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CHAPTER 2

Newton's First Law of Motion—Inertia

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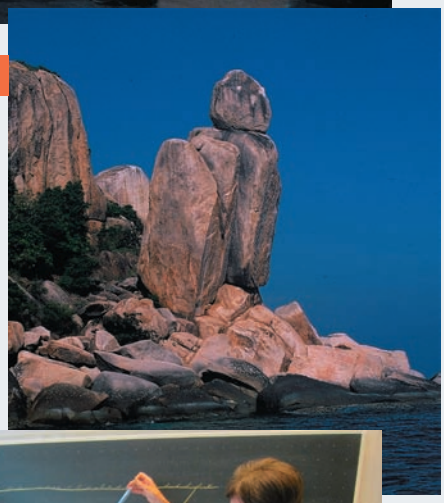
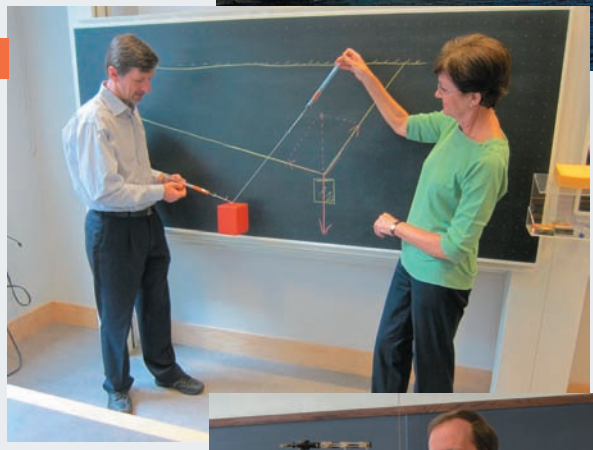






1 Will Maynez shows that the inertia of the anvil on the author's chest is enough to shield the blow of the hammer. 2 The balanced rock strikingly illustrates inertia. 3 Cedric and Anne Linder compare the different tensions in the string that supports the red block. 4 Karl Westerberg asks his students which string, the lower or the upper, will break when he suddenly yanks downward on the lower string.

Not all physics instructors are warm to *Conceptual Physics*. Some greatly prefer a roll-up-the-sleeves approach that immediately gets into problem solving, with little or no time spent on conceptual understanding. In 1992 I was delighted to see an article in the journal *The Physics Teacher* by a professor in South Africa who reported great success with teaching physics conceptually. I contacted him and we've been friends ever since. I'm speaking of Cedric Linder, who grew up and got most of his physics education in South Africa, continued his science education at Rutgers in New Jersey, and then went to the University of British Columbia where he obtained his doctorate in 1989.

As a result of Cedric's article, which praised the conceptual way of teaching, and his research in the field of physics education, educators at Uppsala University in Sweden sought him out. He accepted a position to establish a Division of Physics Education Research in the Department of Physics and Astronomy there. Cedric and his wife Anne now call Uppsala home—with Anne on board as a researcher and administrator in his group.

The Linders draw educators from around the world to their seminars and workshops with highly stimulating physics activities. Some physics teachers have a knack for making physics a delightful experience. How nice that Cedric is among this group—and expanding it.



2.1 Aristotle on Motion

Aristotle divided motion into two main classes: *natural motion* and *violent motion.* We briefly consider each, not as study material, but as a background to present-day ideas about motion.

Aristotle asserted that natural motion proceeds from the "nature" of an object, dependent on the combination of the four elements (earth, water, air, and fire) the object contains. In his view, every object in the universe has a proper place, determined by its "nature"; any object not in its proper place will "strive" to get there. Being of the earth, an unsupported lump of clay will fall to the ground; being of the air, an unimpeded puff of smoke will rise; being a mixture of earth and air but predominantly earth, a feather will fall to the ground, but not as rapidly as a lump of clay. Aristotle stated that heavier objects would strive harder and argued that objects should fall at speeds proportional to their weights: The heavier the object, the faster it should fall.

Natural motion could be either straight up or straight down, as in the case of all things on Earth, or it could be circular, as in the case of celestial objects. Unlike up-and-down motion, circular motion has no beginning or end, repeating itself without deviation. Aristotle believed that different rules apply to the heavens and asserted that celestial bodies are perfect spheres made of a perfect and unchanging substance, which he called *quintessence.*[1] (The only celestial object with any detectable variation on its face was the Moon. Medieval Christians, still under the sway of Aristotle's teaching, ignorantly explained that lunar imperfections were due to the closeness of the Moon and contamination by human corruption on Earth.)

Violent motion, Aristotle's other class of motion, resulted from pushing or pulling forces. Violent motion was imposed motion. A person pushing a cart or lifting a heavy weight imposed motion, as did someone hurling a stone or winning a tug-of-war. The wind imposed motion on ships. Floodwaters imposed motion on boulders and tree trunks. The essential thing about violent motion was that it was externally caused and was imparted to objects; they moved not of themselves, not by their "nature," but because of pushes or pulls.

The concept of violent motion had its difficulties because the pushes and pulls responsible for it were not always evident. For example, a bowstring moved an arrow until

[1]Quintessence is the *fifth* essence, the other four being earth, water, air, and fire.

the arrow left the bow; after that, further explanation of the arrow's motion seemed to require some other pushing agent. Aristotle imagined, therefore, that a parting of the air by the moving arrow resulted in a squeezing effect on the rear of the arrow as the air rushed back to prevent a vacuum from forming. The arrow was propelled through the air as a bar of soap is propelled in the bathtub when you squeeze one end of it.

To summarize, Aristotle taught that all motions are due to the nature of the moving object or due to a sustained push or pull. Provided that an object is in its proper place, it will not move unless subjected to a force. Except for celestial objects, the normal state is one of rest.

Aristotle's statements about motion were a beginning in scientific thought, and, although he did not consider them to be the final words on the subject, his followers for nearly 2000 years regarded his views as beyond question. Implicit in the thinking of ancient, medieval, and early Renaissance times was the notion that the normal state of objects is one of rest. Since it was evident to most thinkers until the 16th century that Earth must be in its proper place, and since a force capable of moving Earth was inconceivable, it seemed quite clear to them that Earth does not move.

CHECK POINT

Isn't it common sense to think of Earth in its proper place and that a force to move it *is* inconceivable, as Aristotle held, and that Earth *is* at rest in this universe?

CHECK YOUR ANSWER

Aristotle's views were logical and consistent with everyday observations. So, unless you become familiar with the physics to follow in this book, Aristotle's views about motion *do* make common sense. But, as you acquire new information about nature's rules, you'll likely find your common sense progressing beyond Aristotelian thinking.

Copernicus and the Moving Earth

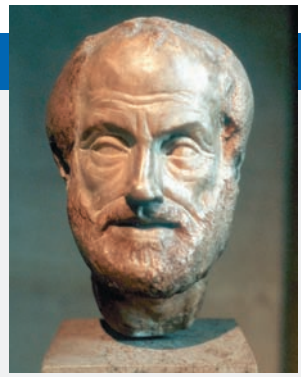


Nicolaus Copernicus (1473–1543)

It was in this intellectual climate that the Polish astronomer Nicolaus Copernicus (1473–1543) formulated his theory of the moving Earth. Copernicus reasoned that the simplest way to account for the observed motions of the Sun, Moon, and planets through the sky was to assume that Earth (and other planets) circles around the Sun. For years he worked without making his thoughts public—for two reasons. The first was the fear of persecution; a theory so completely different from common opinion would surely be taken as an attack on established order. The second reason was that he had grave doubts about it himself; he could not reconcile the idea of a moving Earth with the prevailing ideas of motion. Finally, in the last days of his life, at the urging of close friends, he sent his *De Revolutionibus* to the printer. The first copy of his famous exposition reached him on the day he died—May 24, 1543.

Most of us know about the reaction of the medieval Church to the idea that Earth travels around the Sun. Aristotle's views had become a formidable part of Church doctrine, so to contradict them was to question the Church itself. For many Church leaders, the idea of a moving Earth threatened not only their authority but the very foundations of faith and civilization as well. For better or for worse, this new idea was to overturn their conception of the cosmos—although eventually the Church embraced it.

