

1.1 FORCE IN MECHANICAL SYSTEMS



Objectives

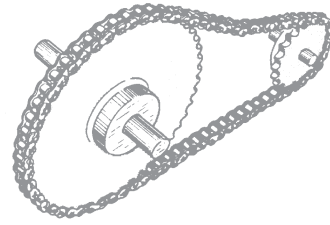
- Define force, and describe how forces are measured.
- Describe what happens when forces on an object are balanced and when they are unbalanced.
- Explain the meaning of Newton's first law of motion.
- Define scalar, vector, weight, mass, and torque.
- Determine the resultant force on an object when two or more forces act on it.
- Solve problems involving force, lever arm, and torque.



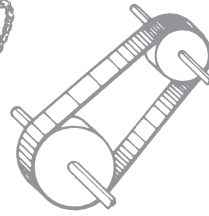
Forces are used in all mechanical systems. Forces are transmitted by a variety of mechanical parts—such as gears, belts, valves, chains, pulleys, screws, cams, linkages, rods, sprockets and pistons. These parts are interconnected in various ways to form mechanical systems.



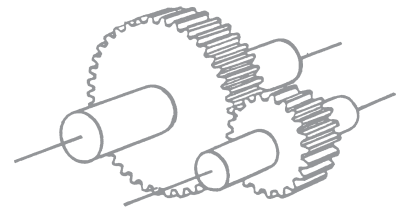
To find out more about force in mechanical systems, follow the links at www.learningincontext.com.



(a) Chain and sprockets



(b) Belts and wheels



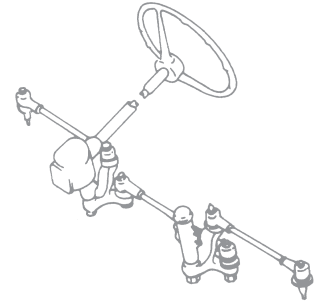
(c) Spur gears



(d) Chain hoist



(e) Piston connecting rod



(f) Linkages

Figure 1.1

Mechanical parts transmit forces in mechanical systems.

A bicycle is a mechanical system. Can you identify the forces used to move a bicycle forward? Or to stop a bicycle? What part do the legs play? How are the forces exerted by the feet on the pedals transmitted to the back wheel of the bicycle? What mechanical parts are involved?

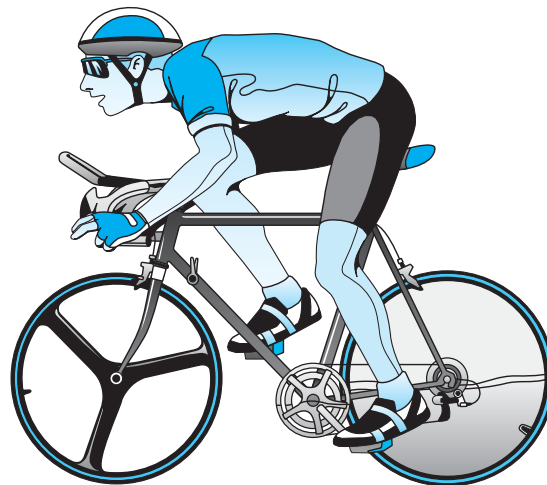


Figure 1.2

A bicycle is a mechanical system.

Measuring Force

Most of the world uses the **metric system** in science, engineering, industry, medicine, and sports. The metric system is the most convenient set of measurements because it is based on powers of ten. The metric system provides units for measuring such quantities as length, mass, and liquid capacity.

But there are many more than three physical quantities that must be measured. For example, speed is a ratio of length over time. Acceleration is a ratio of speed over time. Force is a product of mass and acceleration. Thus, measurements and units of speed, acceleration, and force are dependent on the fundamental, or basic units of length, mass, and time. In fact, all physical quantities can be described as combinations of length, mass, and time, plus four other basic quantities.

In 1971, the International Bureau of Weights and Measures, in Sèvres, France, selected **base units** for the seven basic quantities. These are called the **SI** base units, from Le Système International d'Unités. Table 1.1 lists the seven SI base units.

Table 1.1 SI Base Units

Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Other units are **derived** from the base units. For example, the SI unit of speed is m/s (length/time), acceleration is m/s² (speed/time), and force is the **newton**. You will learn in Chapter 4 that force equals mass (kg) times acceleration (m/s²). So the newton (N) is defined as

$$1 \text{ N} = 1 \text{ kg} \cdot 1 \text{ m/s}^2 \quad \text{or} \quad 1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$$

Some industries in the United States still use the **English** system of units. The English unit for force is the **pound** (lb). In this book, we will use both SI and English units.

Some useful information on units is organized in two tables that follow. Table 1.2 lists SI and English units for length, time, mass, and force. Table 1.3 lists some useful data for converting weight and mass units. You may want to refer to these tables later.

Table 1.2 English and SI Units

	Length	Time	Mass	Force
ENGLISH	foot (ft)	second (s)	slug	pound (lb)
SI	meter (m)	second (s)	kilogram (kg)	newton (N)

Table 1.3 Weight and Mass Conversions

1 pound = 16 ounces	1 kilogram weighs 9.80 N or 2.2 lb
1 pound = 4.45 newtons	1 slug weighs 32.2 pounds
1 kilogram = 1000 grams	1 slug = 14.59 kg

You can measure force with a spring scale. The spring in the scale stretches an amount proportional to the force applied to it. Thus the scale can be calibrated to read force directly. In Figure 1.3, a spring scale is used to measure the weight of a batch of nails. The weight of the nails is a force, directed downward. **Weight** is a force caused by the Earth's gravity.

