Chapter 5: Work, Energy, and Power

Work

What is work?
The word *work* means many different things and can be used in many different ways.

In physics, work is force times distance

If you push a box with a force of one newton for a distance of one meter, you have done exactly one joule of work.

To be exact, work is force times the distance moved in the direction of the force.
A force at an angle (figure 5.2) is not as effective at doing work.

When we apply force to machines we are doing work.
Ex: When a block and tackle machine lifts a heavy weight, force is applied
As a result of the force, the weight moves a distance and work has been done

Work done by a machine
In physics, work is done *by* forces.
Work is done *on* objects.
Ex: If you push a block one meter with a force of one newton, you have done one joule of work *on the block*.
The unit of measurement for work is the joule.
One joule is equal to one newton of force times one meter of distance.
Joules are a combination unit made of force (newtons) and distance (meters).
We want to analyze machines in terms of work input and work output.

Ex: Consider using the block and tackle machine to lift a load weighing 10 newtons. Suppose you lift the load a distance of 1/2 meter. Your machine has done five joules of work on the load (figure 5.4) so the work output is five joules.
What about the work input? You pulled on the string with a force of only five newtons because your machine gave you an advantage of two. But you had to pull the string twice as far as you lifted the block. The weight moved up 1/2 meter, but you pulled one whole meter of string. The work input is the force you apply times the distance you pulled the string. This is five newtons times one meter, or five joules.

The work output of a simple machine can never exceed the work input.
When you design a machine that multiplies force, you pay by having to apply the force over a greater distance.

Efficiency
In a very efficient machine, all (or most) of the work input becomes work output.
An engineer would say the block and tackle machine in the previous example was 100 percent efficient, because all 5 joules of the input work became 5 joules of output work and none was lost.
In real machines, the work output is always less than the work input.
Other forces, like friction, use up some of the input work before it reaches the output of the machine.

Ex: When a wheel turning on an axle gets hot, it means some of the input work is being converted to heat.
The efficiency of a machine is the ratio of work output to work input.
Efficiency is usually expressed in percent.

You calculate efficiency by dividing the work output by the work input; then you can convert the ratio into a percent by multiplying by 100.
Ex:
The ideal machine would be 100 percent efficient.

Power

It makes a difference how fast you do work.
The rate at which work is done is called power.
You can determine the power of a machine by dividing the amount of work done by the time it takes in seconds.

A more powerful machine does the same amount of work in less time than a less powerful machine.
The unit of power is called the watt, named after James Watt.
One watt is equal to one joule of work done in one second.
Another unit of power commonly used is the horsepower, which is equal to 746

watts.

Energy Conservation

What is energy?
Energy is the ability to do work.
Anything with energy can produce a force that is capable of acting over a distance. The force can be any force, and it can come from many different sources, such as your hand, the wind, or a spring.

Energy is measured in joules, the same units as work, because energy is really stored work.
Any object with energy has the ability to use its energy to do work, which means creating a force that acts over a distance.

Potential energy

Potential energy comes from the position of an object relative to the Earth.
Ex: Consider a marble that is lifted off the table. Since the Earth's gravity pulls the marble down, we must apply a force to lift it up. Applying a force over a distance requires doing work, which gets stored as the potential energy of the marble.

It takes work to lift the marble up. Energy is stored work, so the amount of energy must be the same as the amount of work done to lift the marble up.
The force required to lift the marble is the weight of the marble.
From Newton's second law we know that the weight (the force) is equal to mass of the marble (m, in kilograms) times the acceleration of gravity (g, equal to 9.8 m/sec^2).

We also know that work is equal to force times distance.

Since force is the weight of the marble (mg) and the distance is how far we lift the marble (h), the work done equals weight times height.

Objects that have potential energy don't use their energy until they move.
Potential means that something is capable of becoming active.
Any object that can move to a lower place has the potential to do work on the way down
Ex: Ball rolling down a hill

Kinetic Energy

Objects also store energy in motion.
Energy of motion is called kinetic energy.

