Chapter 4 Energy

Learning outcomes

1) familiar with energy, types of energy
2) understanding work and relationship between work and energy
3) understanding mechanic energy, kinetic energy and potential energy
4) Understanding the energy conservation law

Essential Vocabulary (5 – 10 essential vocabulary) (highlighted or bolded)

Introduction of Energy

In human history, there are 3 stages of exploiting energy. In the ancient times before 1860s, humans used firewood as their main source of energy, supplemented by wind and water power. And then in the 1870s after the invention of Watt's steam engine, coal period started as coal began to be mined on a large scale and became the world's main energy source. Until the middle of the 20th century, humans still relied on coal as their main source of energy. In 1965, fossil fuels replaced coal in the first place for the first time, and the world entered the "petroleum age". From the mid-20th century to the present, humans have relied on petroleum as their main source of energy.

Energy will neither be created from thin air nor be destroyed into nothing. It can only be converted from one form to another form, or transferred from one object to another object. During the process of transformation or transfer, its total amount remains conserved.

There are different forms of energy in nature corresponding to different forms: the movement of objects has mechanical energy, the movement of molecules has internal energy, the movement of charges has electrical energy, the movement within atomic nuclei has atomic energy, etc. Different forms of energy can be converted into each other: "Frictional heat generation is the conversion of mechanical energy into internal energy by overcoming friction and doing work; when the water in the kettle boils, the water vapor does work on the lid and lifts the lid, indicating that the internal energy is converted into mechanical energy; electric current can convert electrical energy into internal energy by doing work through the electric heating wire, etc." These examples illustrate that different forms of energy can be converted into each other, and this conversion process is completed through work.

When a certain form of energy decreases, there must be another form of energy increase, and the amount of decrease and the amount of increase must be equal. When the energy of a certain object decreases, there must be an increase in the energy of other objects, and the amount of decrease and the amount of increase must be equal.

4.1 What is energy? How many types of energy are there? What are the properties of energy?

Virtually all human activities require energy. For example, the electric energy supplied by power plants is essential to modern life. Many modern transportations need the chemical energy released by fuel combustion. Nuclear power plants release the nuclear energy when atomic nuclei fission. Human intakes food to produce chemical energy. The growth of plants is relying on solar power…

Energy is one of fundamental measurements of matter, manifested in many forms, but they can be converted into each other. Energy appears in different movements in various forms such as mechanical energy, internal energy, electrical energy, chemical energy, etc., and is converted through work, heat transfer, etc. The units of energy are joules, ergs, kilowatt hours, electron volts, etc.

The word energy was introduced by T. Young when he lectured on natural philosophy at King's College London in 1801. In the view that the product of the square of mass and velocity was called vitality or lifting force, he proposed to use the word “energy” to express the above product as appropriate and related to the work done by the object. However, it has not been taken seriously. People still believe that different movements contain different forces. It was not until the law of conservation of energy was confirmed that the importance of the concept of energy was realized.

Energy is a quantity in physics that describes a system or a process. The energy of a system can be defined as the sum of the work required to convert the system from a defined state of zero energy to the current state of the system. How much energy a system has is not a definite value in physics. It changes with the description of the system. In the process of human life activities, all life activities require energy, such as synthetic reactions of material metabolism, muscle contraction, gland secretion, etc. And these energies mainly come from food. Nutrients contained in animal and plant foods can be divided into five categories: carbohydrates, lipids, proteins, minerals and vitamins. Water can be categorized as the 6th. Among them, carbohydrates, fats and proteins can release energy when oxidized in the body. The three are collectively called "energy-producing nutrients" or "pyrogen".

Energy exists objectively, and everything in nature has its manifestation. Just like matter, there is antimatter; energy also has relative anti-energy. When they meet, the system returns to calm, and there is nothing left, it ceases to exist.

What is energy? In physics, energy is defined as the ability to do work. Energy can be transferred to a body or a physical system, through work or in the form of heat and light. The total amount of energy is conserved—the law of conservation of energy states that energy can be converted in form, but not created or destroyed.

Since the discovery of fire in ancient times, human beings have ended eating raw foods, and have learned to take advantages of all available energy. Another milestone is the invention of the steam engine by James Watt which was the embodiment of the industrial revolution. With the help of multiple inventors, Watt created the most successful and efficient steam engine of its time, which revolutionize the technologies because Watt's steam engine laid the groundwork for the modern world and may go down as one of the most significant technological discoveries to ever be made. The means to exploit energy-dense fossil fuels was given, which changed the world with an era of renewable energy.

Nowadays, coals, charcoal, petroleum, natural gases resulted from organisms buried for over millions of years under high pressure and high temperature. The remains of these organisms were transformed into what we know today as fossil fuels. They are exhaustible and over a short amount of time, it would be very hard to replenish. Burning these fossil fuels, often called dirty energy, impacts our carbon footprint and results in increased pollution levels. Wind turbine, hydropower, solar energy, geothermal energy and nuclear energy are renewable energy as they are inexhaustible, clean and easily to replenish, which become more popular when more and more people become concerned about the climate change caused by the "greenhouse gases".