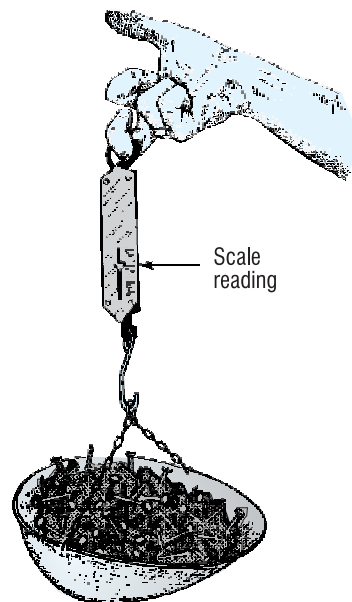


Figure 1.3

A spring scale measures force. Here, it measures the weight of a batch of nails.

Spring scales can measure force in units of either newtons or pounds. It doesn't matter which system we use, as long as we don't mix units in the same problem. For example, a weight of 30 pounds added to a weight of 20 newtons doesn't equal either 50 pounds or 50 newtons. We can't mix units. We must add pounds to pounds or newtons to newtons to find the correct answer.

Force Is a Vector

When you exert a force, for example by pushing on a book, you can push hard or gently. You can push to the right or left, forward or backward, up or down. The effect the force has on the book depends on two things: (1) the **magnitude**, or strength of the force, and (2) the **direction** of the force. When we describe a force, we always give its **magnitude** and its **direction**. A quantity that must be described by both a magnitude and a direction is called a **vector**. Force is a vector quantity. Displacement, velocity, acceleration, and momentum are also vectors. You will learn more about these quantities in Chapter 3 and Chapter 7.

Some physical quantities are described by only a magnitude. These are called **scalars**. Temperature, elapsed time, pressure, and mass are examples of scalars.

The following are correct ways of describing forces:

20 lb to the right
35 N northeast
115 N at an angle of 45° below horizontal

For each force, both magnitude and direction are specified. On the other hand, temperature is a scalar. The following are not correct ways of describing temperatures:

68° F west
 20° C to the left

Such statements have no meaning, since temperature doesn't have a direction. We say simply that the temperature is 68°F or 20°C .

How Do We Represent Forces?

A vector is represented—or drawn—as an arrow. The length of the arrow is proportional to the magnitude of the vector. The arrow points in the direction of the vector.

As an example, consider the worker in Figure 1.4 pulling a cart. The worker pulls with a force of 30 pounds along the rope, and the rope makes an angle

of 30° above the horizontal. How would you draw an arrow to represent the force the rope applies to the cart?

The length of the arrow must be proportional to the magnitude of the force, 30 pounds. So choose a convenient scale—such as one inch equals 10 pounds. Then draw the arrow three inches long, to represent 30 pounds.

Since the force makes an angle of 30° above the horizontal, draw the arrow in the same direction. The final drawing should look like the arrow in Figure 1.5.

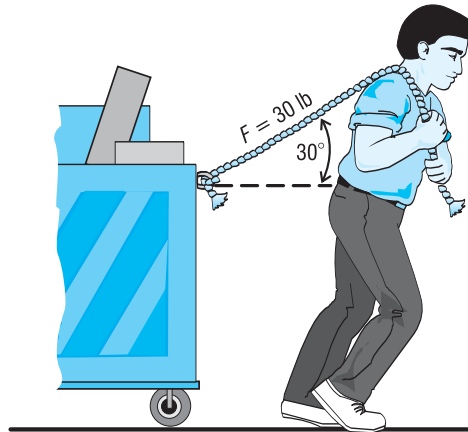


Figure 1.4 Force along rope pulls on cart.

0 lb 10 lb
Scale: 1 inch = 10 lb

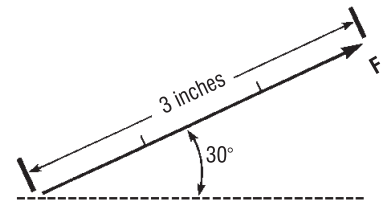


Figure 1.5 Arrow drawn as a vector to represent a 30-lb force acting at an angle of 30° above the horizontal

Balanced and Unbalanced Forces

Figure 1.6 shows two situations where opposing forces act on an object. In one case, two people pull in opposite directions on a door. In the other case, a lawnmower is pushed forward by its engine but there is an opposing force of friction. The vectors representing the forces on each object are drawn below the figures. We use a boldface letter to represent a vector. We use the same variable, but not boldface, to represent the magnitude of the vector. For example, \mathbf{F} represents a vector force, and F represents the magnitude of \mathbf{F} .

Why is it that the door does not move but the lawnmower begins to move forward?

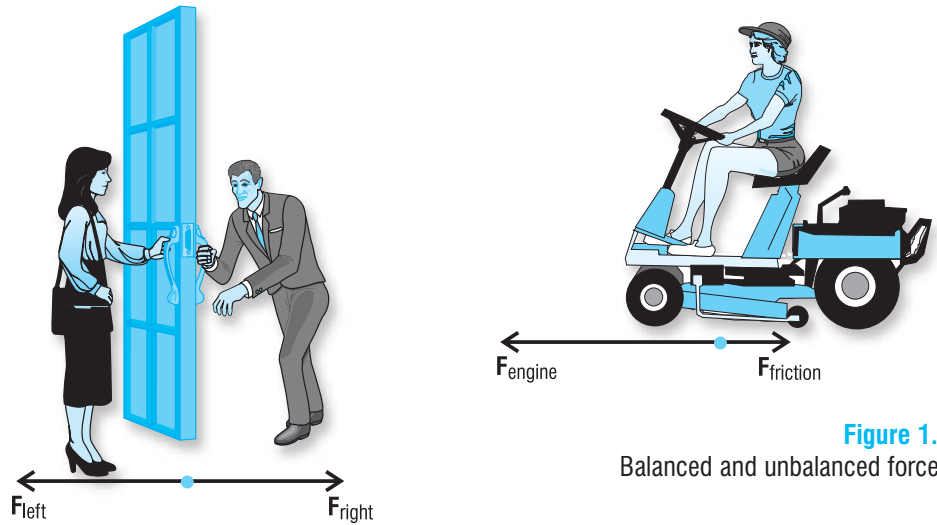
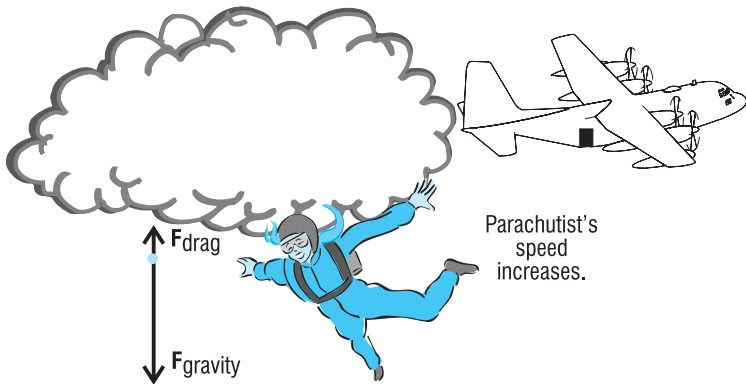


