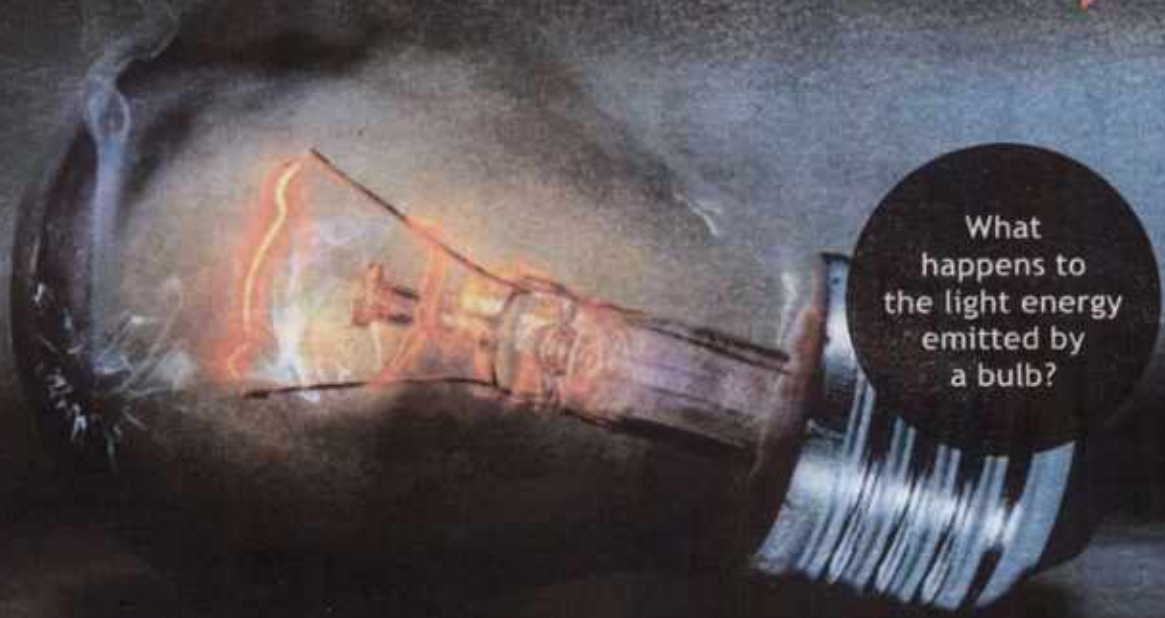


WORK AND ENERGY

UNIT
6



What happens to the light energy emitted by a bulb?

Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-B-60] Define work done.
- [SLO: P-09-B-61] Use the equation work done = force $\times$ distance moved in the direction of the force $W = F \times d$ to solve problems
- [SLO: P-09-B-62] Define energy as the ability to do work.
- [SLO: P-09-B-63] Explain that energy may be stored.
- [SLO: P-09-B-64] Prove that Kinetic Energy $E_k = \frac{1}{2} mv^2$.
- [SLO: P-09-B-65] Prove and use the formula for gravitational potential energy.
- [SLO: P-09-B-66] Use the formulas for kinetic and gravitational potential energy to solve problems involving simple energy conversions.
- [SLO: P-09-B-67] Describe how energy is transferred and stored during events and processes.
- [SLO: P-09-B-68] State and apply the principle of the conservation of energy.
- [SLO: P-09-B-69] Justify why perpetual energy machines do not work.
- [SLO: P-09-B-70] Differentiate between and list renewable and non-renewable energy sources.
- [SLO: P-09-B-71] Describe how useful energy may be obtained from natural resources.
- [SLO: P-09-B-72] Describe advantages and disadvantages of methods of energy generation.
- [SLO: P-09-B-73] Define and calculate power.
- [SLO: P-09-B-74] Define and calculate efficiency.
- [SLO: P-09-B-75] Apply the concept of efficiency to simple problems involving energy transfer.
- [SLO: P-09-B-76] State that a system cannot have an efficiency of 100% due to unavoidable energy losses that occur.



UNIT 6 WORK AND ENERGY

In our daily life work means “to do anything”. But in science, work has specific meaning, i.e. when force is applied and some distance is covered. For example, a man carrying a physics book is doing work but he is not doing work if he is not moving while keeping the physics book on his head. Scientifically, work is done only when an effort or force moves an object. When work is done, energy is used. Thus, work and energy are related to each other. The concept of energy is an important concept in Physics. It helps us to explain the changes that occur when work is done. This unit deals with the concepts of work, energy and power.

6.1 WORK

Work is said to be done when a force displaces a body in its own direction.

When an object moves distance S in the direction of applied force F (figure 6.1), then work done W is given mathematically as

$$\text{Work - done} = \text{Force} \times \text{Displacement}$$

$$W = F \times d \quad \text{--- 6.1}$$

FIGURE 6.1 WORK DONE

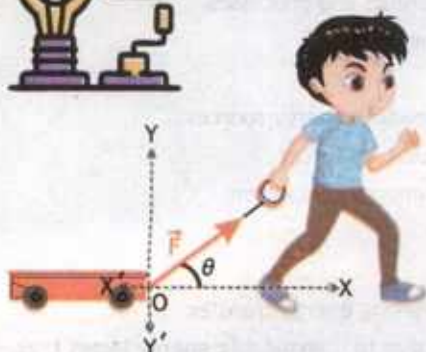


Work is a scalar quantity and in the International System of Units (SI), work is measured in joules (J). One joule is equal to the work done by a one-newton (1 N) force acting over a one-metre (1 m) distance.

$$1 \text{ J} = 1 \text{ N} \times 1 \text{ m}$$



SCIENCE TIDBITS



VECTOR REPRESENTATION

Force is not always applied perfectly in the direction of motion. For example consider a toy car which is moving in horizontal direction and force ‘ F ’ is applied making certain angle ‘ θ ’ with the horizontal. In such situations the force is resolved into its rectangular components as shown in figure 6.2.



CAN YOU TELL?

A man is pushing the truck but truck is at rest, is he doing work? Explain.

EXAMPLE 6.1: WORK DONE

Muhammad Tuaha was pushing a box with a force of 100 N on a flat frictionless surface. How much work he does on the box if he pushes it through a displacement of 200 m?

GIVEN

Force ' F ' = 100 N

Distance ' d ' = 200 m

REQUIRED

Work ' W ' = ?

SOLUTION

By the definition of work: $W = F \times d$ Putting values: $W = 100 \text{ N} \times 200 \text{ m}$

Therefore,

$$W = 20,000 \text{ J} = 20 \text{ kJ}$$

Answer

Muhammad Tuaha does 20 kJ of work on the box.

6.2 ENERGY AND ITS FORMS

We can identify things around us that are capable of doing work, that is, exerting a force to move an object.

- A boy is pushing a toy car. The boy exerts a force on the toy car to move on floor. The work done on toy car is transfer of energy from boy to the toy car.
- A Sharpening a pencil by a child is due to energy transfer to the sharpener.
- Riding a bicycle is possible due to transfer of energy to bicycle by a person.

So energy is defined as 'the capacity of a body to do work'.

Energy has many different forms as shown in table 6.1

UNIT OF ENERGY

The unit of energy is the same as that of work i.e joule (abbreviated $\text{J} = \text{Nm}$).

TABLE 6.1 TYPES OF ENERGY

TYPE	DESCRIPTION	EXAMPLE
Chemical Energy	The energy contained within the bonds between atoms.	These bonds can take many different forms, including energy derived from carbohydrates in food to energy stored in gasoline.
Electromagnetic Energy	Electromagnetic energy (or radiant energy) is energy from light or electromagnetic waves.	Electromagnetic energy from the Sun supplies Earth with all of the energy required to sustain life.
Electrical Energy	The energy associated with charges.	Electrons moving from negatively to positively charged objects.
Sonic Energy	The energy of sound waves. Sound waves travel through the air or another medium.	Sound vibrations cause a person's eardrums to vibrate.
Nuclear Energy	Nuclear energy is energy resulting from changes in the atomic nuclei or from nuclear reactions.	Nuclear power stations use nuclear energy to generate electric energy.

