Chapter 6

Braking

Investigation #6 BRAKING DISTANCE

Table A—Braking Distance

This trial was done using tracks made of old fenceboards, which were propped up by books. The pile of books was 27-cm high and was placed at 1.00 m from the end of the track that touched the floor. The angle of the track was about 15°.

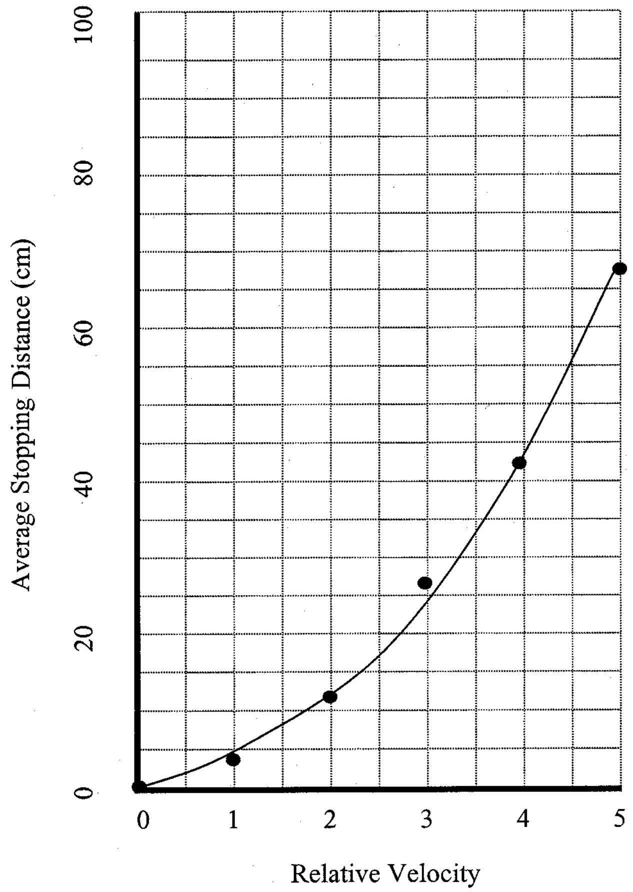
This trial was done with the slider sliding on the surface of a table.

Note: Be sure to position the car so that the middle of the car, the centre of mass, is at the calibrated release point. If the front of the car is used, the first sliding distance will be too large, making the ratios all too small.

Differences between group results can be attributed to the use of different cars.

Table A • Braking Distance

Relative Velocity	Group (cm)						Average Braking Distance (cm)
	#1	#2	#3	#4	#5	#6	
1	3.3	2.4	5.3	2.5	1.5	2.9	2.8
2	13.8	10.9	13.1	9.0	9.2	13.5	11.6
3	29.7	28.3	28.8	20.8	22.9	22.7	25.5
4	50.9	43.7	47.8	30.2	36.9	45.6	42.5
5	81.2	71.9	79.8	51.0	56.7	63.5	67.3



Think About IT!—Page 55

1. The shape of the graph is a curve, curving upwards to the right.

   The braking distance increases more than the velocity.

   If the velocity doubles, the braking distance is 4X.

   This is an **exponential relation**.

2. In terms of driving, one must realize that the braking distance increases more rapidly than velocity.

   Larger velocities require much larger stopping distances.

Challenge—The effects of friction on braking

Students can adjust the surface on which the slider will be sliding.

To simulate gravel, a thin layer of sand, one grain thick, can be used on the table or floor. The following results were obtained.

Again, the different cars had an effect on the stopping distance.

The effect of stopping on the sand was to increase slightly the stopping distance, as a comparison of the average stopping distances from Tables A and B illustrates.

The results below in table B are for Group #1 from Table A.

Table B • Braking on Sand

Relative Velocity	Trial #1 (cm)	Trial #2 (cm)	Trial #3 (cm)	Average Braking Distance (cm)
1	2.5	3.5	3.5	3.2
2	16.5	16.0	15.0	15.5
3	33.0	36.0	34.0	34.3
4	48.0	58.0	53.0	53.0
5	78.0	89.0	80.0	82.3

Think About IT!

Think About IT!—Page 55

1. The effect of snow, rain, and ice is to lengthen braking distance.

These reduce the force of friction between the tires and the road.

With friction supplying the stopping power, and with friction decreased, it will take a longer distance to stop the car.

