4.1 Inertia

SECTION OUTCOMES

- Analyze technological systems to explain their dynamics.
- Explain how a scientific milestone revolutionized thinking in dynamics.

KEY TERMS

- inertia
- kinematics
- dynamics
- mechanics
- force
- inertial mass
- gravitational mass

Figure 4.1 This photograph shows how an object is affected by forces. Forces sometimes stop, sometimes propel, and sometimes restrain an object.

The crash-test dummy in the photograph was in motion before the car abruptly stopped. The dummy continued to move until it experienced a stopping force. Because the dummy was not restrained by a seatbelt, the windshield was the first object to make contact and thus provide a stopping force. The seatbelt would have been a far better option.

If you have ever ridden on a public transit bus or a subway, you may recall being flung backward as the vehicle accelerated away from the stop. Later, upon arriving at the next stop, you were thrown forward when the vehicle came to a halt. In this example, as in the above photo, you see evidence of a property that is shared by all matter — the tendency of an object to resist any change in its motion. This property is called **inertia**.

ELECTRONIC LEARNING PARTNER

A video clip of a crash test can be found on the Electronic Learning Partner.

DEFINITION OF INERTIA

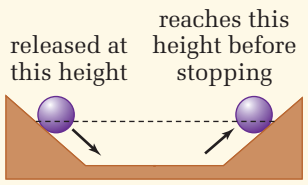
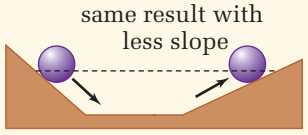
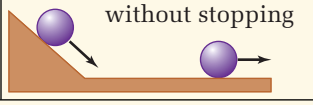
Inertia is the natural tendency of an object to remain in its current state of motion. The amount of an object's inertia is directly related to its mass.

Galileo's Perception of Inertia

Throughout history, inquisitive people have attempted to understand why an object moves or remains at rest. Aristotle's (384–322 B.C.E.) observations led him to conclude that a constant force will yield a constant speed. His idea went unchallenged for nearly 2000 years, but it is, in fact, false. French philosopher, Jean Buridan (1300–1358) believed that objects stayed in motion because they possessed "impetus" — something inside that makes them continue to move.

Galileo carefully considered both ideas. He conducted a three-part thought experiment in an attempt to understand why objects move the way they do.

Table 4.1 Galileo's Thought Experiment on Motion

Observations	Predictions	Assumptions	Diagram
A ball rolling down a slope speeds up. A ball rolling up a slope slows down.	Therefore, a ball rolling on a horizontal surface should continue without speeding up or slowing down	The reason objects do slow down on horizontal surfaces is the result of the force of friction.	
A ball rolling up a slope that is not as steep as the slope it rolled down will continue farther along the shallower slope.	The ball will continue up the shallow slope until it has reached the height from which it was originally released.	The reason objects do not quite reach the same height is due to the force of friction.	
When the second slope is zero (horizontal), the ball will continue to roll.	The ball would continue forever.	Again, the force of friction will prevent this from occurring naturally.	

Summary: An object will naturally remain at rest or in uniform motion unless acted on by an external force.

Galileo's thought experiment challenged the commonly held belief that an object's uniform motion was the result of continued force. Instead, he viewed uniform motion as being a state just as natural as rest. The experiment also contradicted the "impetus" theory proposed by Buridan. According to Galileo, an object's movement remains unchanged, not because of something inside of it, but because there is no force resisting the motion.

Galileo had identified the natural tendency of mass to continue doing what it is already doing — that is, to continue in uniform motion or remain at rest. Galileo was defining inertia. His ingenious ideas were not immediately accepted, but his concept of inertia has stood the test of time and is the only classical law incorporated into Einstein's theories about the nature of our universe.

Language Link

Impetus is commonly used in the English language to describe a stimulus that incites action. For example, "The energetic audience gave the actors the *impetus* to give their very best performances." Notice that, even in this context, the impetus — the motivating force — is external. That is, the impetus comes from the energetic audience, not from within the actors. What other common terms are derived from the word *impetus*?

TRY THIS...

Test Galileo's ideas using a Hot Wheel's™ track and a marble. Although friction is not completely removed, it will be sufficiently reduced to observe what Galileo envisioned in his thought experiments.

How Forces Affect Motion

As you learned in Chapter 2, predicting and describing an object's motion in terms of its displacement, velocity, and acceleration, are aspects of a branch of physics called **kinematics**. The branch of physics that explains *why* objects move the way they do is called **dynamics**. Together, kinematics and dynamics form a branch of physics called **mechanics**. The study of dynamics involves **forces**, which you can regard as a push or a pull on an object. Forces cause *changes* in motion.