Figure 1.6
Balanced and unbalanced forces

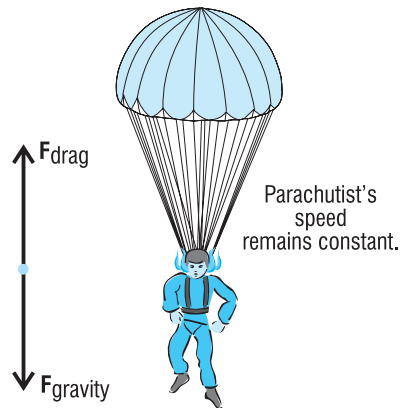
Notice the magnitudes of the forces. The door doesn't move because the force to the left F_{left} is equal in magnitude and opposite in direction to the force to the right F_{right} . Therefore, the pull on one side is balanced by an equal and opposite pull on the other side. The forces acting on the door are *balanced*.

On the other hand, the lawnmower begins to move because the push of the engine, F_{engine} is greater than the opposing force of friction F_{friction} . The forces on the lawnmower are unbalanced, so the lawnmower begins to move.

Balanced and unbalanced forces determine how a parachutist falls. As shown in Figure 1.7, two forces are acting on the parachutist—air drag, F_{drag} , and weight, F_{gravity} . Since weight is the force of gravity, it is directed downward. Air drag is always in a direction opposite to the motion, so it is directed upward. When the parachutist first exits the airplane, the two forces are unbalanced. Weight is greater than air drag, $F_{\text{gravity}} > F_{\text{drag}}$, and the parachutist falls faster and faster. After the parachute opens, air drag increases and soon equals the parachutist's weight, $F_{\text{gravity}} = F_{\text{drag}}$. Now the two forces are balanced. From then on the parachutist's speed remains constant.



(a) Unbalanced forces (weight is greater than drag)



(b) Balanced forces (weight equals drag)

Figure 1.7
Balanced and unbalanced forces

To determine what effect more than one force has on an object, we must find the sum of the forces. The sum is called the **net force** acting on the object.

- If the net force is *not zero*, the applied forces are *unbalanced*. In this case, the net force will cause a change in the object's speed or direction. Which situations in Figures 1.6 and 1.7 show net forces not equal to zero?
- If the net force equals zero, the forces are balanced—they cancel each other out. If there is no net force, the body is in **equilibrium**. There is no change in the object's speed or direction. Which situations in Figures 1.6 and 1.7 show net forces equal to zero?

Newton's First Law of Motion

The motion of a body in equilibrium is described by **Newton's first law of motion**:

Every object will remain at rest, or will continue to move in a straight line with constant speed, unless the object is acted on by a net force.

This is the first of three laws of motion written by the English scientist and mathematician Isaac Newton in 1686 in the *Philosophia Naturalis Principia Mathematica* (usually just called the *Principia*.)

Newton's first law is sometimes called the law of *inertia*. **Inertia** is the property of an object to resist changes in its motion. If a body is at rest, it tends to remain at rest. If a body is moving at constant velocity, it tends to keep moving at that velocity.

Example 1.1 Forces in Equilibrium

A yo-yo weighing 0.25 lb hangs motionless at the end of a string. Draw the forces acting on the yo-yo.

Solution: The yo-yo is the system. The forces of gravity and the string act on the system. Draw a **free-body diagram** of the system, as follows:

- Draw a dot to represent the yo-yo.
- Draw each force acting on the system with an arrow representing the vector. Draw the tail of the arrow on the dot, and point the arrow in the direction of the force.
- Draw the length of each arrow proportional to the magnitude of the force.

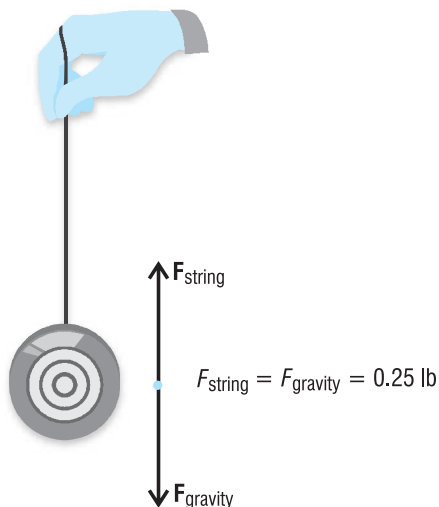


Figure 1.8
Free-body diagram
of the forces acting on a yo-yo

Since the yo-yo is not moving, the system is in equilibrium. The forces acting on it are balanced, and the magnitude of the net force is zero. The force exerted by the string is equal and opposite to the force of gravity.

Adding Forces That Act Along a Line

We add forces to find the net force acting on an object. Forces are easy to add if they act along the same line—either in the same direction or in opposite directions.

