Force and Motion

Force

Force is anything that tends to cause motion, change motion, stop motion, or prevent motion. This force acts on the mass of an object, so to be technically accurate, we should define it in terms of mass. But since this is a practical rather than theoretical text, we will consider the effect of gravity on the mass and use pounds and ounces of weight, rather than poundals of force.

poundal. The unit of force in the foot-pound-second system of measurement that is required to accelerate a mass of 1 pound, 1 foot per second, per second.

Mechanical Advantage

Many mechanical devices allow us to work with the force we have and afford us a mechanical advantage in which we exchange distance for force or speed. The most widely used mechanical advantage devices are the lever, the pulley, the inclined plane, and the gear train.

mechanical advantage. The increase in force or speed produced by mechanical devices such as levers, pulleys, gears, or hydraulic cylinders.

When we have a flat tire on our car, we need some way to increase the amount of force we can produce with our arms so that it will be great enough to lift the car. We normally do this with a jack. If the jack allows us to raise 350 pounds of weight by pushing down on the handle with a force of 35 pounds, the jack gives us a mechanical advantage of 10.

350 Pounds	=	Force out
35 Pounds	=	Force in
$350 \div 35$	=	10

We increase the force we use 10 times, but we do not get something for nothing. Work is the amount of force times the distance the force acts, and we must put exactly the same amount of work into the jack that we get out of it. For each stroke of the jack handle to raise the car 1 inch, we must move the jack handle down 10 inches. The amount of work the jack does is 350 pounds times 1 inch, or 350 inch-pounds. We have done exactly the same amount of work on the jack handle: We have moved a force of 35 pounds through a distance of 10 inches, or we have done 350 inch-pounds of work on the jack handle.

There are several ways we can obtain mechanical advantage and nearly all machines use one or more. *See* Figure 3-18.

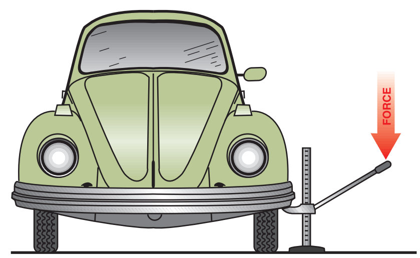


Figure 3-18. *An automobile jack is a form of lever we use to get a mechanical advantage. A small force acting downward produces a much larger force acting upward.*

The Law of the Lever

The basic lever is a rigid arm supported on a fulcrum in such a way that a force can be applied to cause rotation. We see a basic lever in Figure 3-19. A force applied to one end of the lever, the force arm, causes the other end, the weight arm, to move in the opposite direction and lift the weight.

lever. A rigid bar, free to pivot, or rotate about a point called the fulcrum. An input force is applied at one point, and an output force is taken from the lever at another point.

arm. The distance on a lever between the fulcrum and the point of application of the force or the weight.

moment. A force that causes rotation of a lever. A moment is the product of a weight and its arm.

The arm of the lever is the distance between the fulcrum and the point where the force or weight is applied. The lever is balanced when the force moment, the amount of force times the length of the force arm, is equal to the weight moment, the weight times the length of the weight arm. Moments are usually expressed in pounds-feet.

Force · Arm = Force Moment
Weight · Arm = Weight Moment

Moments try to cause rotation, and in Figure 3-19, the force moment tries to rotate the lever in a clockwise direction and is called a positive moment. The weight moment tries to rotate the lever in the counterclockwise direction and is called a negative moment.

In Figure 3-19, we see one of the more important facts about the lever: The lever is balanced when the weight moment equals the force moment. Another way to express this is that the lever is balanced when the algebraic sum of the moments is zero.

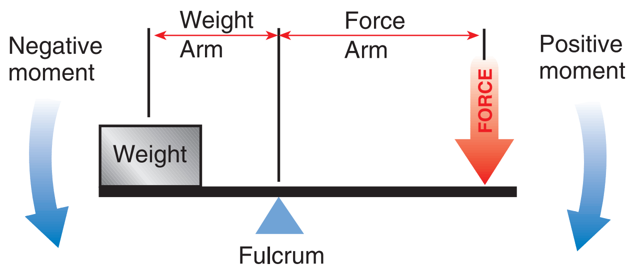


Figure 3-19. *When the lever is balanced, the sum of the moments about the fulcrum is zero.*

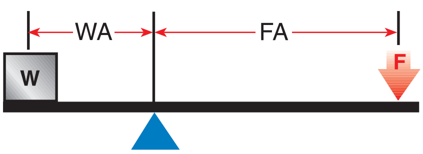


Figure 3-20. *First-class lever*

First-Class Lever

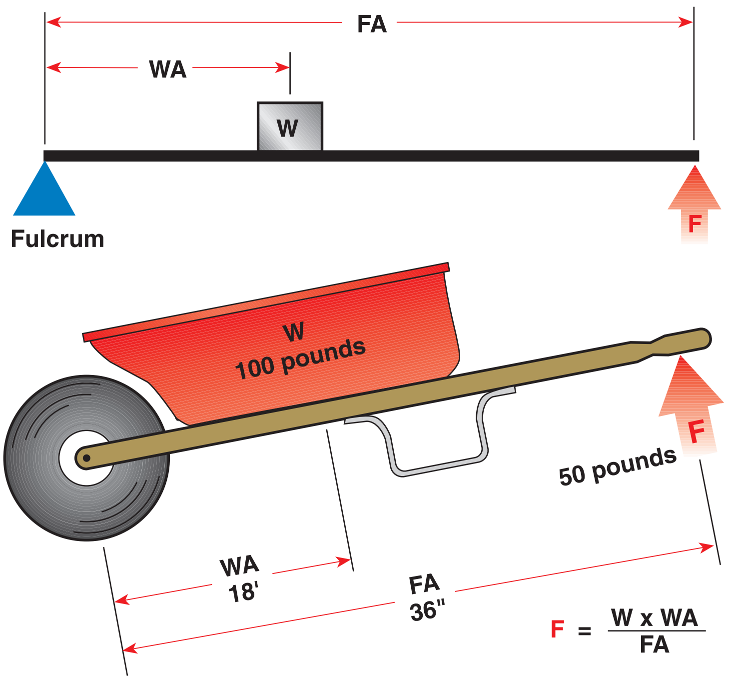
The lever in Figure 3-20 is a first-class lever, one whose fulcrum is between the force and the weight, with the weight moving in the direction opposite the direction of the force.

Second-Class Lever

A second-class lever is one in which the weight is between the fulcrum and the force, and the weight moves in the same direction as the force. A wheelbarrow is a good example of a second-class lever. *See* Figure 3-21.

The wheel of the wheelbarrow acts as the fulcrum, and the center of the handgrip is the point at which the force is applied. The load is the weight.

The same law of the lever applies to the second-class lever as applies to the first-class lever. The lever is balanced when the weight moment and the force moment are equal.



$$F = \frac{W \times WA}{FA} = \frac{100 \times 18}{36} = 50 \text{ pounds}$$

This problem can also be worked as a proportion:

Force:Weight = Weight Arm:Force Arm
Force:100 = 18:36
Force x 36 = 1,800
Force = 1,800 ÷ 36 = 50 pounds

See Page 35 for more on proportion.

Figure 3-21. *Second-class lever*

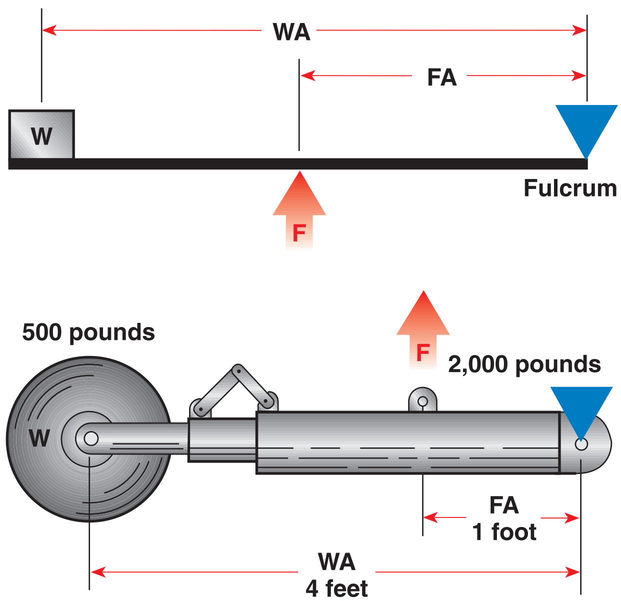
Third-Class Lever

We sometimes want to move the weight a greater distance than the force can act, or we may want the weight to move faster. To do this, we can use a third-class lever in which the force is applied between the fulcrum and the weight, and the weight moves in the same direction as the force.

