THE BIG IDEA

Heat flows from hot to cold.

The study of heat and its transformation into mechanical energy is called thermodynamics. The word *thermodynamics* stems from Greek words meaning "movement of heat." The foundation of thermodynamics is the conservation of energy and the fact that heat flows from hot to cold. It provides the basic theory of heat engines.

24.1 Absolute Zero

✓ **As the thermal motion of atoms in a substance approaches zero, the kinetic energy of the atoms approaches zero, and the temperature of the substance approaches a lower limit.**

24.1 Absolute Zero

As thermal motion of atoms increases, temperature increases.

There seems to be no upper limit of temperature but there is a definite limit at the other end of the temperature scale.

If we continually decrease the thermal motion of atoms in a substance, the temperature will drop.

Absolute zero is the temperature at which no more energy can be extracted from a substance.

24.1 Absolute Zero

At absolute zero, no further lowering of its temperature is possible.

This temperature is 273 degrees below zero on the Celsius scale.

Absolute zero corresponds to zero degrees on the Kelvin, or thermodynamic, scale and is written 0 K (short for “zero kelvin”).

24.1 Absolute Zero

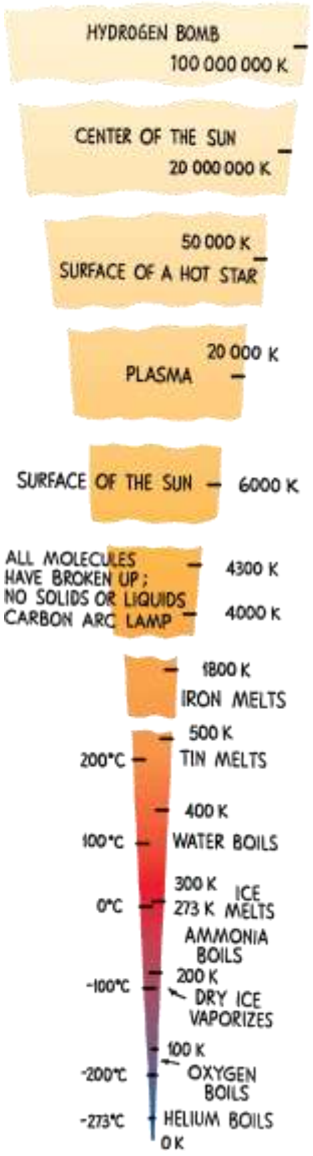
Unlike the Celsius scale, there are no negative numbers on the thermodynamic scale.

Degrees on the Kelvin scale are the same size as those on the Celsius scale.

Ice melts at 0°C, or 273 K, and water boils at 100°C, or 373 K.

24.1 Absolute Zero

The absolute temperatures of various objects and phenomena.



24.1 Absolute Zero

think!

A sample of hydrogen gas has a temperature of 0°C. If the gas is heated until its molecules have doubled their average kinetic energy (the gas has twice the absolute temperature), what will be its temperature in degrees Celsius?

24.1 Absolute Zero

think!

A sample of hydrogen gas has a temperature of 0°C. If the gas is heated until its molecules have doubled their average kinetic energy (the gas has twice the absolute temperature), what will be its temperature in degrees Celsius?

Answer:

At 0°C the gas has an absolute temperature of 273 K. Twice as much average kinetic energy means it has twice the absolute temperature. This would be 546 K, or 273°C.

24.1 Absolute Zero

CONCEPT CHECK

What happens to a substance's temperature as the motion of its atoms approaches zero?

24.2 First Law of Thermodynamics

✓ **The first law of thermodynamics states that whenever heat is added to a system, it transforms to an equal amount of some other form of energy.**

24.2 First Law of Thermodynamics

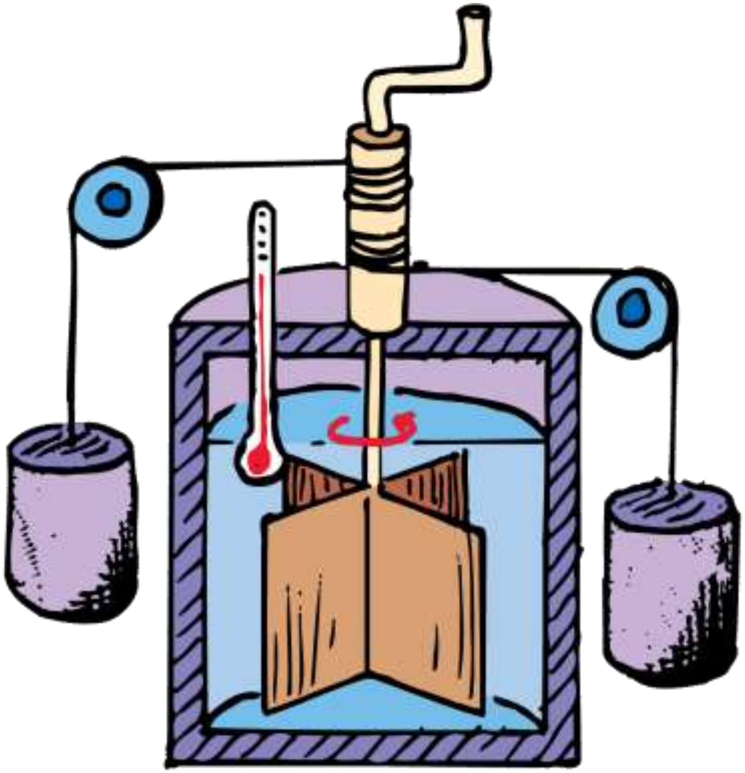
In the eighteenth century, heat was thought to be an invisible fluid called *caloric,* which flowed like water from hot objects to cold objects.

In the 1840s, James Joule demonstrated that the flow of heat was nothing more than the flow of energy itself.

The caloric theory of heat was gradually abandoned.

24.2 First Law of Thermodynamics

As the weights fall, they give up potential energy and warm the water accordingly. This was first demonstrated by James Joule, for whom the unit of energy is named.

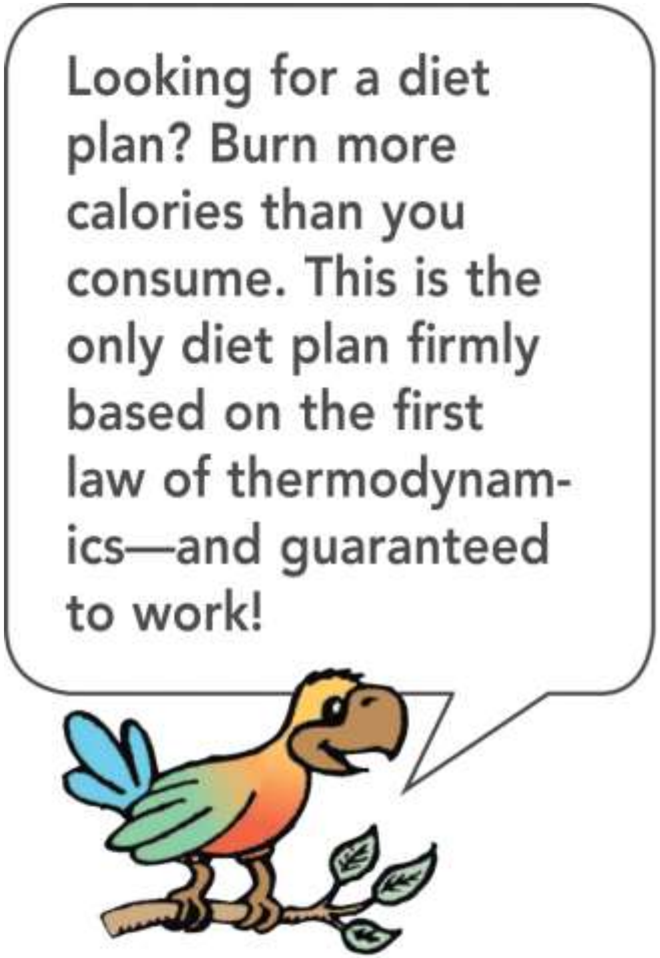


24.2 First Law of Thermodynamics

Today, we view heat as a form of energy.