- If two or more forces act in the same direction, add their magnitudes to get the net force. The direction of the net force is the same as the direction of the added forces.
- If two forces act in opposite directions, subtract their magnitudes to get the net force. The direction of the net force is the same as the direction of the larger force.

Example 1.2 Tug-of-War Problem

Five people compete in a tug-of-war. Three people on the left side each pull with 230 N of force. Two people on the right side each pull with 300 N of force. Who will win the tug-of-war?

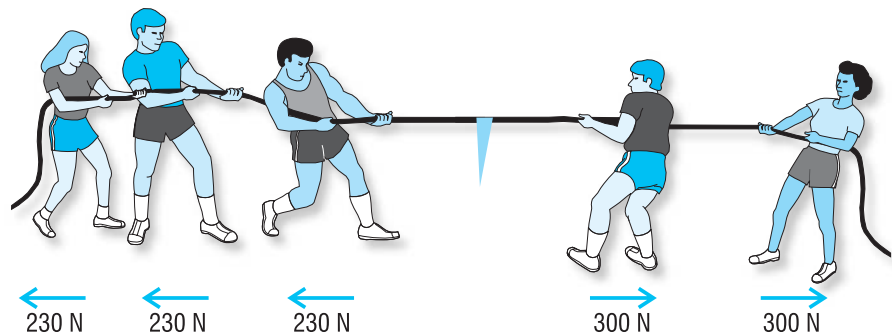


Figure 1.9
Unbalanced forces in a tug-of-war

Solution: The system is the rope, and five forces are acting on the system. Find the vector sum of the five forces. If the sum is zero, the rope will continue to be at rest. If the sum is not zero, the rope will begin to move.

Let F_1 represent the total force exerted by the two people on the right. These two addend forces act in the same direction, so add their magnitudes to find F_1 .

$$F_1 = 300 + 300 = 600 \text{ N to the right}$$

Let F_2 represent the total force exerted by the three people on the left. These three addend forces act in the same direction, so add their magnitudes to find F_2 .

$$F_2 = 230 + 230 + 230 = 690 \text{ N to the left}$$



Figure 1.10
Free-body diagram of the forces

Since F_1 and F_2 act in opposite directions, subtract their magnitudes to find the magnitude of the net force F_{net} . The direction of F_{net} is the same as the direction of F_2 , since F_2 is larger than F_1 . The net force is $690 - 600 = 90 \text{ N}$ to the left.



The rope will begin to move to the left, and the three people on the left will win the tug-of-war.

Adding Forces That Do Not Act Along a Line

If forces on an object don't act along the same line, you can't simply add or subtract their magnitudes to get the net force. But you can solve the problem graphically.

Suppose two people pull a boat with ropes tied to the boat. The ropes form a right angle, as in Figure 1.11. The person on the dock pulls with 40 pounds of force. The person on the shore pulls with 30 pounds of force. What is the net force on the boat?

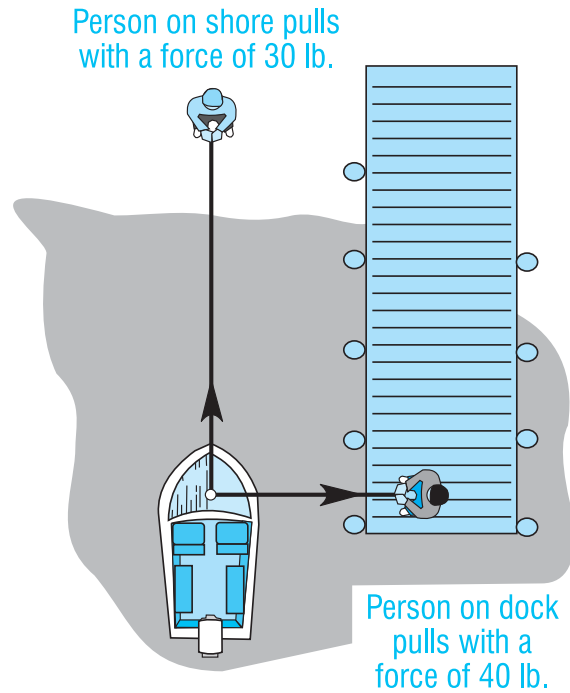


Figure 1.11
Two forces that form a 90° angle are applied to dock a boat.

To find the sum of the two forces, graph the vectors and use the “head-to-tail” method. Follow these five steps:

Step 1: Draw the 40-lb force.

Draw a horizontal line on a sheet of notebook paper, or use a horizontal grid line on a sheet of graph paper. See Figure 1.12. Choose a convenient scale, such as “ $\frac{1}{2}$ inch equals 10 pounds.” (The scale used in Figure 1.12 is shown next to the figure.) Mark off the correct number of divisions along the horizontal line to represent 40 lb. Since we’ve chosen 1 division for each 10 pounds, we mark off 4 divisions, as shown. Draw an arrowhead at the right end to indicate the direction of the 40-lb force. The 40-lb force, drawn as a vector, is represented by the arrow AB in Figure 1.12.

Step 2: Add the 30-lb force to the 40-lb force.

The 30-lb force acts at a right angle, or 90° , to the 40-pound force. So the arrow that represents the 30-lb force must be drawn vertically. In the “head-to-tail” method of vector addition, the tail of the 30-lb force is located at the head of the 40-lb force. So draw a line at 90° to the horizontal line at point B. Mark off 3 divisions to represent 30 lb. Draw the arrowhead at the top end to indicate the direction of the 30-lb force. Arrow BC in Figure 1.12 represents the 30-lb force acting at 90° to the 40-lb force.