In the retractable landing gear in Figure 3-22, the weight of 500 pounds has an arm of 4 feet. This gives a weight moment of 2,000 pounds-feet. This must be balanced with a force whose arm is only 1 foot.

To raise the landing gear, we must apply a force of 2,000 pounds, but we can raise the wheel 4 feet by moving the point where the force is applied by only 1 foot.

This lever requires 4 times as much force as the weight it lifts, but it moves the weight 4 times as far as the force moves, in the same length of time.



$$F = \frac{W \times WA}{FA}$$

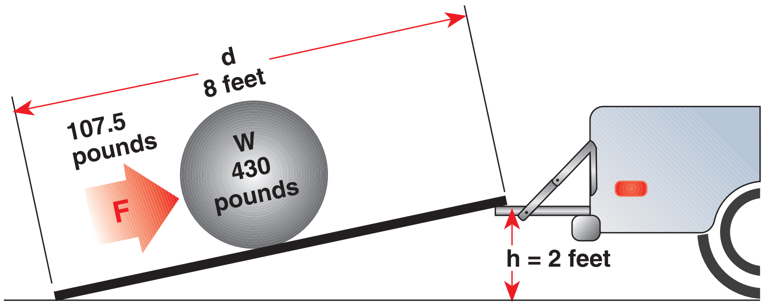
$$= \frac{500 \times 4}{1}$$

$$= 2{,}000 \text{ pounds}$$

Figure 3-22. *Third-class lever*

The Inclined Plane

The inclined plane is one of the simple machines that is used to gain mechanical advantage. Suppose we want to load a drum of oil into a truck, but we do not have any form of hoist with which to lift it. We can use a long board as an inclined plane. Put one end on the bed of the truck and the other end on the ground. We can roll the drum up the board, with much less force than we would need to lift it straight up off the ground.



W = 430 pounds
h = 2 feet
d = 8 feet

$$F = \frac{W \times h}{d}$$

$$= \frac{430 \times 2}{8}$$

$$= 107.5 \text{ pounds}$$

Figure 3-23. *An inclined plane is used to gain a mechanical advantage.*

To find the amount of force needed to roll the drum into the truck, use the formula in Figure 3-23. A force of only 107.5 pounds is needed to roll the 430 pound drum into the truck. However, we will have to roll it 8 feet to raise it only 2 feet.

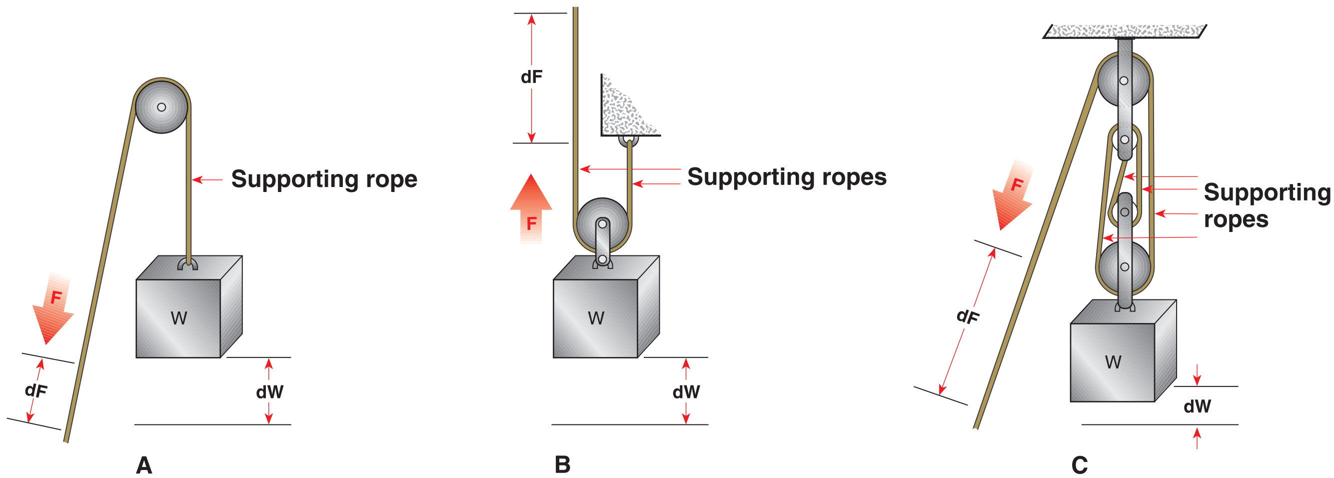
Ropes and Pulleys

One of the oldest methods of gaining mechanical advantage is by using ropes and pulleys, and we find the mechanical advantage by counting the number of sections of ropes that support the weight being lifted.

In Figure 3-24A the weight is supported by 1 section of rope. In order to lift a 100-pound weight, we need a force of 100 pounds; and if we raise the weight 1 foot, we will have to pull the rope 1 foot. The wheel, or pulley, changes the direction of the force, but it does not give any mechanical advantage.

If we attach the pulley to the weight and use 2 sections of rope to support it, as we have in Figure 3-24B, we have a mechanical advantage of 2. We need a force of only 50 pounds to lift it. But, we will have to pull 2 feet of rope to lift the weight 1 foot.

A group of pulleys, such as we see in Figure 3-24C, is called a block and tackle. Here we have four sections of rope supporting the weight. The force required to lift the load is only 25 pounds, but we must pull 4 feet of rope to raise the weight 1 foot.



A. With one section of supporting rope, no mechanical advantage is gained.

B. Two sections of supporting rope give a mechanical advantage of 2.

C. Four sections of supporting rope give a mechanical advantage of 4.

Figure 3-24

Gears

Gears are special wheels with notches and teeth on their outside edge. By meshing the teeth of one gear with the teeth on another, one gear can drive the other gear without slipping.

We can determine the mechanical advantage of a set of gears by counting the teeth of both gears. In the set of gears we see in Figure 3-25, the large drive gear has 90 teeth and turns in a counterclockwise direction. The smaller driven gear has 60 teeth and turns faster, and in the opposite, or clockwise, direction.

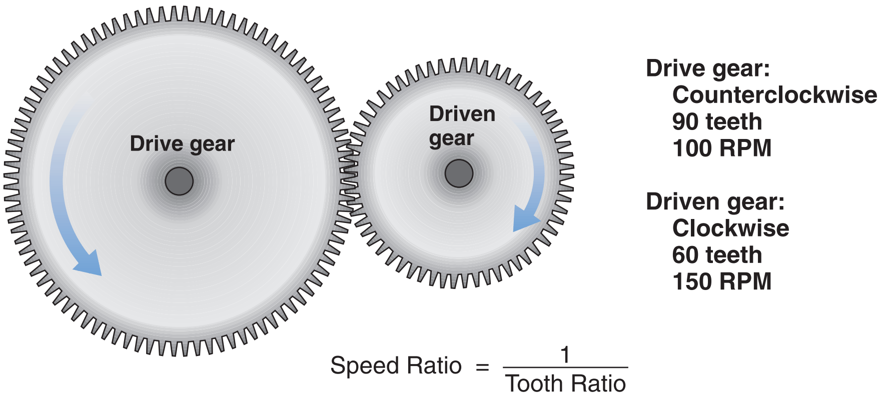


Figure 3-25. *Gears are used to change the direction of rotation between shafts and to gain a mechanical advantage.*

To find the speed of the driven gear, find the ratio of the number of teeth in the two gears. The drive gear has 1.5 times as many teeth as the driven gear, and so the driven gear will turn 1.5 times as fast as the drive gear. When the drive gear turns at 100 RPM, the driven gear will turn at 150 RPM.

Motion

Motion is the action in which objects change their position. Motion requires energy and is an essential component of work. In this section, we will discuss the difference between speed and velocity, see the way vectors can be combined, and consider each of Newton's important laws of motion.

vector. A quantity which has both direction and magnitude.

Speed and Velocity

Speed is a rate of motion, and velocity is a rate of motion in a specified direction. Speed is normally measured in units such as feet per second, miles per hour, or knots, and does not take direction into consideration. If an airplane flies north at 120 miles per hour, its speed is 120 miles per hour, but its velocity is 120 miles per hour, to the north.

