$\mathbf{v} = \frac{\Delta \mathbf{d}}{\Delta t}$$

therefore

$$\Delta \mathbf{d} = \mathbf{v}\Delta t$$

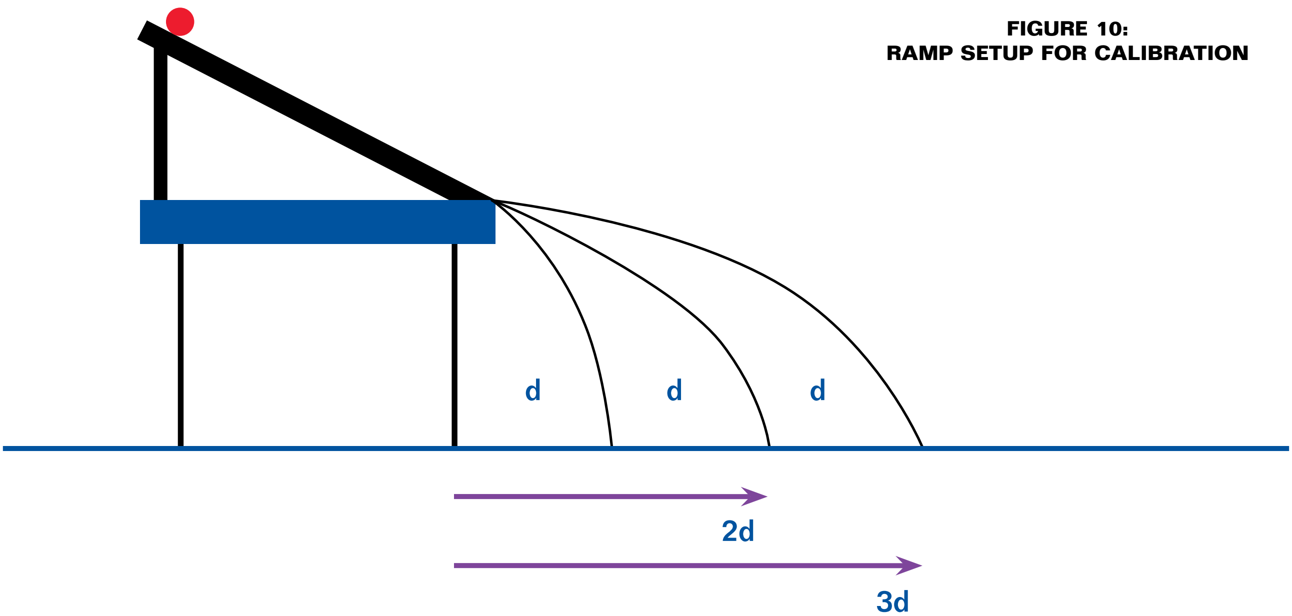
That is, the distance the ball travels horizontally is proportional to the velocity of the ball when it leaves the ramp. Consequently, if we find the release points on the inclined plane such that the successive horizontal displacements are always equal, we will also know that the velocities increase at a constant rate.

Procedure to Calibrate the Inclined Plane

The distance "d" is not critical and will depend on the ramp angle and height of the table. Choose "d" such that you can get at least five or six velocities from your ramp. A typical distance is 12 - 15 cm. In the following example, d = 12 cm (Figure 10).

In order to preserve your mini-Vs, find a marble that travels the same distance as the mini-V car when it is released from the midpoint of the plane.

FIGURE 10:
RAMP SETUP FOR CALIBRATION



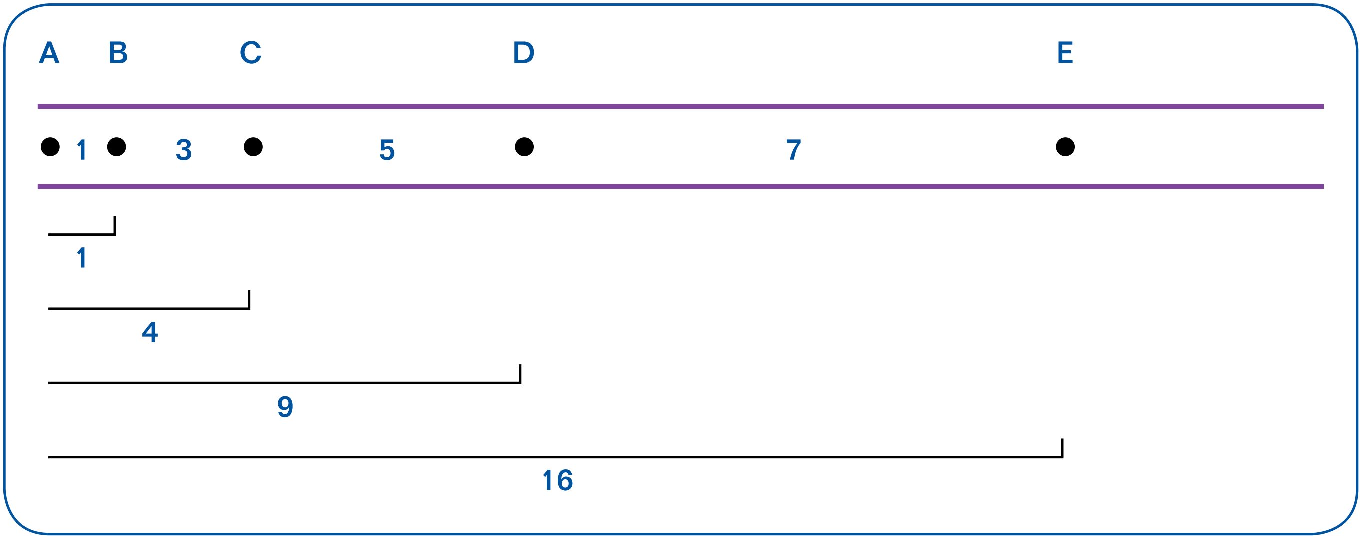
1. Place a narrow object (a pencil works fine) on the floor at a distance 12 cm from the edge of the table (1d) and find the release point on the inclined plane so that the marble lands on this object. Let's say that a ball released from this point has a velocity of v = 1 (arbitrary units). Mark the release point on the ramp with a piece of masking tape.

2. Next, place the pencil at 2d (if d = 12 cm, then 2d = 24 cm) and repeat the procedure. A marble that lands at 2d will have velocity of 2v.

3. Repeat for 3d, 4d and 5d (if d = 12 cm, then 36, 48 and 60 cm). Your ramp is now calibrated. Do not change the angle of the ramp when you begin your investigation. If you change the angle of the ramp, you must recalibrate.

Historical Reasoning

Galileo showed that an object that is accelerating (either in free fall or down an inclined plane) covers a displacement according to the odd numbers (1, 3, 5, 7, etc.) for equal time intervals. In other words, Galileo's ticker tape, if he had one, would look like this:



Since the object is accelerating at a constant rate (due to gravity), the velocity must increase proportionally for these intervals. That is, the velocity at C is twice the velocity at B, and the velocity at D is three times the velocity at B, and so on. Since the distance from the origin follows the pattern 1, 4, 9, 16 (add up the individual displacements), if we release a car from these positions on an inclined plane, we will know that the velocity also increases proportionally. In order to get a greater variation in velocity, we can multiply this pattern by a constant value. A convenient scale for our experiment would start at 5 cm. Table H lists the release points for a typical inclined plane.

Table H

Ratio needed	Scale Factor	Release Point (cm)	Relative Velocity
1	x 5	5	1
4	x 5	20	2
9	x 5	45	3
16	x 5	80	4
25	x 5	125	5

Think About IT!

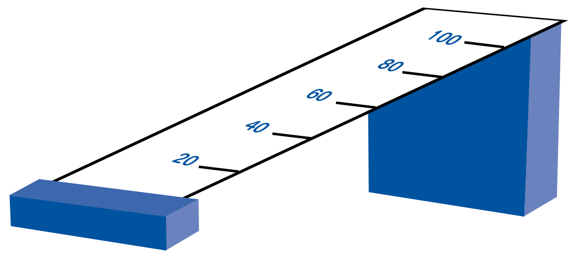
1. How do your calibration ratios compare to Galileo's ratio pattern of 1, 4, 9, 16, 25? (To find your ratio pattern, divide each release point by the first value.)
2. What is the mathematical significance of the pattern 1, 4, 9, 16, 25?

Inertia and Unrestrained Occupants

In a car crash, it is not unusual for the unrestrained occupants to be "thrown" from the vehicle. According to the laws of physics, after the vehicles collide (coming to an abrupt stop), the occupants' inertia will carry them until some external force brings them to a halt. (Remember, an object in motion stays in motion unless acted upon by an unbalanced force.) Inevitably, the external force is the ground, a tree, a building, or some other immovable object. In other words, in every collision there are always two collisions: the vehicles' collision, and the occupants' collision.

Investigation #2 INERTIA AND THE UNRESTRAINED OCCUPANT

In this activity, you will investigate the relationship between the distance an unrestrained occupant travels in a collision and the speed of the vehicle.



Procedure

1. Set up an inclined plane and secure a barrier at the bottom of the plane. Mark the points on the plane from where you will release your car (see previous discussion: calibrating an inclined plane).

2. Make yourself an "occupant" using plasticine and rest your occupant on the hood of a mini-V car.

3. Release your car down the plane such that the velocity increases at regular intervals, and record the distance the occupant is "thrown" after the collision with the barrier.

4. After three trials, calculate the average distance.

Speed	Trial #1	Trial #2	Trial #3	Average distance the occupant is "thrown" (cm)	Comments
1					
2					
3					
4					
5					
6					

Think About IT!

1. Graph the average distance the occupant was thrown versus the speed of the car.
2. What does your graph tell you about the relationship between the distance an unrestrained object is "thrown" and the speed of the vehicle?
3. What are some of the factors (besides speed) that affect the distance the occupant is thrown from trial to trial?

Challenge

Devise an experiment to "idealize" the Inertia and Unrestrained Occupant activity. You will need a device to propel an object at different velocities that increase evenly, and an object that comes to rest in a regular manner.

Summary

The relationship between the distance an unrestrained occupant is "thrown" and the velocity of the car is called an exponential relationship. These types of relationships are common in the ideal world described by our physics equations. In the real world, an exponential relationship means that as one variable increases, the other increases at a faster rate. That is, if you double the speed of a car in a collision, the distance an occupant can be "thrown" increases by more than double. In other words, speed kills.

In our real world experiment, the distance that the occupant is "thrown" varies from trial to trial. The size and symmetry of the occupant, his/her limbs, the angle at which the occupant contacts the ground, and skid all affect where the occupant lands. In an idealized experiment, if you double the speed of a car in a collision, the distance a occupant can be "thrown" increases by a factor of four!

Think About IT!