Energy can neither be created nor destroyed.

The **first law of thermodynamics** is the law of conservation of energy applied to thermal systems.



24.2 First Law of Thermodynamics

Heat

By *system,* we mean any group of atoms, molecules, particles, or objects we wish to deal with.

- The system may be the steam in a steam engine,
- the whole Earth's atmosphere,
- or even the body of a living creature.

It is important to define what is contained within the system as well as what is outside of it.

24.2 First Law of Thermodynamics

If we add heat energy to a system, the added energy does one or both of two things:

- increases the internal energy of the system if it remains in the system
- does external work if it leaves the system

So, the first law of thermodynamics states:

Heat added = increase in internal energy + external work done by the system

24.2 First Law of Thermodynamics

Let’s say you put an air-filled, rigid, airtight can on a hotplate and add a certain amount of energy to the can.

Caution: *Do not actually do this.*

The can has a fixed volume and the walls of the can don’t move, so no work is done.

All of the heat going into the can increases the internal energy of the enclosed air, so its temperature rises.

24.2 First Law of Thermodynamics

Now suppose that we replace the can with a balloon.

As the air is heated it expands, exerting a force for some distance on the surrounding atmosphere.

Some of the heat added goes into doing work, so less of the added heat goes into increasing the enclosed air’s internal energy.

The temperature of the enclosed air will be lower than that of the air in the closed can.

24.2 First Law of Thermodynamics

When a given quantity of heat is supplied to a steam engine, some of this heat increases the internal energy of the steam.

The rest is transformed into mechanical work as the steam pushes a piston outward.

The first law of thermodynamics is the thermal version of the law of conservation of energy.

24.2 First Law of Thermodynamics

Work

Adding heat is not the only way to increase the internal energy of a system.

If we set the “heat added” part of the first law to zero, changes in internal energy are equal to the work done on or by the system.

24.2 First Law of Thermodynamics

If work is done on a system—compressing it, for example—the internal energy will increase.

The temperature of the system rises without any heat input.

If work is done *by* the system—expanding against its surroundings, for example—the system's internal energy will decrease.

With no heat extracted, the system cools.

24.2 First Law of Thermodynamics

When we pump on a bicycle pump, it becomes hot because we put mechanical work into the system and raise its internal energy.

24.2 First Law of Thermodynamics

think!

If 10 J of energy is added to a system that does no external work, by how much will the internal energy of that system be raised?

24.2 First Law of Thermodynamics

think!

If 10 J of energy is added to a system that does no external work, by how much will the internal energy of that system be raised?

Answer:

10 J.

24.2 First Law of Thermodynamics

CONCEPT CHECK

What does the first law of thermodynamics state?

24.3 Adiabatic Processes

✓ **When work is done on a gas by adiabatically compressing it, the gas gains internal energy and becomes warmer.**

24.3 Adiabatic Processes

When a gas is compressed or expanded so that no heat enters or leaves a system, the process is said to be **adiabatic**.

Adiabatic changes of volume can be achieved by performing the process rapidly so that heat has little time to enter or leave or by thermally insulating a system from its surroundings.

24.3 Adiabatic Processes

Do work on a pump by pressing down on the piston and the air is warmed.

24.3 Adiabatic Processes

A common example of a near-adiabatic process is the compression and expansion of gases in the cylinders of an automobile engine.

Compression and expansion occur in only a few hundredths of a second, too fast for heat energy to leave the combustion chamber.

For very high compressions, like those in a diesel engine, the temperatures are high enough to ignite a fuel mixture without a spark plug.

Diesel engines have no spark plugs.

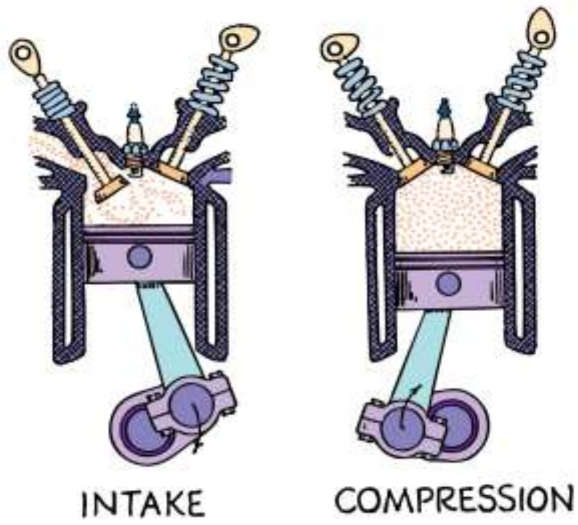
24.3 Adiabatic Processes

INTAKE

a. A fuel–air mixture fills the cylinder as the piston moves down.

One cycle of a four-stroke internal combustion engine.

24.3 Adiabatic Processes

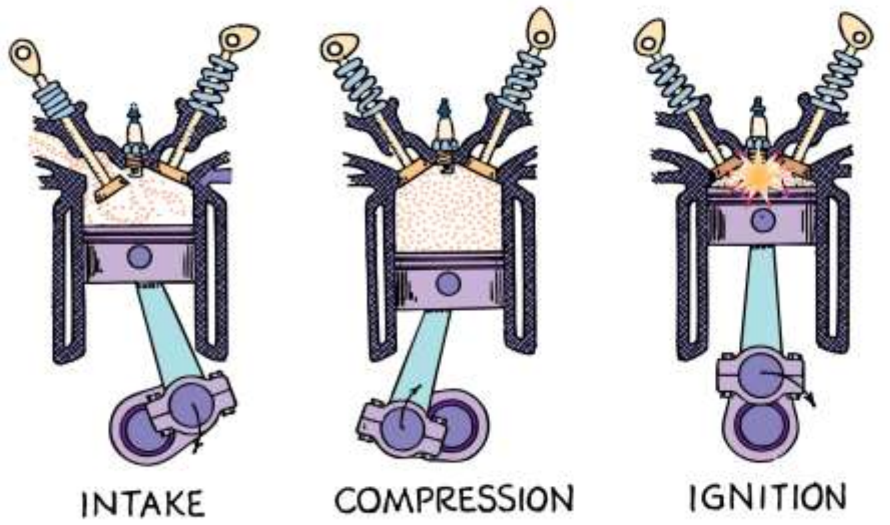


a. A fuel–air mixture fills the cylinder as the piston moves down.

b. The piston moves up and compresses the mixture—adiabatically, since no heat transfer occurs.

One cycle of a four-stroke internal combustion engine.