Change in Speed

When an object increases its speed, it accelerates, and acceleration is measured in feet per second, per second, or feet per second2 (read as feet per second squared). When an object decreases its speed, it decelerates, and deceleration is negative acceleration. If an object falls freely in a vacuum, it is acted upon only by the force of gravity; and as it falls, it accelerates 32.2 feet per second each second it falls. This is called the acceleration due to gravity.

accelerate. To increase speed or to make an object move faster.

We use this value to find the mass of matter. We saw earlier that mass is the amount of matter in an object, and weight is the effect gravity has on the mass. We can find the mass of an object by dividing its weight, in pounds, by 32.2.

$$\text{Mass} = \frac{\text{Weight}}{32.2}$$

To find the amount of thrust a gas turbine engine is producing, first find the mass of the air flowing through the engine, then multiply this mass by the amount the air speeds up as it passes through the engine.

For example, assume that 100 pounds of air passes through an engine each second, and this air speeds up from zero feet per second to 900 feet per second. Find the amount of thrust by the formula:

$f = M \cdot a$

f = the pounds of thrust produced by accelerating the air as it passes through the engine

M = the mass of the air

a = the change in velocity of the air as it passes through the engine

$$f = M \cdot a$$

$$= \frac{100}{32.2} \cdot 900$$

$$= 2{,}795.0 \text{ pounds of thrust}$$

Newton's Laws of Motion

Many of the properties of objects are explained by Newton's three laws of motion.

inertia. The characteristic of all matter that causes an object to remain in its present condition.

Newton's first law explains that when an object is at rest, it tries to remain at rest. But when it is moving, it tries to keep moving in a straight line and will not speed up, slow down, or turn unless it is acted upon by an outside force. This tendency of the object to remain in its original condition of motion is called inertia.

Newton's second law is called the law of acceleration: the amount of acceleration depends upon the mass of the object and the amount of force used. Acceleration is directly proportional to the amount of force that acts upon the object and inversely proportional to its mass.

Newton's third law is called the action-reaction law. It says that for every action, there is an equal and opposite reaction.

Circular Motion

When a bucket of water with a rope tied to its handle is swung in a circle, two interesting things happen. First, the water stays at the bottom of the bucket, which is now straight up and down, and it does not spill out. Also, the faster we swing the bucket, the heavier it becomes.

The bucket of water is obeying two of Newton's laws of motion, the first law which says that an object in motion will try to remain in motion in a straight line unless it is acted upon by an outside force; and the third law which says that for every action there is an equal and opposite reaction. *See* Figure 3-26.

When we start the bucket of water swinging, we put energy into it, and this energy tries to carry the bucket and the water away from us in a straight line. However, the bucket can go only as far from us as the rope allows. The rope holds it in a circular path around our body.

As the bucket is held in its circular path by the rope, it tries to travel in a straight line. The force trying to cause the bucket to travel in a straight line is opposed by the rope and is called centrifugal force. It is greater than the force of gravity that tries to pull the bucket and the water down, and it holds the water against the bottom of the swinging bucket.

As the bucket swings, centrifugal force causes the action that tries to pull it away from us. It is prevented from flying away by the force on the rope, which is the reaction. The faster the bucket swings, the greater the centrifugal force. The force on the rope opposing the centrifugal force is called centripetal force, and its magnitude is exactly equal to the centrifugal force.

Helicopter rotor blades droop when the helicopter is parked on the ramp and the rotor is not turning. This droop is caused by gravity pulling the blades down. But as soon as the rotor starts turning, centrifugal force becomes greater than the force of gravity, and it pulls the blades straight out. *See* Figure 3-27.

On some small helicopters, the centrifugal force acting on the rotor is about 20,000 pounds for each blade. For some of the larger helicopters, this force can be as much as 100,000 pounds for each blade. The hub and blade grips must be strong enough to withstand this great amount of force.

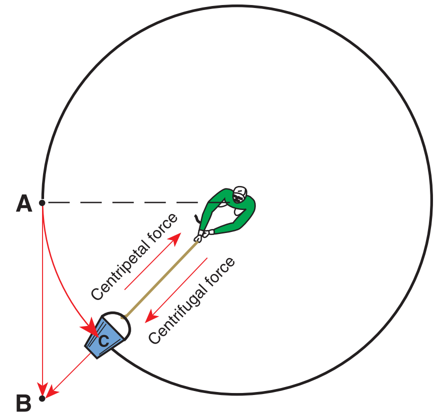


Figure 3-26. *The bucket of water is trying to obey Newton's first law and travel in a straight line from A to B. But the rope holds it along the curved path A to C. The resultant, C-B, is the centrifugal force, and this is the force that holds water in the bucket and makes the bucket heavier.*

magnitude. The amount of a force.

Figure 3-27. *When a helicopter rotor is not turning, gravity causes the blades to droop. But when the rotor is turning, centrifugal force holds the blades straight out.*

Heat and Temperature

Heat and temperature are often thought of as being the same thing, but they are different. Heat is a form of energy that is associated with the movement of the molecules in a material, and temperature is a measurement of this energy.

heat. A form of energy that determines the speed of movement of molecules in a material.

temperature. A measure of the intensity of heat.

Heat

Heat is one of the most important forms of energy because it is easily changed it into other forms and is used extensively to do practical work. In this section, we will see the effect of heat on various materials and study the way it may be transferred from one object to another.

Work Equivalent of Heat

Turbine engine fuel contains chemical energy which, when burned, changes into heat energy. This heat energy enters the air inside the engine, expands it, and produces the thrust that pushes the airplane through the air. In this way, heat energy does work.

Mechanical energy can be changed into heat. This happens when we use the brakes to stop an airplane after it has landed. Kinetic energy in the airplane keeps it rolling down the runway, and in order to stop it, we must use up this kinetic energy. We do this by applying the brakes. The brakes produce friction that makes the wheels hard to turn, and the energy used to turn the wheels against the friction becomes heat energy which causes the brake to get hot. It is not uncommon for the brakes on large jet airplanes to get red hot when the pilot makes an emergency stop.

In the U.S. system, the British thermal unit (Btu) is the basic unit of heat energy. One Btu is the amount of heat energy needed to increase the temperature of 1 pound of water 1°F, and 1 Btu can do 778 foot-pounds of work. In the metric system, the basic unit of heat energy is the calorie, which is the amount of heat energy needed to raise the temperature of 1 gram of water 1°C.

British thermal unit (Btu). The amount of heat energy needed to raise the temperature of 1 pound of pure water from 60° to 61°F.

calorie. A small calorie is the amount of heat energy needed to raise the temperature of 1 gram of water 1°C. A large calorie is the amount of heat energy needed to raise the temperature of 1 kilogram of water 1°C.

Fluid Mechanics

Levers, inclined planes, pulleys, and gears all may be used to gain mechanical advantage. There is another way that is often used to achieve a mechanical advantage, and this is by fluid mechanics in the form of hydraulic or pneumatic systems.

Hydraulic systems transmit a force from one location to another by using an incompressible fluid, usually some form of oil. Hydraulic systems are used for operating the brakes in most airplanes, as well as for operating the retractable landing gear and many of the flight controls on large airplanes. Pneumatic systems use some form of compressible fluid such as air for transmitting force. Some airplanes use pneumatic systems to operate the brakes, flaps, and retractable landing gear.

Pressure Produced by a Fluid

The pressure produced by a column of fluid is determined by the density of the fluid and the height of the column.

The shape or volume of the container does not have any effect on the pressure. In Figure 3-61 we see several containers of different shapes. If we connect them all together at the bottom, the liquid in all of the containers will stay at the same height, h. The pressure shown on the gage is that caused by the height of the fluid.

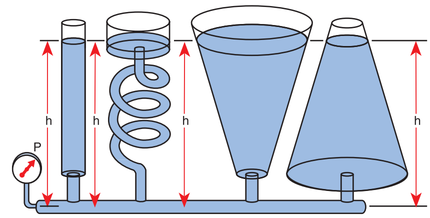


Figure 3-61. *The pressure at the bottom of a column of liquid is caused by the height of the liquid, and it is not affected by the quantity of the fluid or the shape of the container.*

The second thing that determines the pressure produced by a column of fluid is the density of the fluid. Pure water weighs 0.0361 pound per cubic inch, and since one gallon contains 231 cubic inches, a column of water 231 inches high will produce a pressure of 8.34 psi. Other liquids have different densities and specific gravities, and a column of the same height will produce a different pressure. Mercury has a specific gravity of 13.6, and a column of mercury 231 inches high will produce a pressure of 113.42 psi. The specific gravity of gasoline is only 0.72, so a column of gasoline 231 inches high will produce a pressure of 6 pounds per square inch. *See* Figure 3-62.