1. What is the "ideal" relationship between the distance an unrestrained object is "thrown" and the speed of the object?

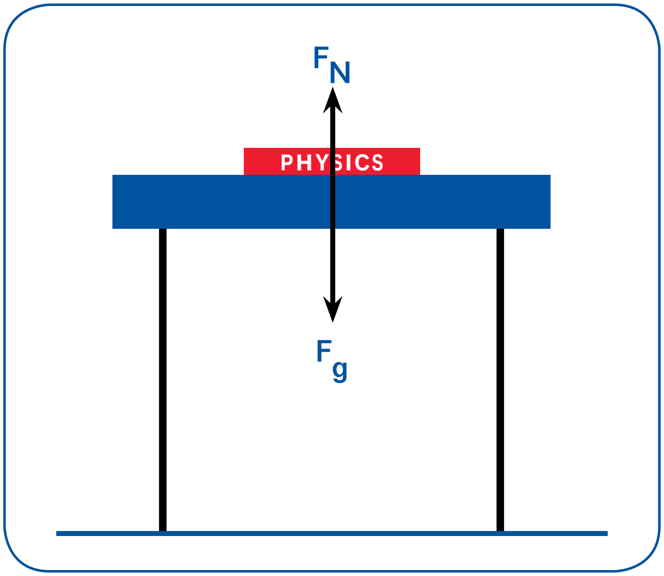
Speed Kills

It is often tempting to drive above the speed limit. However, the laws of physics suggest that assessing the risks associated with speeding are worth consideration. History also proves our point. In the 1970s during the oil crisis, the United States government reduced speed limits to conserve fuel. The number of crashes and deaths were also reduced substantially.

Chapter 4

Forces and Motion

We know from Newton's First Law of Inertia that an object at rest remains at rest and an object in motion remains in motion unless acted upon by an external unbalanced force. A force is unbalanced when it is not cancelled by another force. For example, if a book rests on a table, the force of gravity pulls the book down but the book does not move. Another force, the force of the table pushing up (called the normal force, F_N), balances the force of gravity. If we remove the table, the force of gravity is no longer balanced by the normal force and the book falls to the ground.



There are lots of different ways to exert an unbalanced force on an object. We could push it, pull it with a string or rope, or use gravity, electrical or magnetic forces. Even the force of friction can be an unbalanced force when no other forces are acting on the object.

Atwood's Machine

In 1784, George Atwood published one of the first textbooks on Newtonian mechanics. The textbook, titled *A Treatise on the Rectilinear Motion*, included a device, now known as Atwood's machine, to investigate Newton's laws. Two different masses were suspended over a pulley by a light cord. The pulley turned with a very low friction and the acceleration of the system of masses was measured. We will use a slightly different pulley system, based on Atwood's ideas, to demonstrate the relationships between force, mass and acceleration for a dynamics cart.

Think About IT!

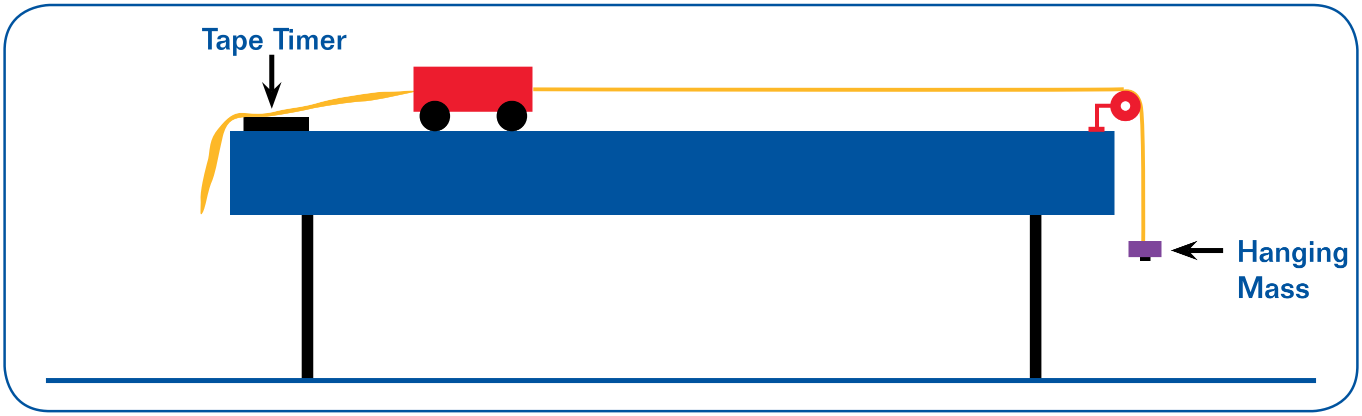
1. A car accelerates from a stoplight, slows down and turns left into a driveway, and then brakes to stop. Summarize the forces that are acting on the car.
2. Draw a diagram to show the forces on the car in question #1. Each time the forces change, draw a new diagram.

Investigation #3 FORCE AND ACCELERATION

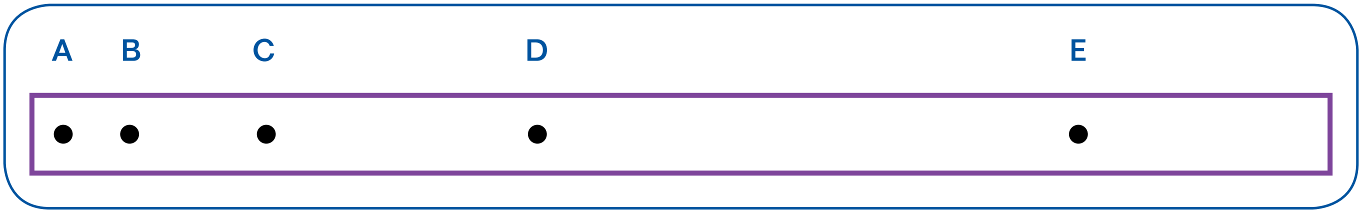
Newton's first law tells us how an object behaves when it is at rest or in motion with no unbalanced forces acting on it. What happens if an unbalanced force acts on an object?

Procedure

1. Set up the following apparatus using a tape timer, a dynamics cart (or similar), and a pulley and mass system.



2. To measure the motion of the cart, use a method similar to Chapter 2. Start the tape timer (you could also use a motion detector or a video recorder) at the same time that you release the falling mass. The force of gravity acting on the mass pulls the cart with a constant force. Examine the spacing of the dots on the ticker tape. A typical dot pattern looks like this:



Think About IT!

1. From the tape and the spacing of the dots, what can you conclude about the relationship between a constant force and motion?

Math Connection

We can more accurately investigate the changes in velocity by graphing instantaneous velocity versus time. Repeat the procedure from Chapter 2 by copying and completing Tables C, D and E from pp. 18 - 20 and the graph of velocity versus time. Remember that the average velocity of an interval closely approximates the instantaneous velocity at the midpoint of the interval. From the graph of velocity versus time, what can you conclude about the relationship between a constant force and the motion?

Summary

We can tell by the spacing of the dots that a constant force causes the cart to accelerate. If we analyse the motion and graph velocity versus time, we find that the line is straight, meaning that the acceleration is constant. That is, a constant force causes constant acceleration.
So far, we have found that:

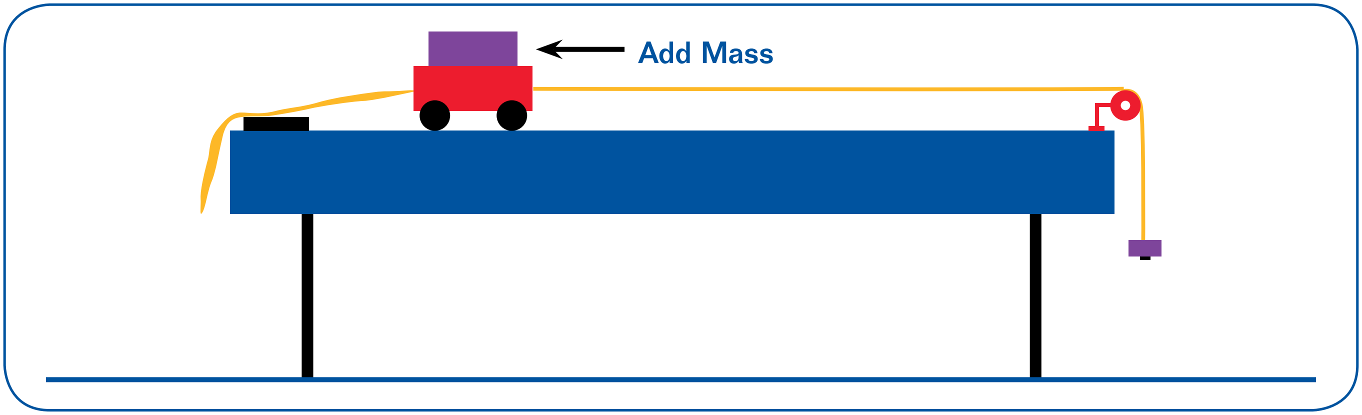
- When the force on an object is zero, the acceleration of the object is also zero (inertia),
- When we apply a constant force to an object, the acceleration of the object will also be constant.

Think About IT!

1. Make and compare 2 concept maps on force and motion. The first concept map uses the central idea, "forces are balanced", and the second uses "forces are unbalanced".

Investigation #4 MASS AND ACCELERATION

To find the relationship between mass and acceleration, we can repeat the experiment using a larger dynamics cart. Increase the mass of your dynamics cart each time and repeat the procedure of Investigation #3 to find the acceleration for each case.



Think About IT!

1. From the data, what do you conclude about the relationship between mass and acceleration?

Math Connection

We can more accurately investigate the relationship by graphing mass versus acceleration. Describe the curve on the graph of mass versus acceleration. From the graph, what do you conclude about the relationship between mass and acceleration?

Investigation #5 FORCE AND MASS

To find a relationship between force and mass, we can repeat the experiment again using another dynamics cart. Double the mass of your dynamics cart and experiment to find the force that produces exactly the same acceleration as the first case.

Think About IT!

1. **From the data, what do you conclude about the relationship between force and mass?**

Summary

We know from our own experiences that if we increase the mass of an object, it becomes more difficult to accelerate. A mass is like a resistance to motion. Therefore, it takes more force to accelerate a larger mass. By carefully examining many different cases, we know that if we double the mass we must double the force in order to produce the same acceleration. In mathematical terms, force is proportional to mass.