We need to know how much kinetic energy a moving object has.
Ex: Consider a shopping cart moving with a speed v. To make the cart move faster you need to apply a force to it. Applying a force means you do some work, which is stored as energy. The higher the speed of the cart, the more energy it has because you have to do work to increase the speed.
If you give the cart more mass, you have to push it with more force to reach the same speed.

Increasing the mass increases the amount of work you have to do to get the cart moving, so it also increases the energy.
Kinetic energy depends on two things: mass and speed.
The energy is equal to the amount of work you have to do to get a mass (m) from rest up to speed (v).

The kinetic energy increases as the square of the speed.
This means if you go twice as fast, your energy increases by four times ($2^2 = 4$).
More energy means more force is needed to stop, which is why driving fast is so dangerous.

Conservation of energy

Nature never creates or destroys energy; energy only gets converted from one form to another. This concept is called the law of conservation of energy.

An example of energy transformation:

The ball leaves your hand with kinetic energy from the speed you give it when you let go. As the ball goes higher, it gains potential energy. The potential energy gained can only come from the kinetic energy the ball had at the start, so the ball slows down as it gets higher.
Eventually, all the kinetic energy has been converted to potential energy. At this point the ball has reached as high as it will go and its upward speed has been reduced to zero.
The ball falls back down again and gets faster and faster as it gets closer to the ground. The gain in speed comes from the potential energy being converted back

to kinetic energy. If there were no friction the ball would return to your hand with exactly the same speed it started with—except in the opposite direction.

At any moment in its flight, the ball has exactly the same energy it had at the start. The energy is divided between potential and kinetic, but the total is unchanged. The law of conservation of energy still holds true, even when there is friction. The energy converted to heat or wear is no longer available to be potential energy or kinetic energy, but it was not destroyed.

5.3 NOTES

Energy Transformation

Following an energy transformation
Sometimes kinetic and potential energy are called mechanical energy because they involve moving things.
There are many other kinds of energy, including *radiant energy, electrical energy, chemical energy* and *nuclear energy*.
Any of these forms of energy can be transformed into each other and back again.

An example of energy transformation:
ENERGY FLOW CHART

Mechanical energy is the energy possessed by an object due to its *motion* or its stored energy of *position*.

Mechanical energy can be either kinetic (energy of motion) or potential (energy of position).
An object that possesses mechanical energy is able to do work.

Mechanical energy is the form involved in the operation of the simple machines.

Radiant (meaning light) energy is also known as electromagnetic energy.

Light is made up of waves called electromagnetic waves
There are many different types of electromagnetic waves, including the light we see, ultraviolet light, X rays, infrared radiation (also known as heat), radio waves, microwaves, and radar.

Radiant heat from the sun is what keeps the Earth warm.

The sun's energy falls on the Earth at a rate of about 1,400 watts for each square meter of surface area.
Not all of this energy reaches the Earth's surface though; even on a clear day, about one-fourth of the energy is absorbed by the Earth's atmosphere.
When we harness the radiant energy from the sun, it is called solar power.

Electrical energy is something we take for granted whenever we plug an appliance into an outlet.
The electrical energy we use in our daily lives is actually derived from other sources of energy.
In a natural gas power plant the energy starts as chemical energy in the gas. The gas is burned, releasing heat energy, which is then used to make high-pressure steam. The steam turns a turbine which transforms the heat energy to mechanical energy. Finally, the turbine turns an electric generator, producing electrical energy.

Chemical energy is the type of energy stored in molecules.
Chemical reactions can either use or release chemical energy.
One example of chemical energy is a battery.
Your body also uses chemical energy when it converts food into energy so that you can walk or run or think.
All the fossil fuels we depend on (coal, oil, gas) are useful because they contain chemical energy we can easily release.

Nuclear energy comes from splitting an atom, or fusing two atoms together.
When an atom is split or fused, a huge amount of energy is released.
Nuclear energy is used to generate or make electricity in power plants.
Nuclear energy is really the basic source for all other energy forms because it is how the sun and stars make energy.
Nuclear energy is also used in medicine to treat cancer and other diseases
Heat is a form of thermal energy.
Heating contractors measure heat using the British thermal unit (Btu).
One Btu is the same amount of energy as 1,055 joule