Material	Density (pounds cubic inches)	Specific Gravity
Mercury	0.4913	13.6
Pure water	0.0361	1.00
Jet engine fuel	0.0289	0.80
Gasoline	0.0260	0.72

Figure 3-62. *Density and specific gravity of various liquids*

We can find the pressure produced by a column of liquid by using the formula:

$$P = D \cdot h$$

P is the pressure in pounds per square inch. D is the density of the liquid in pounds per cubic inch, and h is the height of the column of liquid in inches.

We can use this formula to find the amount of pressure pushing on the bottom of a gasoline tank if the level of the fuel in the tank is 30 inches above the bottom. Gasoline has a density of 0.026 pound per cubic inch.

$$\begin{aligned} P &= D \cdot h \\ &= 0.026 \cdot 30 \\ &= 0.78 \text{ pounds per square inch} \end{aligned}$$

Pascal's law. The law that states that when pressure is applied to a fluid in an enclosed container, the pressure is transmitted equally throughout all of the fluid, and it acts at right angles to the walls that enclose the fluid.

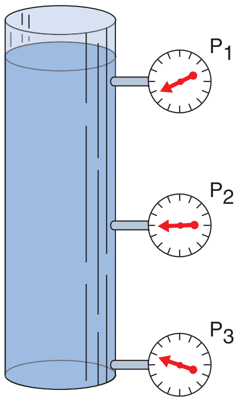


Figure 3-63. *The pressure produced by a liquid in a container is caused by the height of the liquid above the point at which the pressure is measured. The higher the liquid above the gage, the greater the pressure.*

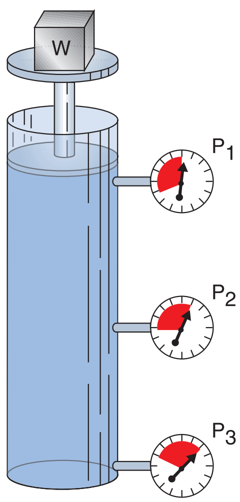


Figure 3-64. *When we apply pressure on the liquid in a closed container, the pressure rises the same amount in all parts of the container.*

Pascal's Law

Pascal's law states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container.

If we have a container of liquid such as the one we see in Figure 3-63, the pressures shown on the gages P_1, P_2, and P_3 are the pressures caused by the height of the liquid above the gage. P_3 shows more pressure than either P_2 or P_1 because there is a greater height of liquid above it.

Put a piston in the container and put a load on it so that it pushes down on the liquid, the pressure will increase on each of the gages. All three gages will show the same amount of increase. *See* Figure 3-64.

In practical hydraulic systems, we do not consider the weight of the fluid in the system, but think only of the changes in pressure caused by the piston pushing on the fluid.

Figure 3-65 shows a practical hydraulic system that uses Pascal's law to give us a mechanical advantage. Here we have a cylinder with an area of 1 square inch connected to a cylinder having an area of 10 square inches. A piston in the smaller cylinder holding a weight of 1 pound balances the piston in the larger cylinder holding 10 pounds.

The 1-pound load on the 1-square-inch piston causes a pressure increase in the cylinder of 1 psi. And, according to Pascal's law, this pressure increase is carried to every part of the fluid and pushes up on the piston in the large cylinder.

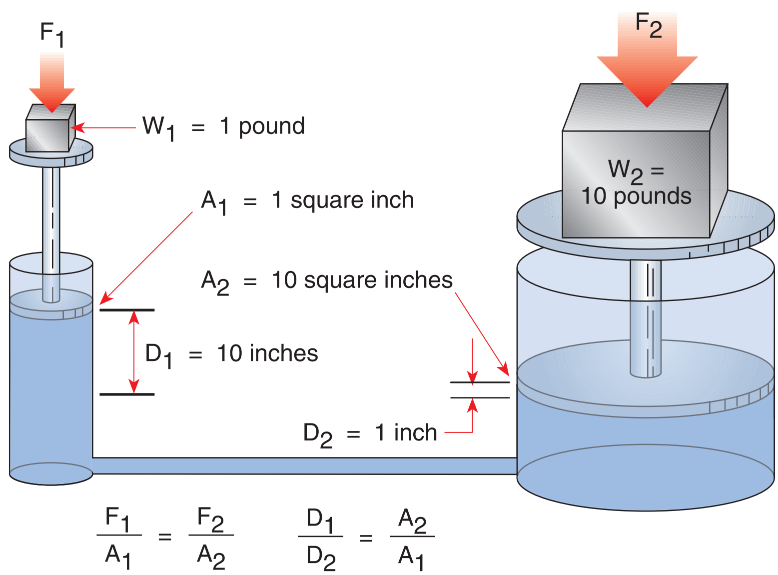


Figure 3-65. *Hydraulic cylinders produce a mechanical advantage. A 1-pound force (F_1) can lift a 10-pound weight (W_2), but no work is gained. The work done by the small piston is the same as that done by the large piston.*

The large piston has an area of 10 square inches, and the fluid pushes on every square inch with a force of 1 pound. So the fluid pushes up on the piston with enough force for it to hold 10 pounds.

This arrangement of two cylinders having unequal area gives a mechanical advantage in the same way a lever does. The force on the small piston (F_1), divided by the area of the small piston (A_1), is equal to the force on the large piston (F_2), divided by the area of the large piston (A_2).

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

Another way in which this hydraulic system resembles the lever is that the work which is done by the small piston is the same as that done by the large piston. When the piston in the small cylinder moves down 10 inches, it forces 10 cubic inches of fluid out of the small cylinder into the large one. This fluid spreads out over all 10 square inches of area and lifts the large piston only 1 inch. The work done by the small piston is the same as the work done by the large piston, 10 inch-pounds.

In our study of Mathematics, we introduced the formula for force: $F = P \cdot A$ (force = pressure times area). A convenient way to remember this formula and all of its possible rearrangements is by the use of the circle we see in Figure 3-65. The top half of the circle labeled F represents the force, and it is equal to the bottom half, labeled A and P, which represents area and pressure.

We can find the area needed to produce a specified force from the available pressure by dividing the top quantity (F) by the known bottom quantity (P). $A = F \div P$. We can also find the pressure required to produce a given amount of force when the area of the piston is known. We can do this by dividing the value represented by the top half of the circle (F) by the known value represented by one of the bottom parts of the circle (A). $P = F \div A$.

From the formula $F = P \cdot A$, we can see that the amount of force produced by a hydraulic system is equal to the amount of pressure in the system times the area of the piston that the pressure acts against. If we have a pressure of 100 psi acting on a piston whose area is 20 square inches, the force produced by the piston is 2,000 pounds. *See* Figure 3-66.

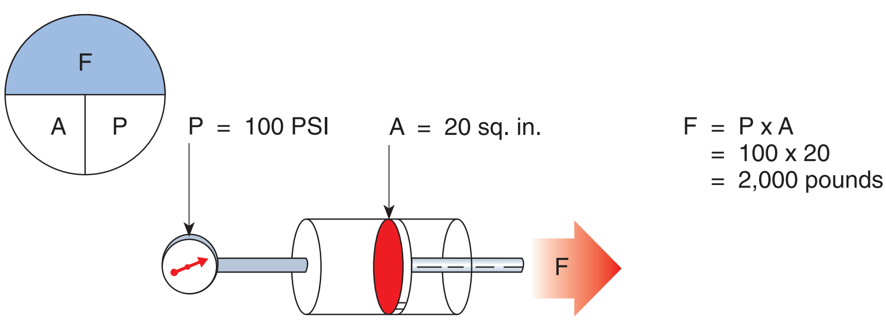
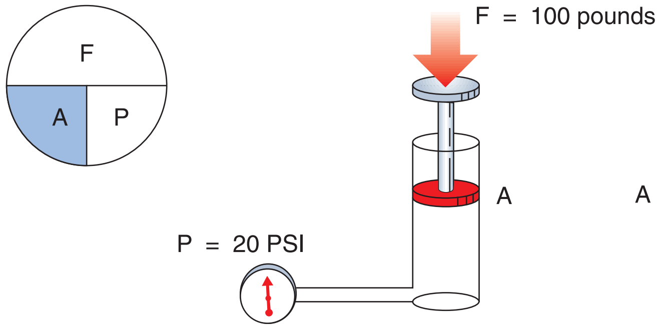


Figure 3-66. *The amount of force produced by the piston in a hydraulic cylinder may be found by multiplying the area of the piston by the amount of pressure inside the cylinder.*

Look at Figure 3-67 to find the area needed to give us a certain amount of force when we know the pressure in the system. In this example, we want to know how large the piston will have to be for it to produce 100 pounds of force with a pressure of 20 psi.