Tremendous efforts have been devoted to more effectively and more efficiently utilize those renewable energies to alleviate the reliance on the traditional energy, and reduce the release of greenhouse gases.

Energy can be categorized into six basic forms: chemical, electrical, radiant, mechanical, thermal and nuclear. More broadly speaking, you may find additional forms mentioned such as electrochemical, sound, electromagnetic and others. Also, energy call be classified into kinetic energy, potential energy, thermal energy, current energy, electrical potential energy, mechanical energy, radiation energy, light energy, chemical energy, atomic energy, and gravitational potential energy.

4.2 What is work? How are work and energy related? What is power? The unit?

In long-term scientific practice, people have discovered that different forms of energy can be converted into each other, and the conversion of energy is closely related to the concept of work because if there is a certain amount of work being done in a process, there must be a change in energy. The calculation of work can provide an analytical basis for the quantitative expression of the change of energy.

When a crane lifts a heavy object vertically, the direction of movement of the weight is consistent with the direction of the force, and the work done by the force on the object is the product of the magnitude of the force and the distance the weight moves as shown in Figure 4.1.

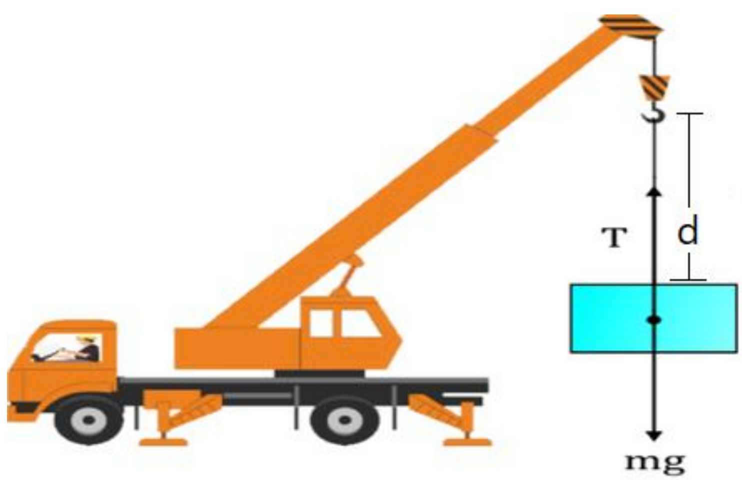

Figure 4.1 A crane conducts work through lifting a block. Adapted from https://quora.com.

A more common situation is that the direction of the object's motion is inconsistent with the direction of the force. For example, when pulling a sled, there is an angle between the direction of the pulling force and the direction of the sled's motion. How should work be calculated in this cae? Mechanical work is a physical quantity that represents the accumulation of force against displacement. It refers to the transformation of energy from one physical system to another, especially the transformation of energy under the action of a force that moves an object in the direction of the force. Like mechanical energy, work is a scalar quantity and its SI unit is the joule. Energy is the ability to do work. Energy is like stored work. When an object does work, it loses energy; When work is done on an object, it gains energy.

In our daily life, day to day the work we think about is like a job or tasks you complete in a certain amount of time. However, in science, the definition of work is very different from the one in day to day life. In physics, **work is defined as the product of the force applied on an object and the distance occurring parallel to the force direction, or a distance as a result of the force.**

$$w = f * d$$

The unit of work is Joule, with 1 Joule(J)=1N*m. It is worth noting that the distance must be parallel to the force direction, which could be as the same as the force direction or the opposite to the force direction.

If a force acts on an object and the object moves a certain distance in or opposite to the direction of the force, work is performed by the force. In order to perform work, the applied force must be not zero; at the same time, there must be a distance which either is along the force direction or against the force direction. If the force on the object is parallel to the direction in which the object is moving, the force will do work on the object. If they are in the same direction, they will do positive work, and if they are in the opposite direction, they will do negative work. When a force is either along or opposite to the direction of a distance, or no distance occurring, no work would be performed. For instance, an example of zero work being done is when a paper clip that holds a stack of paper. The paper clip exerts a force on the stack of paper but, due to the zero-distance, the paper clip performs zero work on the paper. Even if a force is present, no work may be done.

Another example, in uniform circular motion, the centripetal force does no work because the kinetic energy of the object in circular motion does not change. Similarly, a book on the table, although the table has support for the book, does no work because there is no displacement/distance. Another case is that a waiter applying upward force to hold a tray with foods for guests, moves a horizontal distance so as to deliver the foods to the table as shown in Figure 4.2. Since the upward force is perpendicular to the horizontal distance, this waiter does not do any work in physics although he must be super exhausted at the end of his work day. The good news is that he could get paid although he does not conduct any work, as least scientifically.