24.3 Adiabatic Processes



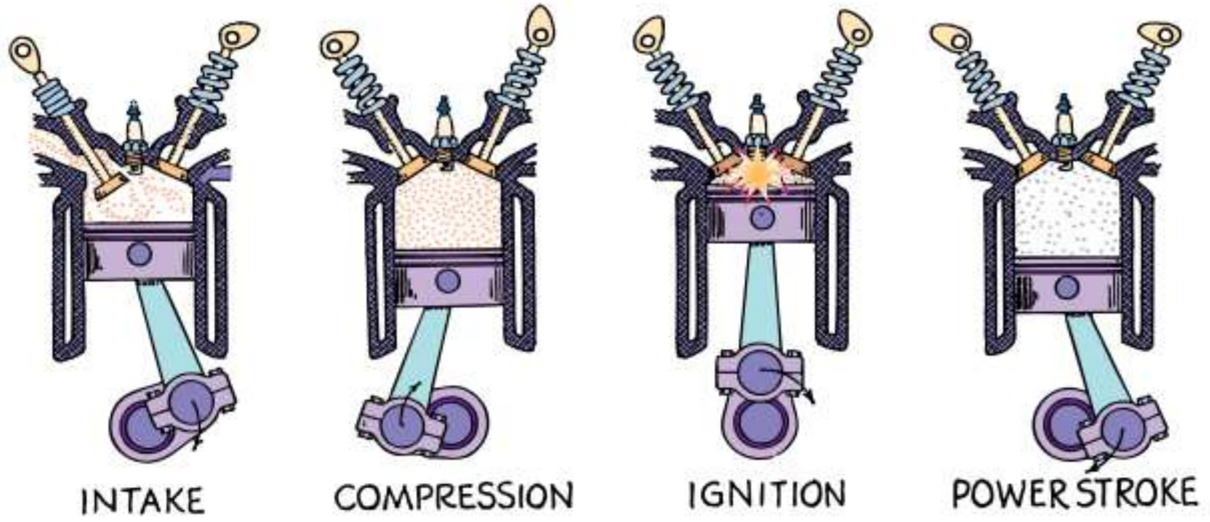
a. A fuel–air mixture fills the cylinder as the piston moves down.

b. The piston moves up and compresses the mixture—adiabatically, since no heat transfer occurs.

c. The spark plug fires, ignites the mixture, and raises its temperature.

One cycle of a four-stroke internal combustion engine.

24.3 Adiabatic Processes



a. A fuel–air mixture fills the cylinder as the piston moves down.

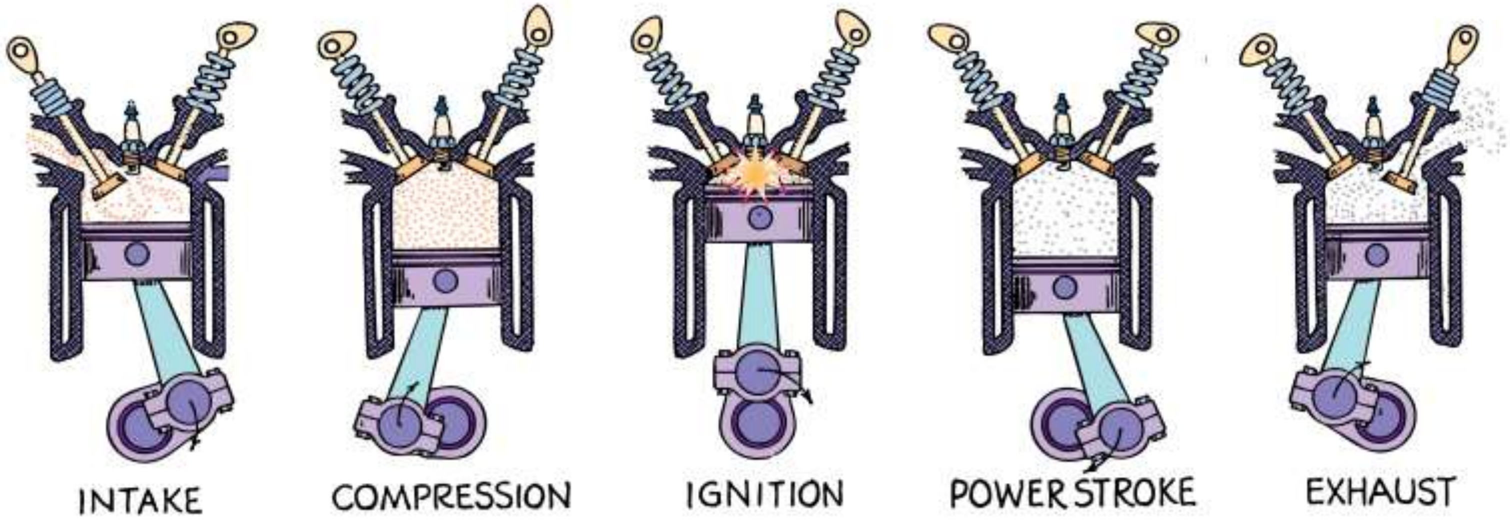
b. The piston moves up and compresses the mixture—adiabatically, since no heat transfer occurs.

c. The spark plug fires, ignites the mixture, and raises its temperature.

d. Adiabatic expansion pushes the piston downward—the power stroke.

One cycle of a four-stroke internal combustion engine.

24.3 Adiabatic Processes



a. A fuel–air mixture fills the cylinder as the piston moves down.

b. The piston moves up and compresses the mixture—adiabatically, since no heat transfer occurs.

c. The spark plug fires, ignites the mixture, and raises its temperature.

d. Adiabatic expansion pushes the piston downward—the power stroke.

e. The burned gases are pushed out the exhaust valve, and the cycle repeats.

One cycle of a four-stroke internal combustion engine.

24.3 Adiabatic Processes

When a gas adiabatically expands, it does work on its surroundings and gives up internal energy, and thus becomes cooler.

24.3 Adiabatic Processes

Blow warm air onto your hand from your wide-open mouth. Now reduce the opening between your lips so the air expands as you blow. Adiabatic expansion—the air is cooled.

24.3 Adiabatic Processes

Heat and Temperature

Air temperature may be changed by adding or subtracting heat, by changing the pressure of the air, or by both.

Heat may be added by solar radiation, by long-wave Earth radiation, by condensation, or by contact with the warm ground.

Heat may be subtracted by radiation to space, by evaporation of rain falling through dry air, or by contact with cold surfaces.

24.3 Adiabatic Processes

For many atmospheric processes, the amount of heat added or subtracted is small enough that the process is nearly adiabatic.

In this case, an increase in pressure will cause an increase in temperature, and vice versa.

We then have the adiabatic form of the first law:

Change in air temperature ~ pressure change

24.3 Adiabatic Processes

Pressure and Temperature

Adiabatic processes in the atmosphere occur in large masses of air that have dimensions on the order of kilometers.