To do this, we divide the force of 100 pounds by the pressure of 20 psi, and find that we need a piston having an area of 5 square inches. *See* Figure 3-67.

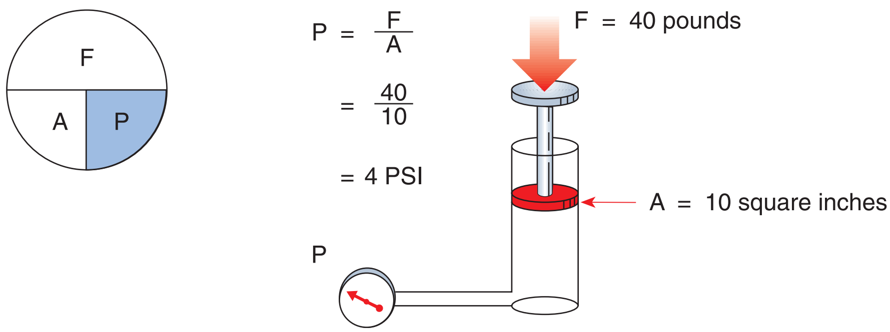
Figure 3-67. *The area of a piston needed to produce a given amount of force with a certain amount of pressure may be found by dividing the amount of force by the pressure.*



$$A = \frac{F}{P} = \frac{100}{20} = 5 \text{ square inches}$$

We can also use our circle to find the amount of pressure that is built up in a cylinder when we know the area of the piston and the amount of force that is pushing on the piston. When a force of 40 pounds pushes on a piston whose area is 10 square inches, the pressure of the fluid in the cylinder increases by 4 psi, as shown in Figure 3-68.

Figure 3-68. *The amount of pressure produced in a hydraulic cylinder may be found by dividing the amount of force on the piston by the area of the piston.*



$$P = \frac{F}{A} = \frac{40}{10} = 4 \text{ PSI}$$

This same kind of circle helps us visualize the relationship between the area of the piston, the distance the piston moves, and the amount of fluid that is forced out of the cylinder.

In Figure 3-69, the shaded half of the circle shows that the volume of the fluid moved by a piston is equal to the area of the piston times the distance the piston moves. When a piston with an area of 2 square inches moves 4 inches into the cylinder, it pushes 8 cubic inches of fluid out of the cylinder.

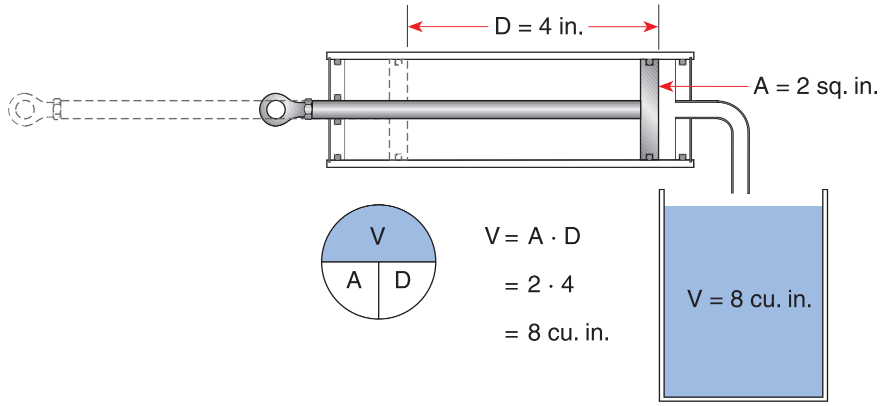


Figure 3-69. *The volume of fluid moved out of a cylinder by a piston may be found by multiplying the area of the piston by the distance the piston is moved.*

This circle can also help us find the piston area needed to expel a given amount of fluid when it is moved a specified distance. In Figure 3-70, the piston moves 4 inches to force 8 cubic inches of fluid from the cylinder. By using the formula shown here, we see that the piston must have an area of 2 square inches.

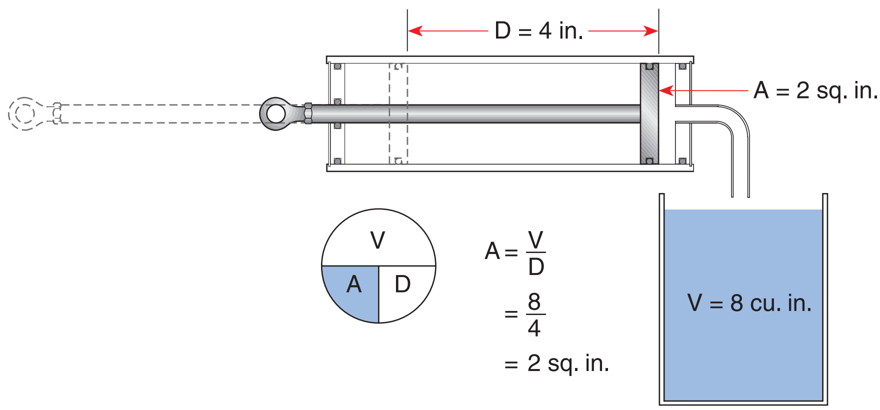


Figure 3-70. *The area of a piston needed to move a given volume of fluid when it moves a certain distance may be found by dividing the volume by the distance the piston is moved.*

And this circle also helps us find the distance a piston of a certain size will have to move in order to force a given amount of fluid out of the cylinder. The illustration in Figure 3-71 (on the next page) shows a piston with an area of 2 square inches moving 8 cubic inches of fluid out of a cylinder. In order to do this, the piston must move for a distance of 4 inches.

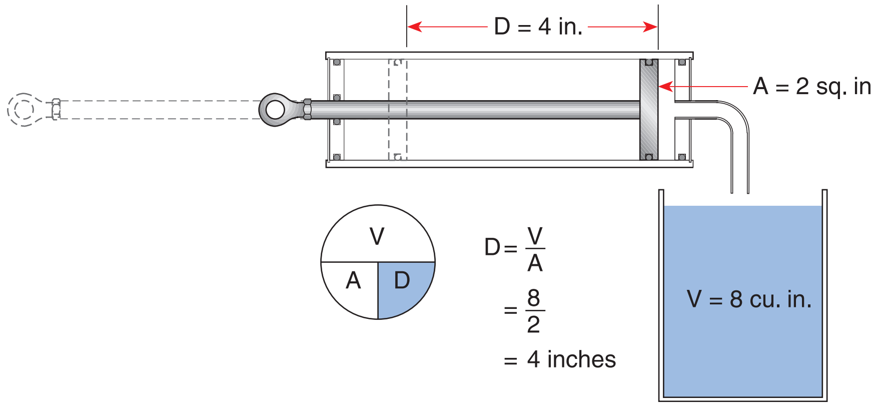


Figure 3-71. *The distance a piston must move to force a given amount of fluid out of a cylinder may be found by dividing the volume of the fluid by the area of the piston.*

Bernoulli's principle. The principle that states that if energy is neither added to nor taken away from a fluid in motion, any increase in its velocity will cause a corresponding decrease in its pressure. The velocity of the moving fluid relates to its kinetic energy, and its pressure relates to its potential energy.

Bernoulli's Principle

Energy exists in two forms: potential and kinetic. In fluid mechanics, pressure is a form of potential energy in a fluid, and the velocity of the fluid is its kinetic energy. In any flow of fluid, the total energy in the fluid is the sum of the kinetic and the potential energy.

Bernoulli's principle explains that if we neither add nor take away energy from a flow of fluid, any increase in the velocity (kinetic energy) of the flow will cause a corresponding decrease in its pressure (potential energy). This principle is extremely important in helping us understand the way an airplane wing or a helicopter rotor produces lift as it passes through the air. It also helps us understand the way in which paint spray guns operate.

A venturi is a specially shaped tube through which a fluid, either a liquid or a gas, flows. There is a restriction in the tube where the area gets smaller, and then it returns to its original size. *See* Figure 3-72.