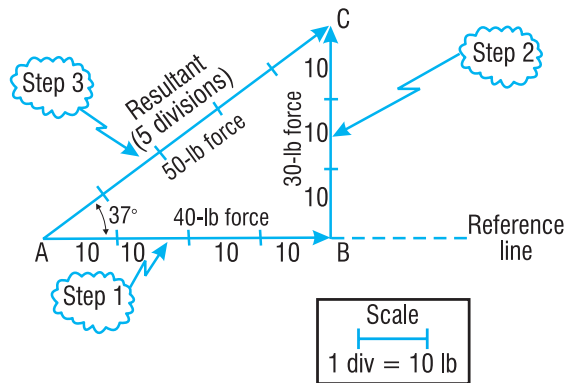


Figure 1.12
Graphical determination
of a resultant force

Step 3: Draw the resultant force.

The single vector representing the sum of two or more vectors is called the resultant. When addend vectors are arranged head-to-tail, as in Figure 1.12, the resultant is found by drawing a vector from the tail of the first vector to the head of the last vector. The resultant of the 40-lb force and the 30-lb force is represented by arrow AC.

Step 4: Determine the magnitude and the direction of the resultant.

The resultant AC measures 5 divisions on the drawing. Since the scale factor is 10 lb per division, the resultant force must equal 50 lb.

Notice that triangle ABC is a right triangle. Therefore, you can also use the Pythagorean Theorem to calculate the magnitude of the resultant. AC is the hypotenuse, and AB and BC are the legs.

$$\begin{aligned}
 AC^2 &= AB^2 + BC^2 \\
 &= 40^2 + 30^2 \\
 &= 2500 \\
 AC &= \sqrt{2500} = 50
 \end{aligned}$$

The magnitude of the resultant force is 50 lb.

To find the force's direction, use a protractor to measure the angle AC makes with the horizontal. This angle is 37°.

Step 5: Now you can draw some conclusions.

The graphical method has shown us that a 40-lb force and a 30-lb force, pulling on an object (boat) at a right angle to each other, can be replaced by a single force (the resultant) of 50 lb pulling at an angle of 37° measured from the direction of the 40-lb force. Note carefully that the result is not 70 pounds, which would have come from adding 30 pounds to 40 pounds as if they were scalars. The resultant of two vectors is always in a direction between the directions of the two vectors.

Weight and Mass Aren't the Same Thing!

If a net force greater than zero acts on an object that is at rest, it will begin to move. For example, if you push a book with a force large enough to overcome friction, the book will start to move and slide across the table. It takes twice the force to start a stack of two books moving. This is because two books have twice the inertia of one book.



Figure 1.13

Two books have twice the inertia of one book.

The amount of inertia of any object depends on the amount of matter (atoms or molecules) contained in the object. The stack of two books has twice the inertia of the single book because the stack has twice the amount of matter. The mass of an object is a measure of the object's inertia, or of the amount of matter it contains. The SI unit of mass is the kilogram, kg.

Your mass is a measure of the total amount of matter contained within your body. Your weight is a measure of the force of the Earth's gravitational pull on the mass of your body.

Suppose your weight on the Earth is 140 pounds, or 623 newtons, and your mass is 63.6 kg. If you travel to the moon, your weight will be only about 23 lb, or 104 N. This is because on the surface of the moon the gravitational pull is about one-sixth of the pull on the surface of the Earth. But on the moon your body will contain the same number and type of atoms and molecules as on Earth. Therefore, your mass will be the same 63.6 kg wherever you go.

Torque and Rotation

Torque is a quantity that causes rotation in mechanical systems. Gears, crankshafts, flywheels, fans, motors, bolts, and screws all turn or rotate. A torque is the effect of a force applied on a body at some distance from the axis of rotation of that body.

Torques can cause either **clockwise** rotations or **counterclockwise** rotations. Clockwise rotations move like the hands of a clock. The abbreviation for clockwise is "cw." Counterclockwise rotations are in the opposite direction. The abbreviation for counterclockwise is "ccw."

Consider the rotating wheel on a pull starter for a chain saw, as shown in Figure 1.14. A force pulling on a rope that’s wrapped around a wheel will cause the wheel to rotate. The torque is caused by the force applied to the rim of the wheel. Torque is equal to the product of the force (F) times the length of the lever arm (AB). The lever arm (distance AB) is always the shortest distance from the rotation axis (labeled “axle”) to the **line of action** of the applied force. The line of action is a line along the applied force that extends in both directions.

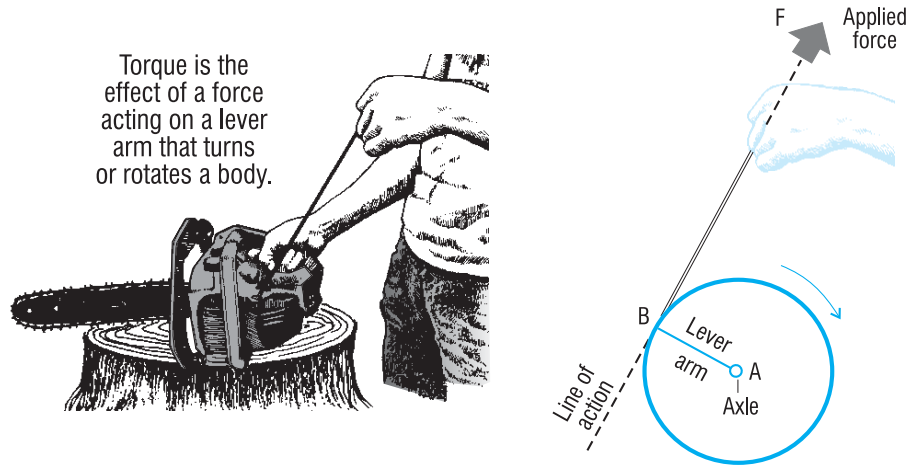


Figure 1.14
Torque causes rotation.