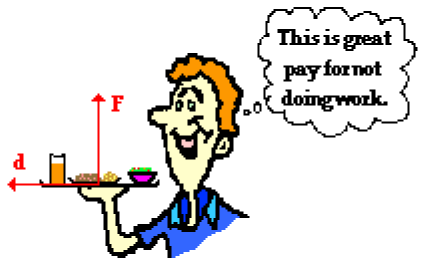

Figure 4.2 in physics, a waiter does not do any work but gets paid. Adapted from: https://www.physicsclassroom.com/class/energy/Lesson-1/Definition-and-Mathematics-of-Work.

Example: as shown in Figure 4.3, if you pick up a 20 kg box and put it on a 1.0-meter shelf. How much work you have to perform in the process?

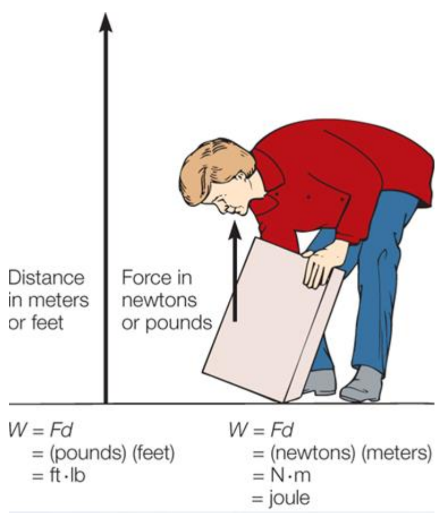

Figure 4.3 lifting force performs work, adapted from McGraw hill publishing company.

Analysis: in order to lift a box off the ground, the minimum lifting force should overcome the box's weight. So

the lift force f =m*g=20*9.81=196.2N

then the lift force is upward, and a distance is upward which is 1.0 meter.

Therefore, $w = f * d = 196.2 * 1 = \boxed{196.2\, Joules}$

Example: a book with 1.0kg on a book shelf with 1.0 m high, falls to the floor, how much work does the gravity perform on the book?

Analysis: when a book is falling to the floor, it only experiences a gravity, which is its weight. And the distance is downward and along the gravity direction. Therefore:

$$w = f * d = w * d = 1.0 * 9.81 * 1 = \boxed{9.81\, Joules}$$

Power:

What is power? Power is a physical quantity that describes how quickly work is done. Power refers to the work done by force per unit time. Power is defined as the rate at which the work is performed or how fast (or slow) the work is conducted. Mathematically,

$$p = \frac{w}{t}$$

In which w is the amount of work, and t is the time. The unit of power is watts;

1 Watt=1 Joule/s.

or 1 horsepower=746 watts.

The watts are often used to describe light bulbs. It indicates the rate at which the light bulb converts electrical energy into light and heat. A bulb with a higher wattage will consume more electricity per unit of time, thus providing more heat or light.

Horsepower is often used to refer to the power generated by a machine. The power required to lift 550 pounds by one foot in one second is about 746 watts. Horsepower is a unit of power in the British system of measurement.

Example: An electric lift can raise a 50.0kg mass a distance of 10.0 m in 5.0 s. what is the power of this lift?

Analysis: according to the equation of power, $p = \frac{w}{t}$, we must find work first. Well, when a lift raises an object,

$$w = m * g * d = 50 * 9.81 * 10 = 4905\,Joules$$

While

$$p = \frac{w}{t} = \frac{4905}{5} = \boxed{981\ watts}$$

Another form of the power can be derived as:

$$w = f * d$$

$$p = \frac{w}{t} = \frac{f * d}{t} = f * \frac{d}{t}$$

We learned that $v = \frac{d}{t}$, therefore,

$$p = f * v$$

Example: An engine of a car engine could provide a driving force of 1200 N. if the car is traveling 20 m in 1 second, what power is generated?

Analysis:

According to the new form of power,

$$p = f * v$$

$$v = \frac{d}{t} = \frac{20m}{1second} = 20\frac{m}{s}$$

Then $$p = f * v = 1200 * 20 = \frac{24000Joule}{second}$$

$$= 24000\,watts = 32.17\,horsepower$$

4.3 **Potential Energy**

Understanding gravitational potential energy is closely correlated to the study of work done by gravity. When the height of an object changes, gravity does work and the potential energy changes; while when the object falls, gravity does positive work and the potential energy decreases; when the object is lifted, gravity does negative work, potential energy increases and when object falls, gravity performs positive work and the potential energy decreases. Therefore, gravitational potential energy is closely related to the work done by gravity,