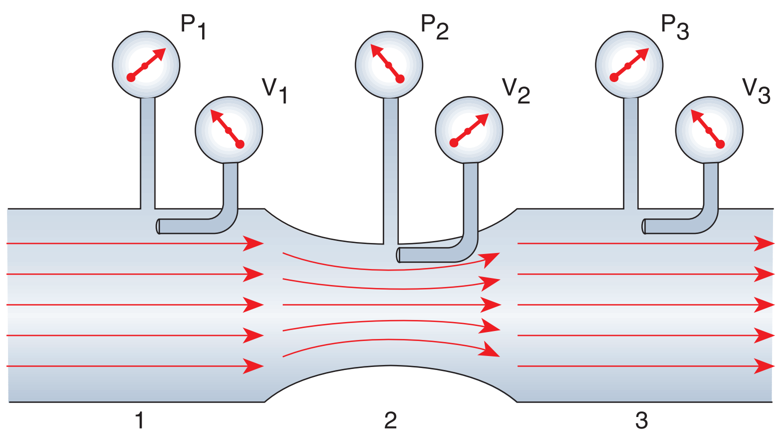


Figure 3-72. *When energy is neither added to nor taken from fluid in motion, any restriction that causes the fluid to speed up will cause the pressure to decrease.*

Fluid flows through this tube, and, at position 1, the pressure is the value P_1. The speed, or velocity, is shown as V_1. If we do not add or take away any energy from the fluid, it must speed up when it reaches the restriction to allow the same volume of fluid to move the same distance through the tube in the same length of time.

When it speeds up, the kinetic energy (velocity) increases. But since no energy was added, the potential energy (pressure) had to decrease. We see this on the gages P_2 and V_2. As soon as the tube returns to its original size, at 3, the fluid slows down so the same volume will move the same distance in the same time. When it slows down, the velocity decreases, but the pressure increases to the value it had originally.

In a spray gun, air is forced through a venturi, and a tube carries the liquid to the restriction point. Here the velocity is the greatest and the pressure is the lowest. Atmospheric pressure forces the liquid out of the tube into the area of low pressure, where it is broken up into tiny droplets by the high-velocity air. *See* Figure 3-73.

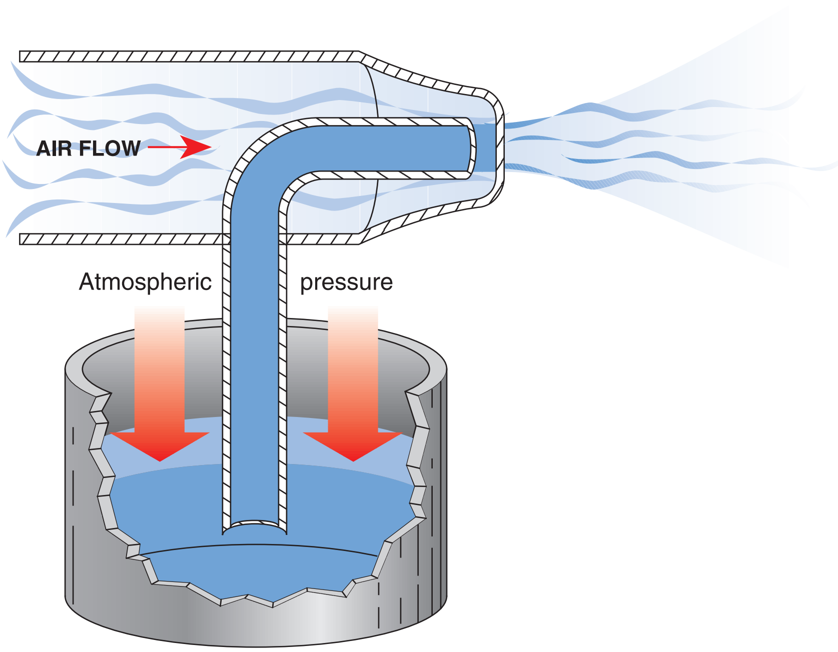


Figure 3-73. *An atomizer, such as is used in a spray gun, is a form of venturi. When the air flow is restricted, the pressure drops, and atmospheric pressure forces the liquid up so that it mixes with the high-velocity air and is broken up into tiny droplets. It is atomized.*

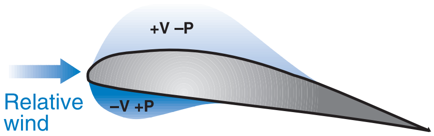


Figure 3-74. *Aerodynamic lift is produced by an airfoil when the kinetic energy (velocity) in the air flowing over its upper surface increases and its potential energy (pressure) decreases. Below the surface, the velocity decreases and the pressure increases.*

Bernoulli's principle also helps us understand the way aerodynamic lift is produced by an airplane wing and by a helicopter rotor.

The cross-sectional shape of a wing or a rotor is much like the one we see in Figure 3-74. As the air strikes the wing and flows over the top, it finds the surface dropping away from it. For the air to continue to cling to the surface, it must speed up. Energy is needed to speed up the air, and this energy comes from changing some of the potential energy, or pressure, into velocity, or kinetic energy. As the pressure over the top of the wing becomes less, it pulls air down to the surface, and a force equal to the weight of the air being pulled down pulls upward on the wing.

The air flowing below the wing encounters the bottom surface rising into its flow path, and it slows down. This loss of velocity increases its potential energy, or pressure, and this pressure pushes the wing up. The low pressure on top of the wing and the high pressure below the wing produce aerodynamic lift.

Buoyancy

buoyancy. The uplifting force that acts on an object when it is placed in a fluid.

There are two types of flying machines that allow us to overcome the force of gravity and rise into the air. Aerodynamic flying machines such as airplanes and helicopters depend upon movement through the air to produce lift. Aerostatic machines such as balloons rise in the air because of their buoyancy.

Balloons are filled with a gas, such as hot air, which is less dense than the colder air surrounding it. They rise because they displace a weight of air greater than their own weight.

If we put a block of aluminum in a container of water, the pressure of the liquid pushes against its top, bottom, and sides. Since the forces on the sides are exactly equal, they cancel each other, but there is more force on the bottom of the block than there is on its top, and the water will try to force the block up. The amount of this force is exactly equal to the weight of the water the block displaces. *See* Figure 3-75.

A 10-inch cube of aluminum has a volume of 1,000 cubic inches, and since its specific gravity is 2.8, the block is 2.8 times as heavy as an equal volume of water.

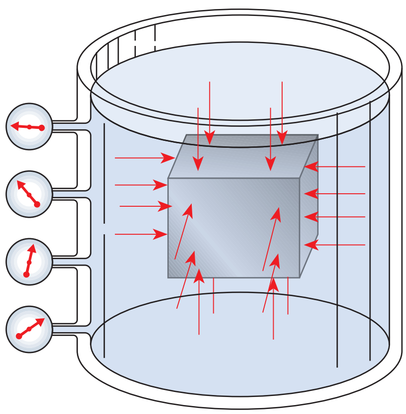


Figure 3-75. *The pressure exerted by the liquid in a container increases with the depth of the liquid, and the pressure is greatest at the bottom.*

When a block of material is submerged in the liquid, the pressure acts on all sides of the block, and since the pressure is greater on the bottom of the block than it is on the top, the liquid tries to force the block up. The block is said to be buoyed up by the liquid.

Archimedes' principle explains the way buoyancy acts on an object that is immersed in a fluid, either a liquid or a gas. We can understand this principle if we support the block of aluminum with a spring scale, as in Figure 3-76, and lower it into a container of water so that some of the water is forced out of the container into another container on the scales.

The aluminum block weighs 101 pounds when it is outside of the water. And when we lower it into the water, it displaces some of the water. As the block pushes the water out, the water pushes up on the block and the scale reads less. When the block is completely submerged in the water, the scale reads 64.9 pounds, because we have forced 36.1 pounds of water out of the container. The aluminum block is buoyed up by the water with a force equal to the weight of the water that was displaced.

Archimedes' principle. The principle that states that a body immersed in a fluid undergoes an apparent loss of weight equal to the weight of the fluid it displaces.