Torque is measured in units of force times distance. In the English system, torque is measured in pound-feet (lb·ft); in SI, torque is measured in newton-meters (N·m). We use the Greek letter τ (*tau*) to represent torque.

$$\text{Torque} = \text{applied force} \times \text{lever arm}$$

$$\tau = F \times L$$

Since torque is equal to the product of an applied force times a lever arm, torque is doubled if we keep the force the same but double the length of the lever arm. Suppose that the nut shown in Figure 1.15a can’t be loosened by the wrench when a certain force F_M is applied with a lever arm L . Then the maximum torque applied in an attempt to loosen the nut is $F_M \times L$ —not enough to do the job.

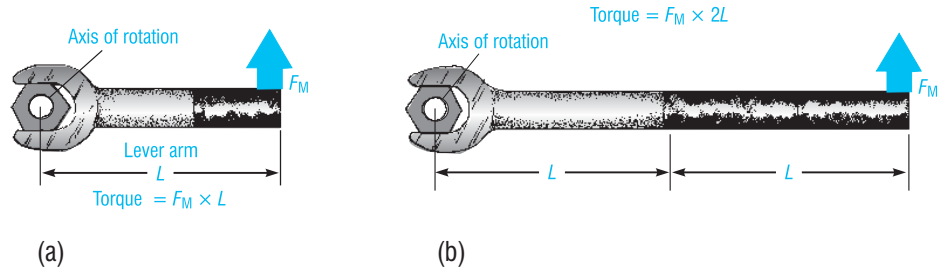


Figure 1.15
Increasing lever arm to increase applied torque

How can we loosen the nut? Let's pick another wrench with the same head span but with a handle twice as long (Figure 1.15b). Now, if we apply the same force F_M at the end of this wrench—with a handle $2L$ long—we should get a torque of $F_M \times 2L$ or $2F_M L$. This is twice as much torque as we were able to apply with the shorter wrench. The increased torque may be large enough to break the nut loose.

A gear is a wheel with notches—or teeth—on its rim. A gear is usually mounted on a shaft. The gear turns with the shaft. Two gears are commonly positioned so that their teeth mesh. When one gear turns, its teeth push on the teeth of the other gear. This causes the second gear to move.

In Figure 1.16, the force applied by driving gear A on driven gear B is labeled F_A . The force comes from one gear tooth pushing on another. The lever arm is equal to the radius of gear B, labeled L . The torque that gear A exerts on gear B is then equal to $F_A \times L$, in lb·ft or N·m. Torque is present in all rotating parts of machinery—in gears, pulleys, and crankshafts. Torque is applied by many hand tools—especially a torque wrench.

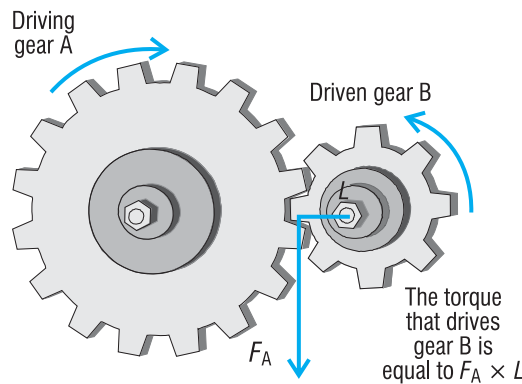


Figure 1.16
Torque is applied by one gear to turn the other.

A torque wrench is a tool used by automotive technicians to tighten bolts to certain specifications. The automotive technician exerts a force on the handle of the wrench. The handle is a fixed length, so the lever arm is constant. The technician applies different torques to the bolt by varying the

force. The larger the force applied on the handle, the larger the torque applied to the bolt. Most torque wrenches found in automotive shops are calibrated in either lb·ft or N·m.

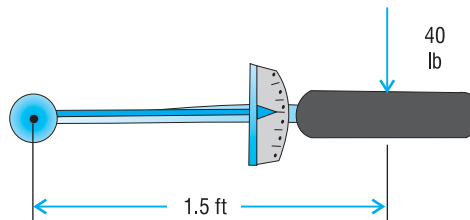


Figure 1.17
Torque wrench used to tighten bolts

Example 1.3 Calculation of Torque Applied by Torque Wrench

A torque wrench has a lever arm of 1.5 ft. A force of 40 pounds is applied at the end of the wrench to tighten a bolt. Find the torque applied to the bolt in

- (a) lb·ft
- (b) N·m



Solution: (a) Torque in lb·ft:

$$\begin{aligned}\tau &= F \times L \\ &= 40 \text{ lb} \times 1.5 \text{ ft} = 60 \text{ lb}\cdot\text{ft}\end{aligned}$$

- (b) Torque in N·m: First change feet to meters, then change pounds to newtons.

Use the conversion factors:

$$\begin{array}{ll} 1 \text{ ft} = 12 \text{ in.} & 1 \text{ in.} = 2.54 \text{ cm} \\ 1 \text{ m} = 100 \text{ cm} & 1 \text{ lb} = 4.45 \text{ N} \end{array}$$

$$(1.5\cancel{ft}) \left[12 \frac{\cancel{in}}{\cancel{ft}} \right] \left[2.54 \frac{\cancel{cm}}{\cancel{in}} \right] = 45.7 \text{ cm}$$

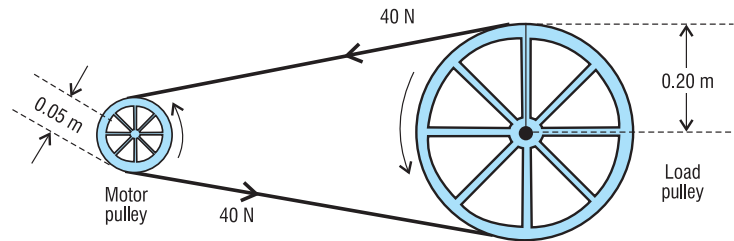
$$(45.7 \cancel{cm}) \left[\frac{1 \text{ m}}{100 \cancel{cm}} \right] = 0.457 \text{ m}$$

$$40 \text{ lb} = 40 \cancel{lb} \left[4.45 \frac{\cancel{N}}{\cancel{lb}} \right] = 178 \text{ N}$$

$$\begin{aligned} \tau &= F \times L \\ &= 178 \text{ N} \times 0.457 \text{ m} = 81.3 \text{ N}\cdot\text{m} \end{aligned}$$

Example 1.4 Torques in a Belt-Driven System

The motor pulley in a belt-drive system has a radius of 5 cm (0.05 m). The large pulley attached to the shaft of a machine has a radius of 20 cm (0.20 m). The dragging or pulling force of the belt is 40 newtons. Assume that the belt doesn't slip as the motor and belt drive the load pulley. What is the torque applied to each pulley?