Table 4.2 lists examples of moving objects that could be studied within the field of dynamics.

Table 4.2 Objects and Their Motion

Object	Motion	Theoretical Explanation
electron	remains in motion near the nucleus of its atom	attracted by positively charged protons in the nucleus
snowflake	drifts toward the ground	Earth's gravity
baseball	flies off after contact with the bat	contact with bat
skydiver	reaches terminal speed while falling to Earth	air friction
Earth	orbits around the Sun	Sun's gravity

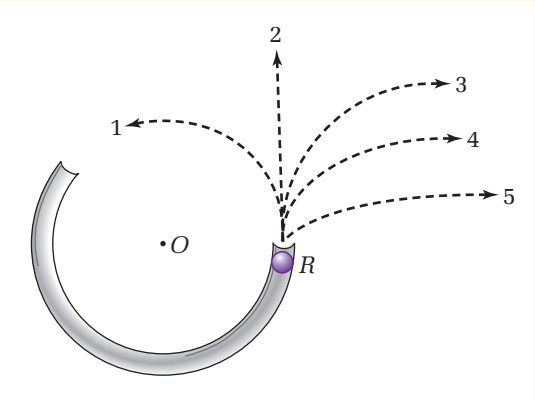
Figure 4.2 These stones were moved without the aid of powerful machines. Once placed, not even a tornado could exert enough force to move them.

Inertial Mass

To summarize what you have just learned, inertia is a property of mass that causes it to resist a change in its motion. A net external force must act on a mass in order to change its motion. Physicists use the term **inertial mass** to describe this property of an object. You are also familiar with another property of mass — gravity. Two masses, such as Earth and a boulder, interact and exert a gravitational force on each other. Physicists use the term **gravitational mass** to include the property of masses that cause them to interact. As well, physicists never assume that two seemingly different properties are related without thoroughly studying them. Over many years of observations and investigations, physicists concluded that inertial mass and gravitational mass are two different manifestations of the same property of matter. In fact, Einstein, in his general theory of relatively, showed why inertial mass and gravitational mass are fundamentally the same.

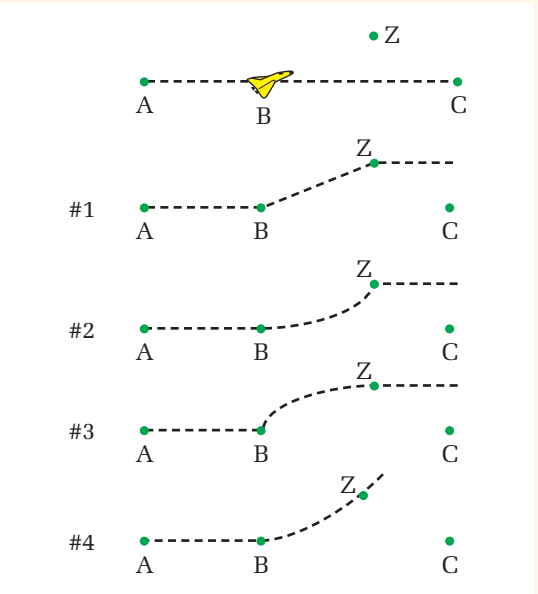
4.1 Section Review

1. K/U A marble is fired into a circular tube that is anchored onto a frictionless tabletop. Which of the five paths will the ball take as it exits the tube and moves across the tabletop? Justify your answer.



2. MC Imagine the following scenario. In a sudden burst of energy, you cleaned your room. A few moments later, your mother saw your room and appeared surprised, but you were not surprised. About an hour later, you went back into your room to find that the books were all on the floor. Your bed was on the wrong side of the room and all of the dresser drawers were on the bed. You were shocked! Use technical terms, including inertia, to explain why you were so surprised.

3. K/U A spacecraft is lost in deep space, far from any objects, and is drifting along from point A toward point C. The crew fires the on-board rockets that exert a constant force exactly perpendicular to the direction of drift. If the constant thrust from the rockets is maintained from point B until point Z is reached, which diagram best illustrates the path of the spacecraft?



4. C Decide whether each of the following statements is true or false. If the statement is false, rewrite it to make it true.

(a) Inertia is the result of stationary mass.

(b) An object will be at rest or slowing down if no force is acting on it.

5. C Galileo thought deeply about motion and its causes.

(a) Describe his thought experiments, including any assumptions that he made.

(b) How did Galileo's conclusions challenge current beliefs of his time?

6. C **(a)** Define kinematics, dynamics, and mechanics.

(b) Produce a table similar to Table 4.2 listing the motion and a theoretical explanation of three different objects.