All forms of energy (Heat, electrical, light, chemical, nuclear and sound) can be classified as one of two types, either potential energy (stored) or kinetic energy (due to motion) collectively termed as mechanical energy.

6.2.1 KINETIC ENERGY

The energy possessed by a body due to its motion is called Kinetic energy.

A moving bullet is able to do work by overcoming forces when it strikes something e.g. wood. Similarly kinetic energy is felt during a collision.

A football is kicked by a boy it moves because it possesses Kinetic energy. Now think a tennis ball and a football moving with same speed. Which possess greater ability to do work? Of course it is the football with larger mass, which is difficult to stop. Similarly now two footballs are approaching you with different speeds, which can do more work? Again it is easy to answer as the football with greater speed is difficult to stop. Thus the object's mass and its speed contribute to its Kinetic energy. Like all energies Kinetic energy is also a scalar quantity.

Consider a constant force ' F ' is acting on an object of mass ' m ' and as a result the object moves on a frictionless surface. The kinetic energy of an object will be equal to work done.

The work done on force-displacement graph can be calculated by finding area of figure under force-displacement graph as shown in figure 6.2.



Change in kinetic energy (E_k) = Work done = $F \cdot d$

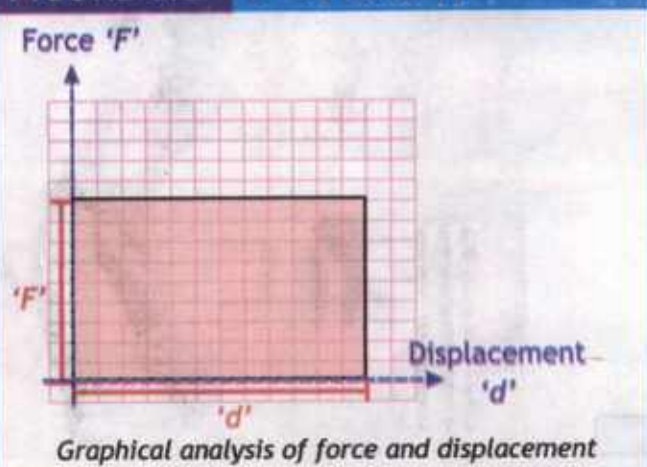
Work done = area under force displacement graph

Here the area under force displacement graph is the area of rectangle, thus:

Change in kinetic energy (E_k) = Area of rectangle = width $\times$ length = $(F)(d)$

or $E_k = (ma)(v_{av} t)$ — 1

FIGURE 6.2 F - D GRAPH



here $v_{ave} = \frac{v_i + v_f}{2}$

As the speed is increasing its velocity from $v_i = 0$ to $v_f = v$, therefore the average speed v_{ave} is therefore

$v_{ave} = \frac{0 + v}{2} = \frac{v}{2}$ — 2

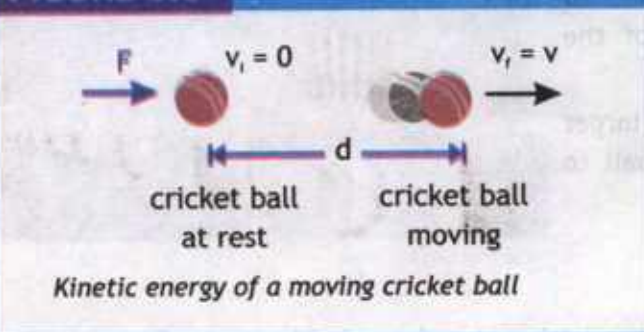
And acceleration can also be written as:

$a = \frac{v}{t}$ — 3

Putting equation 2 and equation 3 in equation 1, we get $E_k = m \frac{v}{t} \cdot \frac{1}{2} vt$

$E_k = \frac{1}{2} mv^2$ — 6.2

FIGURE 6.3 KINETIC ENERGY



By solving equation 6.2 kinetic energy for cricket ball can be found, For example, a 100 g cricket ball moving with a speed of 2.0 m/s has a Kinetic energy of 0.2 J as shown in figure 6.3.

Equally important, it demonstrate the work kinetic energy theorem which

states that the work done on an object is equal to change in energy i.e $W = \Delta E$, Where 'W' is the work done and ' ΔE ' is the change in energy.

EXAMPLE 6.2: SPEED OF CRICKET BALL

Babar Azam hits a cover drive by giving kinetic energy of 50 J to the ball by his bat. At what speed will the ball go to the boundary if mass of the ball is 120 g?

GIVEN

Mass of ball ' m ' = 120 g = 0.12 kg

Kinetic energy of ball ' E_k ' = 50 J

REQUIRED

Speed of cricket ball ' v ' = ?

SOLUTION

Kinetic energy is given by: $E_k = \frac{1}{2}mv^2$

For velocity: $v^2 = \frac{2E_k}{m}$

Taking square root on both sides: $v = \sqrt{\frac{2E_k}{m}}$

Putting values: $v = \sqrt{\frac{2 \times 50 \text{ J}}{0.12 \text{ kg}}}$

Therefore, $v = 28.9 \text{ m/s}$

Answer



At this speed, the ball will touch the boundary line in just 2.5 seconds, which is about 72 m long


DO YOU KNOW

The light emitted by the bulb is converted into other forms of energy like kinetic energy of the surrounding molecules etc.

This means that a football will need a much larger amount of kinetic energy than a cricket ball to make it move at the same speed.

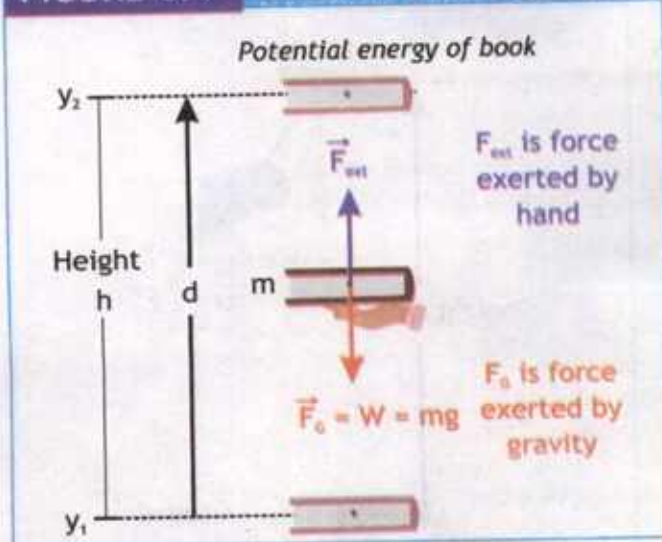

6.2.2 POTENTIAL ENERGY

The energy possessed by a body by virtue of its position (in a force field or in configuration) is called potential energy'.

Consider the work you do on a book when you lift from the floor and place it on the top shelf. The work you did on your book is now stored in the book by virtue of its position.



FIGURE 6.4 STORED ENERGY



By doing work against the force of gravity, you have given your book a special form of potential energy called gravitational potential energy (figure 6.4). If you release book from the top shelf it will accelerate, gaining kinetic energy, thus gravitational potential energy is released and have the ability to do useful work. Gravitational potential energy is only one of several forms of potential energies.