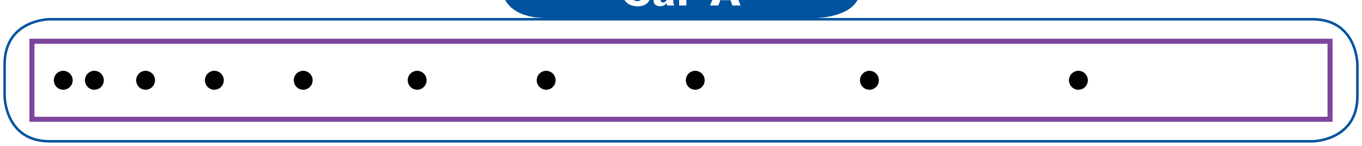
We also know from our own experiences that when we push heavier objects, the objects accelerate more slowly. If we collect several examples and graph mass versus acceleration (when a constant force acts on an object), the graph is an inverse curve. A curve of this type means that as the mass increases, the acceleration decreases at exactly the same rate. In this case, our experiences and the mathematical analysis tell us the same thing.

Force and acceleration are important principles to understand before you drive a car. Cars constantly stop and start their motion, especially in traffic. If we apply large forces, we accelerate rapidly. Remember the dot spacing! This means that for equal intervals of time, the car will cover a larger distance, making it more difficult to react to changes on the road in front of you. Young children often have difficulty judging such distances, making it imperative that the driver accelerate such that the speed of the car increases at a controlled pace.

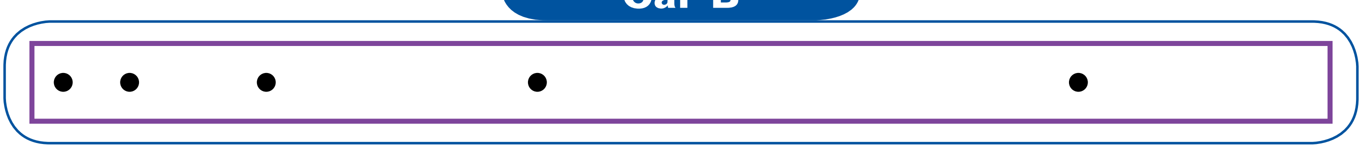
Think About IT!

1. **The following tapes illustrate the interval spacing for two cars accelerating from a stoplight. Some distance down the road, where children are playing, a ball rolls onto the road. Write a paragraph to explain the situation to a new driver in terms of force and motion.**

Car A



Car B



Force and Direction

So far we have considered objects that accelerate by changing their speed in a straight line only. Consider what takes place when a car enters a curve in the road. What happens if the road is slippery (like after a rain) or if the speed of the car is too great as it enters the curve?

Remember Newton's First Law of Inertia? A car in motion will stay in motion unless acted upon by an unbalanced force. In this case, unless there is a force to change the direction of the car, then the car continues in a straight line into the ditch. That is, a force is needed to change the direction of motion.

Physicists refer to any change in motion, including directional changes, as acceleration. For a car negotiating a curve, the external force comes from the friction between the tires and the road. If this force is reduced, then little or no change in direction will occur. For this reason, on an icy day it is not unusual to find a number of cars in the ditch near a curve in the road.

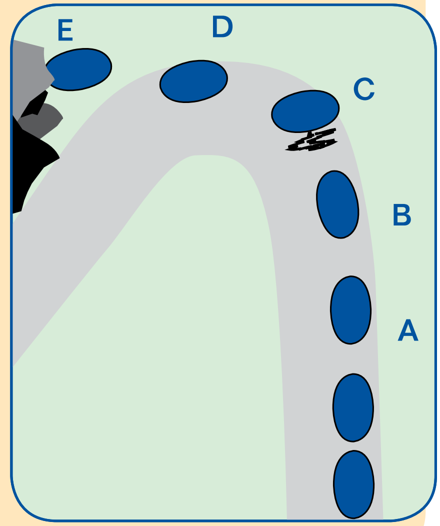
Cornering

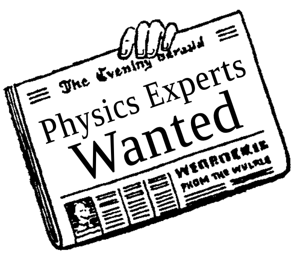
Forces are required to change the direction of motion. In order to maximize and properly balance the cornering forces, cyclists must "lean" when they make a turn. If the cyclist doesn't lean correctly he could topple over or the wheels of the motorcycle could slide out from under him or her. Experience and practice are important to safely learn how to corner a two-wheeled vehicle. In Manitoba, motorcycle instructional courses are mandatory and offered by experienced motorcyclists.

Think About IT!

1. Make a table or concept map linking the main ideas for position, velocity, acceleration, force, direction, and "changes in".
2. Why is a racetrack banked around the corners?
3. A car accelerates rapidly from rest to point B. At point B the driver removes his foot from the gas pedal and enters a curve. At point C, the car encounters "black ice" on the road and the rear wheels of the car skid outside of the radius of curvature of the road. At point D the car continues in a straight line into the ditch at point E, where the car slams into the bank and stops. The windshield is cracked.

   Analyse this scenario in terms of Newton's laws of motion.
4. Why does a water skier (or a hockey player) lean in order to turn?





In the opening chapter of this book, a car crash scenario was described. As a physics expert, review the scenario and write a report to the police describing the motions before and after the collision. Who is telling the truth, the motorcyclist or the car's driver?

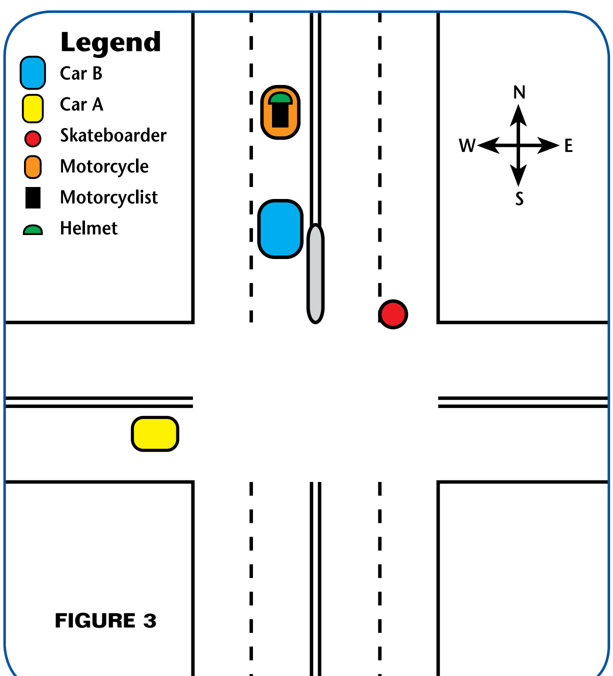


FIGURE 3

Car Crash After

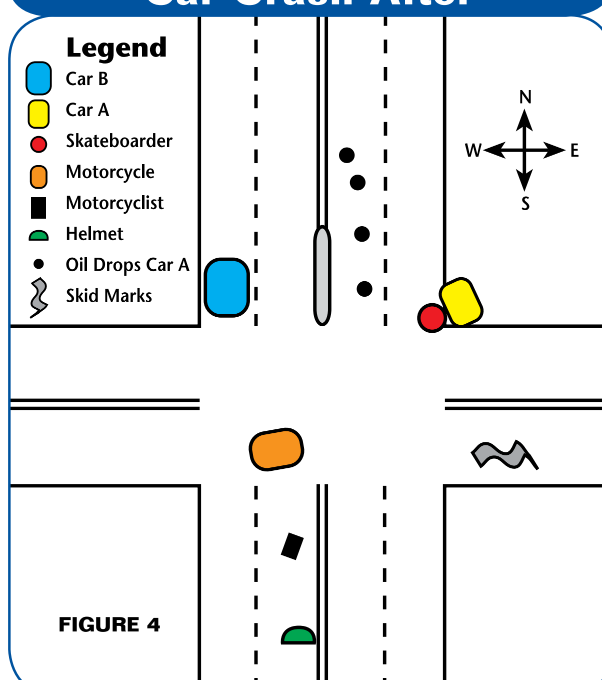
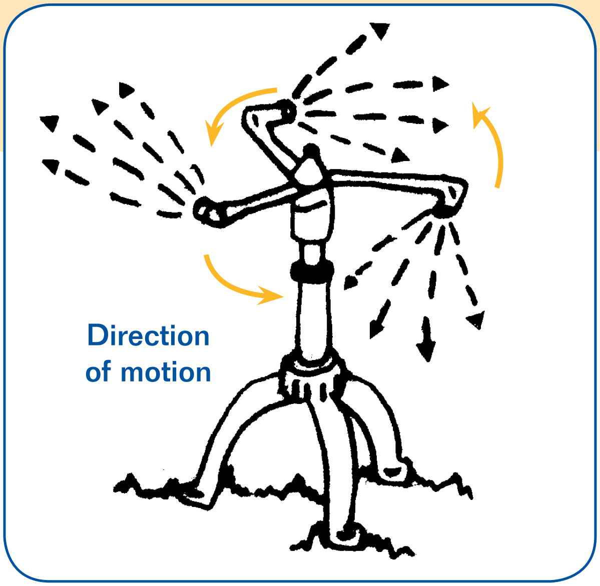


FIGURE 4

Action-Reaction Forces

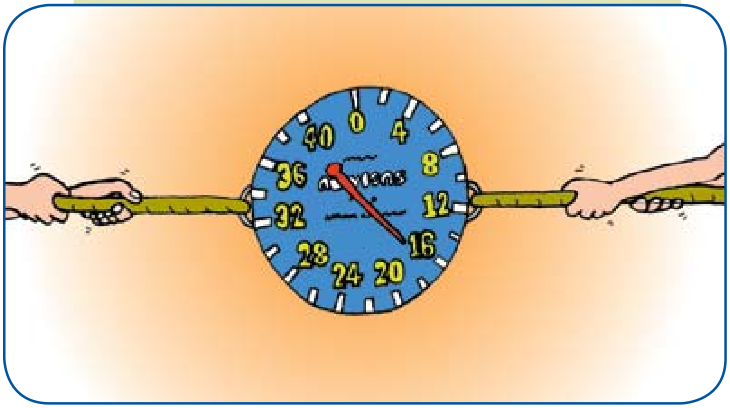
Think About IT!

What makes the sprinkler head turn?



Try IT!

Two students of different masses pull on two pieces of rope that are connected by a spring scale to measure force. What does the scale read? How do we know that the force exerted by the small student is exactly the same as the force exerted by the heavier student?



All forces arise from interactions. Common forces, like the attraction of gravity and the attraction and repulsion of electric and magnetic forces, always occur in pairs. Whenever two objects interact with each other, they exert these types of forces on each other. We call these force pairs or action-reaction forces. Newton summarized these interactions in his third law:

"For every action, there is an equal and opposite reaction."

In all cases, the magnitudes of the forces are equal and the forces act in opposite directions. Consider a book resting on a table. The force of gravity acts downward and the table pushes back with an equal and opposite force. If you're not convinced, try removing the table. Remember the relationship between force and acceleration. Unbalanced forces cause acceleration. Since the force of gravity and the force exerted on the book by the table are balanced, the book resting on a table does not accelerate. If you remove the table, there is no force to balance gravity and the book accelerates downwards.