Math Connection

The ratio is calculated by dividing each stopping distance by the first stopping distance.

Ratio = (Stopping distance) / (First stopping distance)

Table C

Ideal Ratio	Ratio: Table	Ratio: Table with Sand
1	2.8 / 2.8 = 1	3.2 / 3.2 = 1
2	11.6 / 2.8 = 4.1	15.5 / 3.2 = 4.8
3	25.5 / 2.8 = 9.1	34.3 / 3.2 = 11
4	42.5 / 2.8 = 15	53.0 / 3.2 = 17
5	67.3 / 2.8 = 24	82.3 / 3.2 = 26

Again, the result for the average stopping distance for the relative velocity of 1 is the critical measurement. If this value is inordinately small or inordinately large, the values of the ratios are skewed.

PRACTICE—PAGE 56

Note to Teacher: Calculation on page 56 should be d = 0.06 x $(13.92\text{ m/s})^2$.

1. The value of K changes with the surface. It will make the effect of friction on stopping distance evident to the student if stopping distances are computed for all surfaces. (Three significant digits were used in these calculations.)

Table D • Braking Distance (m)

Velocity		Dry Pavement	Wet Concrete	Snow and Ice
km/h	m/s	$d = (.06)v^2$	$d = (.10)v^2$	$d = (.15)v^2$
10	2.78	0.46	0.77	1.15
20	5.56	1.85	3.09	4.63
30	8.33	4.16	6.93	10.4
60	16.7	16.7	27.8	41.7
90	25.0	37.5	62.5	93.8

2. In all cases the braking distance at 60 km/h is 4 times the braking distance at 30 km/h.

Total Stopping Distance

Note To Teacher: To avoid some confusion, convert km/h to m/s first before using the velocity relationship.

It is important to point out to students that units must be the same on each side of the equation.

d = v t

m = ? s

v must have units of m/s in this case.

PRACTICE—PAGE 57

1. Car traveling at 60 km/h on a rain-soaked road. Reaction time is 1.5 s.

Reaction Distance:

t = 1.5 s ; v = 60 km/h ÷ 3.6 = 16.67 m/s = 17 m/s (rounded to 2 significant digits)

d = ?

d = v t

= 17 m/s x 1.5 s = 25 m

Braking Distance:

k = 0.10 for wet concrete.

$d = kv^2$

$= (0.10)(17)^2$

= 29 m

Total stopping distance = Reaction distance + Braking distance

= 25 m + 29 m = 54 m.

Reaction Time

Try IT!

Try IT!—Page 58 and 60

Note to Teacher: Two classes performed this activity to determine their reaction times. The first group did the trials in the order given: no distractions, with impaired visibility, and distracted by talking. The reaction times were basically the same for each case. This can be attributed to the amount of practice the students had before performing each trial.

In the results given below, the students were asked to perform the trials in the reverse order of that given in the *In Motion* booklet. Here, the reaction times for "no distractions" are noticeably better than the times for "with distractions".

Sample Data:

Table E

Student	Average Distance Metrestick Falls (m) **No Distractions**	Reaction Time (s)	Average Distance Metrestick Falls (m) **Distraction—Impaired Visibility**	Reaction Time (s)	Average Distance Metrestick Falls (m) **Distraction—Talking**	Reaction Time (s)
1	0.18	0.19	0.29	0.24	0.51	0.32
2	0.16	0.18	0.39	0.28	0.45	0.30
3	0.06	0.11	0.13	0.16	0.16	0.18
4	0.08	0.13	0.18	0.19	0.29	0.24
5	0.14	0.17	0.24	0.22	0.24	0.22
6	0.10	0.014	0.18	0.19	0.36	0.27
7	0.16	0.018	0.36	0.27	0.34	0.26
8	0.14	0.17	0.20	0.20	0.39	0.28
9	0.51	0.032	0.68	0.37	0.48	0.31
10	0.26	0.023	0.20	0.20	0.45	0.30
11	0.11	0.15	0.24	0.22	0.24	0.22
12	0.13	0.16	0.31	0.25	0.18	0.19
13	0.18	0.19	0.11	0.15	0.65	0.36
14	0.11	0.15	0.11	0.15	0.22	0.21
15	0.13	0.16	0.42	0.29	0.22	0.21
16	0.47	0.47	0.61	0.35	>1.00	>0.45
17	0.13	0.16	0.16	0.18	0.14	0.17
18	0.11	0.15	0.16	0.18	0.14	0.17

Think About IT!—Page 60

1. If a car that is being tail-gated stops suddenly, the tail-gating car crashes into the car. The reason is the reaction distance. The tail-gater's car and the other car should have the same braking distance.