Assume an object with mass of m, from a position A with a height h_1 from the ground as shown in Figure 4.4(a), moves vertically downward to position B with a height of h_2. During this process, the work done by gravity:

$$W = m * g * \Delta h = m * g * (h_1\text{-}h_2)$$

Now let's look at another situation as shown in Figure 4.4(b). An object with mass m still moves from top to bottom. The height is dropped from h_1 to h_2, but it does not move along the vertical direction, but moves downward along a slope to B′, and then moves horizontally to B (The distance that the object moves along the inclined slope is l), and the work done by gravity during this process is

$$W = \underline{m * g * l * \cos(\theta)}$$

$$\underline{= m * g * \Delta h}$$

$$= m * g * (h_1\text{-}h_2)$$

During the horizontal motion from B′ to B, gravity does no work as the distance does not be parallel to the gravity direction. In the above two cases, although the paths of object motion are different, the height of the change is the same, then the work done by gravity is also the same.

Analysis shows that when an object moves, the work done by gravity on it is only proportional to the height of its beginning point relative to the position of the end point, but not to the path of the object's movement. In other words, as long as the positions of the starting point and the end point remain unchanged, no matter what path the object moves along, the work done by gravity is the same. Work is equal to the product of gravitational force on the object and the height difference between the starting point and the end point.

The significance of m*g*h is that it is closely related to the work done by gravity and it is consistent with the characteristics of gravitational potential energy.

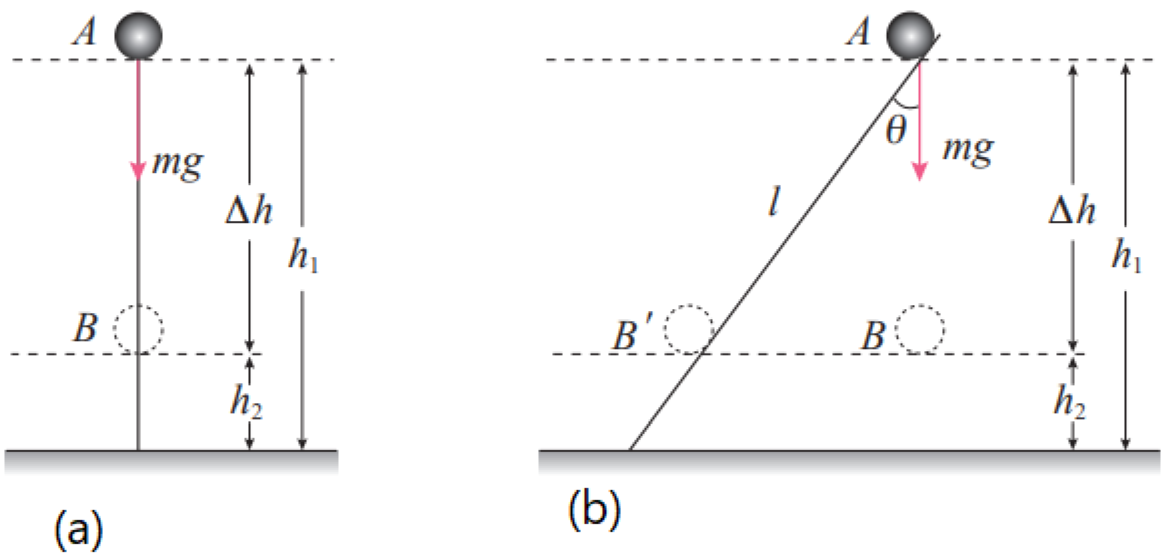

Figure 4.4 Gravity performs the same amount work in different situations in(a) and (b). Adapted from *https://www.physicsforums.com/threads/confused-with-inclined-plane-and-work-done-by-gravity.875845/*

The gravitational potential energy is one type of energy associated with an object’s position. It is defined as a product of gravity and height of an object. Mathematically,

P.E.=m*g*h,

in which m is the mass of an object, g is the gravitational acceleration of Earth of 9.81 m/s^2 and h is an object's height.

The unit of P.E. is still in Joules as $P.E. = m * g * h = kg * \frac{m}{s^2} * m = N * m = Joules$

Example: What is the potential energy of a 20 kg box and put it on a 1.0-meter shelf above the floor?

According to the definition of gravitational potential energy:

$$P.E. = m * g * h = 20 * 9.81 * 1$$

$$= \boxed{196.2\, Joules}$$

Now the connection between this example and work example should be made. Now recall the example we did if a box is on the floor and being lifted to 1.0m shelf, how much work is required to be done? The work needed is $196.2\, Joules$, which is exactly the same as the gravitational potential energy of this box!!! In both examples, it can be clearly seen that the work could change energy level of an object. If you lift up a box and put on a 1 .0-meter shelf, the amount of work you have to perform is equal to the potential energy change, which also explains why the work and energy share the same units.