ARISTOTLE (384–322 BC)



Greek philosopher, scientist, and educator, Aristotle was the son of a physician who personally served the king of Macedonia. At age 17, Aristotle entered the Academy of Plato, where he worked and studied for 20 years until Plato's death. He then became the tutor of young Alexander the Great. Eight years later, he formed his own school. Aristotle's aim was to systematize existing knowledge, just as Euclid had systematized geometry. Aristotle made critical observations, collected specimens, and gathered together, summarized, and classified almost all existing knowledge of the physical world. His systematic approach became the method from which Western science later arose. After his death, his voluminous notebooks were preserved in caves near his home and were later sold to the library at Alexandria. Scholarly activity ceased in most of Europe through the Dark Ages, and the works of Aristotle were forgotten and lost except in the scholarship that continued in the Byzantine and Islamic empires. Various texts were reintroduced to Europe during the 11th and 12th centuries and translated into Latin. The Church, the dominant political and cultural force in Western Europe, first prohibited the works of Aristotle but then accepted and incorporated them into Christian doctrine.

2.2 Galileo's Experiments

Leaning Tower

It was Galileo, the foremost scientist of the early 17th century, who gave credence to the Copernican view of a moving Earth. He accomplished this by discrediting the Aristotelian ideas about motion. Although he was not the first to point out difficulties in Aristotle's views, Galileo was the first to provide conclusive refutation through observation and experiment.

Galileo easily demolished Aristotle's falling-body hypothesis. Galileo is said to have dropped objects of various weights from the top of the Leaning Tower of Pisa to compare their falls. Contrary to Aristotle's assertion, Galileo found that a stone twice as heavy as another did not fall twice as fast. Except for the small effect of air resistance, he found that objects of various weights, when released at the same time, fell together and hit the ground at the same time. On one occasion, Galileo allegedly attracted a large crowd to witness the dropping of two objects of different weight from the top of the tower. Legend has it that many observers of this demonstration who saw the objects hit the ground together scoffed at the young Galileo and continued to hold fast to their Aristotelian teachings.

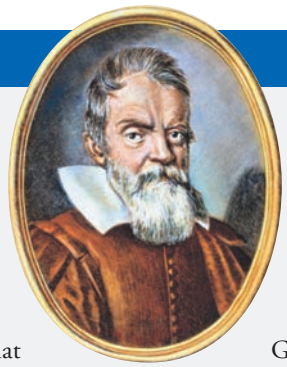


FIGURE 2.1
Galileo's famous demonstration.

Inclined Planes

Galileo was concerned with *how* things move rather than *why* they move. He showed that experiment rather than logic is the best test of knowledge. Aristotle was an astute observer of nature, and he dealt with problems around him rather than with abstract cases that did not occur in his environment. Motion always involved a resistive medium such as air or water. He believed a vacuum to be impossible and therefore did not give serious consideration to motion in the absence of an interacting medium. That's why it was basic to Aristotle that an object requires a push or pull to keep it moving. And it was this basic principle that Galileo rejected when he stated that, if there is no interference with a moving object, it will keep moving in a straight line forever; no push, pull, or force of any kind is necessary.

GALILEO GALILEI (1564–1642)



Galileo was born in Pisa, Italy, in the same year Shakespeare was born and Michelangelo died. He studied medicine at the University of Pisa and then changed to mathematics. He developed an early interest in motion and was soon at odds with his contemporaries, who held to Aristotelian ideas on falling bodies. Galileo's experiments with falling bodies discredited Aristotle's assertion that the speed of a falling object was proportional to its weight, as discussed earlier. But, quite important, Galileo's findings also threatened the authority of the Church, which held that the teachings of Aristotle were part of Church doctrine. Galileo went on to report his telescopic observations, which got him further in trouble with the Church. He told of his sightings of moons that orbited the planet Jupiter. The Church, however, taught that everything in the heavens revolved around Earth. Galileo also reported dark spots on the Sun, but according to Church doctrine, God created the Sun as a perfect source of light, without blemish. Under pressure, Galileo recanted his discoveries and avoided the fate of Giordano Bruno, who held firm to his belief in the Copernican model of the solar system and was burned at the stake in 1600. Nevertheless, Galileo was sentenced to perpetual house arrest. Earlier, he had damaged his eyes while investigating the Sun in his telescopic studies, which led to blindness at the age of 74. He died four years later. Every age has intellectual rebels, some of whom push the frontiers of knowledge further. Among them is certainly Galileo.

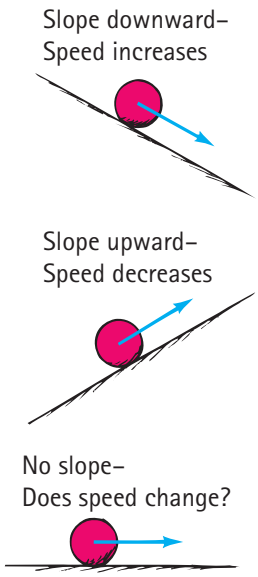


FIGURE 2.2
Motion of balls on various planes.

Galileo tested this hypothesis by experimenting with the motions of various objects on plane surfaces tilted at various angles. He noted that balls rolling on downward-sloping planes picked up speed, while balls rolling on upward-sloping planes lost speed. From this he reasoned that balls rolling along a horizontal plane would neither speed up nor slow down. The ball would finally come to rest not because of its "nature," but because of friction. This idea was supported by Galileo's observation of motion along smoother surfaces: When there was less friction, the motion of objects persisted for a longer time; the less the friction, the more the motion approached constant speed. He reasoned that, in the absence of friction or other opposing forces, a horizontally moving object would continue moving indefinitely.

This assertion was supported by a different experiment and another line of reasoning. Galileo placed two of his inclined planes facing each other. He observed

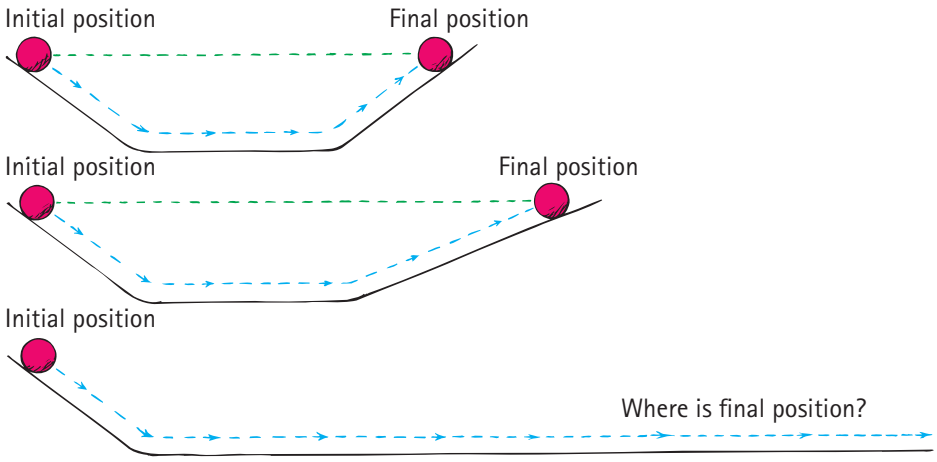


FIGURE 2.3
A ball rolling down an incline on the left tends to roll up to its initial height on the right. The ball must roll a greater distance as the angle of incline on the right is reduced.

that a ball released from a position of rest at the top of a downward-sloping plane rolled down and then up the slope of the upward-sloping plane until it almost reached its initial height. He reasoned that only friction prevented it from rising to exactly the same height, for the smoother the planes, the closer the ball rose to the same height. Then he reduced the angle of the upward-sloping plane. Again the ball rose to the same height, but it had to go farther. Additional reductions of the angle yielded similar results; to reach the same height, the ball had to go farther each time. He then asked the question, "If I have a long horizontal plane, how far must the ball go to reach the same height?" The obvious answer is "Forever—it will never reach its initial height."[2]

Galileo analyzed this in still another way. Because the downward motion of the ball from the first plane is the same for all cases, the speed of the ball when it begins moving up the second plane is the same for all cases. If it moves up a steep slope, it loses its speed rapidly. On a lesser slope, it loses its speed more slowly and rolls for a longer time. The less the upward slope, the more slowly the ball loses its speed. In the extreme case in which there is no slope at all—that is, when the plane is horizontal—the ball should not lose any speed. In the absence of retarding forces, the tendency of the ball is to move forever without slowing down. We call this property of an object to resist changes in motion **inertia**.

Galileo's concept of inertia discredited the Aristotelian theory of motion. Aristotle did not recognize the idea of inertia because he failed to imagine what motion would be like without friction. In his experience, all motion was subject to resistance, and he made this fact central to his theory of motion. Aristotle's failure to recognize friction for what it is—namely, a force like any other—impeded the progress of physics for nearly 2000 years, until the time of Galileo. An application of Galileo's concept of inertia would show that no force is required to keep Earth moving forward. The way was open for Isaac Newton to synthesize a new vision of the universe.

fyi

- Galileo published the first mathematical treatment of motion in 1632—12 years after the Pilgrims landed at Plymouth Rock.

