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Chapter 9 Energy

Summary

THE BIG IDEA **Energy can change from one form to another without a net loss or gain.**

9.1 Work

Work is done when a force acts on an object and the object moves in the direction of the force.

- **Work** is the product of the force on an object and the distance through which the object is moved.
- In the simplest case, when the force is constant, the motion takes place in a straight line in the direction of the force: work = force × distance. In equation form, $W = Fd$.
- Work generally falls into two categories: work done against another force and work done to change the speed of an object. In both categories, work involves a transfer of energy between something and its surroundings.
- The unit of work is the newton-meter (N·m), also called the **joule.** One joule (J) of work is done when a force of 1 N is exerted over a distance of 1 m.

9.2 Power

Power equals the amount of work done divided by the time interval during which the work is done.

- **Power** is the rate at which work is done:

$$\text{power} = \frac{\text{work done}}{\text{time interval}}$$

- A high-power engine does work rapidly. If an engine has twice the power of another engine, this means that it can do twice the work in the same amount of time or the same amount of work in half the time.
- The unit of power is the joule per second, which is also known as the **watt.** One watt (W) of power is expended when one joule of work is done in one second.
- In the United States, we customarily rate engines in units of horsepower and electricity in kilowatts, but either may be used. One horsepower (hp) is the same as 0.75 kW.

9.3 Mechanical Energy

The two forms of mechanical energy are kinetic energy and potential energy.

- The property of an object or system that enables it to do work is **energy.**
- Like work, energy is measured in joules.
- **Mechanical energy** is the energy due to the position of something or the movement of something.

9.4 Potential Energy

Three examples of potential energy are elastic potential energy, chemical energy, and gravitational potential energy.

- Energy that is stored and held in readiness is called **potential energy** (PE) because in the stored state it has the potential for doing work.
- A stretched or compressed spring, a bow that is drawn back, and a stretched rubber band have *elastic potential energy.*
- The chemical energy in fuels is potential energy at the submicroscopic level. This energy is available when a chemical change in the fuels takes place.
- The potential energy due to the elevated position of an object is *gravitational potential energy.*
- The amount of gravitational potential energy possessed by an elevated object is equal to the work done against gravity in lifting it. Gravitational potential energy = weight × height. In equation form, PE = mgh. The height in this equation is the distance above some chosen reference level.

9.5 Kinetic Energy

The kinetic energy of a moving object is equal to the work required to bring it to its speed from rest, or the work the object can do while being brought to rest.

- The energy of motion is **kinetic energy** (KE).
- The kinetic energy of an object is equal to half the object's mass multiplied by the square of its speed. In equation form, this is $\text{KE} = \frac{1}{2}mv^2$.
- The net force on an object multiplied by the distance along which the force acts equals the object's kinetic energy. In equation form, this is $Fd = \frac{1}{2}mv^2$.

9.6 Work-Energy Theorem

The work-energy theorem states that whenever work is done, energy changes.

- The **work-energy theorem** describes the relationship between work and energy.
- Work equals change in kinetic energy. In equation form, Work = ΔKE, where the delta symbol, Δ, means "change in." The work in this equation is the *net* work.
- If you push a box across a floor at a constant speed, you are pushing just hard enough to overcome friction. In this example, the net force and net work are zero, and KE = 0.
- Kinetic energy often appears hidden in different forms of energy. Random molecular motion is sensed as *heat. Sound* consists of molecules vibrating in rhythmic patterns. *Light* energy originates in the motion of electrons in atoms. Electrons in motion make *electric currents.*

9.7 Conservation of Energy

The law of conservation of energy states that energy cannot be created or destroyed. It can be transformed from one form into another, but the total amount of energy never changes.

- The study of the various forms of energy and the transformations from one form into another is the **law of conservation of energy.**
- Everywhere along the path of a pendulum bob, the sum of potential energy and kinetic energy is the same. At the highest points, the energy is only potential energy. At the lowest point, the energy is only kinetic energy.
- The sun shines because some of its nuclear energy is transformed into radiant energy. In nuclear reactors, nuclear energy is transformed into heat.
- Some electric-generating plants transform the energy of falling water into electrical energy. Electrical energy then travels through wires to homes.

9.8 Machines

A machine transfers energy from one place to another or transforms it from one form to another.

- A **machine** is a device used to multiply forces or to change the direction of forces. A machine cannot put out more energy than is put into it.
- A **lever** is a simple machine made of a bar that turns about a fixed point.
- If heat from friction is negligible, the work put into a machine equals the work put out by the machine: work input = work output.
  $(\text{force} \times \text{distance})_{\text{input}} = (\text{force} \times \text{distance})_{\text{output}}$
- The pivot point of a lever is the **fulcrum.**
- The ratio of output force to input force for a machine is called the **mechanical advantage.**
- A type 1 lever has the fulcrum between the input force and the load. If the fulcrum is closer to the load, a small input force exerted through a large distance produces a larger output force over a shorter distance. The directions of input and output are opposite.
- For a type 2 lever, the load is between the fulcrum and the input force. Force is increased at the expense of distance. Input and output forces have the same direction.
- In a type 3 lever, the fulcrum is at one end and the load is at the other. The input force is applied between them. The input and output forces have the same direction.
- A **pulley** is a kind of lever that can be used to change the direction of a force.
- A single pulley with a fixed axis behaves like a type 1 lever. A single pulley with an axis that moves behaves like a type 2 lever.
- A system of pulleys multiplies the force and it may change the direction of the force. The mechanical advantage for a simple pulley system is the same as the number of strands of rope that actually support the load.

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9.9 Efficiency

In any machine, some energy is transformed into atomic or molecular kinetic energy—making the machine warmer.

- The **efficiency** of a machine is the ratio of useful energy output to total energy input, or the percentage of the work input that is converted to work output. No real machine can be 100% efficient. The wasted energy is dissipated as heat.
- An inclined plane is a machine. Its *theoretical* mechanical advantage, assuming negligible friction, is the length of the incline divided by the height of the inclined plane.
- Efficiency can also be expressed as the ratio of actual mechanical advantage to the theoretical mechanical advantage.
- To convert efficiency to percent, express it as a decimal and multiply by 100%.

9.10 Energy for Life

There is more energy stored in the molecules in food than there is in the reaction products after the food is metabolized. This energy difference sustains life.

- Most living organisms on this planet feed on various hydrocarbon compounds that release energy when they react with oxygen. In metabolism of food in the body, carbon combines with oxygen to form carbon dioxide.
- Only green plants and certain one-celled organisms can make carbon dioxide combine with water to produce hydrocarbon compounds such as sugar. This process is called *photosynthesis* and requires an energy input, which normally comes from sunlight.

9.11 Sources of Energy

The sun is the source of practically all our energy on Earth.

- Sunlight is directly transformed into electricity by photovoltaic cells or in the flexible solar shingles on the roofs of buildings. We use the energy in sunlight to generate electricity indirectly as well.
- Wind, caused by unequal warming of Earth's surface, is another form of solar power. Wind can be used to turn generator turbines within specially equipped windmills.
- Hydrogen is the least polluting of all fuels. Because it takes energy to make hydrogen (to extract it from water and carbon compounds), it is not a *source* of energy. In a **fuel cell,** hydrogen and oxygen gas are compressed at electrodes to produce water and electric current.
- The most concentrated form of usable energy is stored in nuclear fuels.
- Earth's interior is kept hot by producing a form of nuclear power, radioactivity.
- Geothermal energy is held in underground reservoirs of hot water.