The gravitational potential energy of an object is always relative to a certain horizontal plane because the height of an object is a relative term. If we select a horizontal place as the reference plane. On this horizontal plane, the gravitational potential energy of the object is 0 because 0 height of the object. If the height of the object above the selected reference plane is a positive value, the gravitational potential energy is also positive; if the height of the object below the selected reference plane is negative, and so is gravitational potential energy. Negative gravitational potential energy represents the location of the object is below the reference level.

Another example is that if we choose the ground on the second floor as the reference plane, the object in the room on the second floor has a positive gravitational potential energy, while any objects in the room on the first floor must have negative gravitational potential energy.

Commonly, the see level is chosen as the reference level. If you choose different reference planes, the values of the object's gravitational potential energy would be different which do not affect how to solve the problems on gravitational potential energy.

4.4 **Elastic Potential Energy**

When objects undergo elastic interactions, they demonstrate elastic deformation. For instance, Like a spring is stretched or compressed; a bow is drawn or struck; or a tennis racket with a ball. Due to the elastic interaction, there is potential energy. This potential energy is called elastic potential energy. Elastic potential energy is related to the magnitude of deformation. For example, within elastic limits, the elastic potential energy of a spring is related to the length by which the spring is stretched or compressed. Or the longer the compression length, the more external work is done in the process of restoring to its original state, then the spring has the greater elastic potential energy. In addition, the elastic potential energy of the spring is also related to the stiffness coefficient. Different springs with different stiffness undergo the same amount of deformation, requiring different external work. The larger the coefficient, the more external work is done by the spring when it returns to its original shape, so the elastic potential energy of the spring is greater.
Gravitational potential energy is determined by the relative positions of the earth and objects on the ground.

Elastic Potential energy is determined by the relative positions of parts of an object undergoing elastic deformation.

4.5 **Kinetic Energy**

The kinetic energy of an object depends on its mass and speed. The greater the mass of an object, the greater its speed, and it has greater kinetic energy. For instance, Under the action of the thrust in the barrel, the cannonball's speed increases, then the kinetic energy increases.

Kinetic energy is one type of energy associated with motion. Kinetic energy is defined as half times mass times the square of speed. Mathematically,

$$K.E. = \frac{1}{2} * m * v^2$$

In which m represents the mass; v is the speed of an object.

Based upon the dimensional analysis, the unit of K.E. is still in joules.

$$K.E. = kg * \left(\frac{m}{s}\right)^2 = kg * \frac{m}{s^2} * m = N * m = Joules$$

In order to have non-zero kinetic energy, the object must be moving. For a stationary object, it has 0 kinetic energy.

Example, a bike and its rider have a mass of 100 kg, moving with a speed of 3 meter/ second. What is their kinetic energy?

Given $m = 100kg, and\ v = 3\frac{m}{s}$

Then plug into the equation

$$K.E. = \frac{1}{2} * 100 * 3^2 = \boxed{450\ Joules}$$

Example: A car of 36000 kg moves with 10m/s and doubles its velocity in 10.0 second and in 150 meters distance. Find the final kinetic energy? Find how much work needed?

Analysis: the initial speed is $v_1 = 10\frac{m}{s}$; then doubles its velocity with $v_2 = 20\frac{m}{s}$. The mass m=36000kg,

Then $K.E._{final} = \frac{1}{2} * m * {v_2}^2 = \frac{1}{2} * 36000 * 20^2 = \boxed{7,200,000\ Joules}$

The initial $K.E. = \frac{1}{2} * m * {v_1}^2 = \frac{1}{2} * 36000 * 10^2 = \boxed{1800000\ Joules}$

Then the work done on this car is:

$$\Delta K.E. = K.E._2 - K.E._1 = 5400000\, Joules$$

Or other way to find the work;

In order to find the work, the force has to be found.

Given $v_1 = 10\frac{m}{s}$ and $v_2 = 20\frac{m}{s}$, along with t=10.second,

Acceleration $a = \frac{v_2 - v_1}{t} = \frac{20-10}{10} = 1.0\frac{m}{s^2}$;

According to Newton's second law:

$$f = m * a = 36000 * 1.0 = 36000N.$$

Then the distance d=150 m,

Therefore, the work is done:

$$w = f * d = 36000 * 150 = \boxed{5400000 \text{ Joules}}$$

From this example, we could learn that the change in kinetic energy is cause by the work done on the system---which is called the kinetic energy theorem. The difference in Kinetic energy is exactly equal to the work done by the force on the object.

4.6 **Mechanic Energy and Conservation of Energy**

When an object slides down a smooth slope, gravity does positive work on the object. Gravitational potential energy decreases. Where does the reduced gravitational potential energy go? We found that during this process, the speed of the object increases, indicating that the object's kinetic energy increases. This shows that the lost gravitational potential energy of the object is converted into kinetic energy gained. Another example is that an object with a certain speed rises along a smooth slope due to inertia, in which gravity does negative work on the object, and the object's speed decreases, which means the object's kinetic energy decreases. But as the object's height increases, its gravitational potential energy increases, which exhibits that the kinetic energy of the object is converted into gravitational potential energy. Similarly, in the case of throwing an object vertically upward, as the height of the object increases, its speed will decrease; when the object reaches the highest point, it will turn downward, and at the same time the speed gradually increases. During the process kinetic energy and gravitational potential energy can be converted into each other.