CHECK POINT

Would it be correct to say that inertia is the *reason* a moving object continues in motion when no force acts upon it?

CHECK YOUR ANSWER

In the strict sense, no. We don't know the reason for objects persisting in their motion when no forces act upon them. We refer to the property of material objects to behave in this predictable way as *inertia.* We understand many things and have labels and names for these things. There are many things we do not understand, and we have labels and names for these things also. Education consists not so much in acquiring new names and labels, but in learning which phenomena we understand and which we don't.

In 1642, several months after Galileo died, Isaac Newton was born. By the time Newton was 23, he developed his famous laws of motion, which completed the overthrow of the Aristotelian ideas that had dominated the thinking of the best minds for nearly two millennia. In this chapter, we consider the first of Newton's laws, a restatement of the concept of inertia as proposed earlier by Galileo. (Newton's three laws of motion first appeared in one of the most important books of all time, Newton's *Principia*.)



Inertia isn't a kind of force; it's a *property* of all matter to resist changes in motion.

[2]From Galileo's *Dialogues Concerning the Two New Sciences*.

2.3 Newton's First Law of Motion

VIDEO: Newton's Law of Inertia

Aristotle's idea that a moving object must be propelled by a steady force was completely turned around by Galileo, who stated that, in the *absence* of a force, a moving object will continue moving. The tendency of things to resist changes in motion was what Galileo called *inertia*. Newton refined Galileo's idea and made it his first law, appropriately called the **law of inertia**. From Newton's *Principia* (translated from the original Latin):

> **Every object continues in a state of rest or of uniform speed in a straight line unless acted on by a nonzero net force.**



FIGURE 2.4
Inertia in action.

The key word in this law is *continues:* An object *continues* to do whatever it happens to be doing unless a force is exerted upon it. If it is at rest, it *continues* in a state of rest. This is nicely demonstrated when a tablecloth is skillfully whipped from under dishes on a tabletop, leaving the dishes in their initial state of rest. We stress that this property of objects to resist changes in motion is what we call inertia.

If an object is moving, it *continues* to move without turning or changing its speed. This is evident in space probes that continuously move in outer space. Changes in motion must be imposed against the tendency of an object to retain its state of motion. In the absence of net forces, a moving object tends to move along a straight-line path indefinitely.

VIDEO: The Old Tablecloth Trick

You can think of inertia as another word for *laziness* (or resistance to change).

FIGURE 2.5
Examples of inertia.



Why will the coin drop into the glass when a force accelerates the card?



Why is it that a slow continuous increase in the downward force breaks the string above the massive ball, but a sudden increase breaks the lower string?

Why does the downward motion and sudden stop of the hammer tighten the hammerhead?



VIDEO: Toilet Paper Roll

VIDEO: Inertia of a Cylinder

VIDEO: Inertia of an Anvil

CHECK POINT

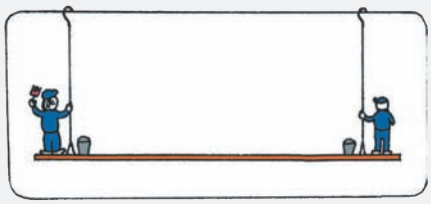
A hockey puck sliding across the ice finally comes to rest. How would Aristotle have interpreted this behavior? How would Galileo and Newton have interpreted it? How would you interpret it? *(Think before you read the answers below!)*

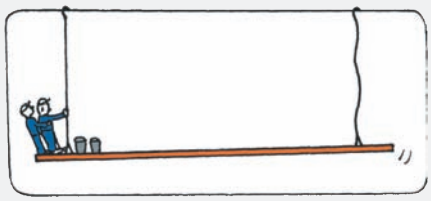
CHECK YOUR ANSWERS

Aristotle would probably say that the puck slides to a stop because it seeks its proper and natural state, one of rest. Galileo and Newton would probably say that, once in motion, the puck continues in motion and that what prevents continued motion is not its nature or its proper rest state, but the friction the puck encounters. This friction is small compared with the friction between the puck and a wooden floor, which is why the puck slides so much farther on ice. Only you can answer the last question.

PERSONAL ESSAY

When I was in high school, my counselor advised me not to enroll in science and math classes and instead to focus on what seemed to be my gift for art. I took this advice. I was then interested in drawing comic strips and in boxing, neither of which earned me much success. After a stint in the Army, I tried my luck at sign painting, and the cold Boston winters drove me south to warmer Miami, Florida. There, at age 26, I got a job painting billboards and met a man who became a great intellectual influence on me, Burl Grey. Like me, Burl had never studied physics in high school. But he was passionate about science in general, and he shared his passion with many questions as we painted together. I remember Burl asking me about the tensions in the ropes that held up the scaffold we were on. The scaffold was simply a heavy horizontal plank suspended by a pair of ropes. Burl twanged the rope nearest his end of the scaffold and asked me to do the same with mine. He was comparing the tensions in both ropes—to determine which was greater. Burl was heavier than I was, and he reasoned that the tension in his rope was greater. Like a more tightly stretched guitar string, the rope with greater tension twangs at a higher pitch. The finding that Burl's rope had a higher pitch seemed reasonable because his rope supported more of the load.



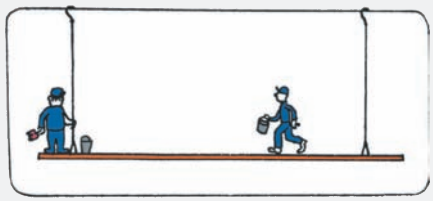


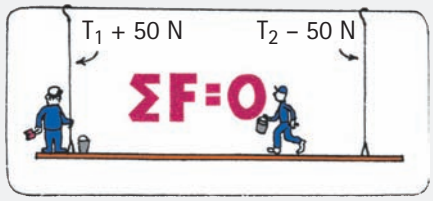
When I walked toward Burl to borrow one of his brushes, he asked if the tensions in the ropes had changed. Did the tension in his rope increase as I moved closer? We agreed that it should have, because even more of the load was supported by Burl's rope. How about my rope? Would its tension decrease? We agreed that it would, for it would be supporting less of the total load. I was unaware at the time that I was discussing physics. Burl and I used exaggeration to bolster our reasoning (just as physicists do). If we both stood at an extreme end of the scaffold and leaned outward, it was easy to imagine the opposite end of the scaffold rising like the end of a seesaw—with the opposite rope going limp. Then there would be no tension in that rope. We then reasoned that the tension in my rope would gradually decrease as I walked toward Burl. It was fun posing such questions and seeing if we could answer them.

A question that we couldn't answer was whether or not the decrease in tension in my rope when I walked away from it would *exactly* compensate the increase in tension in Burl's rope. For example, if my rope underwent a decrease of 50 newtons, would Burl's rope gain 50 newtons? (We talked pounds back then, but here we use the scientific unit of force, the *newton*—abbreviated N.) Would the gain be *exactly* 50 N? And, if so, would this be a grand coincidence? I didn't know the answer until more than a year later, when Burl's stimulation resulted in my leaving full-time painting and going to college to learn more about science.[3]

At college, I learned that any object at rest, such as the sign-painting scaffold that supported us, is said to be in equilibrium. That is, all the forces that act on it balance to zero. So the sums of the upward forces supplied by the supporting ropes indeed do add up to our weights plus the weight of the scaffold. A 50-N loss in one would be accompanied by a 50-N gain in the other.

I tell this true story to make the point that one's thinking is very different when there is a rule to guide it. Now when I look at any motionless object I know immediately that all the forces acting on it cancel out. We





view nature differently when we know its rules. Without the rules of physics, we tend to be superstitious and to see magic where there is none. Quite wonderfully, everything is connected to everything else by a surprisingly small number of rules, and in a beautifully simple way. The rules of nature are what the study of physics is about.

[3]I am forever indebted to Burl Grey for the stimulation he provided, for when I continued with formal education, it was with enthusiasm. I lost touch with Burl for 40 years. Then a student in my class at the Exploratorium in San Francisco, Jayson Wechter, who was a private detective, located him in 1998 and put us in contact. Friendship renewed, we once again continue in spirited conversations.

2.4 Net Force and Vectors

SCREENCAST: Net Force Vectors

VIDEO: Definition of a Newton

Changes in motion are produced by a force or combination of forces (in the next chapter we'll refer to changes in motion as *acceleration*). A **force**, in the simplest sense, is a push or a pull. Its source may be gravitational, electrical, magnetic, or simply muscular effort. When more than a single force acts on an object, we consider the ***net* force**. For example, if you and a friend pull in the same direction with equal forces on an object, the forces combine to produce a net force twice as great as your single force. If you both pull with equal forces in *opposite* directions, the net force is zero. The equal but oppositely directed forces cancel each other. One of the forces can be considered to be the negative of the other, and they add algebraically to zero, with a resulting net force of zero.