For example, doing work on an elastic spring by stretching it stores elastic potential energy in elastic spring, (slingshot, shock absorber, winding spring in toys and watches are all example of

elastic potential energy). Chemical potential energy stored in the food you eat. A battery contains both chemical and electrical potential energy during working of battery. Similarly, in a capacitor, which consists of two conductive plates with opposite charges, electrostatic potential energy is stored in the electric field between the plates.

FIGURE 6.5



Mathematically, Gravitational potential energy is the product of mass 'm', the acceleration due to gravity 'g', and the change in height 'h'.

$$E_{p,grav} = mgh$$

Like all energies potential energy is also a scalar quantity. For example if we lift a stone of mass 5 Kg from the ground to 20m high the work is done against the force of gravity, this work appears as 980 J of potential energy.



UNIT 6 WORK AND ENERGY

Consider an object of mass ' m ' being lifted vertically by a force ' F ' to ' h ' as shown in figure 6.6. The work done by the force F is given by equation.

$$W = E_{p,grav} = FS \quad \text{--- 1}$$

Since the force in this case is equal to its weight

$$F = W = mg \quad \text{--- 2}$$

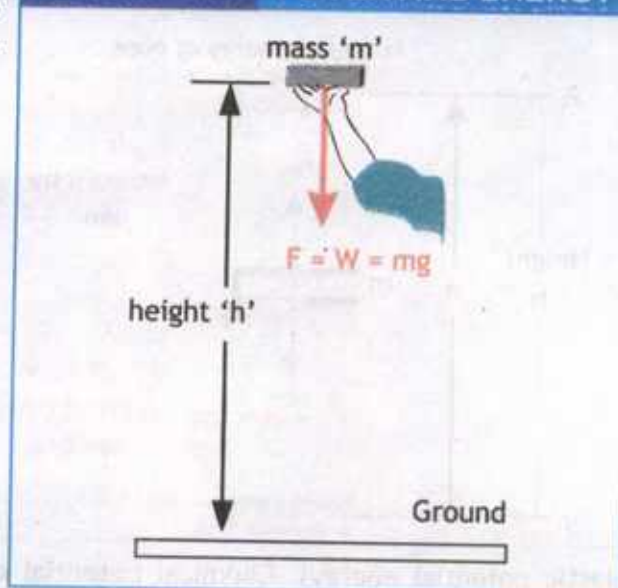
Here the distance moved is the height ' h '

$$S = h \quad \text{--- 3}$$

putting equation 2 and 3 in equation 1, we get

$$E_{p,grav} = mg \times h = mgh \quad \text{--- 6.3}$$

FIGURE 6.6 POTENTIAL ENERGY



EXAMPLE 6.3: POTENTIAL ENERGY

At School sports gala, Kamil made a record in high jump at his school. He jumped 1.5 m high. What will be his potential energy if his mass is 60 kg? From where does this potential energy come?

GIVEN

Mass ' m ' = 60 kg Height ' h ' = 1.5 m

Acceleration due to gravity ' g ' = 9.8 m/s²

REQUIRED

Potential Energy ' $E_{p,grav}$ ' = ?

SOLUTION

Potential energy is given by: $E_{p,grav} = mgh$

Putting values: $E_{p,grav} = 60 \text{ kg} \times 9.8 \text{ m/s}^2 \times 1.5 \text{ m}$

Therefore,

$$E_{p,grav} = 882 \text{ J}$$

Answer



This gravitational potential energy comes from pushing himself upward with kinetic energy of 882 J.



6.2.3 ENERGY CONVERSION AND CONSERVATION

Think of a book lying on a shelf. The book has gravitational potential energy when it is on the shelf. What happens if the book falls off the shelf? Its potential energy changes into kinetic energy. This change in energy from one form to another is conversion of energy. For example consider the following examples

A. Generation of electricity: Potential energy of water which is stored at a certain height is converted into kinetic energy by making it fall on turbine to produce electricity as shown in figure 6.7.

FIGURE 6.7 ENERGY CONVERSION



B. A cyclist going up to the top of a hill: Stored chemical energy in the body of cyclist allows him to do work against gravity (see figure 6.7). At the top of the hill, he will possess gravitational potential energy which will allow him to go down the hill with increasing kinetic energy even without pedaling.

When current passes through bulb, electrical energy is converted into light energy and thermal energy. In a car driven with petrol the chemical energy stored in the fuel is converted into kinetic energy of car. Engineers are concerned with the technologies associated with transformation from sources such as fossil fuels into conveniently used forms such as electrical energy and heating.

FIGURE 6.8 ALTERNATE ENERGY SOURCES



It must be noted that during this conversion process all the energy is not converted into useful forms. Scientists term this lost energy as dissipated energy. For example, in an automobile driven with petrol only a small portion (17 to 21%) of the chemical energy of gasoline is converted into energy that moves the car. The remaining portion (80%) is lost to the environment as heat and other forms of energy. Electric cars are far more energy efficient than internal combustion engine cars.

Energy cannot be destroyed or created it is only converted from one form to the other.

The law of conservation of energy states that,

'Energy can neither be created nor destroyed in any process. It can be converted from one form to another, but the total amount of energy remains constant'.

This means that if the work done 'W' is zero then, the change in energy ' ΔE ' is also zero.

$$\Delta E = 0$$

If the total energy at final stage is E_{Tf} and the total energy at initial stage is E_{Ti} , then by conservation of energy principle

$$E_{Tf} - E_{Ti} = 0$$

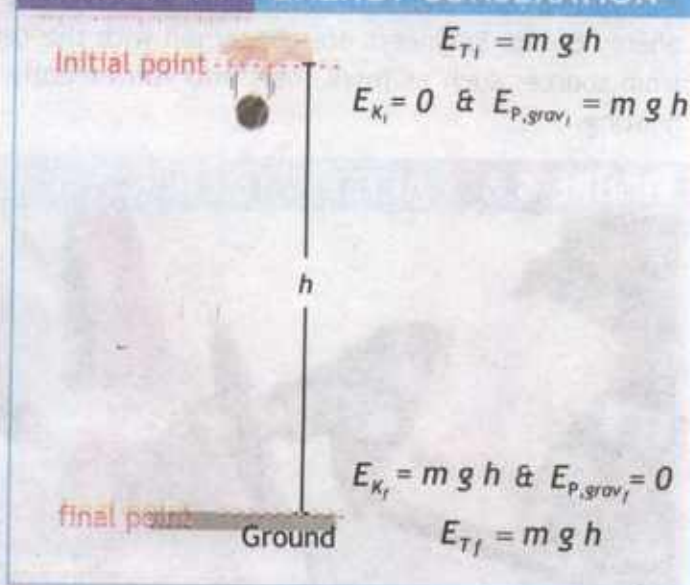
$$E_{Tf} = E_{Ti} \quad \text{--- 6.4}$$

Thus the initial energy of a system is equal to its final energy. However, some time this principle appears to be violated. For example, when electrical energy is provided to fan some of this energy is used in rotating the fan, the remaining energy is not lost or destroyed but converted into other forms of energy (such as thermal energy). In this way, the total energy remains constant.

In certain processes, both the total energy and the total mechanical energy are conserved, meaning they stay the same. An example of this can be seen in Figure 6.9, where a ball is falling. The ball starts from a rest position and drops from a height 'h', above the ground. As the ball falls, its gravitational potential energy is converted into kinetic energy, causing it to move faster. However, its mechanical energy remains constant. This can be expressed mathematically as:

$$E_{K_f} + E_{P,grav_f} = E_{K_i} + E_{P,grav_i} \quad \text{--- 1}$$

FIGURE 6.9 ENERGY CONSERVATION





As energy at initial point is totally because of gravitational potential energy ' $E_{p, grav}$ ' Which is totally transformed into kinetic energy ' E_k ' at final point, therefore equation 1 can be:

$$E_k = E_{p, grav} \quad \text{--- 2}$$

When the frictional forces, such as air resistance acts between initial and final points, the gravitational potential energy ' $E_{p, grav}$ ' at initial point apart from converting into kinetic energy ' E_k ' ' E_k ' is dissipated into work done against friction ' W_{fr} '. Thus equation A can be written as

$$E_k + W_{fr} = E_{p, grav} \quad \text{--- 6.5}$$

EXAMPLE 6.4: FOOTBALL KICK

A player kicks the football of mass 450 g is thrown vertically upward at a speed of 22 ms^{-1} .