   The problem is the distance the tail-gating car travels while the driver is reacting. That extra distance the tail-gating car travels is enough to cover the distance between the two cars. Hence, the two cars crash.

Note to Teacher: Students can test their reaction time and find the reaction distance, braking distance, and total stopping distance using a Java applet found at:

<http://www.phy.ntnu.edu.tw/java/Reaction/reactionTime.html>

This is an excellent activity that clearly demonstrates the factors that affect the total stopping distance of a vehicle. Students can change the speed of the vehicle to demonstrate the effect of increasing or decreasing speed on the total stopping distance.

<http://www.javacommerce.com/cooljava/games-normal/reactiontime.html>

This site allows students to test their reaction time.

PRACTICE—PAGE 60

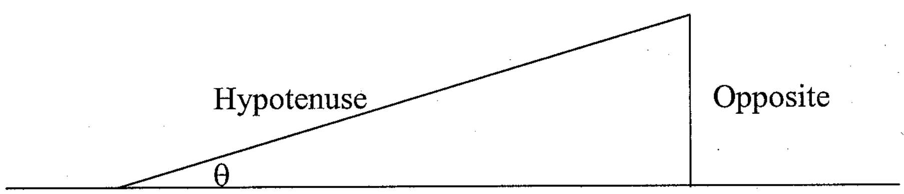
1. For the ideal case with no distractions, the reaction time of a typical student measured by catching a falling ruler is about 0.2 s. Using the applets above, a typical reaction time is about 0.4 s for depressing a mouse button.

   The acceleration of the Mini-V down the ramp can be found with the following method. The acceleration of the Mini-V is given by the relationship

   $a = \sin q\ (980\ \text{cm/s/s})$,

   where q = the angle the ramp makes with the horizontal.

   Sin q is the ratio of the vertical height to a point on the ramp, divided by the distance that point is up the ramp from the end that touches the table (opposite/hypotenuse).



   The formula $v^2 = 2aDd$ can then be used to find the final velocity with which the Mini-V rolls off the ramp.

   In this case, v = final velocity and Dd = the distance from the bottom of the ramp to the release point of the car.

   Remember, the midpoint of the car should be positioned at each release point.

The trials used a vertical rise of 27 cm for a hypotenuse of 100 cm.

Thus, sin q = 27/100 = 0.27 and the acceleration if the Mini-V was
a = sin q (980 cm/s/s), a = 0.27 (980 cm/s/s) = 265 cm/s/s

The relative velocity for release point 1 (5.0 cm) can be calculated.

a = 265 cm/s/s and Dd = 5.0 cm
v^2 = 2aDd = 2 (265 cm/s/s) (5.0 cm) = 2650
v = 51.5 cm/s

The other velocities are just multiples of 51.5 cm/s.

The reaction distance is calculated using Dd = vDt.

The total braking (stopping) distance is the sum of the reaction distance and the braking distance (measured in the activity on page 55).

Table F

Relative Velocity	Actual Velocity (cm/s)	Braking Distance (cm)	Reaction Time (s)	Distance Traveled During Reaction Time (cm)	Total Braking Distance (cm)
1	51.5	2.83	0.200	(51.5)(0.200) = 10.3	11.1
2	103	11.6	0.200	(103)(0.200) = 20.6	32.2
3	154	25.5	0.200	(154)(0.200) = 30.9	56.4
4	206	42.5	0.200	(206)(0.200) = 41.2	83.7
5	258	67.3	0.200	(258)(0.200) = 51.6	118.9

If a reaction time of 0.400 s is used, the reaction distance will double, which will increase dramatically the total braking distance at high speeds.

Table F

Relative Velocity	Actual Velocity (cm/s)	Braking Distance (cm)	Reaction Time (s)	Distance Traveled During Reaction Time (cm)	Total Braking Distance (cm)
1	51.5	2.83	0.400	(51.5)(0.400) = 20.6	23.4
2	103	11.6	0.400	(103)(0.400) = 41.2	52.8
3	154	25.5	0.400	(154)(0.400) = 61.8	87.3
4	206	42.5	0.400	(206)(0.400) = 82.4	124.9
5	258	67.3	0.400	(258)(0.400) = 103	170

Again, the effect of reaction time and increased velocity can be illustrated by the applets mentioned earlier in this section.