Think About IT!

1. In each of the following cases, sketch the situation and label the action-reaction pairs.
   a) A person leans against the wall.
   b) A car rounds a corner with a constant velocity.
   c) A fish swims.
   d) A skateboarder jumps.
   e) A gun recoils.
   f) A hockey player takes a slapshot.
2. While driving down the road, a mosquito collides with the windshield of your car. Which of the two forces is greater: the force that the mosquito exerts on the windshield, or the force that the windshield exerts on the mosquito?
3. Two students are facing each other while standing on their skateboards. One student throws a mass (such as a medicine ball) to the other student. Describe what happens in terms of force and motion.

4. In terms of action-reaction force pairs, explain why it is important to use helmets, elbow pads, knee pads, and other protective clothing when using skateboards or in-line skates.

Design Challenge: The "Rocket" Car Race

Use the principles of Newton's Third Law to build and race a rocket car. The car that goes the furthest is the winner.

Suggestions for propulsion – a balloon, a straw, a slingshot design, a mousetrap.

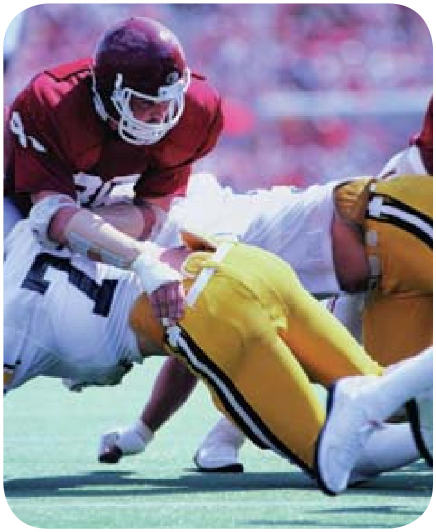
Suggestions for wheels – CDs, pop bottle tops, styrofoam cups (cut to fit), spools.

Suggestions for the frame – cardboard, styrofoam plates.

Chapter 5

Momentum and Energy

Momentum



In everyday life, we often use the word momentum to describe a sports team or a political party that is "on a roll" and is going to be difficult to stop. The common usage of the term momentum has roots in the physics world. Any object that is moving has momentum, and in order to bring the object to rest we must change this momentum to zero.

What makes an object difficult to bring to rest? Would you rather collide with a train moving at 2 m/s or a mosquito moving at the same speed? The answer is obvious: the train can crush a car. However, in the second case, the pesky mosquito never even dents your windshield.

Momentum is a term we use in physics to describe a quantity of motion. If an object is in motion then it has momentum. What are the characteristics of momentum?

Well, from our train and mosquito example, we know that the mass of the train makes it more difficult to stop than a mosquito moving at the same speed. This should make sense if you recall from our discussion of Newton's laws that mass is a resistance to acceleration. Certainly, more mass means more resistance to acceleration, and the more difficult it is to bring the object to rest. However, momentum is not the same as mass. A massive boulder resting on the side of the road has no momentum at all – it is already at rest!

Objects that are moving fast are also hard to stop. Bullets have a very small mass but it can be extremely difficult to try and stop one! If we wish to bring an object in motion to rest, we must take into account its velocity as well as its mass. Newton called this the principle of momentum. Simply stated, if a moving object has more mass, it has more momentum, and if an object has more velocity, it has more momentum. That is, if either the mass or velocity (or both) of an object increases, the object will be more difficult to bring to rest.

Think About IT!

1. In the table below, try to order the following objects according to their momentum. Comment on the reasoning for your choices.
   Transit bus, football, sprinter, statue, race car, marathon runner, slapshot, building, skateboarder

Object	Amount of Momentum (describe in your own words)	Comments

Math Connection

Since the momentum of an object is directly proportional to both its mass and its velocity, we can easily write this as a mathematical relationship.

$$\text{Momentum} = (\text{mass})(\text{velocity})$$

or in SYMBOLIC FORM $\mathbf{P} = m\mathbf{v}$

(Why do you suppose physicists use the symbol P to represent momentum?)

Momentum is a vector quantity. Its direction is always the same as the direction of the objects' velocity.

We can compare the momentum of the objects in the table by multiplying their mass by their velocity. In the following table, the mass of each object is given. Estimate the velocity of the objects in km/h and calculate their momentum. Compare the calculated results to your order in the previous table.

Object	Mass (kg)	Velocity (km/h)	Momentum (kg-km/h)	Comments
Transit bus	**8 000**			
Football pass	**0.5**			
Sprinter	**75**			
Golden Boy statue	**1 650**			
NASCAR Stock Car	**1 545**			
Marathon runner	**65**			
Slapshot	**0.15**			
Building	**1 000 000**			
Skateboarder	**68**			

Impulse and Momentum

In order to change motion we need to apply a force. If we continue to apply a force for a long period of time, the object will continue to accelerate, increasing (or decreasing) its velocity more and more. Since we defined momentum as mv, then as the velocity of the object increases, so does its momentum. Therefore, in order to find a change in momentum, we must also know for how much time a force is applied. We call the amount of force and the time during which the force is applied the impulse. If we have more force, we have more impulse. Additionally, if we apply the force for a longer period of time, we also have more impulse. In this way, impulse is proportional to force and time. Consequently, we can define impulse as the product of force and time.

$$\text{Impulse} = (\text{force})\ (\text{time})$$

or in SYMBOLIC FORM

$$\mathbf{I} = \mathbf{F} \times t$$

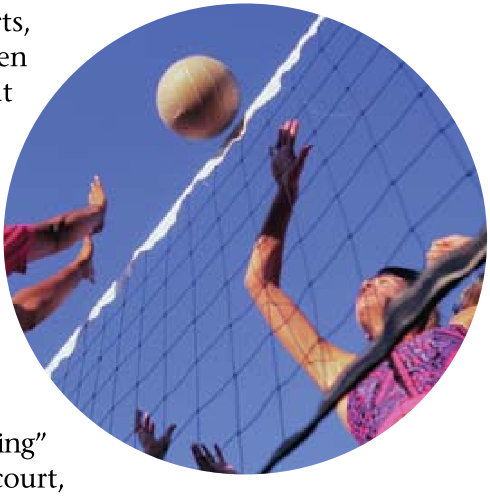
Impulse is also a vector quantity. It has the same direction as the applied force.

The fact that impulse depends on both force and time means that there is more than one way to apply a large impulse to an object – you can apply a very large force for some time, or apply a smaller force for a very long time (or both!).

If an unbalanced force acts on an object it will always cause the object to accelerate. The object either speeds up or slows down. If the force acts opposite to the object's motion, the object slows down. If a force acts in the same direction as the object's motion, then the object speeds up.

Thus, when the velocity of the object is changed, the momentum of the object is also changed. When something exerts a force on you, it also exerts an impulse on you. Forces and impulses always go together. Very simply stated, impulse changes momentum. This relationship is very closely related to Newton's Second Law.

Using the Impulse-Momentum Relationship



If you play sports, your coach has been teaching you about impulse and momentum for many years. In most sports we wish to change the velocity of an object for many different purposes. Hitting a home run, "bumping" on the volleyball court, deflecting a shot on goal, driving a golf ball, or serving on the tennis court require that we change the velocity (and therefore the momentum) of the ball or puck by applying an impulse. In order to improve your performance, the coach might first suggest that you hit the ball harder by building up strength. Increasing your fitness enables you to apply a larger force. Later, your coach will constantly remind you about "following through" in your technique. By developing sound technique, as you follow through, you can increase the amount of time the force acts on the object. Sometimes we want small forces applied on objects, and other times we want large forces. However, if you try to apply too much force you can lose control and your timing is less accurate.

Think About IT!

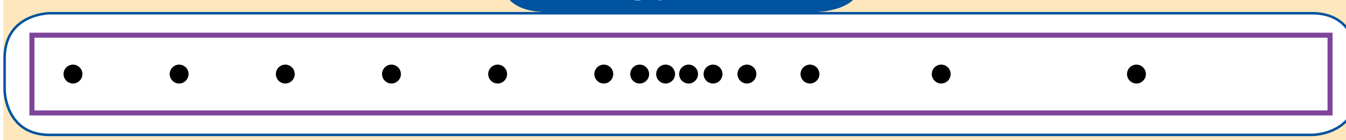
1. Impulse depends on both force and time. Give an example for each case:
   a) a large force for a short time
   b) a small force for a long time
   c) a large force for a long time
   d) a small force for a short time

2. Analyse each of the following situations in terms of impulse and momentum changes. Discuss possible ways to improve performance.

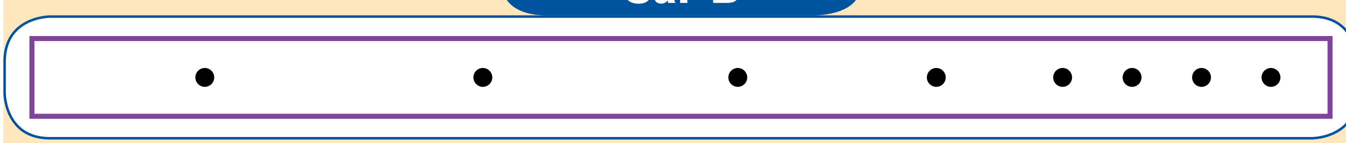
   a) A professional golfer needs a larger impulse on his drives and a much smaller impulse for his putting.
   b) A gymnast performs a reverse somersault as he dismounts from the high bar.
   c) A volleyball player "sets up" a spike shot.
   d) A baseball player hits a grand slam.
   e) A car brakes for a yellow light.
   f) A bat catcher catches a fastball.

3. Two cars of equal mass are driving down Portage Avenue with equal velocities. They both come to a stop over different lengths of time. The ticker tape patterns for each car are shown on the diagram below.

Car A



Car B



   a) At what approximate location on the diagram (in terms of dots) does each car begin to experience an impulse?
   b) Which car (A or B) experiences the greatest change in momentum? Explain.
   c) Which car (A or B) experiences the greatest impulse? Explain.
   d) Which car (A or B) experiences more than one impulse?

4. A halfback in a football game (m = 60 kg) runs across the field at 3.2 m/s. An opposing lineman (m = 120 kg) is running toward him at 1.8 m/s. What is the result of their head-on collision?

5. If both the boulder and the boy have the same momentum, will the boulder crush the boy? Explain using the principles of impulse and momentum.

6. It is said that a fool and his money are soon parted. Suppose we place the fool and a gold brick in the middle of a frictionless, frozen lake (Galileo's ideal frozen lake). How can the fool rescue himself? Is he still a fool?