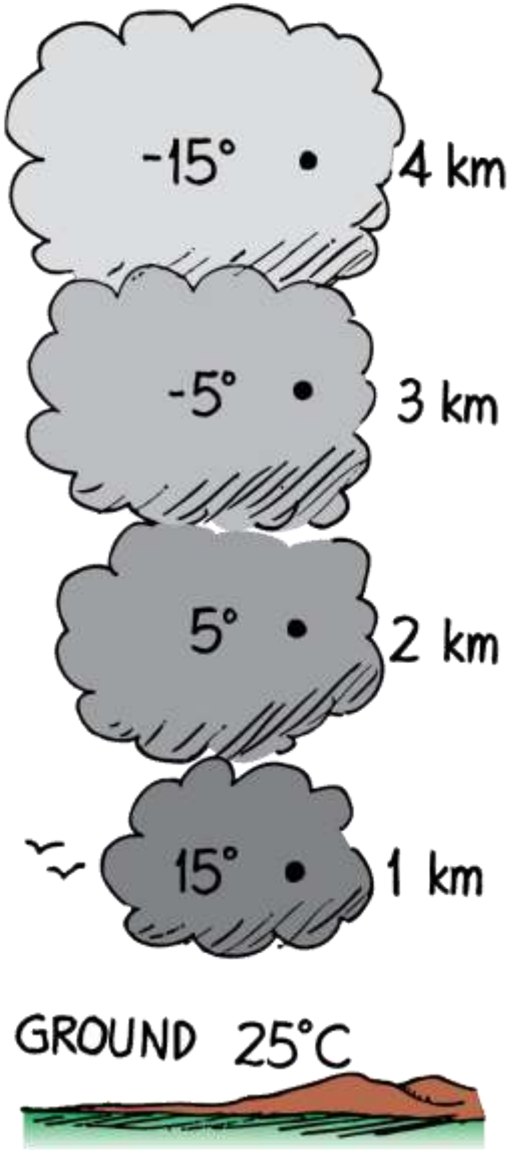
We'll call these large masses of air *blobs.*

As a blob of air flows up the side of a mountain, its pressure lessens, allowing it to expand and cool.

The reduced pressure results in reduced temperature.

24.3 Adiabatic Processes

The temperature of a blob of dry air that expands adiabatically changes by about 10°C for each kilometer of elevation.



24.3 Adiabatic Processes

Air flowing over tall mountains or rising in thunderstorms or cyclones may change elevation by several kilometers.

Air at 25°C at ground level would be -35°C at 6 kilometers.

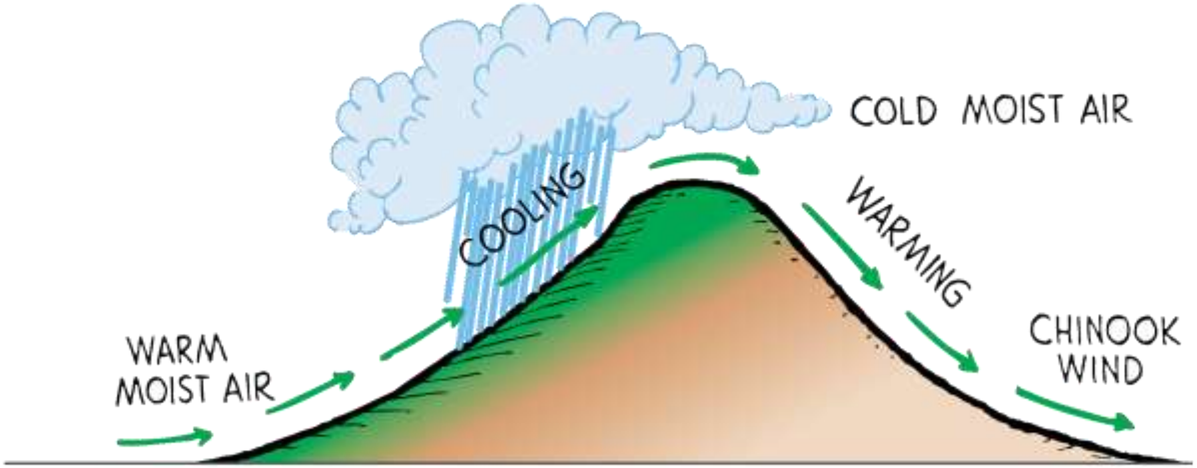
If air at -20°C at an altitude of 6 kilometers descended to the ground, its temperature would be a roasting 40°C.

24.3 Adiabatic Processes

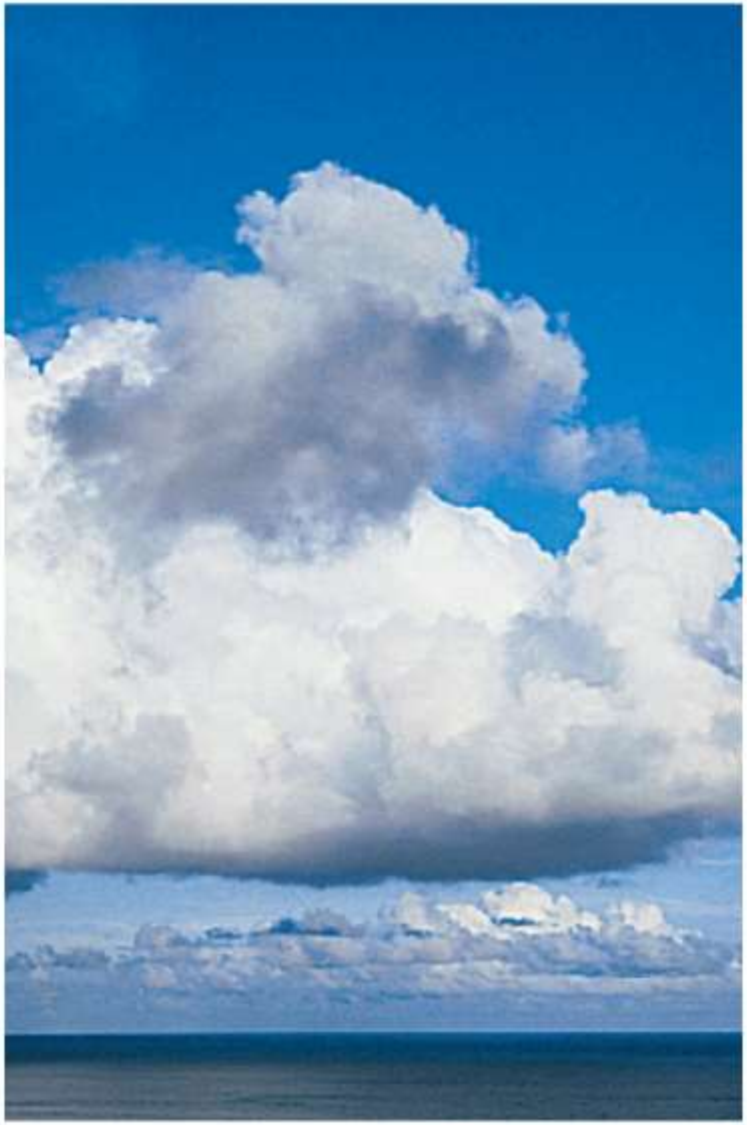
An example of this adiabatic warming is the *chinook*—a warm, dry wind that blows from the Rocky Mountains across the Great Plains.

Cold air moving down the slopes of the mountains is compressed into a smaller volume and is appreciably warmed.

Communities in the paths of chinooks experience relatively warm weather in midwinter.



24.3 Adiabatic Processes



A thunderhead is the result of the rapid adiabatic cooling of a rising mass of moist air. Its energy comes from condensation and freezing of water vapor.

24.3 Adiabatic Processes

think!

Imagine a giant dry-cleaner’s garment bag full of air at a temperature of -10°C floating like a balloon with a string hanging from it 6 km above the ground. If you were able to yank it suddenly to the ground, what would its approximate temperature be?

24.3 Adiabatic Processes

think!

Imagine a giant dry-cleaner’s garment bag full of air at a temperature of -10°C floating like a balloon with a string hanging from it 6 km above the ground. If you were able to yank it suddenly to the ground, what would its approximate temperature be?

Answer:

If it were pulled down so quickly that heat conduction was negligible, it would be adiabatically compressed by the atmosphere and its temperature would rise to a piping hot 50°C (122°F), just as compressed air gets hot in a bicycle pump.