Not only can gravitational potential energy be converted into kinetic energy, but also elastic potential energy can also be converted into kinetic energy. For example, a compressed spring has elastic potential energy. When the spring returns to its original shape, it pushes out the objects in contact with it. During this process, when the elastic force does positive work, the elastic potential energy of the spring decreases, and the object 's kinetic energy increases while it gains a certain speed. Another example, when an athlete bounces off a springboard, the bounce of the springboard converts potential energy into the athlete's kinetic energy.

Gravitational potential energy, elastic potential energy and kinetic energy are all in mechanical energy forms. Therefore, **Gravitational potential energy, elastic potential energy and kinetic energy collectively are called mechanical energy**. To do work, mechanical energy can be converted from one form to another.

Is there some quantitative relationship between the mutual conversion of kinetic energy and potential energy?

Here We discuss the situation where an object slides down a smooth curved surface to illustrate the mutual conversion of kinetic energy and gravitational potential energy as shown in Figure 4.5.

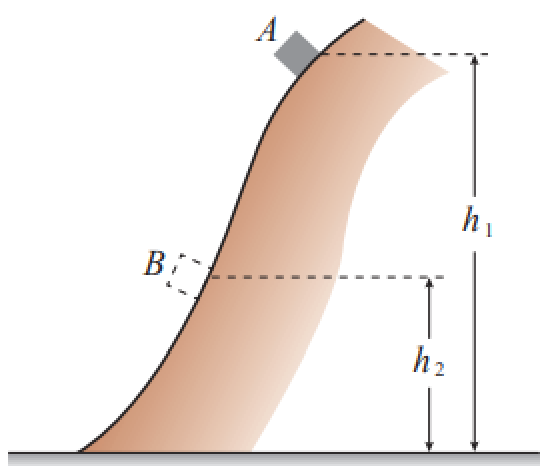

Figure 4.5 The conversion of potential energy into kinetic energy. Adapted from https://www.fire2fusion.com/kinetic-energy/potential-and-kinetic-energy.html

In Figure 4.5, the object is affected by gravity and surface support forces. as the direction of the support force is related to the motion and the direction of motion is vertical, the supporting force does no work, so only gravity does work. Assuming the height of the object at A with h_1 and its speed at this time is v_1. After a period of time, the object falls to B position with a heighth_2 and and its speed at this time is v_1. Then w represents the work done by gravity during the process. From the kinetic energy theorem, we know that the work done by gravity on an object is equal to the increase in the kinetic energy of the object, that is

$$w = m * g * (h_1 - h_2)$$

Also

$$\Delta K.E. = \frac{1}{2} m * {v_2}^2 - \frac{1}{2} m * {v_1}^2$$

Combine with what we know, $w = \Delta K.E.$

Then

$$m * g * (h_1 - h_2) = \frac{1}{2} m * {v_2}^2 - \frac{1}{2} m * {v_1}^2$$

After rearranging the terms:

$$m * g * h_1 + \frac{1}{2} m * {v_1}^2 = m * g * h_2 + \frac{1}{2} m * {v_2}^2 \text{ (1)}$$

$$m * g * h_1 + \frac{1}{2} m * {v_1}^2 = M.E.\text{(initial)}$$

$$m * g * h_2 + \frac{1}{2} m * {v_2}^2 = M.E.\text{(final)}$$

The left side of the equation (1) is the sum of the initial state kinetic energy and potential energy of the object, and the right side of the equation (1) is the sum of kinetic energy and potential energy in the initial state of an object. It can be seen that in a system where only gravity does work, the total mechanical energy remains unchanged with kinetic energy being converted into gravitational potential energy, or vice versa.

.

It can also be proved that in a system in which only elastic force does work, the kinetic energy and elastic potential energy can be converted into each other, the total mechanical energy remains unchanged.

In a system where, gravitational force or elastic force does work, kinetic energy and potential energy can be converted into each other, the total mechanical energy remains unchanged. This is called mechanical energy conservation. **The total mechanical energy remains unchanged which is also called the law of conservation of mechanical energy (law of conservation of mechanical energy).** It is an important universal law in classical mechanics.

For instance, when the skier slides down the slope, the support force of the slope and the direction of movement vertically, no work is done; if the work done by the resistance is less and can be ignored, then only gravity does the work. In this case, kinetic energy and gravitational potential energy can be converted into each other, the total mechanical energy is conserved. If the work done by the resistance is large and cannot be ignored, then the mechanical energy is not conserved. Mechanical energy is the sum of kinetic and potential energy. The principle of conservation of mechanical energy states that if an isolated system is subject only to conservative forces, then the mechanical energy is constant. Conservative forces are gravitational forces, electric forces and magnetic forces. One of non-conservative forces is friction, which is a dissipated force causing the mechanical energy to convert into heat or other forms to lose.