Solution: (a) Motor pulley:

$$\begin{aligned} \tau &= F \times L \\ &= 40 \text{ N} \times 0.05 \text{ m} \\ &= 2 \text{ N}\cdot\text{m} \end{aligned}$$

(b) Load pulley:

$$\begin{aligned} \tau &= 40 \text{ N} \times 0.20 \text{ m} \\ &= 8 \text{ N}\cdot\text{m} \end{aligned}$$

Opposing Torques

Often, opposing torques, like opposing forces, act on a rotating system. If the torques cancel each other, the system is a balanced system. It is said to be in equilibrium. That means that, if the system is at rest when the torques

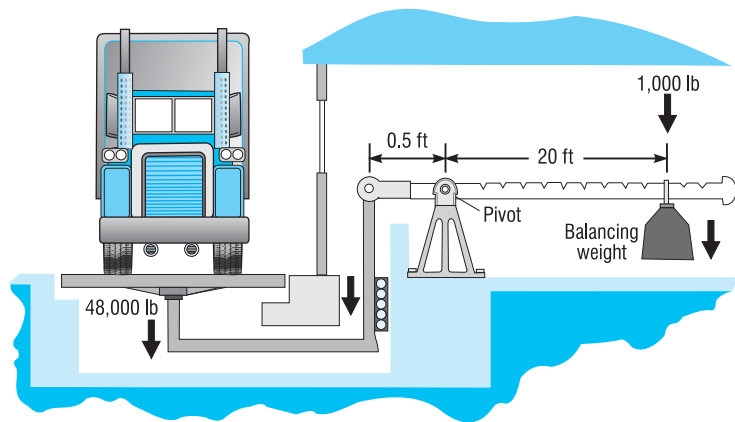
are applied, it remains at rest. If it's rotating when the torques are applied, the system continues rotating at the same rate. If the torques don't cancel each other out, a net torque greater than zero exists. The system is then said to be unbalanced. The net torque will cause a change in the rotational speed of the system, by causing it to speed up or slow down.

An example of opposing torques is illustrated by the unequal-arm balance used in truck scales. The forces that cause opposite torques about the axis of rotation are (1) the weight of the truck, and (2) a known balance weight.

Example 1.5 Truck Scales Involve Opposing Torques

A 48,000-pound truck sits on the platform of truck-weighing scales. The truck weight acts on a 0.5-ft lever arm about the pivot point. A 1000-pound balancing weight is hung on the opposite side of the pivot point, 20 ft away. Find:

- Torque of truck about pivot point.
- Torque of balance weight about pivot point.
- Whether or not the torques are balanced.



Solution: (a) Torque of truck about pivot

$$\begin{aligned}\tau &= F \times L \\ &= 48,000 \text{ lb} \times 0.5 \text{ ft} = 24,000 \text{ lb}\cdot\text{ft}\end{aligned}$$

(b) Torque of balance weight about pivot

$$\begin{aligned}\tau &= F \times L \\ &= 1000 \text{ lb} \times 20 \text{ ft} = 20,000 \text{ lb}\cdot\text{ft}\end{aligned}$$

(c) No, torques are not balanced. The torque exerted by the truck is 4000 lb·ft greater. Thus, a net torque of 4000 lb·ft would cause the truck platform to move down. (Can you see that this is like a seesaw?)

Summary

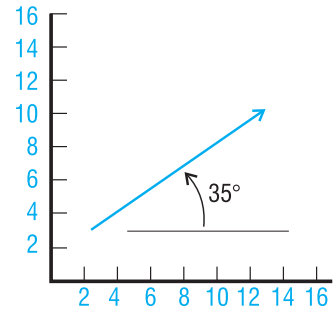
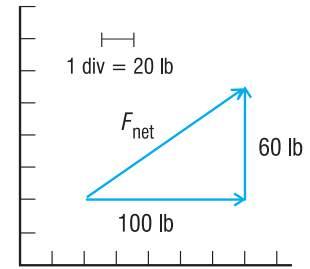
- A force is a push or a pull.
- Force is a vector. It has both magnitude and direction. Its magnitude is measured in pounds or in newtons.
- Newton's first law says that an object will remain at rest or will continue to move in a straight line unless it is acted on by a net force.
- Unbalanced forces result in a net force acting on an object. Balanced forces result in no net force acting on an object.
- If two forces act on an object and the forces act in a straight line, the magnitude of the resultant is either the sum of or the difference between the two forces' magnitudes.
- If two forces act on an object and the forces do not act in a straight line, the resultant can be found using the head-to-tail method of vector addition.
- The mass of an object is a measure of the object's inertia. The weight is a measure of the force exerted on the object by gravity.
- A torque is exerted on a body when a force is applied and the line of action of the force does not pass through the body's axis of rotation. The torque equals the force times the lever arm.
- If no net torque is exerted on a body, it will remain at rest or will continue to rotate at a constant rate.

Exercises

1. Name two units of measure for force.
2. To completely describe a force, what two things must be specified?
3. When you add vectors graphically, you draw arrows to represent the vectors. How do you know how long to draw the arrows?
4. What causes an object to change speed or the direction of motion?
5. Two forces act on an object. The forces have a magnitude of 34 newtons and act along the same line, but in opposite directions. What is the magnitude of the net force acting on the object?
6. Three forces act on an object. If the magnitude of the net force is zero, the object is said to be in _____ .