24.3 Adiabatic Processes

CONCEPT CHECK

What is the effect of adiabatic compression on a gas?

24.4 Second and Third Laws of Thermodynamics

The second law of thermodynamics states that heat will never of itself flow from a cold object to a hot object.

24.4 Second and Third Laws of Thermodynamics

If a hot brick is next to a cold brick, heat flows from the hot brick to the cold brick until both bricks arrive at thermal equilibrium.

If the hot brick takes heat from the cold brick and becomes hotter, the first law of thermodynamics is not violated.

However, this would violate the *second law of thermodynamics*.

The **second law of thermodynamics** describes the direction of heat flow in natural processes.

24.4 Second and Third Laws of Thermodynamics

Heat flows one way, from hot to cold.

- In winter, heat flows from inside a warm heated home to the cold air outside.
- In summer, heat flows from the hot air outside into the home's cooler interior.
- Heat can be made to flow the other way, but only by imposing external effort—as occurs with heat pumps.

24.4 Second and Third Laws of Thermodynamics

There is a huge amount of internal energy in the ocean.

All this energy cannot be used to light a single flashlight lamp without external effort.

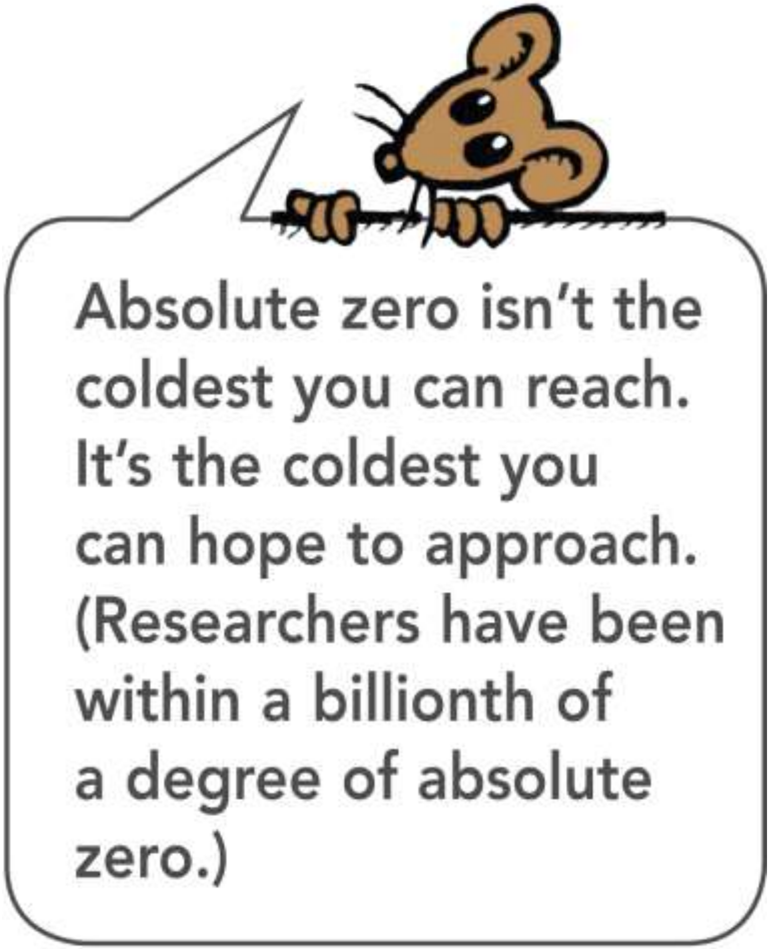
Energy will not of itself flow from the lower-temperature ocean to the higher-temperature lamp filament.

24.4 Second and Third Laws of Thermodynamics

There is also a *third law of thermodynamics*: no system can reach absolute zero.

As investigators attempt to reach this lowest temperature, it becomes more difficult to get closer to it.

Physicists have been able to record temperatures that are less than a millionth of 1 kelvin—but never as low as 0 K.



24.4 Second and Third Laws of Thermodynamics

CONCEPT CHECK

What does the second law of thermodynamics state about heat flow?

24.5 Heat Engines and the Second Law

✓ **According to the second law of thermodynamics, no heat engine can convert all heat input to mechanical energy output.**

24.5 Heat Engines and the Second Law

It is easy to change work completely into heat—simply rub your hands together briskly.

All the work you do in overcoming friction is completely converted to heat.

However, changing heat completely into work can never occur.

The best that can be done is the conversion of some heat to mechanical work.

24.5 Heat Engines and the Second Law

Heat Engine Mechanics

A **heat engine** is any device that changes internal energy into mechanical work.

The basic idea behind a heat engine is that mechanical work can be obtained as heat flows from high temperature to low temperature.

Some of the heat can be transformed into work in a heat engine.

24.5 Heat Engines and the Second Law

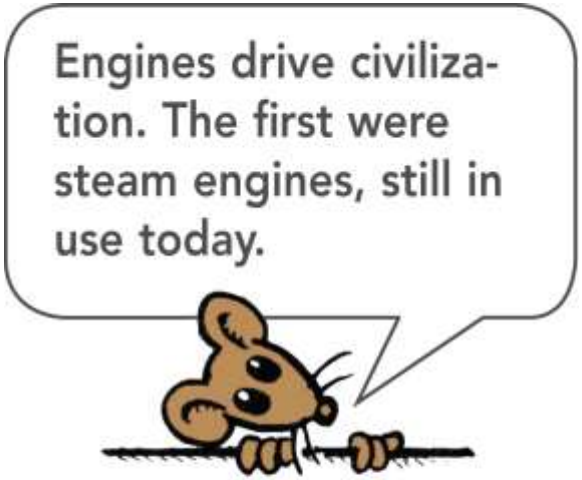
In considering heat engines, we talk about *reservoirs:*

- We picture a “high-temperature reservoir” as something from which we can extract heat without cooling it down.
- Likewise we picture a “low-temperature reservoir” as something that can absorb heat without itself warming up.
- Heat flows out of a high-temperature reservoir, into the heat engine, and then into a low-temperature reservoir.

24.5 Heat Engines and the Second Law

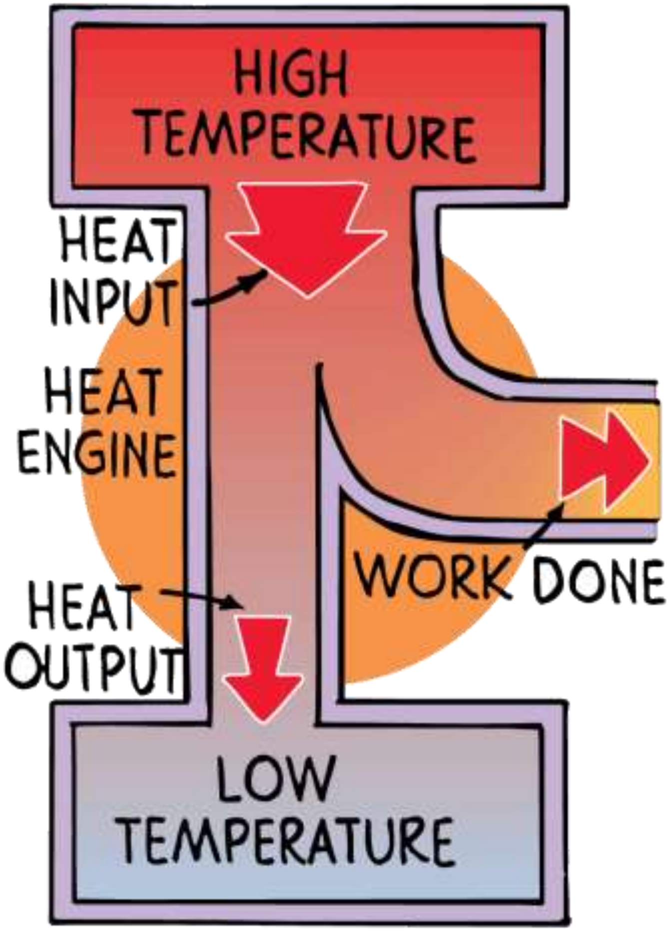
Every heat engine will

- increase its internal energy by absorbing heat from a reservoir of higher temperature,
- convert some of this energy into mechanical work, and
- expel the remaining energy as heat to some lower-temperature reservoir.