7. How can a spacecraft change direction when it is in deep space?

Cushioning the Blow

The impulse-momentum relationship is extremely important for understanding how to protect yourself and your occupants from personal injury in a car collision. A 2 000-kg car moving at 50 km/h has a tremendous amount of momentum. In order to stop the car, the car's momentum must be reduced to zero. The only way to do this is to apply an impulse opposite to the car's motion. To safely brake the vehicle, we apply an impulse by exerting a force on the wheels for a long period of time. In cases where the car stops rapidly, as in a collision, the impulse is applied over a short duration of time, resulting in very large, destructive forces acting on the car and its occupants. In order to cushion the blow, manufacturers have invented several devices that use the impulse-momentum relationship by increasing the amount of time for the impulse and, consequently, decreasing the applied force.

It's kind of like an egg toss. If you catch the egg without allowing your hands to "give", then the force is usually too large for the egg and the egg breaks.

Challenge

Can you and your classmates design another activity to demonstrate the cushioning effect of the impulse-momentum relationship?

Try IT!

Two students hold a large blanket upright. Another student throws an egg into the blanket.

You should curl the bottom of the blanket so that the egg doesn't drop on the floor.

Be sure to throw it hard.

Cushioning Devices

Bumpers

Bumpers are designed to minimize the damage to a vehicle in a collision by absorbing some of the impulse. Today, cars use bumpers that have the ability to compress because of their material and/or through the use of a special kind of bumper mechanism.

Crumple Zones

A crumple zone is a part of a car that is designed to compress during an accident to absorb the impulse from an impact. A crumple zone increases the amount of time it takes the car to stop, and therefore decreases the amount of force in the impulse. Crumple zones mean that the impulse is reduced before it is passed on to the occupant compartment.

Padded Dashboards

If a driver or occupant hits the dashboard in a collision, then the force and time required to stop their momentum is exerted by the dashboard. Padded dashboards increase the duration of the impact, minimizing the amount of the force of the impulse.

Think About IT!

Why are the bumpers on cars today much more absorbent than cars fifty years ago?

Try IT!

A crumple zone behaves much like a pop can crusher.

Seat Belts

According to the law of inertia, if a car stops abruptly, the occupants and all other objects in the car maintain their forward momentum. In order for an occupant to come to rest, another collision is required. In a vehicle collision, the seat belt restrains the occupant and prevents him or her from impacting the steering wheel, dashboard or windshield, and helps absorb the occupant's forward momentum. Injuries are reduced as the impact force is distributed to the strongest parts of the body. An unrestrained occupant who is thrown from a vehicle is likely to be severely injured.

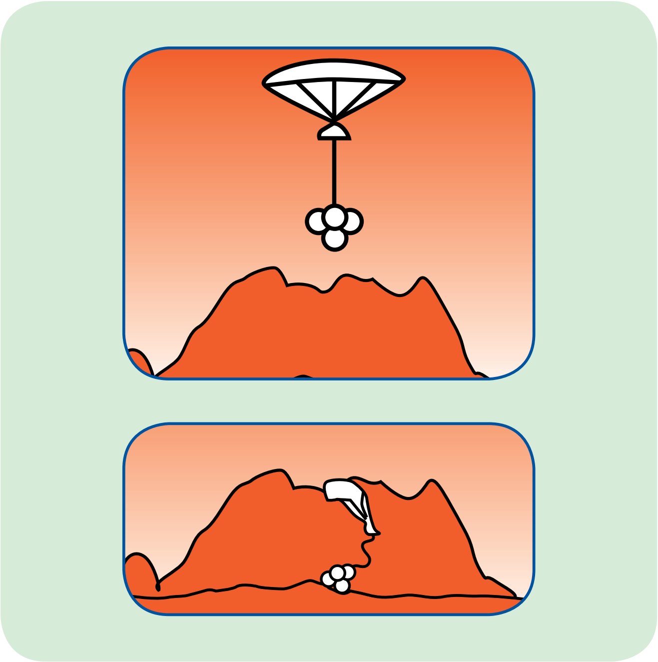
Car crash researchers estimate that seat belts reduce the risk of fatal injury to front-seat occupants by up to 45 per cent and the risk of serious injury by 50 per cent. The United States National Highway Traffic Safety Administration reports that 3 out of every 5 people killed in vehicle collisions in the US would have survived their injuries if they had buckled their seat belt.

Air Bags

In a car crash, the driver and occupant keep moving according to the law of inertia. A second collision is required to bring the occupant to rest. These secondary collisions are caused by impacting the steering wheel, dashboard, windshield, or other rigid structures. Since the secondary collisions happen very rapidly, a large force is being exerted over a very short period of time. Air bags can be used to minimize the force on a person involved in a collision. Air bags cushion the blow by increasing the amount of time during which the force is applied. Since the time of impact increases, the amount of force of the impulse decreases.

Research shows that air bags can save lives by reducing the risk of fatality in frontal impacts by about 30 per cent. However, air bags can be dangerous to children and small adults if they are not seated correctly when the air bag is activated. All occupants of vehicles with air bags need to be aware of the correct seating for maximum protection from collisions. Children and infants should be buckled into the rear seat in a properly installed car or booster seat. Infants should never ride in the front seat and should be carefully belted into a rear-facing safety seat.

Air bags are so effective that they were even used to cushion the impact for the Mars Pathfinder. Today, air bags are standard equipment in most automobiles, and some manufacturers are now including side air bags to help prevent injury caused by side impacts.



Head Restraints

Head restraints, or headrests, prevent soft tissue or "whiplash" injuries by stopping your head and neck from overextending in the event of a crash. Once again, in order to reduce the force of the impulse, a cushioning material is used to extend the duration of the impact, which reduces the force. However, head restraints only work if they're adjusted properly. The upper edge of the headrest should be the same height as the top of your head. The distance between your head and the headrest should be as small as possible and should not exceed 4 cm.

Rigid Occupant Cell

Safety systems are not just good practice for occupant cars. According to the latest Canadian statistics (for 1990 to 1996), 146 Canadians were killed on farms when the tractors they were driving rolled over and crushed them. Most of these deaths could have been prevented if the driver had been protected inside the tractor's cab by a rollover protective structure and the use of a seatbelt.

A rollover protective structure (ROPS) is a rigid structure built around the cab of a vehicle. In case of a rollover, the ROPS can support the weight of the vehicle and prevent the driver being crushed. devices in their work. They call the area inside the ROPS structure the "zone of protection", and appropriate precautions are taken so that the driver never leaves the safe zone. That includes the use of seat belts to keep the driver from being thrown against the ROPS frame, against the windshield, or completely out of the vehicle.

Child Safety Seats

According to Transport Canada, about 10,000 children 12 years and under are injured every year in traffic collisions in Canada. Children are not the same size as adults and require special consideration and protection when they are travelling in a vehicle. While it is mandatory for children under 5 years of age to be buckled in an approved child restraint system, as many as 90% of child safety seats are not properly installed or correctly used. Every forward-facing seat must be tethered to an anchor bolt; it's the law. The following table highlights the proper use of child restraint systems.

Protect Our Children. Always Use Children's Safety Seats Correctly.

	Type of Seat	Seat Position
Infants	Infants under 10 kg (22 lb) and 66 cm (26 in) must be in a rear-facing safety seat that is secured to the vehicle using the vehicle's restraint system (lap belt).	**Rear-facing only**
Toddlers	Toddlers 10 to 18 kg (20 to 40 lb) and 66 to 101 cm (26 to 40 in) tall must be in a forward-facing safety seat that must be tethered to the metal frame of the vehicle by an anchor bolt.	**Forward-facing**
Young Children	Children weighing more than 18 kg (40 lb) must be in a booster seat that is secured using the vehicle's restraint system.	**Forward-facing**
Older Children	Children weighing more than 32 kg (70 lb) may use a regular seat belt system. The lap belt should be worn low over the hips, and the shoulder belt should always be across the chest, never touching the face or neck.	**Forward-facing**

Manitoba Public Insurance, in collaboration with Manitoba Fire Departments, conducts free child car seat safety inspections at participating community fire stations. Call the MPI Road Safety Department at (204) 985-7199 for more information.

Help Protect Our Children!

Think About IT!

1. Research one of the safety devices, how it works, and statistics that show its effectiveness, future development, and safety standards. Make a poster and invite classmates and guests for a gallery walk to inspect the posters.
2. Design a car using the most modern safety features available.
3. Investigate NASCAR regulations that require drivers to adhere to strict safety protocols including rollover cages, seat belts, neck and head restraint systems, and crumple zones.
4. What are some other examples of devices that might use crumple zones, padded cushions, air bags, rollover cages, or bumpers?
5. Research the contribution of the following individuals to car safety.
   a) Dr. Claire Straith
   b) Bela Berenyi
   c) Nils Bohlin
   d) John Hetrick
   e) Ralph Nader

Protecting Occupants

The Great Egg Drop Competition

According to Newton's physics, occupants in motion will continue in motion until they experience an impulse to reduce their momentum to zero. Safety engineers build protective devices that cushion the blow to reduce injury. Your task is to design and construct an occupant compartment that will protect the occupant (a raw egg) from injury (breaking) when dropped from some height.

Think About IT!

1. Should your package be made rigid or is it better if it collapses?
2. Should the egg be able to move or should it be held secure?
3. What kinds of materials or structures will absorb the shock of impact?
4. Is your compartment pleasing to look at? Remember, no one wants to buy an ugly car.

Guidelines

1. The compartment must be an original design.
2. Use common materials like cardboard, styrofoam, cotton, clear wrap, elastics, straws, ribbon, felt and tape to build your device.
3. The compartment must be no larger than a 10 cm x 10 cm x 10 cm cube.
4. You must be able to easily remove your occupant (the egg) from the compartment for inspection.
5. Drop your compartment from some height to a hard surface. The compartment that best protects the occupant from the highest drop wins.

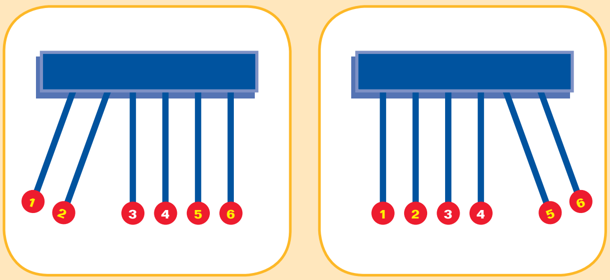
Scoring Rubric

1. **Originality** – Is the design unique, creative, and aesthetically pleasing? (maximum 25 points)
2. **Performance (Challenge One)** – All designs that protect the occupant to a height of 3 metres will be awarded full credit. (maximum 25 points)
3. **Performance (Challenge Two)** – The compartment that protects the occupant to the greatest height receives the most points. Points are prorated for compartments that work at a height of more than 3 metres but less than the greatest height. (maximum 25 points)
4. **Written report** – Include a written summary of the physics principles pertaining to your compartment. Try to use analogies to other safety devices. (maximum 25 points)
5. In case of a tie, the lightest compartment wins.