(a) Neglecting air resistance how high would it reach. (b) If due to air friction the ball only rises to 20 m, what is the work done against air resistance?

GIVEN

Mass ' m ' = 450 g = 0.45 kg

Speed ' v ' = 22 ms^{-1}

Acceleration due to gravity ' g ' = 9.8 ms^{-2}

Height with air friction ' h_{fr} ' = 20 m

REQUIRED

(a) Height ' h ' = ? (without friction)

(b) Work by friction ' W_{fr} ' = ?

SOLUTION: (a) Without frictional loss:

$$E_k = E_{p, grav}$$

$$\text{or } \frac{1}{2}mv^2 = mgh \quad \text{or } h = \frac{v^2}{2g} \quad \text{putting values } h = \frac{(22 \text{ ms}^{-1})^2}{2 \times 9.8 \text{ ms}^{-2}}$$

Hence

$$h = 24.7 \text{ m}$$

Answer



(b) Due to friction when the ball only raises to 20 m, then:

$$\text{loss in KE} + \text{Work against friction} = \text{gain in PE} \quad \text{or } E_k + W_{fr} = E_{p, grav}$$

$$\text{or } W_{fr} = E_{p, grav} - E_k \quad \text{Hence } W_{fr} = mgh_{fr} - \frac{1}{2}mv^2$$

$$\text{putting values } W_{fr} = 0.45 \text{ kg} \times 9.8 \text{ ms}^{-2} \times 20 \text{ m} - \frac{0.45 \text{ kg} \times (22 \text{ ms}^{-1})^2}{2}$$

Therefore,

$$W_{fr} = 88.2 \text{ J} - 108.9 \text{ J} = -20.7 \text{ J}$$

Answer

Where the negative sign shows that work done by friction retard the motion of the object.

So 20.7 J of energy is lost due to friction of 108.9 J of the available energy.

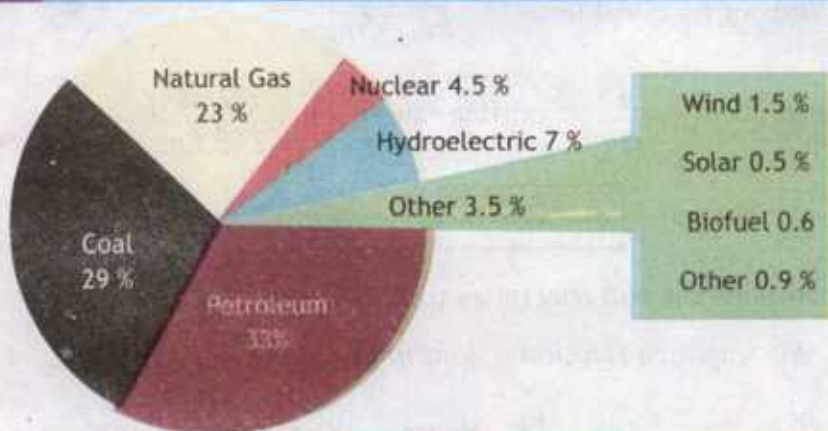
6.3 MAJOR ENERGY RESOURCES

The progress in science and technology has propelled society from a time when human strength was the primary source of energy, to a time where various forms of energy are harnessed. However, in every conversion of energy, there is always a loss of useful energy. It is evident that society cannot persistently consume increasing amounts of energy without taking into account the needs of future generations. The forthcoming challenge lies in the development of energy sources and processes that are sustainable. A sustainable resource is one that does not diminish over time and does not harm the delicate biosphere of the Earth, while still meeting the energy requirements of society. On this classification the energy resources are divided into two groups – renewable and nonrenewable.

Non-renewable energy resource is an energy resource that is limited and cannot be replaced naturally in short time. Most of the energy we use comes from non-renewable energy resources, for example fossil fuels like coal, natural gas and petroleum.

Renewable energy resource is an energy resource that is replaced rapidly by a natural process. Renewable energy resources capture their energy from an on-going natural processes, such as sunshine, wind, flowing water and biological processes. They are part of the planet's physical structure, which means they are constantly being renewed by natural means and cannot simply run out (technology not fuel). Apart from this advantage many renewable energy systems are better for the environment, compared to non-renewable energy sources.

FIGURE 6.10 ENERGY CONSUMPTION



Energy conversion involves transforming available energy resources into a useful form. These resources provide the raw materials or sources used to generate energy for various purposes, including electricity generation, transportation, heating, and industrial processes. Nowadays, many energy converters focus on converting energy into electrical form. This process is facilitated by various devices and systems known as energy converters. Achieving a sustainable and reliable energy supply requires us to increase the use of renewable energy sources, enhance energy efficiency, and create new technologies to minimize environmental impacts.



It is important to strike a balance between energy requirements and environmental and social concerns.

The impact on the environment caused by the electricity system is influenced by different factors such as the generation and distribution methods used. In general, the environmental effects can include:

- Emissions of greenhouse gases and other air pollutants, especially when a fuel is burned.
- Use of water resources to produce steam, provide cooling, and serve other functions.

TABLE 6.2 ENERGY RESOURCES	
NONRENEWABLE	RENEWABLE
Fossil Fuels (Coal, Oil and Natural Gas)	Solar radiation
	Geothermal resources
	Winds
	Bio-fuels
Nuclear fuel	Tides
	Waves in seas and oceans
	Hydroelectric resources
	Waste as fuel

- Discharges of pollution into water bodies, including thermal pollution (water that is hotter than the original temperature of the water body).
- Generation of solid waste, which may include hazardous waste.
- Land use for fuel production, power generation, and transmission and distribution lines.
- Effects on plants, animals, and ecosystems that result from the air, water, waste, and land impacts.

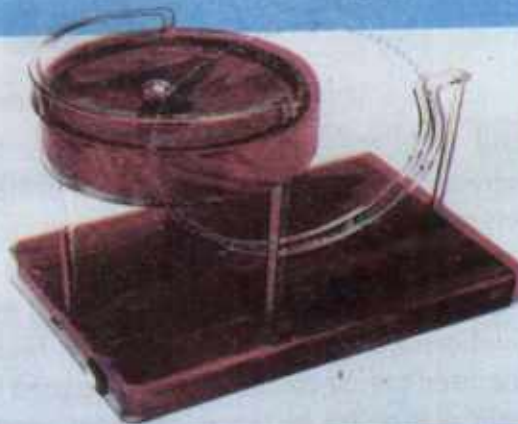
The use of energy resources raises various social concerns that involve impacts on communities, public health, and overall societal well-being. To tackle these social issues, it is important to take a holistic and inclusive approach. This involves involving the community, engaging stakeholders, and carefully considering the potential effects of energy projects. Policymakers, industry stakeholders, and communities need to collaborate in order to create sustainable and socially conscious energy solutions.

FOR YOUR INFORMATION

Perpetual motion is the motion of bodies that continues forever in an unperturbed system.

A perpetual motion machine is a hypothetical machine that can do work infinitely without an external energy source.

This kind of machine is impossible, as it would violate either the first or second law of thermodynamics, or both.