24.5 Heat Engines and the Second Law

When heat energy flows in any heat engine from a high-temperature place to a low-temperature place, part of this energy is transformed into work output.



24.5 Heat Engines and the Second Law

The second law states that when work is done by a heat engine running between two temperatures, T_{hot} and T_{cold}, only some of the input heat at T_{hot} can be converted to work.

The rest is expelled as heat at T_{cold}.

24.5 Heat Engines and the Second Law

There is always heat exhaust, which may be desirable or undesirable.

Hot steam expelled in a laundry on a cold winter day may be quite desirable.

The same steam on a hot summer day is something else. When expelled heat is undesirable, we call it *thermal pollution.*

24.5 Heat Engines and the Second Law

Heat Engine Efficiency

French engineer Sadi Carnot carefully analyzed the heat engine and made a fundamental discovery:

The upper fraction of heat that can be converted to useful work, even under ideal conditions, depends on the temperature difference between the hot reservoir and the cold sink.

24.5 Heat Engines and the Second Law

The **Carnot efficiency,** or ideal efficiency, of a heat engine is the ideal maximum percentage of input energy that the engine can convert to work.

$$\text{Ideal efficiency} = \frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{hot}}}$$

T_{hot} is the temperature of the hot reservoir.

T_{cold} is the temperature of the cold.

24.5 Heat Engines and the Second Law

Ideal efficiency depends only on the temperature difference between input and exhaust.

When temperature ratios are involved, the absolute temperature scale must be used, so T_{hot} and T_{cold} are expressed in kelvins.

The higher the steam temperature driving a motor or turbogenerator, the higher the efficiency of power production.

24.5 Heat Engines and the Second Law

For example, when the heat reservoir in a steam turbine is 400 K (127°C) and the sink is 300 K (27°C), the ideal efficiency is

$$\frac{(400 - 300)}{400} = \frac{1}{4}$$

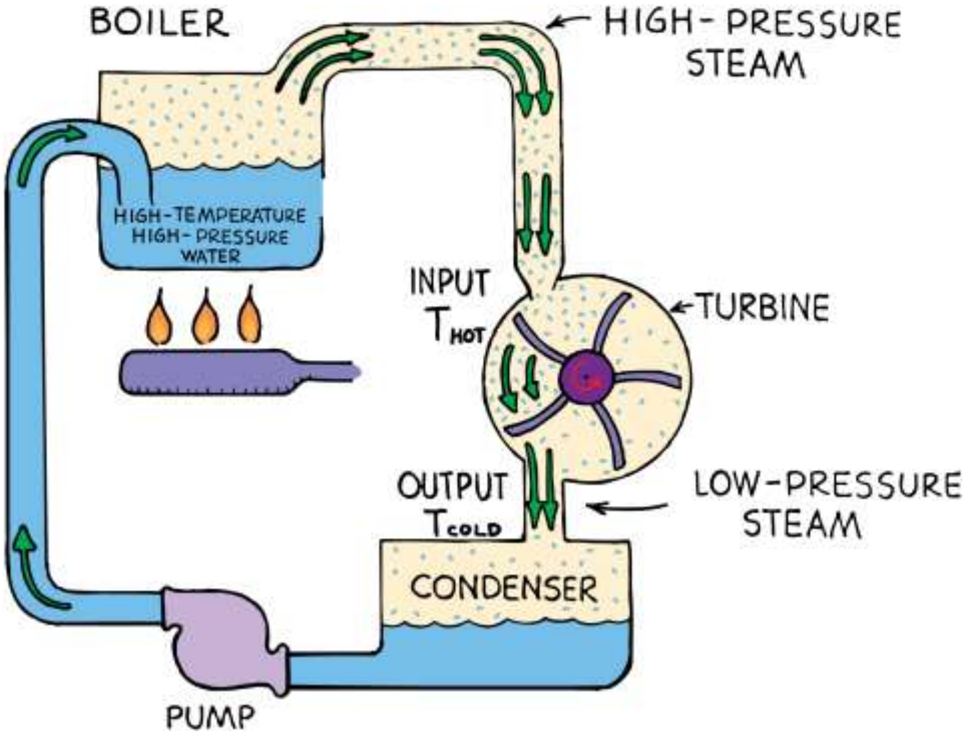
Under *ideal* conditions, 25% of the internal energy of the steam can become work, while the remaining 75% is expelled as waste.

Increasing operating temperature to 600 K yields an efficiency of (600 — 300)/600 = 1/2, twice the efficiency at 400 K.

24.5 Heat Engines and the Second Law

Heat Engine Physics

A steam turbine engine demonstrates the role of temperature difference between heat reservoir and sink.



24.5 Heat Engines and the Second Law

- Steam from the boiler is the hot reservoir while the sink is the exhaust region after the steam passes through the turbine.
- The hot steam exerts pressure and does work on the turbine blades when it pushes on their front sides.
- Steam pressure is also exerted on the *back sides* of the blades.
- A pressure *difference* across the blades is vital.

24.5 Heat Engines and the Second Law

By condensing the steam, the pressure on the back sides is greatly reduced.

With confined steam, temperature and pressure go hand in hand—increase temperature and you increase pressure.

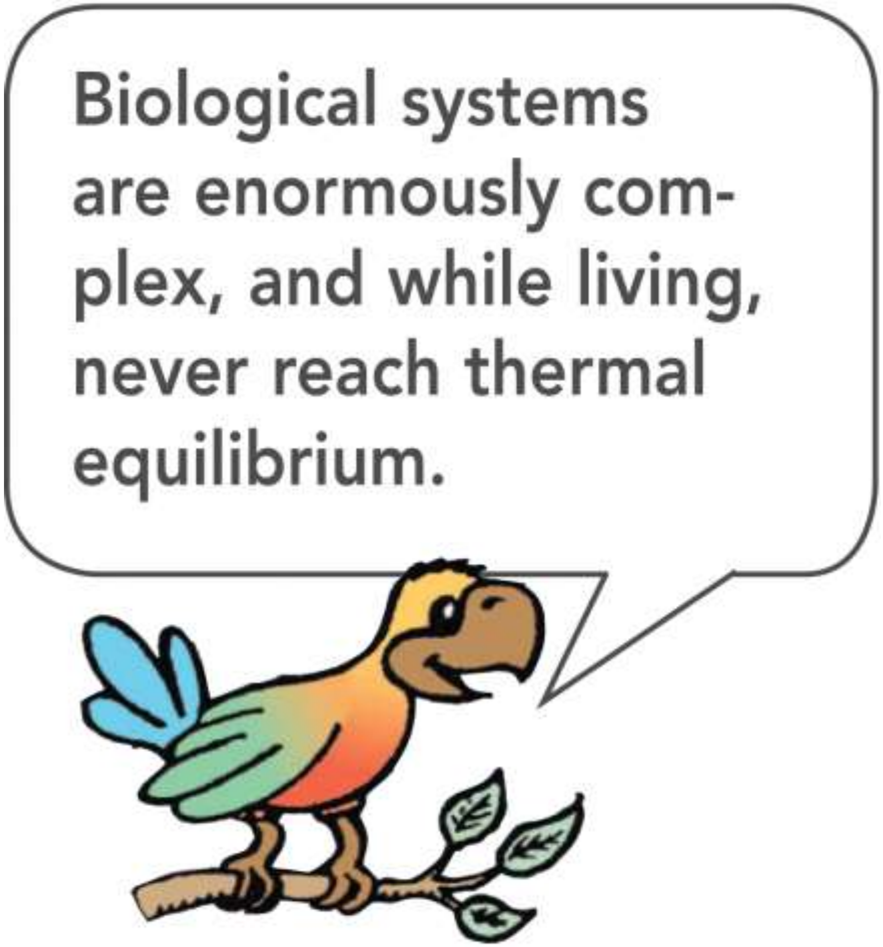
The pressure difference is directly related to the temperature difference between the heat source and the exhaust.