2. When the first car begins to brake, the driver of the second car must perceive this action, process the information, and react by putting his foot on the brake. This reaction time results in the second car traveling the “reaction distance.”

If both cars are assumed to stop equally well when braking, the reaction distance will represent the minimum following distance that the second car can safely follow the first car.

<http://www.visualexpert.com/Resources/reactiontime.html>
The website above includes information on the factors that affect reaction time.

The reaction distance is calculated using a typical reaction time of 1.50 s. The speed of the car is 60 km/h, which must be converted to m/s by dividing by 3.6.

v = 60 / 3.6 = 16.7 m/s
Dt = 1.50 s
Dd = vDt
= (16.7 m/s) (1.50 s) = 25.0 m

Again, this is the absolute minimum following distance.

3. At 70 km/h, the speed is 70 / 3.6 = 19.4 m/s.
The reaction distance is (19.4 m/s) (1.50 s) = 29.1 m.
This is about seven car lengths with a bit of a cushion.

At 80 km/h, the speed is 80/3.6 = 22.2 m/s.
The reaction distance is (22.2 m/s) (1.50 s) = 33.3 m/s.
This is about eight car lengths with a bit of a cushion.

At 90 km/h, the speed is 90/3.6 = 25.0 m/s.
The reaction distance is (25.0 m/s) (1.50 s) = 37.5 m.
This is about nine car lengths with a bit of a cushion.

The safe following distance for a car should be about one car length per 10 km/h.

The recommended safe following distance has been replaced with a safe following time. This following time should be 3–4 s.

4. Using the answers to Practice #1, page 56, on dry pavement, the braking distance is 16.7 m at 60 km/h. A speed of 60 km/h would seem to be a good guess to be able to stop in 35 m.

The calculation of stopping distance requires the calculation of reaction distance, using Dd = vDt plus the calculation of braking distance using Dd = kv^2. In both cases, v must be in m/s.

At 60 km/h:

v = 60 / 3.6 = 16.7 m/s and Dt = 1.50 s

Reaction distance: Dd = vDt = (16.7 m/s)(1.50 s) = 25.0 m

Braking distance is 16.7 m.

Total stopping distance is 41.7 m. The pedestrian would be struck by the car.

If we try a speed of 50 km/h, we get the following stopping distance.

V = 50 / 3.6 = 13.9 m/s and Dt = 1.50 s

Reaction distance: Dd = vDt = (13.9 m/s)(1.50 s) = 20.8 m

Braking distance: $d = kv^2 = (0.06)\ (13.9\ \text{m/s})^2 = 11.6$ m

Stopping distance = 32.4 m.

A car would have to be traveling at about 50 km/h in order to stop in time to avoid hitting the pedestrian.

5. The three-second rule for a safe following distance allows the driver of the second car to travel with a reaction time of 1.5 s without braking, then hit the brakes, and still stop in time to avoid a collision with the car ahead.

The braking distance varies with the square of the speed of the car. If the speed doubles, the braking distance increases by a factor of 4. However, since both cars are assumed to brake equally well, the braking distance will be the same for each vehicle.

If cars follow at a certain distance, say 10 m, this may be more than the reaction distance at a low speed. As the speed increases, the reaction distance increases in proportion to the speed of the vehicle. If the speed doubles, the reaction distance doubles. So the 10-m following distance would no longer be a safe following distance.

However, if the following time is used, the car will automatically increase the following distance to keep it safe. In 3 s, the car will travel twice as far if the speed is doubled. Since this is now the following distance, it will be a safe distance. The car will be able to stop in the reaction distance.

In inclement weather, the braking distance increases. The extra second provides a larger following distance, a cushion, which can be used up by the extra braking distance the second car may have.

The Final Challenge—Car Crash

Note to Teacher: This treatment of the crash scene is contingent upon using the revised crash scene map as outlined in the Preface, page A262.

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

The motorcycle had significant kinetic energy (energy related to motion). This energy was transformed into other forms as the motorcycle came to a stop. Part of the energy was used to do work in damaging the motorcycle and the car's body. Other forms of energy, such as heat and sound, were also produced as a result of the collision event.