Momentum and Energy in a Collision

Think About IT!

The device in the figure is called Newton's cradle.



In each of the following cases, predict what will happen before you release the spheres.

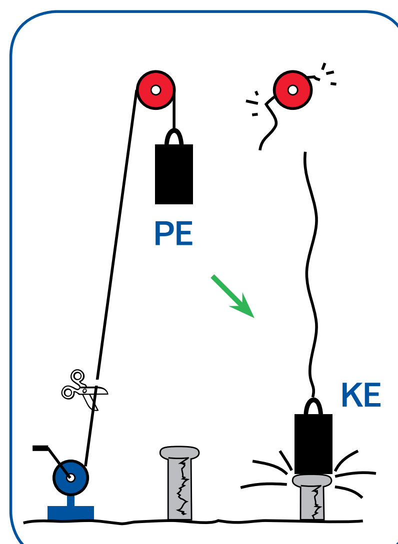
1. **Pull one sphere away from equilibrium and release.**
2. **Pull two spheres away and release them at the same time.**
3. **Pull three spheres away and release them at the same time.**
4. **Pull one sphere away from each side and release them at the same time.**

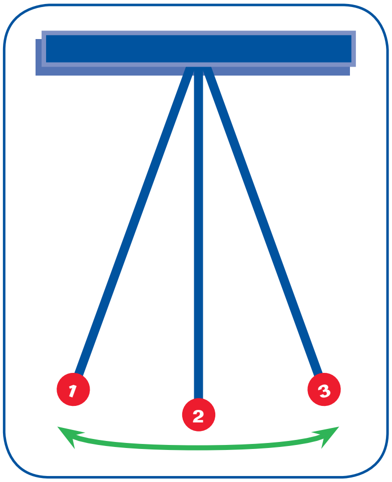
Collisions between objects are governed by laws of momentum and energy. Careful measurements before and after ideal collisions show that the momentum of all objects before a collision equals the momentum of all objects after the collision (provided there are no net external forces acting upon the objects). When a collision occurs in an isolated system, the total momentum of the system is always conserved. If there are only two objects involved in the collision, then the momentum lost by one object exactly equals the momentum gained by the other object.

Energy

At the beginning of this chapter we asked the question "what makes an object difficult to bring to rest?" We concluded that every moving object has a "quantity of motion" that was proportional to its velocity that we called momentum (mass x velocity). We also found that to change momentum we needed an impulse – a force that was applied over a period of time. All of these concepts fit very nicely with Newton's second law. However, we can think about motion differently.

If we push a book across the desk so that it accelerates, we give the book an impulse – we apply a force on the book for a period of time. However, the book also moves some distance during this time. That is, we also apply the force across a distance. Whenever we apply a force on an object across a distance, we say that we are doing work on that object. Work is the transfer of energy to an object by applying a force to the object through some distance. When we do work on the object, we change some condition of the object, either its position in space or its velocity. If we change its position, such as lifting a mass above the surface of the earth, the work we do is stored as gravitational potential energy (PE). If we change its velocity, the work is stored as kinetic energy (KE).



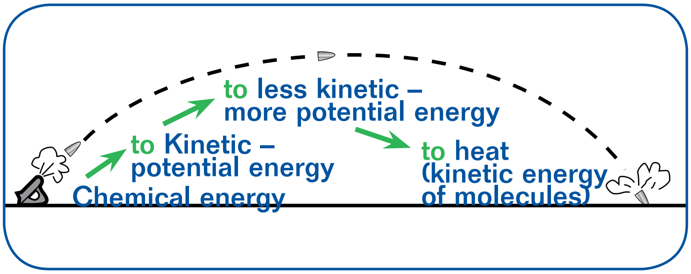


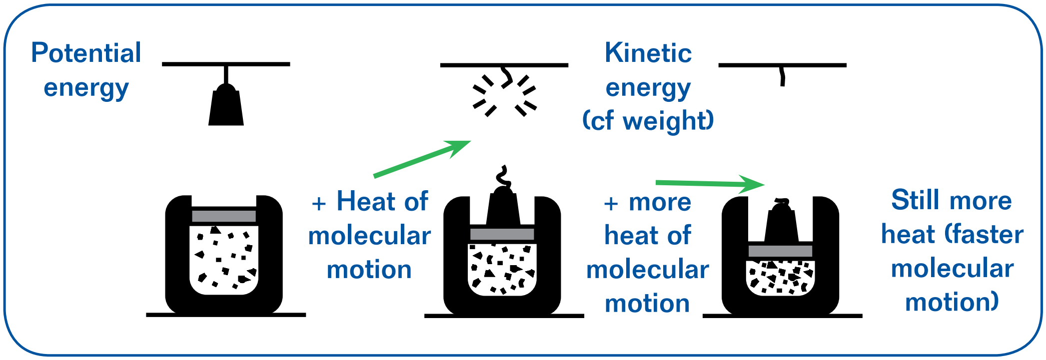
Suppose that a mass is attached to the end of a string and is set in motion as shown in the diagram. The pendulum comes to rest at the top of its swing (1) then falls back in the other direction. As the pendulum bob falls back, it reaches a maximum speed at the bottom of its swing (2). Then, it rises up the other side as its velocity decreases and once again comes to rest at the top of its swing (3). The motion repeats, and if there is no friction or outside forces (as in Galileo's thought experiments) the pendulum will swing forever. We can explain this motion by the principles of work and conservation of energy. Initially, we do work on the mass to raise it above its starting position. This work is stored as potential energy. When we release the mass, gravity does work on the mass and some potential energy is converted to kinetic energy. At the bottom of the swing all of the energy is stored as kinetic energy. In turn, the kinetic energy is transformed back into potential energy as the pendulum rises on the other side of its swing. The cycle repeats and, in the absence of any outside forces, the motion continues forever.

Energy can be transformed into other forms besides potential and kinetic. The kinetic energy of molecules in motion is known as heat and if we displace molecules of air by creating a pressure wave, the energy is transmitted as a sound wave.

René Descartes argued that energy must be conserved; otherwise, the world would run down like a tired old clock. Scientists, beginning with James Prescott Joule, have since made very careful measurements to show that energy is conserved in all interactions.

In the real world there are always outside forces. However, the principle of conservation of energy still remains valid. Energy can be stored in other forms besides gravity and motion. Energy can be stored electrically, chemically, in elastics and springs, as sound energy, and as thermal energy. If you rub your hands together very quickly, what do you feel? Your hands will feel warm as the kinetic energy of the motion of your hands is converted to thermal energy through friction. If you clap your hands together rapidly, what do you hear? If you stretch an elastic band and then release it, what happens? As you do work stretching the band, the energy is initially stored as potential energy in the band. Then, as you release the band the potential is transformed into the kinetic energy of the motion of the parts of the band as the ends accelerate toward each other. Finally, as the particles of the band collide, they compress the molecules of the air and the energy is transferred to your ear as a sound wave.





In a car crash, since the final kinetic energy and momentum of the vehicles are zero, all of the initial kinetic energy must be dissipated during the collision to other forms of energy. Unrestrained occupants and objects in the vehicle are like missiles with huge amounts of energy. In order to stop these moving objects, forces are required. These forces often cause severe personal and property damage.

Think About IT!

1. **What would the world be like if energy was not conserved? Give examples.**
2. **Where does the kinetic energy come from when a car accelerates from rest?**

PRACTICE

In the following cases, analyse the transformations of energy in terms of conservation of energy.

1. The motion of a car on a roller coaster. NOTE: This roller coaster was manufactured by Galileo's Ideal Physics Factory.

2. The motion of the bungee jumper.

3. Car A accelerates from a stoplight until it reaches the posted speed limit of 30 km/h. At the intersection, a pickup truck "runs" the stop sign. The driver of Car A applies the brakes and in an attempt to avoid the collision leaves skid marks on the road. A loud crash is heard as the car impacts the side panel of the truck.

4. A pole vaulter.

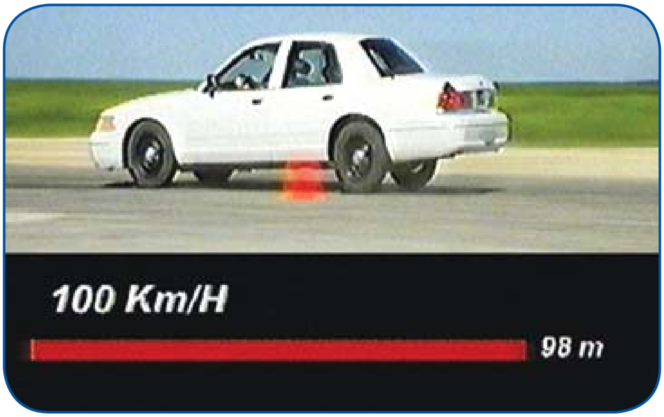
5. A child on a pogo stick.

6. Two cars with spring-loaded bumpers collide at a low speed and bounce off each other. Describe the collision in terms of the energy transformations that occur for the cars. What about the occupants of the cars?

Chapter 6

Braking

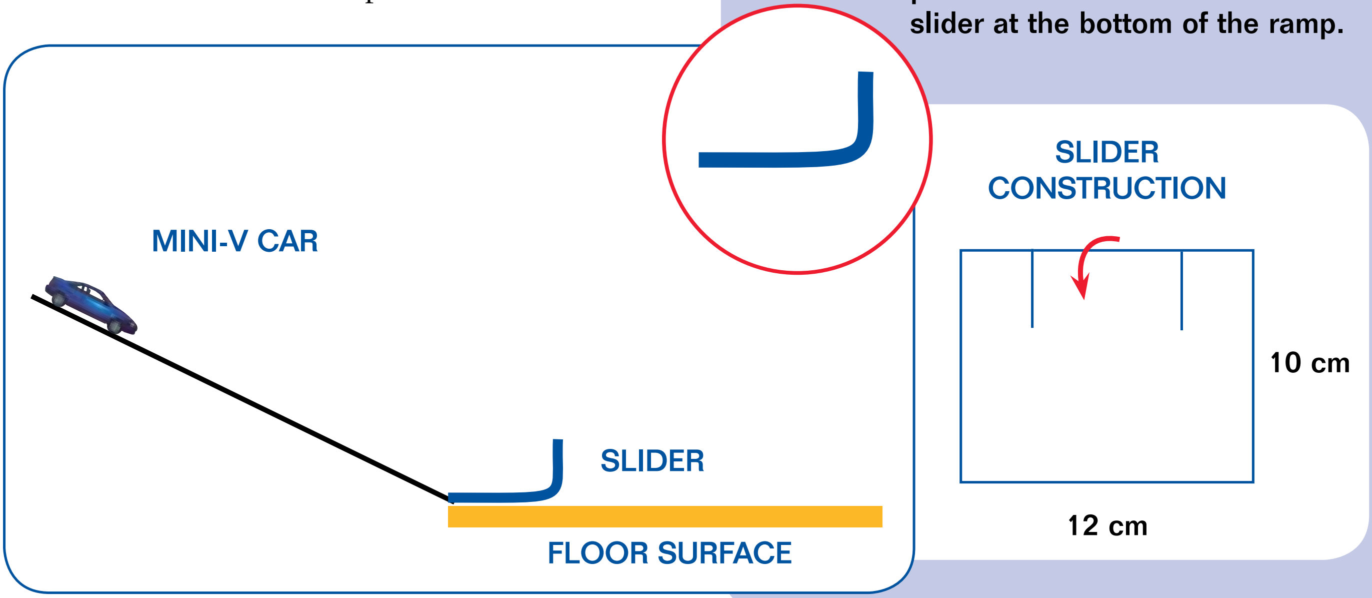
When a driver applies the brakes, the brake pads are pressed against part of a rotating wheel to apply a frictional force on the wheel. This frictional force causes the car to slow down and eventually stop. The distance the car travels while it is trying to stop is called the braking or stopping distance. The slope or grade of the road and the frictional resistance between the road and the car's tires can affect the braking distance. A car with new tires on a dry, level road will be less likely to skid and will stop more quickly than one with worn tires on a wet road.