Example: A 1.0kg book falls from a height of 1.0m, what is its velocity just as it hits the floor assuming there is no air resistance?

Analysis: if a system is only under the influence of gravity or elastic forces, the mechanic energy is conserved.

$$\text{Then } M.E.(initial) = M.E.(Final)$$

$$m * g * h_{initial} + \frac{1}{2} * m * {v_{initial}}^2 = m * g * h_{final} + \frac{1}{2} * m * {v_{final}}^2$$

Then $h_{initial} = 1.0\ m$ and $v_{initial} = 0$, and $h_{final} = 0, and\ v_{final} =?$

$$\text{Then:} \quad 1.0*9.81*1.0+0=0+\frac{1}{2}*1.0*{v_{final}}^2$$

$$\text{Then } {v_{final}}^2 = 19.62$$

$$\text{Then } v_{final} = \sqrt{19.62} \cong \boxed{4.43\frac{m}{s}}$$

Another typical example is a pendulum for the conversion of potential energy and kinetic energy. When the resistance is negligible, the ball hung by a thin wire swings under the pull of gravity. The tension on the string is perpendicular to the direction of the ball's motion and does no work, so only gravity does work in this process, and mechanical energy is conserved. The ball only has gravitational potential energy and 0 kinetic energy at the highest point. The difference between the gravitational potential energy at the highest point and the lowest point, according to the conservation of mechanical energy, we can get its kinetic energy at the lowest point, and thus calculate its kinetic energy at the lowest point, thus figuring out its speed at the lowest point.

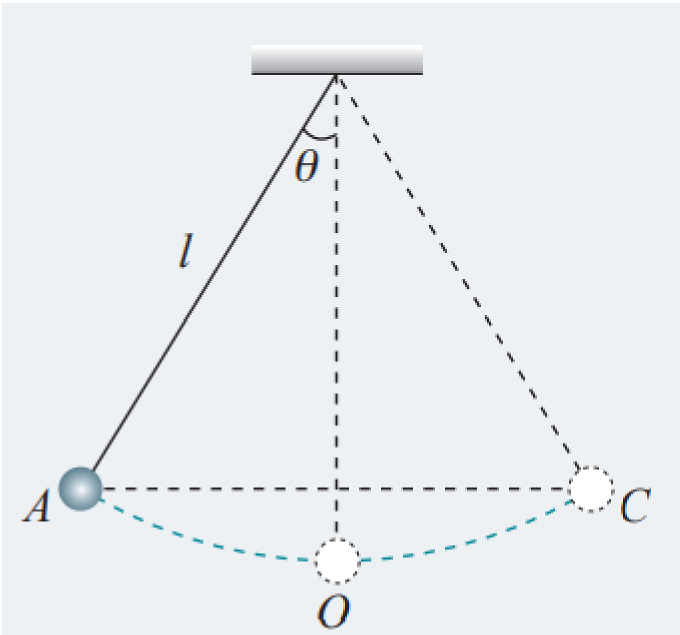

Figure 4.6 A pendulum demonstrates the conversion of potential energy and kinetic energy

4.6 **Mechanical Advantage**

From ancient times, human beings already knew to take advantage of simple lever by utilizing mechanical energy. Machines make our work easier by magnifying the effect of the force applied through a machine. A machine is “a device for multiplying forces or simply changing the direction of forces.” A machine, such as a see saw, changes direction by allowing one person to push down on one end, this making the other end go up. The downward movement equals the upward movement (conservation of energy). This means the work put into a system is equal to the output work.

By leveraging the energy conservation theorem of the fact that

$$F_{input} * d_{input} = F_{output} * d_{output}$$

the relatively longer D_{input} would require the smaller amount of F_{input} to lift the heavy object off the ground as shown in Figure 4.7.

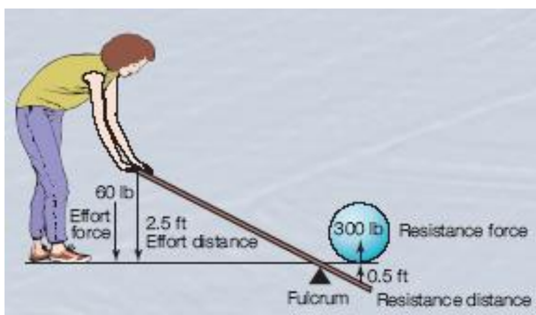

Figure 4.7 taking advantage of lever to lift off the heavy object. Adapted from: https://www.khanacademy.org/science/physics/work-and-energy/mechanical-advantage/v/introduction-to-mechanical-advantage

Many tools utilize the principle of leverage in our daily lives. A lot of lever principles and science knowledge are applied in manufacturing bicycles’ structure and use. Bicycles do not consume electricity and fuels like trains and cars, but take advantage of a simple combination of machinery and the principle of mechanical balance. The axle device is composed of a large and small flywheel like a foot pedal and a rear wheel. It is more laborious to apply forces to the axle. Only when the force is applied to the wheel that can save effort. The design of handlebar is a labor-saving lever when turning. The brake is also a lever that saves effort.