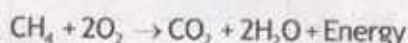


UNIT 6 WORK AND ENERGY

6.3.1 FOSSIL FUELS

Fossil fuels are the remains of million year old plant life (now coal) or aquatic animal life (now gasoline and natural gas). Chemical energy stored in fossil fuels is obtained through a process called combustion. Fossil fuels, which include coal, oil, and natural gas, are rich in hydrocarbons—molecules made up of hydrogen and carbon atoms. When these hydrocarbons burn, they combine with oxygen from the air to create carbon dioxide, water, and energy.

The general chemical equation for the combustion of a hydrocarbon, such as methane (CH_4) found in natural gas, is as follows:

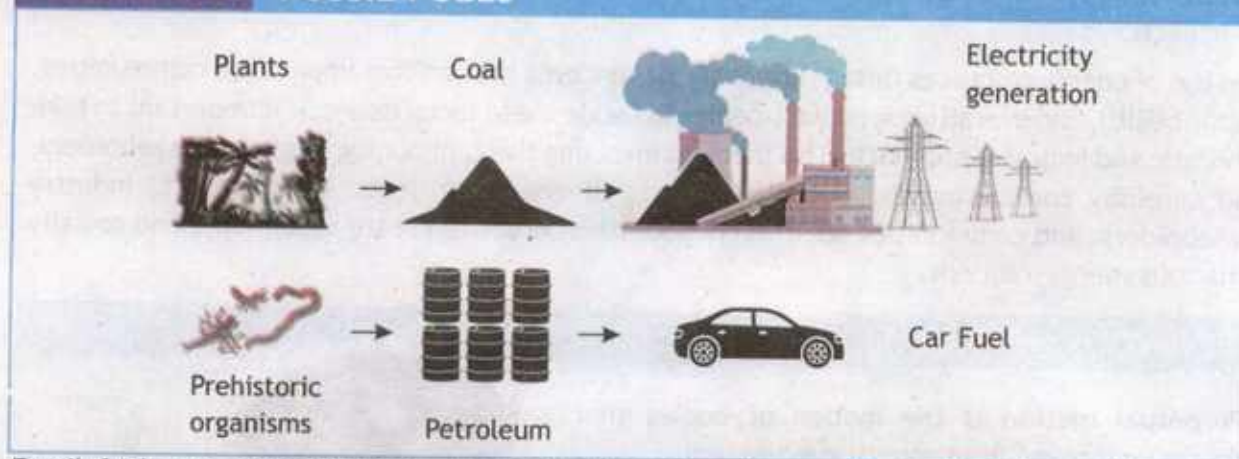


A. COAL: Coal, the most abundant fossil fuel globally, possesses an estimated reserve of one million metric tonnes. However, the combustion of coal leads to significant atmospheric pollution.

B. OIL: Crude oil undergoes refining processes to yield various energy products, including gasoline, jet fuel, and heating oil. Despite the limited global reserves of oil, it is favored over coal due to its higher energy output for the same quantity.

C. NATURAL GAS: Natural gas, often a byproduct of oil extraction, comprises a mixture of gases, primarily methane. One advantage of natural gas is its ease of transportation.

FIGURE 6.11 FOSSIL FUELS



Fossil fuels are extracted from the Earth through various methods. Coal is usually mined, whereas, oil and natural gas is often drilled and extracted from reservoirs. The extracted fossil fuels may undergo refining and processing to separate impurities and obtain usable forms of the fuel.

To extract energy fossil fuel is burned in the presence of oxygen, typically in a combustion chamber or engine. This combustion reaction releases energy in the form of heat. The heat generated during combustion can be used to produce steam, drive turbines, or power engines. In power plants, for instance, the heat produced is often used to generate steam, which in turn drives turbines connected to generators to produce electricity.



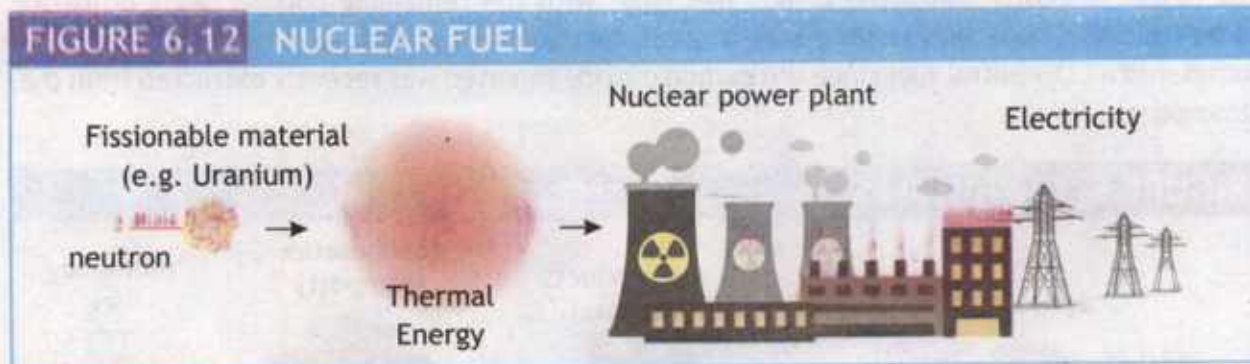
Fossil fuels serve as a significant energy resource due to their inherent value. The process of extracting them is relatively cost-effective. Furthermore, they possess the advantage of being easily stored, transported via pipelines, or shipped to any location across the globe. It is crucial to acknowledge that although fossil fuels play a significant role as an energy source, their combustion leads to the emission of carbon dioxide (CO_2) and other harmful substances into the atmosphere. This contributes to environmental problems like air pollution and climate change. Consequently, there is an increasing focus on the advancement and implementation of cleaner and more sustainable energy alternatives.

6.3.2 NUCLEAR FUEL

Nuclear energy is often considered a nonrenewable energy source, even though nuclear energy itself is renewable. The material used in nuclear power plants, such as uranium, is not renewable. Nuclear power plants harness the energy in the nucleus of an atom through nuclear fission, where the atom's nucleus splits. These plants are complex machines that can control nuclear fission to generate electricity. While uranium is found in rocks worldwide, nuclear power plants typically use a rare type called U-235. Plutonium-239 is another material that can be used as nuclear fuel. It is often produced within nuclear reactors by irradiating U-238 which is common.

The process of nuclear fission involves splitting heavy atoms like uranium or plutonium, resulting in a significant amount of thermal energy. This heat is used to boil water, which then generates electricity.

FIGURE 6.12 NUCLEAR FUEL



Nuclear energy is a popular method for generating electricity globally because small amount of nuclear fuel can produce a large amount of energy and it doesn't pollute the air or emit greenhouse gases. These power plants can be constructed in rural or urban areas without harming the environment. Nevertheless, harnessing nuclear energy is challenging. Building and operating nuclear power plants is a complicated process that requires skilled scientists and engineers, which many communities lack.

However, nuclear energy produces radioactive waste, which is highly toxic and can cause severe health issues like burns, cancers, blood diseases, and bone decay.