Investigation #6 BRAKING DISTANCE

The purpose of this investigation is to determine the relationship between the distance a car takes to brake and the velocity of the car. In Investigation #2 (p. 31), we calibrated an inclined plane such that we knew that the velocity of our car increased at a constant rate. In this activity, we can use the same procedure to calibrate the inclined plane.

Set up a mini-V activity as shown. Perform the investigation on a clean, dry surface to simulate good road conditions. A lab table or a tile surface will work just fine. To simulate braking, build a slider from a piece of 10 cm x 12 cm paper as shown in the diagram. Release the car down the ramp such that it collides with the slider at the bottom of the ramp.



Procedure

1. Release the car from the position for the first velocity (see calibrating the inclined plane on p. 28 to determine release points). Let the car collide with the braking sled at the bottom of the ramp.

2. Measure the braking distance (how far the slider moves from the end of the ramp) and repeat three times. Calculate the average braking distance.

3. Release the car from the next position up the ramp and repeat step #2. Continue until you have calculated the braking distance for 5 or 6 velocities.

4. Graph braking distance versus velocity.

Table A • Braking Distance

Relative Velocity	Trial #1 (cm)	Trial #2 (cm)	Trial #3 (cm)	Average (cm)	Comments
1					
2					
3					
4					
5					
6					

Think About IT!

1. Describe the shape of the graph. What can you conclude about the relationship between braking distance and velocity?
2. What does this mean in terms of how fast one drives a vehicle?

Challenge

The Effects of Friction on Braking

Design an investigation to examine the effects of friction on braking. How can you account for poor road conditions such as snow, ice and gravel?

Think About IT!

1. What do you conclude about the effects of snow, rain and ice on the braking distance?

Math Connection

We found in the previous activities that as speed increases, the braking distance increases at a faster rate. That is, if you double your speed, the braking distance more than doubles. In an ideal experiment, if you double your speed, the braking distance increases four times (2^2) and if your speed triples, your braking distance increases nine times (3^2).

1. Check your experimental data. How close is it to the ideal case?

A relationship where one factor increases at a faster rate than the other is called a power relationship. We can write this as a proportion statement which reads that:

"braking distance is proportional to the square of the velocity"

or in SYMBOLIC FORM

$$\mathbf{d} \propto \mathbf{v}^2$$

We also find that the braking distance depends on the friction between the two surfaces. Physicists account for the frictional effects by using a mathematical constant for different kinds of surfaces. In this way, the proportion can be represented by an equation such as:

$$\mathbf{d} = k\mathbf{v}^2$$

Where the constant k depends on the friction of the two surfaces in contact with each other, surfaces with a lot of friction have a low value for k, and slippery surfaces have a high value of k. Approximate values for the constant k can be found in the table. The values are given for velocities in m/s.

Rubber tire on:	Frictional constant k when velocity is in m/s
dry pavement	0.06
wet concrete	0.10
snow and ice	0.15

Example:

Find the braking distance for a car with a velocity of 50 km/h on dry pavement.

$d = kv^2$

v = 50 km/h = 50/3.6 m/s (change units to match)

v = 13.9 m/s

$d = 0.06 \text{ x } (13.92 \text{ m/s})^2$

d = 11.6 m

Therefore, the braking distance is 11.6 m in the direction of motion.

PRACTICE

1. Calculate the braking distance for a car driving at 10, 20, 30, 60, and 90 km/h.

2. Compare the braking distances for a car travelling at 30 km/h and a car travelling at 60 km/h. What do you conclude?

Total Stopping Distance

Our calculations of braking distances were for ideal cases only. In a real braking instance, a certain amount of time elapses before the driver recognizes a hazardous situation and applies the brakes. Consequently, the total stopping distance of a vehicle is made up of the distance the vehicle travels during the driver's reaction time plus the vehicle's braking distance. For example, let's suppose that a car is moving at 50 km/h on dry pavement. Suddenly, 34 m away, a small dog darts into the roadway. Typically, the driver takes 1.5 seconds to recognize and react to such a dangerous situation. The distance the vehicle travels during this reaction time can be found from our understanding of the relationship between distance, velocity and time. We know that:

$$\text{velocity} = \frac{\text{distance}}{\text{time}}$$

therefore

$$\text{distance} = \text{velocity x time}$$

And

reaction distance = 50 km/h x 1.5/3 600 h (changing seconds to hours to match units)

reaction distance = 0.021 km or 21 m

Total Stopping Distance = reaction distance + braking distance

Previously, we calculated the braking distance of a car travelling at 50 km/h on dry pavement as 11.6 m.

therefore

Total Stopping Distance = 21 m + 11.6 m = 32.6 m
A hazardous situation for the dog!

PRACTICE

1. Calculate the total stopping distance for a car that is traveling at 60 km/h on a rain-soaked road (use 1.5 seconds as the driver's reaction time).

Reaction Time

Driver Reaction Time

The driver reaction time is made up of three components: the vehicle response time, human perception time, and human reaction time.

Vehicle Response Time

Once the brakes are applied, the vehicle response time depends on the type and working order of the braking system including: tire tread and pressure, vehicle weight, the suspension system, and the braking technique applied by the driver. Vehicle response times will vary but a properly maintained vehicle will always respond better than one in poor condition.

Human Perception Time

Human perception time is how long the driver takes to see the hazard and then realize that it is a hazard. This perception time can vary considerably from about 0.5 of a seconds to as long as 3 or 4 seconds. In this time, the driver must decide if there is time to brake or whether steering is a better response. Moreover, drivers tend to hesitate when they encounter other vehicles or pedestrians in potentially hazardous situations because they wait for the vehicle or pedestrian to change their behaviour.

Human Reaction Time

Once the brain realizes that there is a hazardous condition, braking commences. Human reaction time is how long the body takes to move the foot from the accelerator to the brake pedal. Again, this reaction time can vary from person to person. Less experienced drivers are often slower to realize a dangerous situation.

Try IT!

You can find your reaction time as follows:

1. **Hold your thumb and forefinger about 5 cm apart. Have a partner hold a metre-stick such that the zero mark is level with your thumb.**
2. **Without warning, your partner releases the metre-stick and you catch it by closing your thumb and forefinger. Record the distance mark where you catch it.**
3. **Repeat three times and take the average.**
4. **To find your reaction time, divide your catching distance in metres by 5 and take the square root of this number.**

For example, you catch the metre-stick at the 17-cm mark. Your reaction time will be

$$\text{reaction time} = \sqrt{\frac{0.17}{5}} = 0.18 \text{ seconds}$$

Perception and reaction times also vary according to the surrounding environment of the driver. These times increase due to poor visibility, bad weather, alcohol, drugs, fatigue, and the driver's concentration and alertness.

Alertness

The driver who is alert and aware of his or her driving will have the best reaction time possible. At best, a good reaction time will be 0.7 seconds, of which 0.5 is perception time and 0.2 seconds is human reaction time. However, most hazardous situations are unexpected or surprise events that increase our perception time to 1.5 seconds or more.

A driver's alertness is also greatly influenced by the in-car environment. In-car displays, radio and CD controls, cell phones, and distractions caused by other occupants cause delays in reaction times of up to 1 second or more.

Poor Visibility

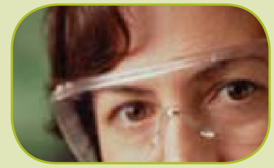
Poor weather also increases the driver's perception time in different ways, especially at night. Normally, we see an object when light reflects from the object back to our eye. Rain acts like a lens so that the light is scattered in different directions. As a result, visibility is reduced. Fog produces a similar phenomenon by scattering light and making it extremely difficult to see. Since blue light scatters more than yellow light, some experts recommend yellow fog lights. However, the illumination of yellow light is much lower and visibility is actually reduced. Fog droplets are generally too large to scatter light of different wavelengths, so yellow scatters the same as blue.

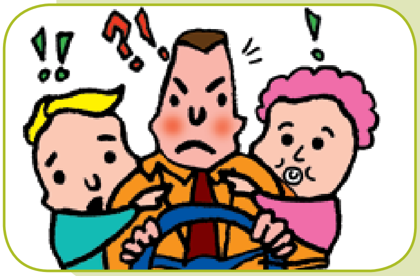
Poor weather conditions also create other kinds of visibility hazards. Rain influences our ability to see through the windshield of a car. Windshield wipers themselves obstruct our vision and the splash and sound of rain draws the attention of the driver away from the road. Poor visibility also forces drivers to concentrate their attention straight ahead in order to see where they are going. This decreases the peripheral field of vision so that it becomes more difficult to see another car or pedestrian approaching from the side.

Try IT!

Repeat the calculation of your reaction time under the following situations.

1. Simulate "poor visibility" by wrapping cellophane around a pair of safety goggles. What happens to your reaction time when your visibility is reduced?





2. Two persons act as distracters by asking the person who is testing their reaction time a series of "rapid fire" questions such as: "What did you do this weekend?", "What time did you get up?", "Who did you go out with?", and so on. Try answering the questions while a radio plays. What happens when you must concentrate on other things besides the reaction test?

Think About IT!

1. Why does a tailgating car usually not stop in time when the car ahead suddenly applies the brakes?

PRACTICE

1. Using the data from the braking distance investigation and your reaction time, calculate the total stopping distance for your car.