Figure 2.6 shows how forces combine to produce a net force. A pair of 5-newton forces in the same direction produce a net force of 10 newtons (the newton, N, is the scientific unit of force). If the 5-newton forces are in opposite directions, the net force is zero. If 10 newtons of force is exerted to the right and 5 newtons to the left, the net force is 5 newtons to the right. The forces are shown by arrows. When the length and direction of such arrows are drawn to scale, we refer to the arrow as a **vector**.

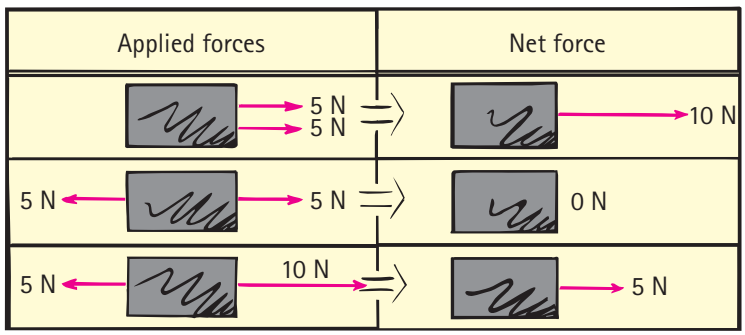
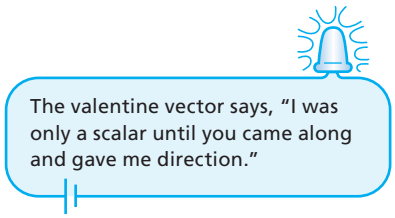


FIGURE 2.6
Net force (a force of 5 N is about 1.1 lb).

Any quantity that requires both magnitude and direction for a complete description is a **vector quantity** (Figure 2.7). Examples of vector quantities include force, velocity, and acceleration. By contrast, a quantity that can be described by magnitude only, not involving direction, is called a **scalar quantity**. Mass, volume, and speed are scalar quantities.

FIGURE 2.7
This vector, scaled so that 1 cm equals 20 N, represents a force of 60 N to the right.

Adding vectors that act along parallel directions is simple enough: If they act in the same direction, they add; if they act in opposite directions, they subtract. The sum of two or more vectors is called their **resultant**. To find the resultant of two



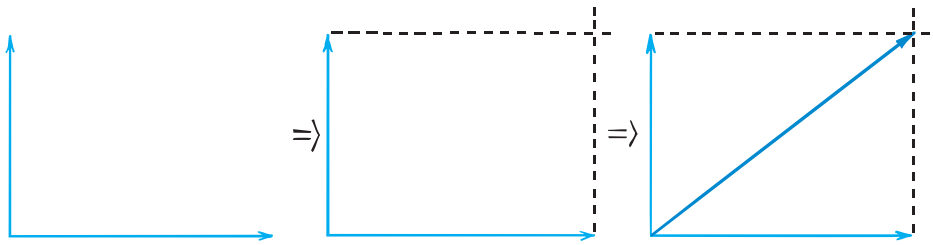


FIGURE 2.8
The pair of vectors at right angles to each other make two sides of a rectangle, the diagonal of which is their resultant.

vectors that don't act in exactly the same or opposite direction, we use the *parallelogram rule.*[4] Construct a parallelogram in which the two vectors are adjacent sides—the diagonal of the parallelogram shows the resultant. In Figure 2.8, the parallelograms are rectangles.

In the special case of two vectors that are equal in magnitude and perpendicular to each other, the parallelogram is a square (Figure 2.9). Since for any square the length of a diagonal is $\sqrt{2}$, or 1.41, times one of the sides, the resultant is $\sqrt{2}$ times one of the vectors. For example, the resultant of two equal vectors of magnitude 100 acting at a right angle to each other is 141.

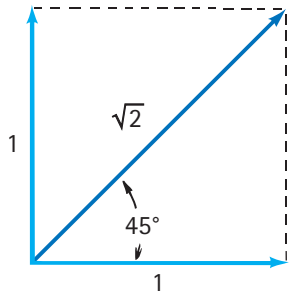


FIGURE 2.9
When a pair of equal-length vectors at right angles to each other are added, they form a square. The diagonal of the square is the resultant, $\sqrt{2}$ times the length of either side.

Force Vectors

Figure 2.10 shows a pair of forces acting on a box. One is 30 newtons and the other is 40 newtons. Simple measurement shows that the resultant of this pair of forces is 50 newtons.

Figure 2.11 shows Nellie Newton hanging at rest from a clothesline. Note that the clothesline acts like a pair of ropes that make different angles with the vertical. The three steps show there are three forces acting on Nellie: her weight, a tension in the left-hand side of the rope, and a tension in the right-hand side of the rope. Because of the different angles, different rope tensions will occur in each side. Because Nellie hangs in equilibrium, the two rope tensions must add vectorially to be equal and opposite to her weight. Which side has the greater tension? The parallelogram rule shows that the tension in the right-hand rope is greater than the tension in the left-hand rope. If you measure the vectors, you'll see that the tension in the right rope is about twice the tension in the left rope. Both rope tensions combine to support Nellie's weight.

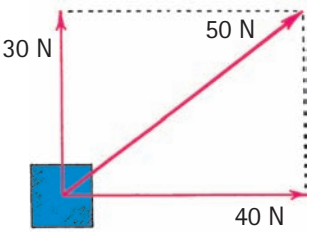


FIGURE 2.10
The resultant of the 30-N and 40-N forces is 50 N.

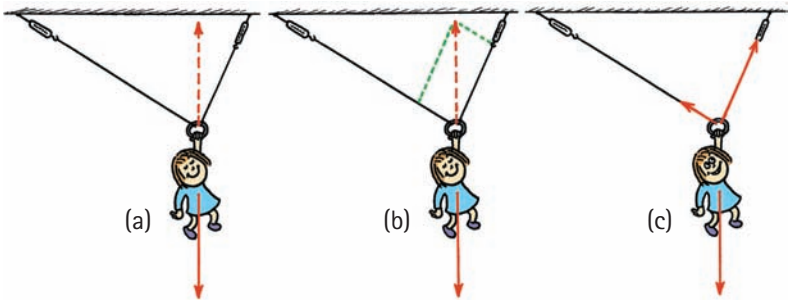
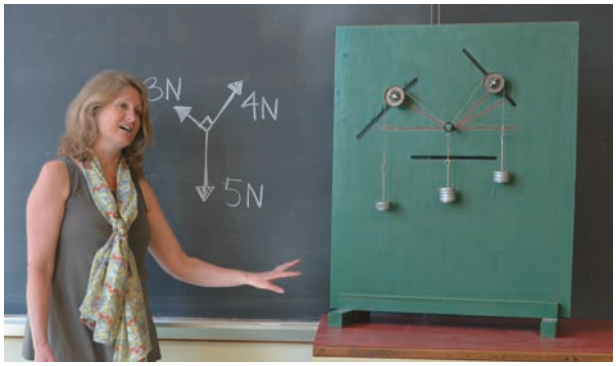


FIGURE 2.11
(a) The force due to gravity on Nellie is shown by the downward vertical vector. An equal and opposite vector is needed for equilibrium, shown by the dashed vector. (b) This dashed vector is the diagonal of a parallelogram defined by the green lines. (c) Both rope tensions are shown by the constructed vectors. Tension is greater in the right rope, the one more likely to break.

FIGURE 2.12
Diana Lininger Markham illustrates the vector arrangement of Figure 2.11.



SCREENCAST: Nellie's Rope Tension

SCREENCAST: Nellie's Ropes

[4]A parallelogram is a four-sided figure with opposite sides parallel to each other. Usually, you determine the length of the diagonal by measurement, but in the special case in which the two vectors **X** and **Y** are perpendicular (a square or a rectangle), you can apply the Pythagorean theorem, $\mathbf{R^2 = X^2 + Y^2}$, to find the resultant: $\mathbf{R = \sqrt{X^2 + Y^2}}$.

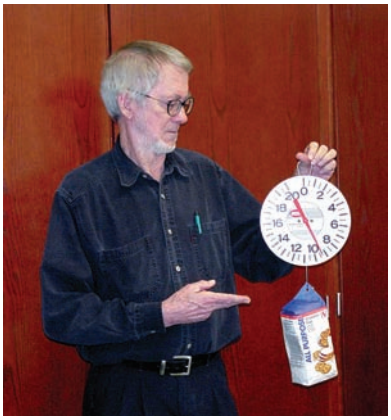


FIGURE 2.13
Burl Grey, who first introduced the author to tension forces, suspends a 2-lb bag of flour from a spring scale, showing its weight and the tension in the string of about 9 N.