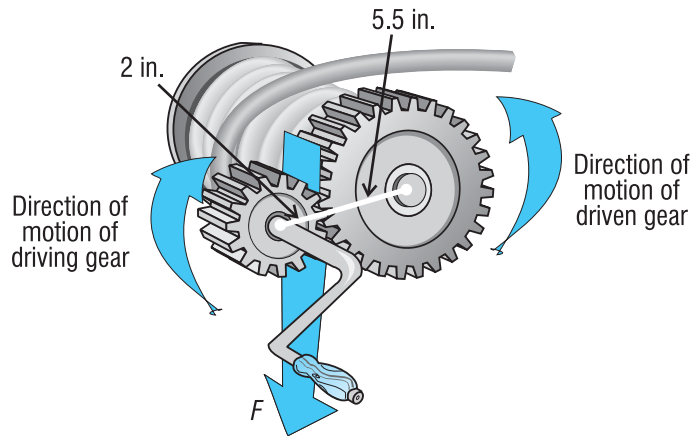
Use the diagram at the right to answer Exercises 7 and 8.

7. Find the magnitude of the net force (F_{net}) in the diagram shown.
8. The direction of the 60-pound force is north, and the direction is east for the 100-pound force. Describe the direction of the net force.
9. Write a complete description of the vector shown in the diagram at the right.



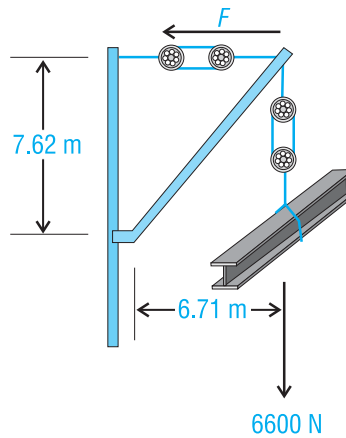
10. A hot-air balloon is acted on by two forces. One force is its weight, equal to 2448 newtons. The second force is a buoyant force acting straight up, equal to 2448 newtons. What change in the motion of the balloon will result from the action of these two forces? Explain your answer.
11. The balloon pilot from Exercise 10 lights the burner, which adds heat to the balloon. The buoyant force increases to 2492 newtons. Write a complete description of the net force on the balloon. What change in the motion of the balloon will result from this net force?
12. Suppose you drive in a straight line 10 km north from home, then turn west and drive 12 km in a straight line. How far are you from home?
13. Suppose you drive 10 km north from home, then turn west and drive until you are 12 km away from home. How far west did you drive?
14. A satellite makes small changes to its position with thrusters. A thruster expels gas through a nozzle, which results in the application of a force to the satellite. To make one change, the satellite fires three thrusters at the same time. Thruster A exerts a force of 20 N directed to the right. Thruster B exerts a force of 30 N directed to the right at an angle of 30° above the horizon. Thruster C exerts a force of 20 N directed straight up.
 - (a) Graphically add the forces in the order $A + B$, then add the result to C. This result is the vector sum $A + B + C$.
 - (b) Graphically add the forces in the order $C + B$, then add the result to A. This result is the vector sum $C + B + A$.
 - (c) What can you conclude about the order in which the forces are added?

15. Mike's car has a flat tire. He is trying to remove a lug nut that the tire shop overtightened with an impact wrench. Mike applies a force of 80 pounds to the end of a lug wrench that is 1.2 feet long.
- Find the torque applied to the lug nut by the wrench.
 - The torque Mike applies to the lug nut does not make it turn. What is the net torque on the lug nut?
 - Describe any torques, other than Mike's, acting on the lug nut.
16. Sandra and Maria are loading their ski boat onto a boat trailer. The trailer has a hand winch to pull the boat into position on the trailer. The winch has a pair of gears to multiply the torque Sandra produces when she pulls or pushes on the winch handle. One gear is 2 inches in diameter and the other is 5.5 inches in diameter. A torque of 10 lb-ft is applied to the smaller gear. What torque is produced by the larger gear?



17. Explain the difference between the weight and mass of an object.
18. An astronaut in orbit removes two identical metal containers from a storage compartment. One container is empty and one is full of water. But both containers are “weightless.” How can the astronaut tell which container is full of water without opening either container?
19. When you drive your car on the highway at constant velocity, the net force acting on the car is zero. Why must you continue to press on the accelerator?
20. Carlos stands and applies his full weight to a pedal on his bike. A torque of 50.2 newton·meters is applied to the rear wheel. The wheel has a rolling radius of 0.387 meter. What is the magnitude of the force that the wheel applies to the road?
21. The engine of a jet plane applies a horizontal thrust force of 6500 lb to an airplane that weights 12,000 pounds. The wings apply a vertical lift force of 14,500 lb. Find the net force by graphing.

22. The Earth exerts a downward force of 9.8 newtons on an object with a mass of 1 kilogram, and a force of 49 newtons on a object with a mass of 5 kilograms.
- What is the mass of an object if it weighs 22,500 newtons? Show each step in your solution.
 - Describe a general method to find the weight of an object on Earth if the mass is known.
23. The ratio of the weight of a object, on Earth, to its mass is 9.8 newtons/kilogram. The ratio of weight to mass is only $1/6$ as much on the moon. How much does a 25-kg object weigh on the moon?
24. The jib crane shown in the figure is holding the beam at rest. What is the horizontal force F required at the top of the jib boom to balance the torque on the boom?



25. The planetary rover shown in the figure has a robotic arm that will pick up a rock and return it to the landing craft. The rock has a weight of 4.1 newtons. What is the magnitude of the vertical force that must be exerted on the rock? When the rock is lifted, how much torque will be applied to the joint at A in the robot arm? How much torque will be applied to the joint at B?