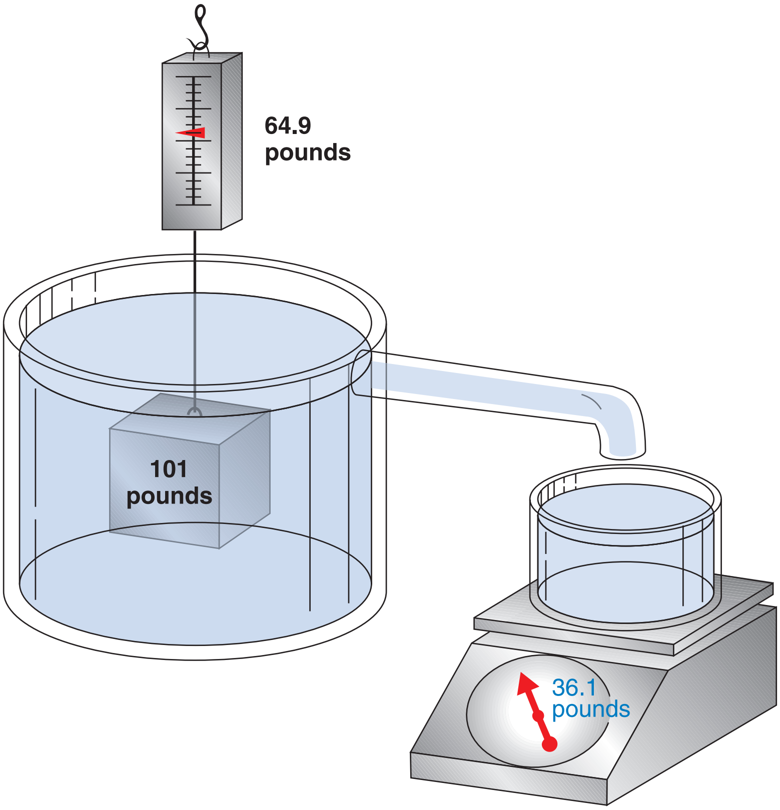


Figure 3-76. *Aluminum weighs 0.101 pound per cubic inch, so a 10 · 10 · 10 inch block of aluminum weighs 101 pounds. When the block is lowered into a container of water, it takes the place of 1,000 cubic inches of water, which weighs 36.1 pounds. The block is buoyed up by a force equal to the weight of the water it displaced, and it now pulls down on the spring scale with a force of only 64.9 pounds.*

The same size block of wood, with a specific gravity of 0.50, weighs 18.15 pounds outside of the water; and when lowered into the water, it forces out only 500 cubic inches of water. The scale will read zero because the block has displaced its own weight of water and the water holds up the entire weight of the block. The block floats.

Hot air balloons rise into the air because the heated air inside the balloon is less dense than the surrounding cooler air. The balloon displaces a weight of air equal to the weight of the balloon with its basket and occupants.

Physical Changes Caused by Heat

When heat energy is added to a material, it speeds up the movement of the material's molecules, and this increased movement usually causes the material to change some of its characteristics. Most materials expand when they absorb heat, and some change their form or shape. When ice absorbs enough heat, it melts, and when it absorbs yet more heat, it turns into steam.

Sensible Heat

sensible heat. Heat that raises the temperature of a substance without changing its state.

Sensible heat is the heat that raises the temperature of a material without changing its physical state. The temperature of most materials increases when they absorb heat. For example, if we put a pan of cold water on a stove, heat from the stove enters the water and increases its temperature. The water remains liquid, and its temperature continues to rise until it reaches 100°C. It is sensible heat that causes the temperature of a material to increase without changing its physical state.

Latent Heat

latent heat. Heat that changes the state of a substance without raising its temperature.

If we leave the pan of water on the stove after it reaches a temperature of 100°C and continue to add heat to it, the temperature of the water does not go any higher, but the water changes from a liquid into a gas and boils away, or evaporates. The heat that causes it to change its physical state but stay at the same temperature is called latent heat. *See* Figure 3-44.

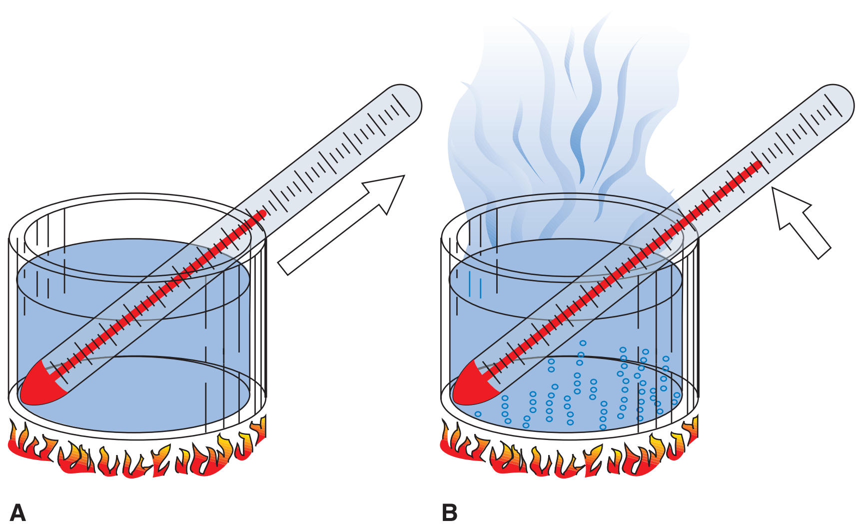


Figure 3-44.

When sensible heat is added to water, its temperature increases, but the water does not change its physical state.

When latent heat is added to water, its temperature remains constant, but the water changes its state from liquid water into steam.

When water evaporates, the latent heat remains in the water vapor. Then, when the vapor cools enough to change back into liquid water, the latent heat is released and warms the surrounding air.

Dimensional Changes Caused by Heat

When heat energy is added to a material, the molecules increase their speed, and this actually causes the material to expand. This is called thermal expansion, and it takes place in almost all types of matter. Liquids expand the least and solids expand in different amounts. Gases expand the most. When the air inside a turbine engine is heated by the burning fuel, it expands a great deal, and this expansion produces thrust.

thermal expansion. The increase in size of a material caused by the absorption of heat energy.

It is important when working with any kind of engine to understand the way different metals change their size when they are heated. Because of this change, many engine parts are assembled with what is called an interference fit. If a steel part is to be installed in a hole in an aluminum casting so it will not loosen when the parts get hot, the steel part is made slightly larger than the hole into which it is to fit. Then the aluminum casting is heated in an oven and the steel part is chilled with dry ice. The aluminum expands, making the hole larger, and the steel part shrinks. In this way, the two parts can be easily assembled. But when the two metals reach the same temperature, the aluminum shrinks around the steel and produces a tight fit that will not loosen when the parts both become hot during normal engine operation.

specific heat. The ratio of the amount of heat energy needed to raise the temperature of a certain mass of a material 1°C to the amount of heat energy needed to raise the temperature of the same mass of pure water 1°C.

Specific Heat

Specific heat is the ratio of the amount of heat energy needed to raise the temperature of a specific mass of material 1°C, to the amount of heat energy needed to raise the temperature of the same mass of pure water 1°C. One gram of pure water requires 1 calorie of heat energy to raise its temperature 1°C, and water is given a specific heat value of 1.00.

Figure 3-45 shows the specific heat values of several commonly used materials, and since water has a specific heat of 1.00, it is used as a reference. Aluminum has a specific heat of 0.22. This means that the temperature of 1 gram of aluminum can be raised 1°C with less heat than we need for water. Only 0.22 calorie is needed.

Material	Specific Heat
Water	1.00
Alcohol	0.59
Ice	0.50
Aluminum	0.22
Glass	0.19
Iron	0.11
Copper	0.09
Silver	0.05
Mercury	0.03
Lead	0.03

Figure 3-45. *Specific heat of various materials*

Transfer of Heat

Energy can neither be created nor destroyed, but other forms of energy can be turned into heat, and heat can be turned into other forms of energy. We can also transfer, or move, heat from one object to another. There are three ways by which this can be done: conduction, convection, and radiation.

conduction. The method of heat transfer by direct contact.

convection. The method of heat transfer by vertical currents within a fluid.

radiation. The method of heat transfer by electromagnetic wave action.