More about force vectors can be found in Appendix D at the end of this book and in the *Practicing Physics* book. In the next chapter we'll discuss velocity vectors.

2.5 The Equilibrium Rule

If you tie a string around a 2-pound bag of flour and hang it on a weighing scale (Figure 2.13), a spring in the scale stretches until the scale reads 2 pounds. The stretched spring is under a "stretching force" called *tension.* The same scale in a science lab is likely calibrated to read the same force as 9 newtons. Both pounds and newtons are units of weight, which in turn are units of *force.* The bag of flour is attracted to Earth with a gravitational force of 2 pounds—or, equivalently, 9 newtons. Hang twice as much flour from the scale and the reading will be 18 newtons.

Note that there are two forces acting on the bag of flour—tension force acting upward and weight acting downward. The two forces on the bag are equal and opposite, and they cancel to zero. Hence, the bag remains at rest. In accord with Newton's first law, no net force acts on the bag. We can look at Newton's first law in a different light—*mechanical equilibrium.*

When the net force on something is zero, we say that something is in **mechanical equilibrium**.[5] In mathematical notation, the **equilibrium rule** is

$$\Sigma \boldsymbol{F} = 0$$

The symbol Σ stands for "the vector sum of" and $\boldsymbol{F}$ stands for "forces." For a suspended object at rest, like the bag of flour, the rule says that the forces acting upward on the object must be balanced by other forces acting downward to make the vector sum equal to zero. (Vector quantities take direction into account, so if upward forces are $+$, downward ones are $-$, and, when added, they actually subtract.)

In Figure 2.14, we see the forces involved for Burl and Paul on their sign-painting scaffold. The sum of the upward tensions is equal to the sum of their weights plus the weight of the scaffold. Note how the magnitudes of the two upward vectors equal the magnitude of the three downward vectors. The net force on the scaffold is zero, so we say it is in mechanical equilibrium.

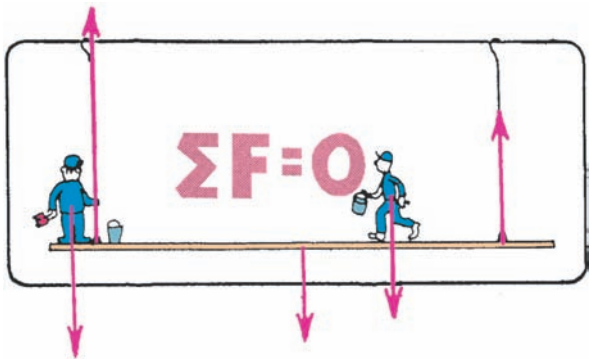


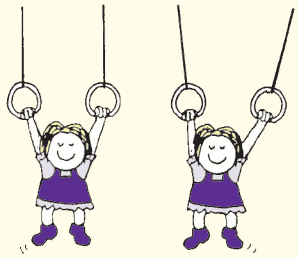
FIGURE 2.14
The sum of the upward forces equals the sum of the downward forces. $\Sigma \boldsymbol{F} = 0$ and the scaffold is in equilibrium.

SCREENCAST: Force Vector Diagrams

[5]Something that is in equilibrium is without a change in its state of motion. When we study rotational motion in Chapter 8, we'll see that another condition for mechanical equilibrium is that the net *torque* equals zero.

CHECK POINT

Consider the gymnast hanging from the rings.



1. **If she hangs with her weight evenly divided between the two rings, how will the scale readings in both supporting ropes compare with her weight?**
2. **Suppose she hangs with slightly more of her weight supported by the left ring. How will the right scale read?**

Everything not undergoing changes in motion is in mechanical equilibrium. That's when $\sum F = 0$.

SCREENCAST: Equilibrium Rule

SCREENCAST: Equilibrium Problems

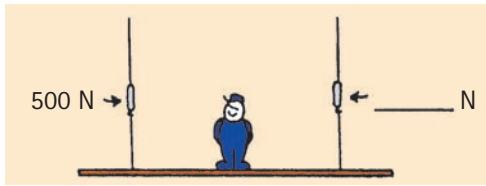
CHECK YOUR ANSWERS

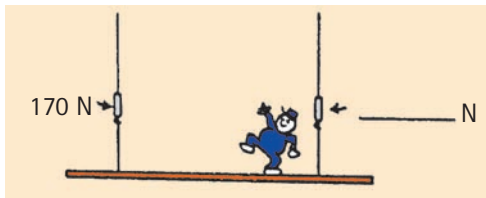
(Are you reading this before you have formulated reasoned answers in your thinking? If so, do you also exercise your body by watching others do push-ups? Exercise your thinking: When you encounter the many Check Point questions throughout this book, think before you read the answers!)

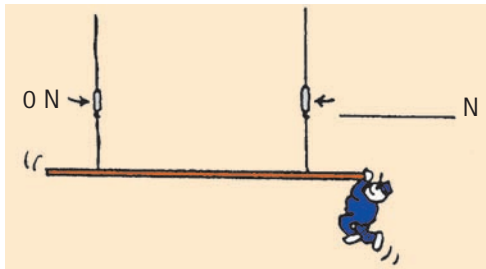
1. The reading on each scale will be half her weight. The sum of the readings on both scales then equals her weight.
2. When more of her weight is supported by the left ring, the reading on the right scale will be lower. Can you see that this is a less exaggerated situation than was shown in Figure 2.11, with the left and right ropes reversed?

PRACTICING PHYSICS

1. When Burl stands alone in the exact middle of his scaffold, the left scale reads 500 N. Fill in the reading on the right scale. The total weight of Burl and the scaffold must be _____ N.
2. Burl stands farther from the left end. Fill in the reading on the right scale.
3. In a silly mood, Burl dangles from the right end. Fill in the reading on the right scale.







Practicing Physics Answers

Do your answers illustrate the equilibrium rule? In question 1, the right rope undergoes **500 N** of tension because Burl is in the middle and both ropes support his weight equally. Since the sum of upward tensions is 1000 N, the total weight of Burl and the scaffold must be **1000 N**. Let's call the upward tension forces +1000 N. Then the downward weights are −1000 N. What happens when you add +1000 N and −1000 N? The answer is that they equal zero. So we see that $\sum F = 0$.

For question 2, did you get the correct answer of **830 N**? Reasoning: We know from question 1 that the sum of the rope tensions equals 1000 N, and since the left rope has a tension of 170 N, the other rope must make up the difference—that is, 1000 N − 170 N = 830 N. Get it? If so, great. If not, talk about it with your friends until you do. Then read further.

The answer to question 3 is **1000 N**. Do you see that this illustrates $\sum F = 0$?

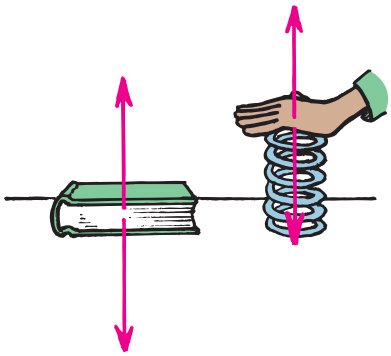


FIGURE 2.15
(Left) The table pushes up on the book with as much force as the downward force of gravity on the book. (Right) The spring pushes up on your hand with as much force as you exert to push down on the spring.

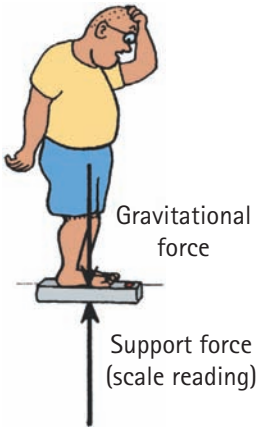


FIGURE 2.16
Your weight is the force you exert on a supporting surface, which when in equilibrium is the gravitational force on you. The scale reading shows both your weight and the support force.

2.6 Support Force

Consider a book lying at rest on a table. It is in equilibrium. What forces act on the book? One force is that due to gravity—the *weight* of the book. Since the book is in equilibrium, there must be another force acting on the book to produce a net force of zero—an upward force opposite to the force of Earth's gravity. The table exerts this upward force. We call this the upward *support force.* This upward support force, often called the *normal force,* must equal the weight of the book.[6] If we call the upward force positive, then the downward weight is negative, and the two add to zero. The net force on the book is zero. Another way to say the same thing is $\sum \boldsymbol{F} = 0$.