24.5 Heat Engines and the Second Law

Carnot's equation states the upper limit of efficiency for all heat engines.

The higher the operating temperature (compared with exhaust temperature) of any heat engine, the higher the efficiency.

Only some of the heat input can be converted to work—even without considering friction.



24.5 Heat Engines and the Second Law

think!

What is the ideal efficiency of an engine if both its hot reservoir and exhaust are the same temperature—say, 400 K? The equation for ideal efficiency is as follows:

$$\text{Ideal efficiency} = \frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{hot}}}$$

24.5 Heat Engines and the Second Law

think!

What is the ideal efficiency of an engine if both its hot reservoir and exhaust are the same temperature—say, 400 K? The equation for ideal efficiency is as follows:

$$\text{Ideal efficiency} = \frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{hot}}}$$

Answer:

Zero efficiency; (400 - 400)/400 = 0. This means no work output is possible for any heat engine unless a temperature difference exists between the reservoir and the sink.

24.5 Heat Engines and the Second Law

CONCEPT CHECK

How does the second law of thermodynamics apply to heat engines?

24.6 Order Tends to Disorder

✓ **Natural systems tend to proceed toward a state of greater disorder.**

24.6 Order Tends to Disorder

The first law of thermodynamics states that energy can be neither created nor destroyed.

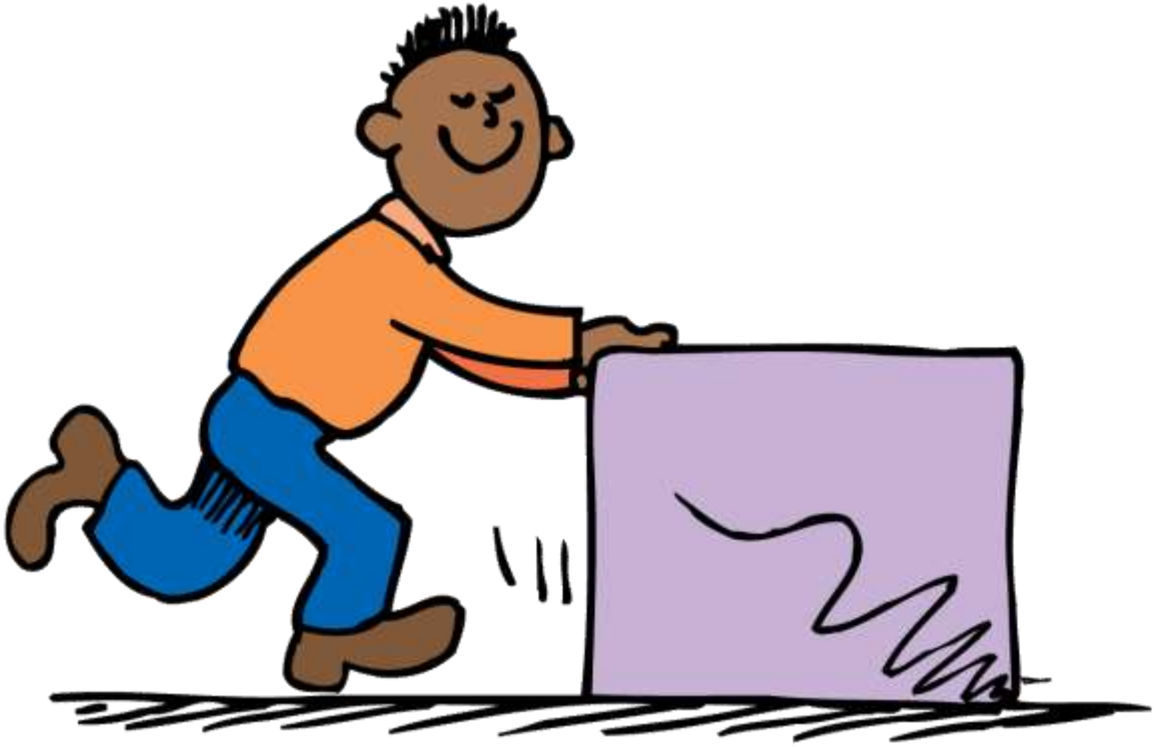
The second law adds that whenever energy transforms, some of it degenerates into waste heat, unavailable to do work.

Another way to say this is that organized, usable energy degenerates into disorganized, nonusable energy.

It is then unavailable for doing the same work again.

24.6 Order Tends to Disorder

Push a heavy crate across a rough floor and all your work will go into heating the floor and crate. Work against friction turns into disorganized energy.



24.6 Order Tends to Disorder

Organized energy in the form of electricity that goes into electric lights in homes and office buildings degenerates to heat energy.

The electrical energy in the lamps, even the part that briefly exists in the form of light, turns into heat energy.

This energy is degenerated and has no further use.

24.6 Order Tends to Disorder

The Transamerica® Pyramid and some other buildings are heated by electric lighting, which is why the lights are on most of the time.

24.6 Order Tends to Disorder

We see that the quality of energy is lowered with each transformation.

Organized energy tends to disorganized forms.

24.6 Order Tends to Disorder

Imagine that in a corner of a room sits a closed jar filled with argon gas atoms.

When the lid is removed, the argon atoms move in haphazard directions, eventually mixing with the air molecules in the room.

24.6 Order Tends to Disorder

The system moves from a more ordered state (argon atoms concentrated in the jar) to a more disordered state (argon atoms spread evenly throughout the room).

24.6 Order Tends to Disorder

The argon atoms do not spontaneously move back into the jar to return to the more ordered containment.

With the number of ways the argon atoms can randomly move, the chance of returning to an ordered state is practically zero.

24.6 Order Tends to Disorder

Disordered energy can be changed to ordered energy only at the expense of work input.

Plants can assemble sugar molecules from less organized carbon dioxide and water molecules only by using energy from sunlight.

In the broadest sense, the message of the second law is that the tendency of the universe, and all that is in it, tends to disorder.

24.6 Order Tends to Disorder

CONCEPT CHECK

What happens to the orderly state of any natural system?

24.7 Entropy

✓ **According to the second law of thermodynamics, in the long run, the entropy of a system always increases for natural processes.**

24.7 Entropy

Entropy is the measure of the amount of disorder in a system.