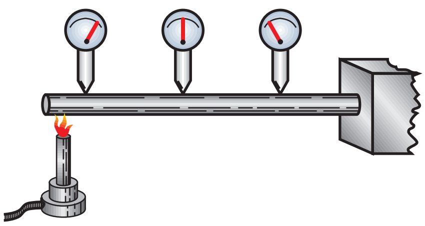


Figure 3-46. *When the end of the bar is heated with the flame, heat is transferred through the bar by conduction.*

Conduction

If we heat the end of a bar of metal with a flame and measure the temperature at different points along the bar, we find that the point nearest the flame will be hotter than points farther away from the flame (*see* Figure 3-46). This is because the heat energy from the flame forces the molecules in the metal into violent motion and raises the temperature of the metal. The molecules receiving the most heat touch other molecules and cause them to move faster. In this way, heat is conducted throughout the metal as each molecule affects the one next to it. The molecules farthest from the flame receive the least heat, and their motion is the least violent, so the temperature at that point in the metal will be the lowest. Most metals are good conductors of heat, but materials such as wood, cloth, paper, and most plastics are not; they are insulators.

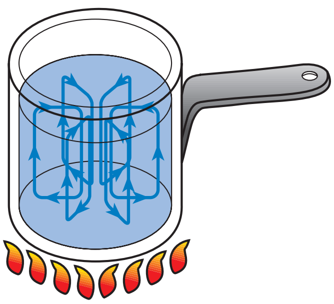


Figure 3-47. *When water in a container is heated by conduction, it becomes less dense and rises, forcing the cold water down to where it can be heated. This is heat transfer by convection.*

Convection

Convection is a method of moving heat inside a gas or a liquid by means of vertical currents inside the fluid. When a pan of water is placed on a hot stove, the water at the bottom of the pan is heated by conduction, and the molecules of water that touch the metal absorb heat from the pan.

Then, as the movement of these molecules increases, the water becomes less dense and rises. The water that has not been heated is forced down to the bottom where it absorbs heat from the metal of the pan. *See* Figure 3-47.

Radiation

Both conduction and convection depend upon direct physical contact with the source of heat. But heat can be transferred from one object to another without this direct contact. This method of heat transfer is called radiation. *See* Figure 3-48.

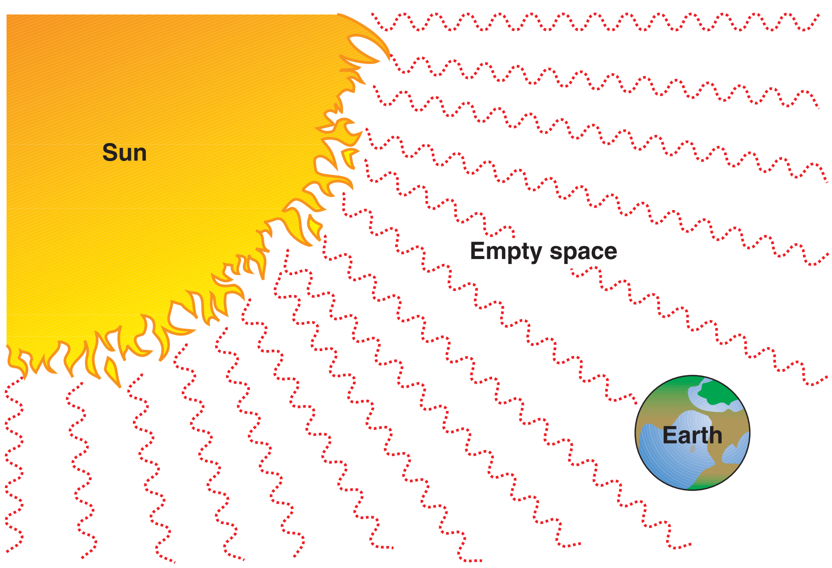


Figure 3-48. *Heat energy from the sun reaches the earth through the vacuum of empty space by radiation. Invisible heat energy passes through empty space in the same way as visible light energy.*

The heat energy we receive from the sun reaches us in the form of electromagnetic waves. Some of these waves have frequencies that make them visible, and this is the light we see. Others, with shorter wavelengths, are not visible, but they are able to penetrate solid substances. These are called cosmic rays.

Of primary interest are the waves of energy that are longer than those of visible light. When these waves strike the earth, they are absorbed by physical matter and release their energy into the molecules of the matter. This absorbed energy causes the matter to get hot.

All objects radiate energy, and the hotter the object, the more energy it radiates; and all objects absorb radiation. The only way an object can remain at the same temperature is for it to radiate exactly the same amount of energy as it receives.

Temperature

Heat is a form of energy that causes the molecules of a material to move around, and temperature is a measure of the amount of this motion. Normally, the molecules of a material are moving around all the time, and the hotter they are, the faster they move. There is a point, though, at which all of this molecular motion stops. This point is called absolute zero, and we use it as the reference point for absolute temperature measurement.

absolute temperature. Temperature measured from absolute zero. Absolute temperature is measured in degrees Kelvin or degrees Rankine.

absolute zero. The temperature at which all molecular movement inside a material stops. It is zero degrees on both the Kelvin and Rankine scales and -273°C and -460°F.

The two most commonly used systems for measuring temperature do not start with absolute zero but are based instead on two points, the freezing point and boiling point of pure water.

The Celsius, formerly Centigrade, scale sets the freezing point of pure water as 0° and the boiling point as 100°. The scale is continued in steps of equal size, both above and below the range between 0° and 100°. Absolute zero, or the point at which all molecular movement stops, is -273°C.

The Fahrenheit system uses the freezing temperature of a mixture of salt, ice, and water as its 0° mark. Pure water freezes at 32°F and boils at 212°F. The difference between boiling and freezing is divided into 180 equal divisions, and this scale is continued both below and above this range. On the Fahrenheit scale, all molecular movement stops at -460°F.

For temperature measurement in scientific calculations, there are two temperature scales based on absolute zero. The Kelvin scale uses the same divisions as the Celsius system, and 0 K is absolute zero. Pure water freezes at 273 K and boils at 373 K.

The other absolute temperature system is the Rankine system, and its divisions are the same size as those used in the Fahrenheit system. All molecular movement stops at 0°R, and pure water freezes at 492°R and boils at 672°R. *See* Figure 3-49.

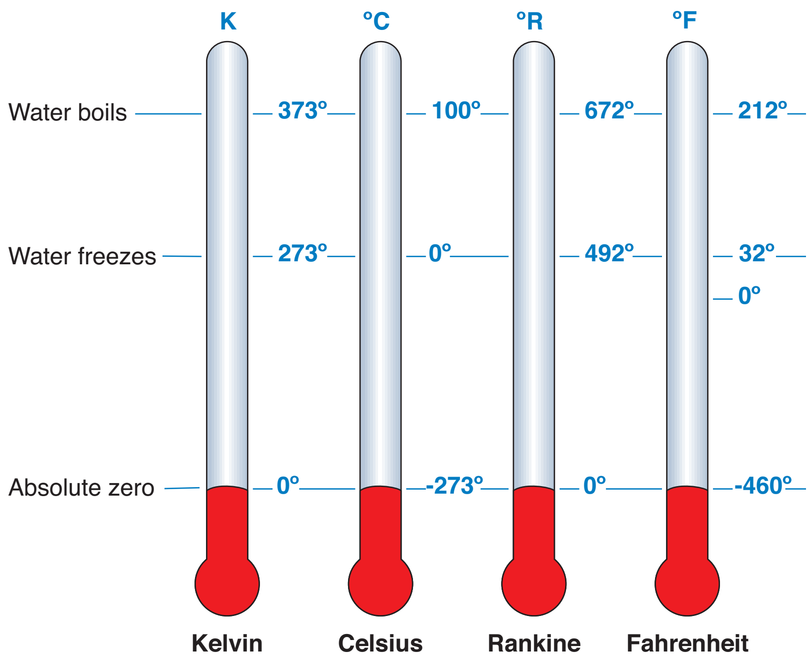


Figure 3-49. *The four temperature scales have values for absolute zero and for the points at which pure water freezes and boils.*

To change °C into °F, multiply °C by 1.8, then add 32.

$$°F = 1.8\,(°C) + 32$$

Another way to do this is to multiply °C by 9 and divide by 5, then add 32.

$$°F = 9/5\,(°C) + 32$$

To change °F into °C, subtract 32 from °F, and then divide by 1.8.

$$°C = (°F - 32) \div 1.8$$

Another way is to subtract 32 from the °F, and multiply this by 5 and divide by 9:

$$°C = (°F - 32) \cdot 5/9$$

We can change °C into K by adding 273 to the °C.

$$K = °C + 273$$

To change K into °C, subtract 273 from the K.

$$°C = K - 273$$

We can also change °F into °R by adding 460 to the °F.

$$°R = °F + 460°$$

Or, to change °R to °F, subtract 460 from the °R.

$$°F = °R - 460°$$