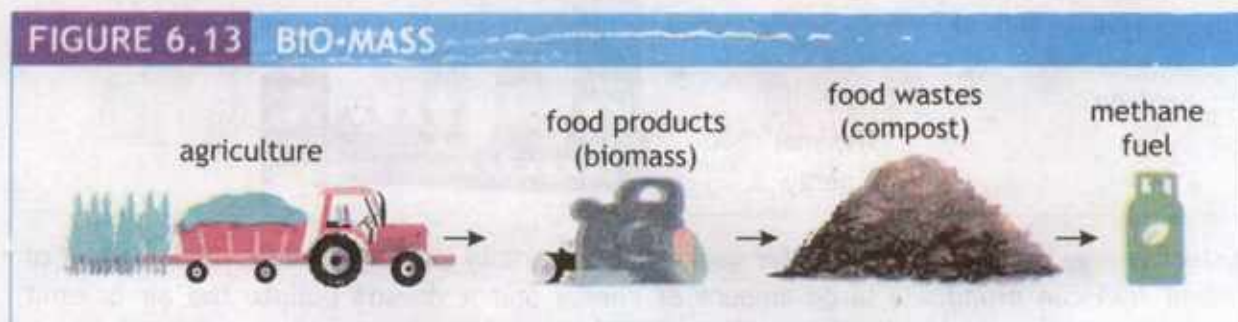
6.3.3 BIO-MASS FUEL

Bio-mass, refers to the material that provides bio-energy. The energy contained in biomass comes from the sun, as plants capture sunlight through photosynthesis and convert it into chemical energy, specifically carbohydrates. Only green plants and photosynthetic algae with chlorophyll can utilize solar energy. The most basic way to harness this energy is through consumption. Whenever you eat a fruit, vegetable, or a processed form of either, you are benefiting from the energy stored as biomass.

Bio-mass has many types, this includes logs, branches, wood chips, sawdust, and other by-products from forestry and wood processing. Agricultural residues such as straw, corn stalks, and rice husks can be used as biomass fuel. Certain crops, like switchgrass and miscanthus, are grown specifically for energy production. Livestock waste, such as dung, can be used as a biomass fuel.

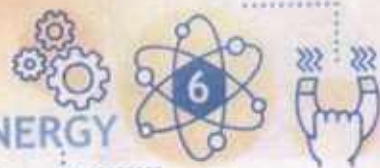
There are many methods currently used around the world to make the best possible use of biomass energy. Biomass can be burned directly to produce heat or used in combustion processes to generate steam, which drives turbines connected to generators for electricity production. It can also be used as biochemical conversion which involves the use of microorganisms or enzymes to break down biomass into biofuels, such as ethanol and biodiesel. Apart from this, processes like pyrolysis and gasification can convert biomass into gases (syngas), bio-oil, or charcoal.

Bacteria decompose decaying plants, resulting in the production of biogas. A tonne of food waste can generate 85 m³ of biogas, consisting of methane, carbon dioxide, and hydrogen sulfide gas. The biogas is mostly composed of 60% methane, with the remaining portion being primarily carbon dioxide. This biogas serves as a great fuel source for heat and power plants. It is considered a CO₂ neutral fuel since the carbon dioxide released was recently extracted from the atmosphere.



Biogas is renewable energy system ideal for treating liquid manure and industrial wastes, providing nutrient-rich fertilizers from the residues. Implementing biogas systems for farm manure helps decrease nitrate pollution and the risk of water contamination by E-coli bacteria.

However the effectiveness of biogas systems depends on the collaboration between regional farmers and industrial sites to support a centralized plant, which can be challenging to accomplish.

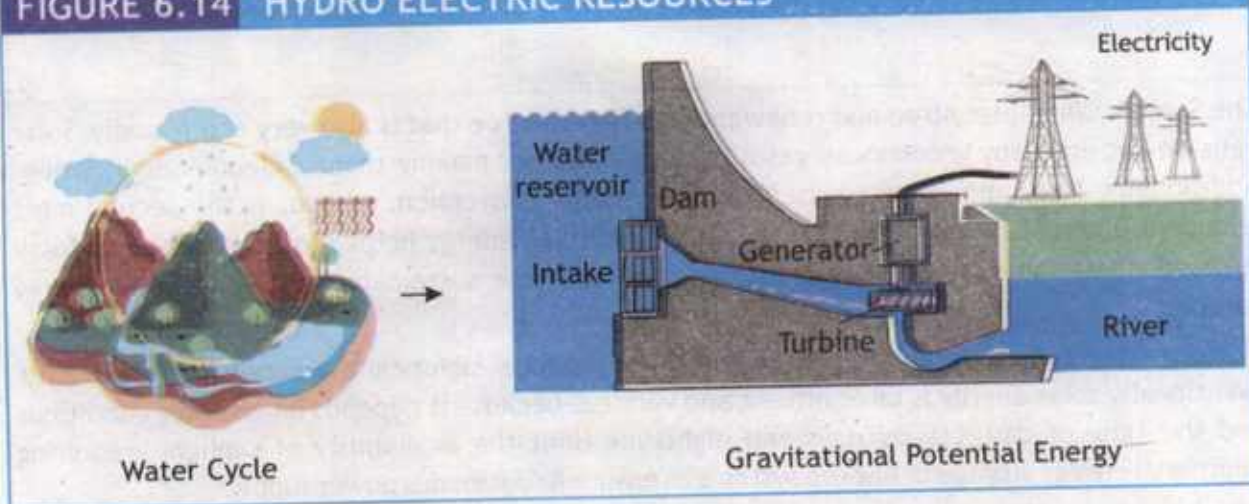


6.3.4 HYDRO ELECTRIC RESOURCES

Hydroelectric generation is the process of using the gravitational potential energy of water to generate electric energy. The force of gravity pulls the water down, giving it a lot of kinetic energy. This kinetic energy is then converted into electric energy by large turbines.

Sometimes, these large reservoirs flood a large area of farmland, thereby significantly changing the ecosystem, and we don't know what the consequences will be. In the past, engineers didn't have the technology to economically use smaller reservoirs for generating electricity. But now, with advancements in technology, smaller generation facilities are becoming more popular.

FIGURE 6.14 HYDRO ELECTRIC RESOURCES



Hydroelectric power is renewable and efficient. Once the facilities are raised and running, they have minimal impact on the environment. However, generating power from water requires fast-flowing water, and it often causes ecological damage when using large facilities.

6.3.5 SOLAR RADIATION

The energy from direct sun light can be used to produce electricity. Today, solar cells are used to power everything from calculators and watches to small cities.

Solar radiation is harnessed in two main ways for energy. The first method involves solar photovoltaic cells, also known as solar cells, which directly convert sunlight into electricity. These cells are made of semiconductor materials like silicon, which generate an electric current when exposed to sunlight. Solar panels are created by connecting multiple solar cells together to form a module. These panels can be installed on rooftops, solar farms, or other locations with access to sunlight.

The second method is through solar thermal systems, which utilize the heat from sunlight for various applications such as electricity generation, water heating, and space heating. Concentrated Solar Power (CSP) systems concentrate sunlight onto a small area using mirrors or lenses.

The concentrated sunlight is then used to heat a fluid, like water or a heat transfer fluid, which in turn produces steam. This steam is used to drive a turbine connected to a generator for electricity production.

FIGURE 6.15 SOLAR SYSTEM



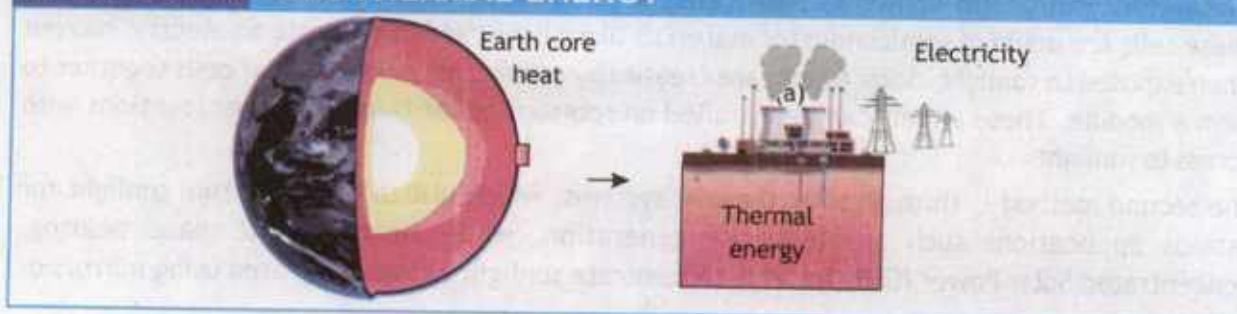
The Sun is a completely free and renewable energy resource that is also very eco-friendly. Solar cells do not emit any greenhouse gases during operation, making them a clean energy option. Additionally, the main material used in solar energy conversion, silicon, is the second most abundant element in the Earth's crust. The use of solar energy helps reduce reliance on fossil fuels, decrease greenhouse gas emissions, and promote sustainable and renewable energy sources.