Disorder increases; entropy increases.

24.7 Entropy

Gas molecules escaping from a bottle move from a relatively orderly state to a disorderly state.

Organized structures in time become disorganized messes. Things left to themselves run down.

When a physical system can distribute its energy freely, entropy increases and energy of the system available for work decreases.

24.7 Entropy

This run-down house demonstrates entropy. Without continual maintenance, the house will eventually fall apart.

24.7 Entropy

Entropy normally increases in physical systems.

However, when there is work input, as in living organisms, entropy decreases.

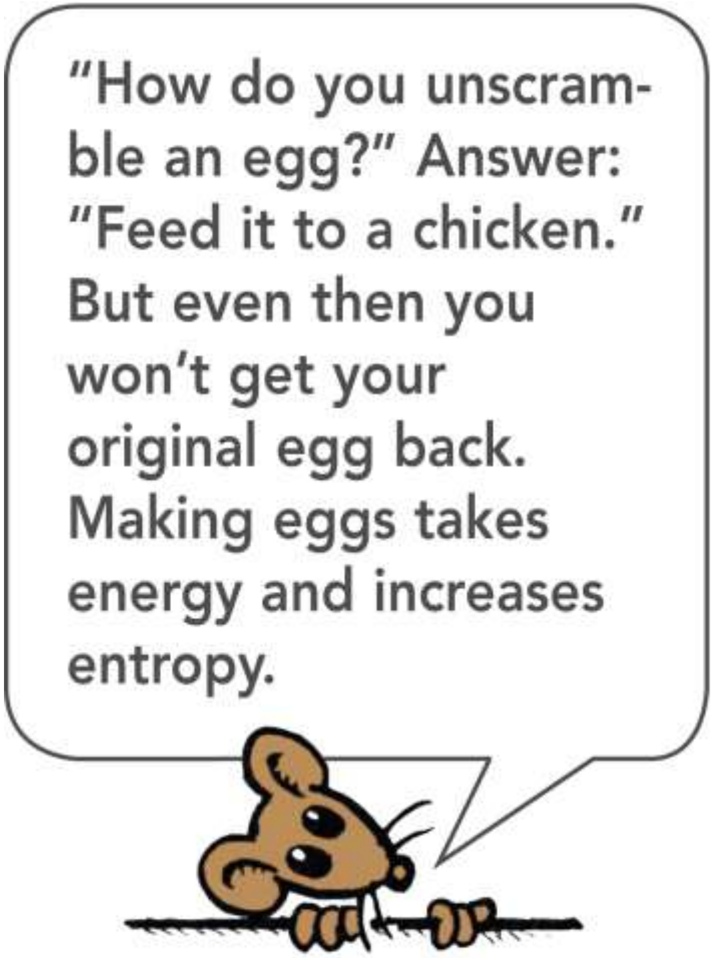
All living things extract energy from their surroundings and use it to increase their own organization.

This order is maintained by increasing entropy elsewhere.

24.7 Entropy

For the system “life forms plus their waste products” there is still a net increase in entropy.

Energy must be transformed into the living system to support life. When it is not, the organism soon dies and tends toward disorder.



24.7 Entropy

The first law of thermodynamics is a universal law of nature for which no exceptions have been observed.

The second law, however, is a probability statement. Disordered states are much more probable than ordered states.

24.7 Entropy

Even the most improbable states may occur, and entropy spontaneously decrease:

- haphazard motions of air molecules could momentarily become harmonious in a corner of the room
- a barrel of pennies dumped on the floor could show all heads
- a breeze might come into a messy room and make it organized

The odds of these things occurring are infinitesimally small.

24.7 Entropy

The motto of this contractor—“Increasing entropy is our business”—is appropriate because by knocking down the building, the contractor increases the disorder of the structure.

24.7 Entropy

The laws of thermodynamics are sometimes put this way:

- You can’t win (because you can’t get any more energy out of a system than you put in).
- You can’t break even (because you can’t even get as much energy out as you put in).
- You can’t get out of the game (entropy in the universe is always increasing).

24.7 Entropy

CONCEPT CHECK

What always happens to the entropy of systems?

Assessment Questions

1. The lowest possible temperature is absolute zero, at
   a. 0 on the Kelvin scale and 0 degrees on the Celsius scale.
   b. 0 on the Kelvin scale and -100 degrees on the Celsius scale.
   c. 0 on the Kelvin scale and -273 degrees on the Celsius scale.
   d. 373 on the Kelvin scale and -273 degrees on the Celsius scale.

Assessment Questions

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   a. 0 on the Kelvin scale and 0 degrees on the Celsius scale.
   b. 0 on the Kelvin scale and -100 degrees on the Celsius scale.
   c. 0 on the Kelvin scale and -273 degrees on the Celsius scale.
   d. 373 on the Kelvin scale and -273 degrees on the Celsius scale.

Answer: C

Assessment Questions

2. When heat is added to a system, the amount of heat added can
   a. decrease the temperature, decrease internal energy, and do no external work.
   b. increase the temperature, increase internal energy, and do external work.
   c. increase the temperature, decrease internal energy, and do external work.
   d. decrease the temperature, increase internal energy, and do no external work.

Assessment Questions

2. When heat is added to a system, the amount of heat added can
   - a. decrease the temperature, decrease internal energy, and do no external work.
   - b. increase the temperature, increase internal energy, and do external work.
   - c. increase the temperature, decrease internal energy, and do external work.
   - d. decrease the temperature, increase internal energy, and do no external work.

Answer: B

Assessment Questions

3. When you breathe on your hand, the temperature of the exhaled air reaching your hand

   a. always increases.

   b. always decreases.

   c. remains unchanged.

   d. depends on how you blow.

Assessment Questions

3. When you breathe on your hand, the temperature of the exhaled air reaching your hand
   - a. always increases.
   - b. always decreases.
   - c. remains unchanged.
   - d. depends on how you blow.

Answer: D

Assessment Questions

4. The second law of thermodynamics tells us that heat cannot flow from
   a. hot to cold ever.
   b. cold to hot ever.
   c. hot to cold without external energy.
   d. cold to hot without external energy.

Assessment Questions

4. The second law of thermodynamics tells us that heat cannot flow from
   a. hot to cold ever.
   b. cold to hot ever.
   c. hot to cold without external energy.
   d. cold to hot without external energy.

Answer: D

Assessment Questions

5. Heat engines such as jet engines are more efficient when run at
   - a. high temperatures.
   - b. constant temperatures.
   - c. low temperatures.
   - d. a constant rate.

Assessment Questions

5. Heat engines such as jet engines are more efficient when run at
   a. high temperatures.
   b. constant temperatures.
   c. low temperatures.
   d. a constant rate.

Answer: A

Assessment Questions

6. The direction of natural processes is from states of
   - a. higher order to lower order.
   - b. lower order to higher order.
   - c. disorganization to organization.
   - d. disorder to equilibrium.

Assessment Questions

6. The direction of natural processes is from states of
   a. higher order to lower order.
   b. lower order to higher order.
   c. disorganization to organization.
   d. disorder to equilibrium.

Answer: A

Assessment Questions

7. As entropy in a system increases, energy in the system
   - a. becomes more ordered.
   - b. becomes less ordered.
   - c. reaches equilibrium.
   - d. moves toward destruction.

Assessment Questions

7. As entropy in a system increases, energy in the system
   a. becomes more ordered.
   b. becomes less ordered.
   c. reaches equilibrium.
   d. moves toward destruction.

Answer: B