Machines make completing work easier by multiplying the forces of the machine, not by multiplying the work or the energy. Mathematically, the expression is

$$Work_{input} = Work_{output}$$

By inserting the formula for work (F*d), this means

$$F_{input} * d_{input} = F_{output} * d_{output}$$

If you increase distance on the input side and decrease force the output will be impacted as well.

We consider those machines to be more efficient as others. We used to move objects by hooking horses up to a wagon and letting them pull the wagon. When we made engines that did the same amount of work, we had six horsepower of energy; however, the engine was more efficient than six horses. Efficiency compares the work done compared to the energy used.

$$Efficiency = \frac{(work\ done)}{(energy\ used)}$$

Although the lever structure is common in daily life and in many machines for labor-saving, its effect is limited and cannot significantly improve efficiency, so it cannot play a greater role in saving energy.

Summary

By understanding energy, you can compare and contrast the types of energy. Potential energy is impacted by changes in position, while the velocity of the object impacts kinetic energy. The mass of the object can impact either potential or kinetic energy. An object's potential energy can be transformed into kinetic energy, but no energy can be created in either case.

You can also see why energy is needed to do work. Work involves forces and the distance the object moves. Machines make doing work easier by magnifying the effects of the forces applied by the machines.

All that said, being able to give concrete examples of energy is difficult because energy is abstract. It is easier to see the effect of energy, not the energy itself.

Exercises

1. The energy only can be transformed from one form into another form.

A. true B. False

2. The watt (W) is a unit of

A. potential energy.
B. kinetic energy.
C. power.
D. force.

3. Which one of the following has an appropriate unit?

A. energy- joule
B. force - watt
C. power - newton
D.All of the above

4. If there is a light bulb labeled as 30 W, it means that

A. the bulb consumes 60 J of electric energy when it is lit.
B. current must be 30 amperes passing through it
C. every second, the bulb converts 60 J of electrical energy to heat and light.
D. the bulb must have 60 Voltage across it

5. The gravitational potential energy can be negative

a) true b) false

6. if there is a non-zero force acting upon an object, and the object keeps moving. This force must perform work on this object.

a) never b) always c) sometimes, d) no clue

7. If an object is only under the influence of the gravity, the mechanical energy of it must be conserved

a) true b) false

8. If one object is moving, it must possess non-kinetic energy.

a) true b) false

9. In a pendulum, at the highest position, the pendulum only has potential energy, and when it reaches the bottom, it only has the kinetic energy.

a) true b) false

10) If a certain amount of work performed on one object, the energy level of this object must be changed.

a) true b) false

Problems:

1. A crane lifts a mass of 2.0 × 10^3 kg of objects, how much work is done by the crane in the wire as it is raised 5 m at a constant speed?
2. A crane lifts a mass of 2.0 × 10^3 kg of objects for 5-meter-high, how much work does gravity do?
3. The output power of an electric motor is 10 kW. Use it to increase 2.7 × 10^4 kg of cargo at a constant speed, what will the speed be?

4. An object with mass of 631 kg, is moving with a speed of 7.6 km/h, what is its kinetic energy?
5. If a ball is dropped from 10 meter to the floor, what is the velocity when it strikes the floor assuming there is no air resistance?
6. An object with mass of 20 kg, is moving with a speed of 15 m/s, what is its kinetic energy?
7. If a ball hits the ground with a velocity of 30 m/s, being dropped from a building, how tall is the building assume there is no air resistance?
8. A 30 N force drags an object for 30 meters long, how much work is done by the force?
9. A Car is driving with a speed of 15 m/s, and engine's driving force is 300 N, what is the power of the car's engine?
10. In 20 seconds, a force of 50 N pushes a box to move 15 meters, how much work is done? What is the power?

References:

1. https://www.fire2fusion.com/kinetic-energy/potential-and-kinetic-energy.html
2. https://www.khanacademy.org/science/physics/work-and-energy/mechanical-advantage/v/introduction-to-mechanical-advantage
3. https://www.physicsforums.com/threads/confused-with-inclined-plane-and-work-done-by-gravity.875845/
4. https://justenergy.com/blog/mechanical-energy-beginners-guide/#:~:text=Mechanical%20energy%20(kinetic%20energy%20or,a%20driver%20of%20renewable%20energy.
5. https://www.thoughtco.com/main-energy-forms-and-examples-609254