To understand better that the table pushes up on the book, compare the case of compressing a spring (Figure 2.15). If you push the spring down, you can feel the spring pushing up on your hand. Similarly, the book lying on the table compresses atoms in the table, which behave like microscopic springs. The weight of the book squeezes downward on the atoms, and they squeeze upward on the book. In this way, the compressed atoms produce the support force.

When you step on a bathroom scale, two forces act on the scale. One is your downward push on the scale—the result of gravity pulling on you—and the other is the upward support force of the floor. These forces squeeze a mechanism (in effect, a spring) within the scale that is calibrated to show the magnitude of the support force (Figure 2.16). The force with which you push down on the scale is your weight, which has the same magnitude as the upward support force. When you are in equilibrium your weight equals the force of gravity acting on you.

CHECK POINT

1. **What is the net force on a bathroom scale when a 150-pound person stands on it?**
2. **Suppose you stand on two bathroom scales with your weight evenly divided between the two scales. What will each scale read? What will happen if you stand with more of your weight on one foot than the other?**

CHECK YOUR ANSWERS

1. Zero, as evidenced by the scale remaining at rest. The scale reads the *support force,* which has the same magnitude as weight—not the net force.
2. The reading on each scale will be half your weight. Then the sum of the scale readings will balance your weight and the net force on you will be zero. If you lean more on one scale than the other, more than half your weight will be read on that scale but less on the other, so they will still add up to your weight. Like the example of the gymnast hanging by the rings, if one scale reads two-thirds your weight, the other scale will read one-third your weight.



A zero net force on an object doesn't mean that the object must be at rest, but that its state of motion remains unchanged. It can be at rest or moving uniformly in a straight line.

2.7 Equilibrium of Moving Things

Rest is only one form of equilibrium. An object moving at constant speed in a straight-line path is also in equilibrium. Equilibrium is a state of no change. A bowling ball rolling at constant speed in a straight line is in equilibrium—until it hits the pins. Whether an object is at rest (static equilibrium) or steadily rolling in a straight-line path (dynamic equilibrium), $\sum \boldsymbol{F} = 0$.

It follows from Newton's first law that an object that is under the influence of only one force cannot be in equilibrium. The net force couldn't be zero. Only when two or more

[6]In geometry, "normal to" means "at right angles to." Since this force pushes up at right angles to the surface, it is called a "normal force."

forces act on an object can it be in equilibrium. We can test whether or not something is in equilibrium by noting whether or not it undergoes changes in its state of motion.

Consider a crate being pushed horizontally across a factory floor. If it moves at a steady speed in a straight-line path, it is in dynamic equilibrium. This tells us that more than one force acts on the crate. Another force exists—likely the force of friction between the crate and the floor. The fact that the net force on the crate equals zero means that the force of friction must be equal and opposite to our pushing force.

The equilibrium rule, $\sum \boldsymbol{F} = 0$, provides a reasoned way to view all things at rest—balancing rocks, objects in your room, or the steel beams in bridges or in building construction. Whatever their configuration, if an object is in static equilibrium, all acting forces always balance to zero. The same is true of objects that move steadily, not speeding up, slowing down, or changing direction. For dynamic equilibrium, all acting forces also balance to zero. The equilibrium rule is one that allows you to see more than meets the eye of the casual observer. It's nice to know the reasons for the stability of things in our everyday world.

There are different forms of equilibrium. In Chapter 8, we'll talk about rotational equilibrium, and, in Part 4, we'll discuss thermal equilibrium associated with heat. Physics is everywhere.

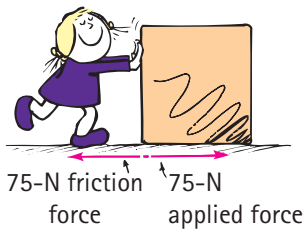


FIGURE 2.17
When the push on the crate is as great as the force of friction that the floor exerts on the crate, the net force on the crate is zero and it slides at an unchanging speed.

CHECK POINT

An airplane flies at constant speed in a horizontal straight path. In other words, the flying plane is in equilibrium. Two horizontal forces act on the plane. One is the thrust of the propeller that pushes it forward, and the other is the force of air resistance that acts in the opposite direction. Which force is greater?

CHECK YOUR ANSWER

Both forces have the same magnitude. Call the forward force exerted by the propeller positive. Then the air resistance is negative. Since the plane is in dynamic equilibrium, can you see that the two forces combine to equal zero? Hence the plane neither gains nor loses speed.

2.8 The Moving Earth

When Copernicus announced the idea of a moving Earth in the 16th century, the concept of inertia was not understood. There was much arguing and debate about whether or not Earth moved. The amount of force required to keep Earth moving was beyond imagination. Another argument against a moving Earth was the following: Consider a bird sitting at rest at the top of a tall tree. On the ground below is a fat, juicy worm. The bird sees the worm, drops vertically, and catches it. This would be impossible, it was argued, if Earth moved as Copernicus suggested. If Copernicus were correct, Earth would have to travel at a speed of 107,000 kilometers per hour to circle the Sun in one year. Convert this speed to kilometers per second and you get 30 kilometers per second. Even if the bird could descend from its branch in 1 second, the worm would have been swept by the moving Earth a distance of 30 kilometers away. It would be impossible for a bird to drop straight down and catch a worm. But birds in fact *do* catch worms from high tree branches, which seemed to be clear evidence that Earth must be at rest.

Can you refute this argument? You can if you invoke the idea of inertia. You see, not only is Earth moving at 30 kilometers per second but so are the tree, the branch of the tree, the bird on the branch, the worm below, and even the air in between. All are moving at 30 kilometers per second. Things in motion remain in motion if no unbalanced forces are acting upon them. So, when the bird drops from the branch,



FIGURE 2.18
Can the bird drop down and catch the worm if Earth moves at 30 km/s?



FIGURE 2.19
When you flip a coin in a high-speed airplane, it behaves as if the airplane were at rest. The coin keeps up with you—inertia in action!

its initial sideways motion of 30 kilometers per second remains unchanged. It catches the worm, quite unaffected by the motion of its total environment.

Stand next to a wall. Jump up so that your feet are no longer in contact with the floor. Does the 30-kilometer-per-second wall slam into you? It doesn't, because you are also traveling at 30 kilometers per second—before, during, and after your jump. The 30 kilometers per second is the speed of Earth relative to the Sun, not the speed of the wall relative to you.

People 400 years ago had difficulty with ideas like these, not only because they failed to acknowledge the concept of inertia but because they were not accustomed to moving in high-speed vehicles. Slow, bumpy rides in horse-drawn carriages did not lend themselves to experiments that would reveal the effect of inertia. Today we flip a coin in a high-speed car, bus, or plane, and we catch the vertically moving coin as we would if the vehicle were at rest. We see evidence for the law of inertia when the horizontal motion of the coin before, during, and after the catch is the same. The coin keeps up with us. The vertical force of gravity affects only the vertical motion of the coin.

Our notions of motion today are very different from those of our ancestors. Aristotle did not recognize the idea of inertia because he did not see that all moving things follow the same rules. He imagined that the rules for motion in the heavens were very different from the rules for motion on Earth. He saw vertical motion as natural but horizontal motion as unnatural, requiring a sustained force. Galileo and Newton, on the other hand, saw that all moving things follow the same rules. To them, moving things require *no* force to keep moving if there are no opposing forces, such as friction. We can only wonder how differently science might have progressed if Aristotle had recognized the unity of all kinds of motion.

For instructor-assigned homework, go to www.masteringphysics.com MP

SUMMARY OF TERMS (KNOWLEDGE)

Inertia The property of things to resist changes in motion.

Newton's first law of motion (the law of inertia) Every object continues in a state of rest or of uniform speed in a straight line unless acted on by a nonzero net force.

Force In the simplest sense, a push or a pull.

Net force The vector sum of forces that act on an object.

Vector An arrow drawn to scale used to represent a vector quantity.

Vector quantity A quantity that has both magnitude and direction, such as force.

Scalar quantity A quantity that has magnitude but not direction, such as mass and volume.

Resultant The net result of a combination of two or more vectors.

Mechanical equilibrium The state of an object or system of objects for which there are no changes in motion. In accord with Newton's first law, if an object is at rest, the state of rest persists. If an object is moving, its motion continues without change.

Equilibrium rule For any object or system of objects in equilibrium, the sum of the forces acting equals zero. In equation form, $\sum \boldsymbol{F} = 0$.