However, Significant land area is required to produce significant amounts of electricity. Additionally solar energy is intermittent and variable because it depends on weather conditions and the time of day. Cloudy days and nighttime limit the availability of sunlight, requiring additional energy storage or backup systems to ensure a continuous power supply.

6.3.6 GEOTHERMAL RESOURCES

Geothermal energy comes from the Earth's core and is formed by the trapped energy from billions of years ago and the heat produced by decaying radioactive elements. It is, in fact, not considered a renewable energy source because the heat is extracted faster than it is replenished. However, due to the immense size of the Earth, it would take thousands of years to deplete this energy source, making it practically renewable.

FIGURE 6.16 GEOTHERMAL ENERGY





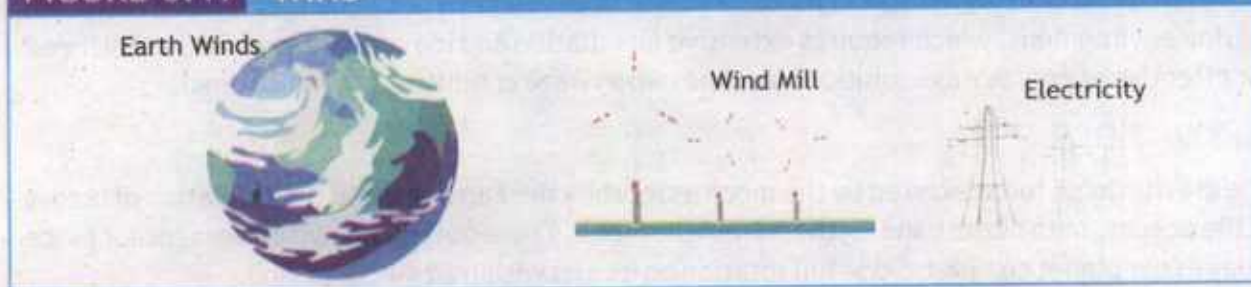
Geothermal energy is abundant and does not produce greenhouse gas emissions. It is a reliable source of power that is not affected by weather conditions. Nonetheless, it is only economically viable in certain locations on Earth, and the discharge of hydrogen sulfide gas can be toxic and even deadly in high concentrations.

6.3.7 WIND

The kinetic energy of the wind can be used to turn turbine which in turn produce electricity. Wind turbines are the main technology used to capture wind energy. They have big rotor blades connected to a hub, gearbox, and generator. The blades convert wind's kinetic energy into rotational energy. The design, length, and shape of the blades are important for the turbine's efficiency. Modern turbines usually have three blades that can be adjusted for better energy capture. Control systems are installed in wind turbines to adjust blade pitch or shut down the turbine in strong winds to prevent damage.

The generator converts the rotational energy into electricity, usually alternating current (AC). Wind turbines are often grouped together in wind farms to maximize energy production. These farms are strategically located in areas with consistent and strong winds, like coastal regions, plains, or mountain passes.

FIGURE 6.17 WIND



Generating electricity from wind is eco friendly and renewable energy source with zero greenhouse gas emissions and a low risk of accidents.

However, developing turbines to meet infrastructure needs is expensive. They are only viable in areas with constant and strong winds. Wind farms require a significant amount of open space.

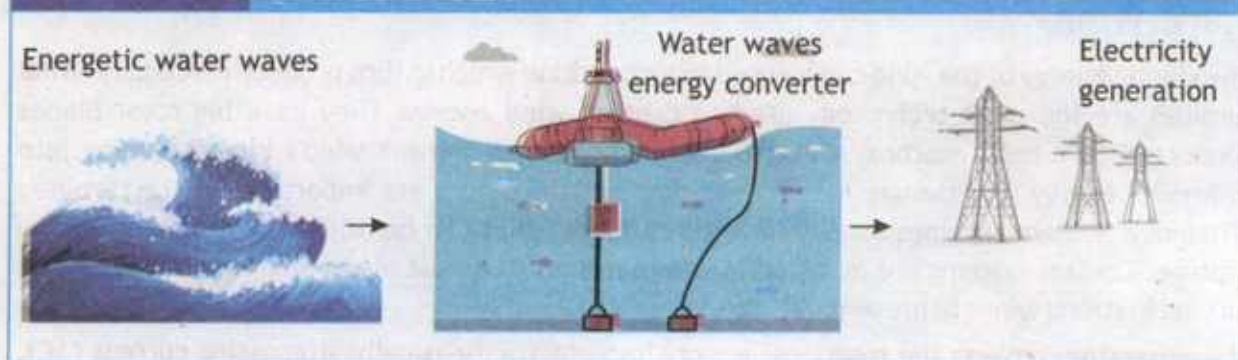
6.3.8 WAVES IN THE SEA

Wave energy, also called ocean wave energy, is obtained from the movement of surface waves on the ocean. Wave Energy Converters (WECs) are devices created to capture the kinetic energy of these waves. There are different types of WECs, each with its own design and working principle.

One type is point absorbers, which move up and down with the waves. This vertical motion powers a system that converts the mechanical energy into electricity, such as a hydraulic pump or an electrical generator. Another type is attenuators, which are long floating structures that move with the waves. The relative motion between the segments of the attenuator is used to generate electricity.

Oscillating water columns utilize the rising and falling motion of waves to create air movement in a chamber. This moving air is then used to drive a turbine connected to a generator, producing electricity. In this way, the mechanical motion of the waves is converted into electrical energy.

FIGURE 6.18 WAVES IN SEA



Wave energy has the advantage of being more predictable compared to some other renewable sources, as it is influenced by factors like wind patterns and ocean currents. Countries with access to an ocean can potentially harness wave power, which poses minimal threat to the environment.

However, the technology is still in its early stages of development. Challenges include the harsh marine environment, which requires extensive installation and maintenance, as well as the need for effective energy storage solutions for times when wave conditions are not optimal.

6.3.9 TIDES

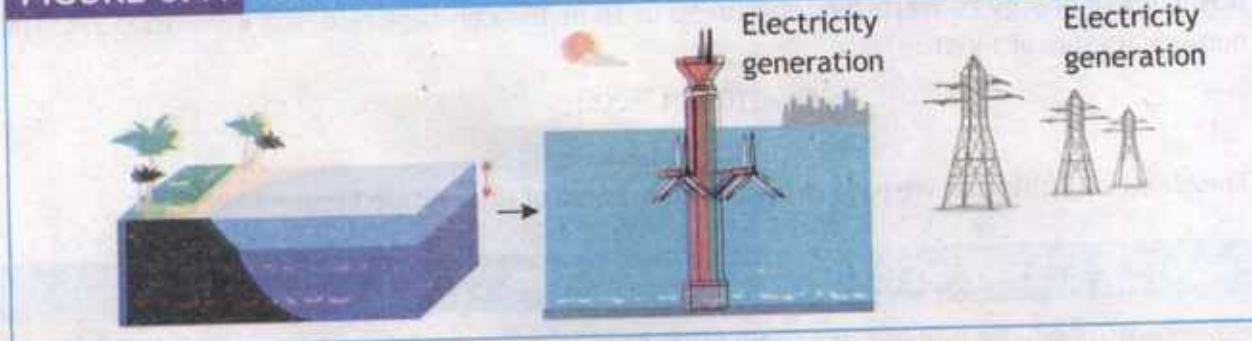
The gravitational force exerted by the moon as it orbits the Earth leads to the formation of bulges in the oceans, both closest and farthest from the moon. These bulges, known as tides, occur twice a day as our planet completes one full rotation on its axis within a 24-hour period.