Relative Velocity	Braking Distance (cm)	Reaction Time (s)	Distance Travelled During Reaction Time (cm)	Total Braking Distance (cm)
1				
2				
3				
4				
5				
6				

2. If two cars are moving at 60 km/h, how far behind must the second car travel if it can safely stop?

3. For question #2, estimate the number of car lengths for each 10 km/h increase in speed.

4. A pedestrian wearing dark clothing at night is only visible at a distance of about 35 m to a driver using low beams. Calculate the maximum speed a car could have such that a driver could brake and avoid a collision (use a 1.5 second reaction time).

5. Some Driver Education experts recommend that "when the vehicle ahead of you passes a certain point, such as a sign, count 'one-thousand-one, one-thousand-two, one-thousand-three.' This takes about 3 seconds. If you pass this same point before you finish counting, you are following too closely." They also suggest a "4 second or more cushion" in inclement weather. Using the laws of physics and your understanding of braking distance, write a rationale for this rule.

Summary

Some people feel safer in large vehicles, such as Sport Utility Vehicles (SUVs). However, whether you are riding a tricycle or a 4 x 4, the laws of physics still apply. Understanding the laws of physics helps us to realize the importance of safe driving habits. It's simple – slow down before you hurt somebody, and leave a space cushion around your vehicle at all times. Arrive alive and enjoy life.

The Final Challenge

As a new physics expert, return to the car crash scenario in Chapter 1. Analyse the collision using your knowledge of Newton's laws, impulse, momentum and energy. Whose story is true, the motorcyclist's or the car driver's? Is that your final answer?

Report your findings to the class.

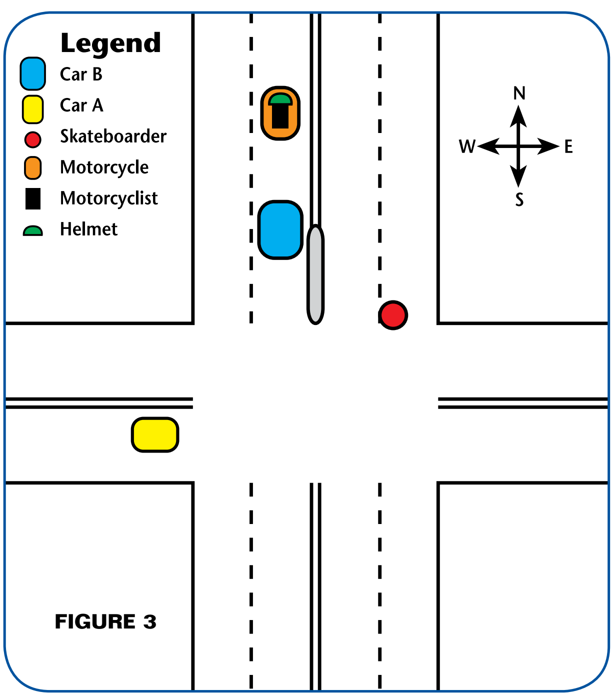


FIGURE 3

Car Crash After

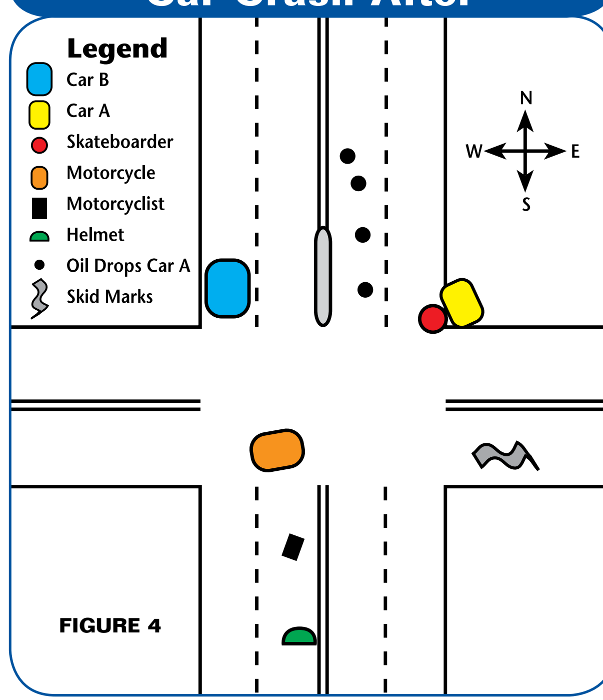


FIGURE 4

Chapter 7

Driving Responsibly

In today's fast-paced society, driving safely is everybody's responsibility. Our personal habits and lifestyle choices influence not only our own health, but sometimes the well-being of others. In society today, we must make difficult choices when innocent persons are victimized by the irresponsibility of others. Understanding the laws of physics enables us to make more informed choices when decisions need to be made to reduce personal injury, property damage, and emotional trauma caused by careless driving. In the following case studies, try to use your scientific knowledge to assess the situation and implement a plan of action to improve attitudes and personal habits, and to promote safe driving.

Case Study #1

Mr. Smith is 52 years of age. One night around 9:00 p.m., he was driving down Gladstone Street at the posted speed limit of 60 km/h. He promised to pick up his wife at 8:45 p.m. and he was late. Mr. Smith was listening to the hockey game on the car radio while he looked for his turn on Tower Blvd. Ms. Martin, wearing a dark blue coat, crossed in the middle of the street without looking both ways for oncoming traffic. When Mr. Smith noticed her, he applied the brakes but he did not stop in time, and his car collided with Ms. Martin. Police arrived and questioned Mr. Smith who said that he never saw the pedestrian. He admitted that he had a few beers before he left home, and a test revealed his blood-alcohol content was 0.06, below the legal limit of 0.08. The police did not charge him with any offences.

Challenge

After a large number of motor vehicle collisions similar to Mr. Smith's, the Chief of Police calls on you to submit a report to:

- **assess and clarify the problem**
- **review the police actions**
- **evaluate the available research**
- **develop a course of action to reduce such incidents**

Case Study #2

In your notebook, complete the following anticipation guide before and after you read the news article that follows on the next page.

Anticipation Guide

Drivers who have serious accidents are likely to be the common "troublemakers".	Before: After: Comments:
Criminal charges should be laid against young drivers who are involved in accidents.	Before: After: Comments:
The laws of physics suggest cars that are out of control can be brought back into control.	Before: After: Comments:
Most serious accidents caused by teenage drivers are the result of illegal narcotics or high blood-alcohol levels.	Before: After: Comments:
New driving laws, like Graduated Driver Licencing, drafted specifically for novice drivers are intended to maintain unreasonable control over young adults.	Before: After: Comments:

Lebanon teen-ager dies of injuries suffered in crash

By GISELLE GOODMAN and DAVID HENCH, Portland Press Herald Writers •

A 14-year-old Lebanon boy died Friday from injuries he suffered in a car crash the previous day.

Authorities are considering criminal charges against the 16-year-old driver, who got his license two months ago and was not supposed to have passengers. Colin Robinson, a junior firefighter known for his helpful nature, suffered fatal injuries in the crash at 11 a.m. Thursday on Long Swamp Road in Lebanon. Also injured were his brother Chadd Robinson, 17, and the driver, whose name has not been released because he is a juvenile facing the possibility of criminal charges. Both teen-agers were listed in stable condition Friday at local hospitals.

The three Lebanon teen-agers, students at Noble High School, were headed for the driver's house when he lost control of his Mercury Sable, which crashed into an oncoming car and landed in a water-filled ditch. Colin Robinson, who would have been 15 next month, died at 2 a.m. Friday at Maine Medical Center in Portland and his organs were donated to others. "He was dedicated to helping the community," said Jason Cole, Lebanon's assistant rescue chief. Robinson became a junior firefighter with the Lebanon Rescue Squad two years ago and wanted to be a firefighter or police officer when he grew up, Cole said. Whatever he became, Cole said, he was certain that Robinson would do something to help others. "He never caused any problems," Cole said. "He was just a good kid." In fact, when Cole blew a tire on Route 202 in Lebanon a few nights ago, it was Robinson, pedalling by on the bike he always rode, who stopped to help. Cole said all three of the boys in the car Thursday were good kids. "If (the driver) was thinking, he never would have done anything to hurt the other kids," Cole said. At Noble High on Friday, students who went to school knowing their classmates had been hurt in an accident learned with an awful jolt that Robinson, a freshman, was dead. "You're not sure if you talked to him just yesterday, or if you were mean to him," said 16-year-old Lindsey Adams. "I just haven't put it all together yet." Spencer Eldredge, a junior, said he didn't know Robinson well. But that didn't matter. He was still shaken by the news. "Death is just really final," Eldredge said. "I feel so bad for those who were pretty good friends with him. It puts a big black eye on the whole school year."

The school allowed grieving students to go home and offered counselling to students who needed it. Peggy Paine, of Crisis Response Services of York County, was one of those counsellors. She said the students she talked to were shocked and numbed by the news. "It's not normal and it's not fair," she said. "There have been a lot of tears, sobs and then the kids taking care of each other." Those who knew him might say Robinson would have been one of those caretakers. "Whenever we needed a hand," Cole said, "he was there to help." Maine State Police Trooper Mark Holmquist, the primary accident investigator, routinely uses photographs of fatal accidents to teach Noble High students about the dangers of driving too fast. But this one "may be too powerful," he said.

The three boys had stopped at the Cumberland Farms in Berwick to buy gas before heading to the driver's house in the middle of the school day, Holmquist said. He did not know if they made any other purchases or what they did earlier that morning. The driver was headed north when he drove off the side of the road, then overcorrected and hit an oncoming Honda. The driver of the Honda and his young daughter were not seriously injured. The Honda was travelling slowly and was able to stop before the cars collided, possibly avoiding additional deaths, Holmquist said. The side of the Mercury, between the front and rear passenger doors, slammed into the front of the Honda. Colin Robinson, the back-seat passenger, was fatally injured even though he was wearing a seatbelt. Investigators spent Friday reconstructing the accident to determine precisely what happened and how fast the car was going when it crashed. Preliminary estimates put the speed at between 60 and 80 mph, police said. The posted speed limit in that area is 35 mph.

Police are still trying to find out why the students were not in class and why they were headed to the driver's house. Holmquist said the driver's mother and possibly his father were out of town when the accident occurred. Since getting his license, the driver had not been convicted of any infractions, Holmquist said, although he will do more research to determine whether any complaints are pending. Under state law, young drivers cannot give rides to young people outside of their family for the first 90 days they have their license. "It's an opportunity to allow new, young drivers to get comfortable behind the wheel and not have peer pressures on them in the first couple months," said Domna Giatas, director of communications for the Secretary of State's Office. The law was passed in 2000, in part because speed is statistically the greatest threat to young drivers. Police met Friday with prosecutors from the York County District Attorney's Office to review the case. Officials expect to make a decision early next week about what charges, if any, to bring against the driver.

Staff Writer David Hench can be contacted at 791-6327 or at: dhench@mainetoday.com

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