READING CHECK QUESTIONS (COMPREHENSION)

Most chapters in this book conclude with a set of questions, activities, problems, and exercises. ***Reading Check Questions*** *are designed to help you comprehend ideas and grasp the essentials of the chapter material. You'll notice that answers to the questions can be found within the chapters.* ***Think and Do*** *activities focus on hands-on applications (there are none in this chapter). Simple* ***Plug and Chug*** *one-step problems are for equation familiarization (there are none in this chapter). Your math skills are applied to* ***Think and Solve*** *problems, followed by* ***Think and Rank*** *tasks that prompt you to analyze and compare the magnitudes of various quantities.The most important end-of-chapter items are* ***Think and Explain*** *exercises, which stress synthesizing material and focus on thinking rather than mere recall of information. Unless you cover only a few chapters in your course, you will likely be expected to tackle only a few of these exercises for each chapter.* ***Think and Discuss*** *questions follow and, as the name implies, are meant to elicit discussions with your classmates. Put on your thinking cap and begin!*

2.1 Aristotle on Motion

1. What class of motion, natural or violent, did Aristotle attribute to motion of the Moon?
2. What state of motion did Aristotle attribute to Earth?
3. What relationship between the Sun and Earth did Copernicus formulate?

2.2 Galileo's Experiments

4. What did Galileo discover in his legendary experiment on the Leaning Tower of Pisa?
5. What did Galileo discover about moving bodies and force in his experiments with inclined planes?
6. Is inertia the *reason* for moving objects maintaining motion or the *name* given to this property?

2.3 Newton's First Law of Motion

7. How does Newton's first law of motion relate to Galileo's concept of inertia?
8. What type of path does a moving object follow in the absence of a force?

2.4 Net Force and Vectors

9. What is the net force on a cart that is pulled to the right with 100 pounds of force and to the left with 30 pounds of force?
10. Why do we say that force is a vector quantity?
11. According to the parallelogram rule, what quantity is represented by the diagonal of a constructed parallelogram?
12. What is the resultant of a pair of 1-pound forces at right angles to each other?
13. Consider Nellie hanging at rest in Figure 2.11. If the ropes were vertical, with no angle involved, what would be the tension in each rope?

2.5 The Equilibrium Rule

14. Can force be expressed in units of pounds and also in units of newtons?
15. What is the net force on an object that is pulled with forces of 80 newtons to the right and 80 newtons to the left?
16. What is the net force on a bag pulled down by gravity with a force of 18 newtons and pulled upward by a rope with a force of 18 newtons?
17. What does it mean to say something is in mechanical equilibrium?
18. State the equilibrium rule for forces in symbolic notation.

2.6 Support Force

19. Consider a book that weighs 15 N at rest on a flat table. How many newtons of support force does the table provide? What is the net force on the book in this case?
20. When you stand at rest on a bathroom scale, how does your weight compare with the support force by the scale?

2.7 Equilibrium of Moving Things

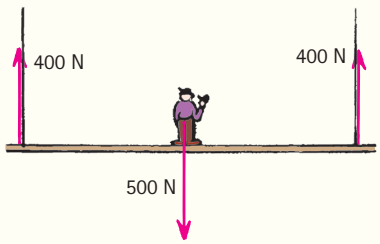
21. A bowling ball at rest is in equilibrium. Is the ball in equilibrium when it moves at constant speed in a straight-line path?
22. What is the net force on an object in either static or dynamic equilibrium?
23. If you push on a crate with a force of 100 N and it slides at constant velocity, how great is the friction acting on the crate?

2.8 The Moving Earth

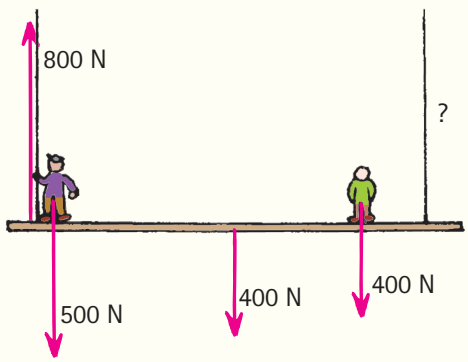
24. What concept was not understood in the 16th century when people couldn't conceive of a moving Earth?
25. A bird sitting in a tree is traveling at 30 km/s relative to the faraway Sun. When the bird drops to the ground below, does it still move at 30 km/s, or does this speed become zero?
26. Stand next to a wall that travels at 30 km/s relative to the Sun. With your feet on the ground, you also travel at the same 30 km/s. Do you maintain this speed when your feet leave the ground? What concept supports your answer?

THINK AND SOLVE (MATHEMATICAL APPLICATION)

27. Lucy Lightfoot stands with one foot on one bathroom scale and her other foot on a second bathroom scale. Each scale reads 350 N. What is Lucy's weight?
28. Henry Heavyweight weighs 1200 N and stands on a pair of bathroom scales so that one scale reads twice as much as the other. What are the scale readings?
29. The sketch shows a painter's scaffold in mechanical equilibrium. The person in the middle weighs 500 N, and the tensions in each rope are 400 N. What is the weight of the scaffold?

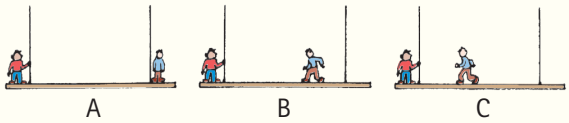


30. A different scaffold that weighs 400 N supports two painters, one 500 N and the other 400 N. The reading in the left scale is 800 N. What is the reading in the right-hand scale?

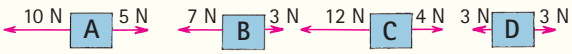


THINK AND RANK (ANALYSIS)

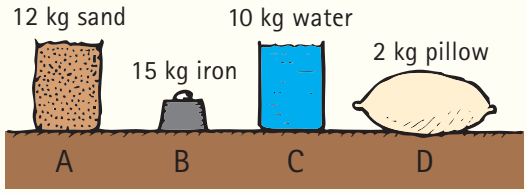
31. The weights of Burl, Paul, and the scaffold produce tensions in the supporting ropes. Rank the tensions in the *left* rope, from most to least, in the three situations, A, B, and C.



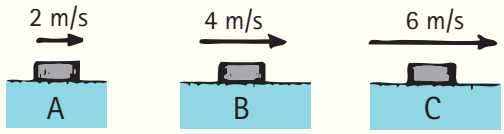
32. Rank the net forces on the blocks from least to most in the four situations, A, B, C, and D.



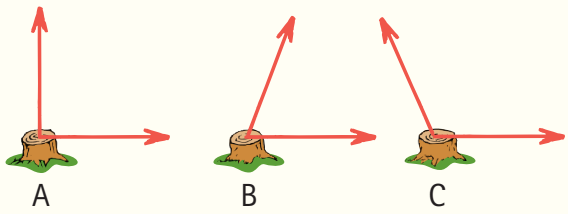
33. Different materials, A, B, C, and D, rest on a table.
    (a) Rank how much they resist being set into motion, from greatest to least.
    (b) Rank the support (normal) forces the table exerts on them, from greatest to least.



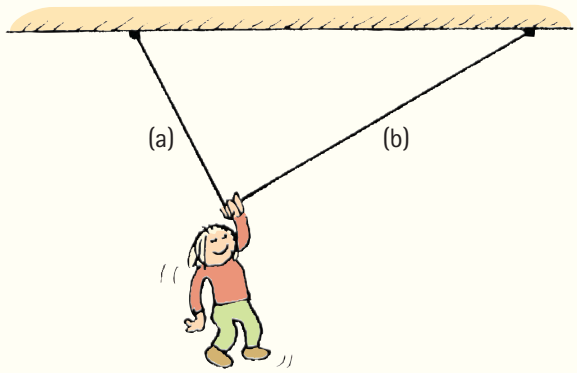
34. Three pucks, A, B, and C, are shown sliding across ice at the noted speeds. Air and ice friction forces are negligible.
    (a) Rank the forces needed to keep them moving, from greatest to least.
    (b) Rank the forces needed to stop them in the same time interval, from greatest to least.



35. As seen from above, a stubborn stump is pulled by a pair of ropes, each with a force of 200 N, but at different angles as shown. From greatest to least, rank the net forces on the stumps.



36. Nellie hangs motionless by one hand from a clothesline. Which side of the line, a or b, has the greater tension?



THINK AND EXPLAIN (SYNTHESIS)

Please do not be intimidated by the large number of exercises in this book. As mentioned earlier, if your course work is to cover many chapters, your instructor will likely assign only a few exercises from each.