The motorcyclist and her helmet are found south of the intersection and the motorcycle itself. Since the motorcyclist was traveling south when the motorcycle crashed into the car, the motorcyclist and her helmet, which were in motion, continued in motion until an unbalanced force acted on them. That unbalanced force was provided by the road. This is an application of Newton's First Law. When the motorcyclist landed on the ground, the force of friction between the road and the motorcyclist brought her to a stop. Again, this is an instance of Newton's Second Law in operation.

Again, the motorcyclist possessed significant kinetic energy. This energy was converted into other forms, like heat as the motorcyclist slid along the road.

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

The skidding car would lose kinetic energy. The tires sliding on the road heated up enough to leave marks on the road. After Car A's rear tires stopped sliding, Car A continued in motion forward, ending up on the walkway where the skateboarder was located. When the skateboarder bailed (as we assume occurred), his skateboard, already in motion, stayed in motion until acted upon by an unbalanced force during its collision with the rear fender of Car A.

Oil Drops:

The oil drops are drawn in the incorrect position in the diagram as seen in *In Motion — A Student Resource*. They should be positioned, as indicated, in the intersection near the spot where the motorcycle came to rest. If this was the correct placement of these drops, then the drops act like the dots on a ticker timer. The dots trace out the path of some vehicle that may or may not have been involved in the incident. For instance, the skidmarks could have been from a driver who entered the intersection at the time of the accident, was struck, but then took evasive action and fled the scene altogether. Students should actively speculate on this or similar scenarios.

Another point in favour of the version of the story given by Car A's driver is the fact that the skateboarder was crossing the intersection, moving to the east (or west), which meant that Car A, going east, should have had a green light. This final bit of information should demonstrate that the motorcyclist ran the red light. Or did she…?

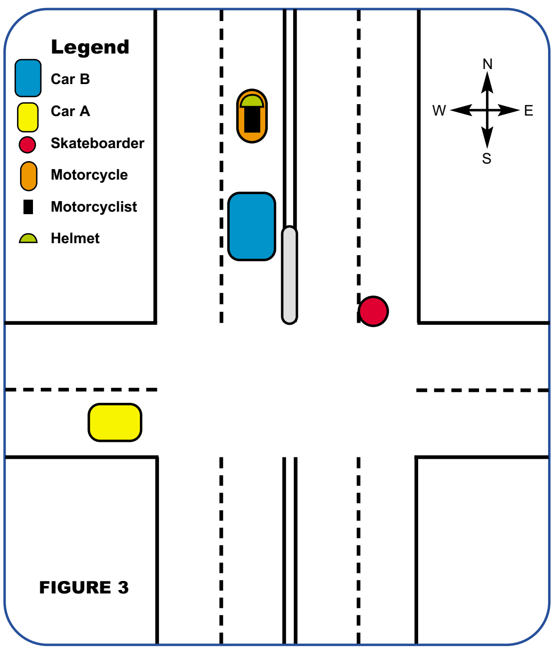


FIGURE 3

Car Crash After

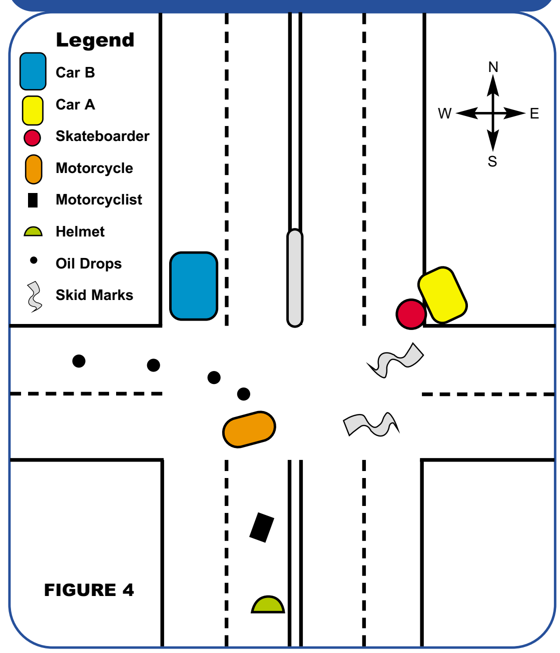


FIGURE 4