37. Knowledge can be gained by philosophical logic and also by experimentation. Which of these did Aristotle favor, and which did Galileo favor?
38. A ball rolling along a floor doesn't continue rolling indefinitely. Is this because it is seeking a place of rest or because some force is acting upon it? If the latter, identify the force.
39. Copernicus postulated that Earth moves around the Sun (rather than the other way around), but he was troubled about the idea. What concepts of mechanics was he missing (concepts later introduced by Galileo and Newton) that would have eased his doubts?
40. What Aristotelian idea did Galileo discredit in his fabled Leaning Tower demonstration?
41. What Aristotelian idea did Galileo demolish with his experiments with inclined planes?
42. Was it Galileo or Newton who first proposed the concept of inertia?
43. Asteroids have been moving through space for billions of years. What keeps them moving?
44. A space probe may be carried by a rocket into outer space. What keeps the probe moving after the rocket no longer pushes it?

45. In doing the tablecloth pull demonstration of inertia of Figure 2.4, why is it important that you pull slightly downward when you attempt to whip the cloth from beneath the dishes? (What occurs if you pull slightly upward?)
46. In tearing a paper towel or plastic bag from a roll, why is a sharp jerk more effective than a slow pull?
47. If you're in a car at rest that gets hit from behind, you can suffer a serious neck injury called whiplash. What does whiplash have to do with Newton's first law?
48. In terms of Newton's first law (the law of inertia), how does a car headrest help to guard against whiplash in a rear-end collision?
49. Why do you seem to lurch forward in a bus that suddenly slows? Why do you seem to lurch backward when the bus picks up speed? What law applies here?
50. Consider a pair of forces, one having a magnitude of 20 N and the other a magnitude of 12 N. What is the strongest possible net force for these two forces? What is the weakest possible net force?
51. When any object is in mechanical equilibrium, what can be correctly stated about all the forces that act on it? Must the net force necessarily be zero?
52. Which of the following are scalar quantities, which are vector quantities, and which are neither? (a) force; (b) age; (c) acceleration; (d) temperature.
53. What can you correctly say about a pair of vectors that add together to equal zero?
54. Which is more likely to break: a hammock stretched tightly between a pair of trees or one that sags more when you sit on it?
55. A heavy bird sits on a clothesline. Will the tension in the clothesline be greater if the line sags a lot or if it sags a little?
56. The rope supports a lantern that weighs 50 N. Is the tension in the rope less than, equal to, or greater than 50 N? Use the parallelogram rule to defend your answer.



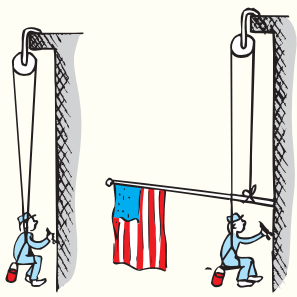
57. A monkey hangs stationary at the end of a vertical vine. What two forces act on the monkey? Which, if either, is greater?
58. The rope of Exercise 56 is repositioned as shown and still supports the 50-N lantern. Is the tension in the rope less than, equal to, or greater than 50 N? Use the parallelogram rule to defend your answer.



59. Can an object be in mechanical equilibrium when only a single nonzero force acts on it? Explain.
60. When a ball is tossed straight up, it momentarily comes to a stop at the top of its path. Is it in equilibrium during this brief moment? Why or why not?
61. A hockey puck slides across the ice at a constant speed. Is it in equilibrium? Why or why not?
62. Your friend sits at rest on a chair. Can you say that no force acts on her? Or is it correct to say that no *net* force acts on her? Defend your answer.
63. Nellie Newton hangs at rest from the ends of the rope as shown. How does the reading on the scale compare with her weight?



64. Harry the painter swings year after year from his bosun's chair. His weight is 500 N and the rope, unknown to him, has a breaking point of 300 N. Why doesn't the rope break when he is supported as shown at the left? One day, Harry is painting near a flagpole, and, for a change, he ties the free end of the rope to the flagpole instead of to his chair, as shown at the right. Why did Harry end up taking his vacation early?



65. For the pulley system shown, what is the upper limit of weight the strong man can lift?



66. If the strong man in the preceding exercise exerts a downward force of 800 N on the rope, how much upward force is exerted on the block?
67. A force of gravity pulls downward on a book on a table. What force prevents the book from accelerating downward?

68. How many significant forces act on a book at rest on a table? Identify the forces.
69. Place a heavy book on a table and the table pushes up on the book. Why doesn't this upward push cause the book to rise from the table?
70. As you stand on a floor, does the floor exert an upward force against your feet? How much force does it exert? Why aren't you moved upward by this force?
71. Suppose that you jounce up and down while weighing yourself on a bathroom scale. Which varies: the upward support force or the force of gravity on you? Why is your weight reading best shown when you stand at rest on the scale?
72. An empty jug of weight W rests on a table. What is the support force exerted on the jug by the table? What is the support force when water of weight w is poured into the jug?
73. If you pull horizontally on a crate with a force of 200 N, it slides across the floor in dynamic equilibrium. How much friction is acting on the crate?
74. In order to slide a heavy cabinet across the floor at constant speed, you exert a horizontal force of 600 N. Is the force of friction between the cabinet and the floor greater than, less than, or equal to 600 N? Defend your answer.
75. Consider a crate at rest on a factory floor. As a pair of workmen begin lifting it, does the support force on the crate provided by the floor increase, decrease, or remain unchanged? What happens to the support force on the workmen's feet?
76. Two people each pull with a force of 300 N on a rope in a tug-of-war. What is the net force on the rope? How much force is exerted on each person by the rope?
77. Two forces act on a parachutist falling in air: the force of gravity and air resistance. If the fall is steady, with no gain or loss of speed, then the parachutist is in dynamic equilibrium. How do the magnitudes of gravitational force and air resistance compare?
78. A child learns in school that Earth is traveling faster than 100,000 kilometers per hour around the Sun and, in a frightened tone, asks why we aren't swept off. What is your explanation?

THINK AND DISCUSS (EVALUATION)

79. In answer to the question "What keeps Earth moving around the Sun?" a friend asserts that inertia keeps it moving. Discuss and correct your friend's erroneous assertion.
80. Your friend says that inertia is a force that keeps things in their place, either at rest or in motion. Do you and your discussion partners agree? Why or why not?
81. Consider a ball at rest in the middle of a toy wagon. When the wagon is pulled forward, the ball rolls against the back of the wagon. Discuss and interpret this observation in terms of Newton's first law.
82. Suppose that you're in a moving car and the motor stops running. You step on the brakes and slow the car to half speed. If you release your foot from the brakes, will the car speed up a bit, or will it continue at half speed and slow due to friction? Defend your answer with your discussion partners.
83. When you push a cart, it moves. When you stop pushing, it comes to rest. Does this violate Newton's law of inertia? Discuss and defend your answer.
84. Each bone in the skeletal chain of bones forming your spine is separated from its neighbors by disks of elastic tissue. What happens, then, when you jump heavily onto your feet from an elevated position? (*Hint:* Think about the hammerhead in Figure 2.5.) Discuss why you think you are a little taller in the morning than at night.
85. Start a ball rolling down a bowling alley and you'll find that it moves slightly slower with time. Does this violate Newton's law of inertia? Discuss and defend your answer.
86. Consider the normal force on a book at rest on a tabletop. If the table is tilted so that the surface forms an inclined plane, will the magnitude of the normal force change? If so, how?
87. When you push downward on a book at rest on a table, you feel an upward force. Does this force depend on friction? Discuss and defend your answer.
88. Before the time of Galileo and Newton, some learned scholars thought that a stone dropped from the top of a tall mast of a moving ship would fall vertically and hit the deck behind the mast by a distance equal to how far the ship had moved forward while the stone was falling. In light of your understanding of Newton's first law, what do you think about this?
89. Because Earth rotates once every 24 hours, the west wall in your room moves in a direction toward you at a linear speed that is probably more than 1000 kilometers per hour (the exact speed depends on your latitude). When you stand facing the wall, you are carried along at the same speed, so you don't notice it. But when you jump upward, with your feet no longer in contact with the floor, why doesn't the high-speed wall slam into you?
90. If you toss a coin straight upward while riding in a train, where does the coin land when the motion of the train is uniform along a straight-line track? When the train slows while the coin is in the air?
91. Discuss and answer the preceding question for when the train is rounding a corner.
92. The smokestack of a stationary toy train consists of a vertical spring gun that shoots a steel ball a meter or so straight into the air—so straight that the ball always falls back into the smokestack. Suppose the train moves at constant speed along the straight track. Do you think the ball will still return to the smokestack if shot from the moving train? What if the train gains speed along the straight track? What if it moves at a constant speed on a circular track? Discuss why your answers differ.