There are primarily two main approaches to harnessing energy from tides. The first method involves utilizing tidal stream systems, also referred to as tidal current systems, which harness the kinetic energy generated by the movement of water caused by tidal currents. Specifically designed underwater turbines are strategically placed in areas with strong tidal currents to capture the kinetic energy and convert it into electricity. On the other hand, tidal range systems make use of the difference in height between high tide and low tide, known as the tidal range. To generate electricity, a tidal barrage or a dam-like structure is constructed across the entrance of a tidal basin. Sluice gates within the barrage allow water to flow into the basin during high tide and release it during low tide, thereby producing electricity. Another method involves capturing high-tide waters and releasing them through turbines during low tide to generate electrical power from the ocean.

Tidal energy systems, whether based on tidal streams or tidal ranges, are considered renewable sources of energy and possess the advantage of predictability due to the regular and cyclic nature of tides.



FIGURE 6.19 TIDES



Physicists have calculated that the rise and fall of tides dissipate energy at a rate of two to three million megawatts. However, only a small fraction of this energy, approximately 23,000 MW worldwide, or about 1%, is currently recoverable. The deployment of tidal energy technologies is hindered by challenges related to environmental impact and the high costs associated with installation. Furthermore, the viability of tidal facilities is limited to only a few locations across the globe.

6.4 POWER

The definition of work makes no reference to the passage of time. But often we need to know how fast is being done or how fast energy is being converted from one form to another. We describe this in terms of power. Power is the time rate at which work is done or the rate at which energy is consumed. Mathematically

$$P = \frac{W}{t} = \frac{E}{t} \quad \text{--- 6.6}$$

Like work power is a scalar quantity. The SI unit of power is watt (W), in honour of James Watt, a Scottish physicist who invented the first steam engine. From equation (6.7), the unit of power is given by

$$1 \text{ watt} = 1 \text{ joule} / 1 \text{ second}$$

$$\text{Or in symbols, } 1 \text{ W} = 1 \text{ Js}^{-1}$$

FIGURE 6.20 POWER RATING ON LIGHTING DEVICES



The power rating (sometimes called the "wattage") of a light bulb tells you how fast it will convert electric energy into heat and light. 100 W filament bulb and 40 W tube light are shown in the figure 6.20.

For practical purpose, a larger unit is often used, the horse power (hp). One horse power (hp) is defined as 550 ft.lb/s which equals 746 W.

$$1 \text{ hp} = 746 \text{ W}$$



UNIT 6 WORK AND ENERGY

A unit of energy (work) can now be defined in terms of the unit of power. One kilowatt hour (kWh) is the energy converted or consumed in 1h at the constant rate of $1 \text{ kW} = 1000 \text{ J/s}$. The numerical value of 1 kWh is,

$$1 \text{ kWh} = (10^3 \text{ W})(3600\text{s})$$

$$\text{Or } 1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

The electricity bills that we pay are measured in terms of this unit i.e 1 unit = 1 kWh.

EXAMPLE 6.5: POWER OF AN ENGINE

How powerful will be a Tesla Car's engine if it does $3 \times 10^7 \text{ J}$ of work in 1 minute? What will be its power in hp?

GIVEN

$$\text{Work 'W'} = 3 \times 10^7 \text{ J}$$

$$\text{Time 't'} = 1 \text{ min} = 60 \text{ s}$$

REQUIRED

Power in horsepower 'P' =?

SOLUTION

Power is given by the relation: $P = \frac{W}{t}$

$$\text{Putting values: } P = \frac{3.69 \times 10^7 \text{ J}}{60 \text{ s}}$$

$$\text{Hence } P = 6.15 \times 10^5 \text{ W} = 615 \text{ kW}$$

$$\text{since, } 1 \text{ hp} = 746 \text{ watt} \quad \text{or} \quad 1 \text{ watt} = \frac{1}{746} \text{ hp}$$

$$\text{or } P = 6.15 \times 10^5 \times \frac{1}{746} \text{ hp}$$

Therefore,

$$P = 825 \text{ hp}$$

Answer



Thus, power of such an engine will be 615 kW or 825 hp.

6.5 EFFICIENCY

The principle of conservation of Energy suggests that energy can neither be created nor destroyed. That is the total energy output of a machine must be equal to its energy input.

However, it is found that the energy output is always less than the energy input. This is mainly due to the work that must be done against frictional forces.

A car engine is designed to convert chemical energy stored in the fuel into kinetic energy for the car. A light bulb is designed to convert electric energy into light energy. While the car engine and the light bulb are transforming some of the potential energy into the desired form of energy, part of its energy is 'lost'.



The lost energy is converted into form that does not serve the intended purpose. Often the lost energy is transformed into heat. The efficiency ' η ' of a machine or device describes the extent to which it converts input energy or work into useful type of output energy or work.

Efficiency ' η ' is the ratio of useful work output ' W_o ' to the total work input ' W_i '.

$$\text{efficiency} = \frac{\text{useful output work}}{\text{input work}} \quad \text{or} \quad \eta = \frac{W_o}{W_i} \quad \text{--- 6.7}$$

In terms of energy equation 6.4 can be written as:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \quad \text{or} \quad \eta = \frac{E_o}{E_i} \quad \text{--- 6.8}$$

Efficiency has no unit as it is the ratio of same quantities and therefore units cancels. The efficiency of an energy transformation is sometimes given in percentage as follows

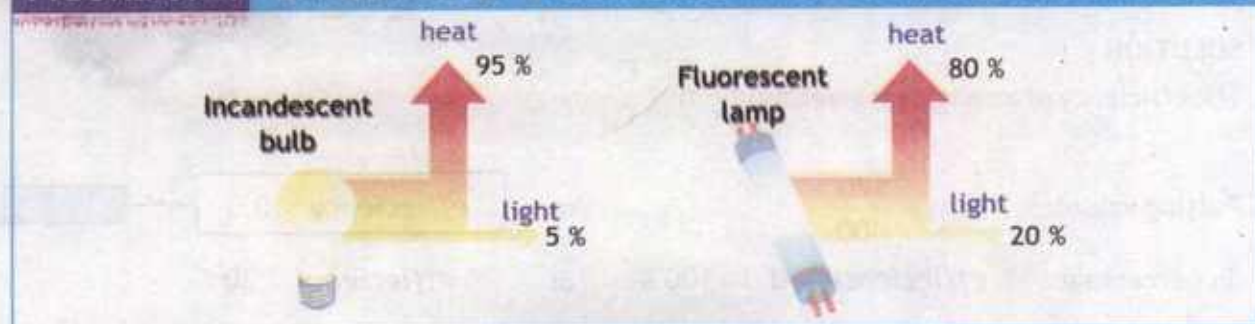
$$\eta = \frac{E_o}{E_i} \times 100\% \quad \text{--- 6.9}$$

The correlation between power and efficiency becomes apparent when considering the output power of an energy conversion process. The output power ' P_{out} ' of a given system is directly proportional to its input power ' P_{in} ' through the efficiency ' η ' factor:

$$P_{out} = \eta \times P_{in} \quad \text{--- 6.10}$$

Equation 6.10 clearly demonstrates that the output power is a fraction of the input power, determined by the efficiency of the system. In the event that the system operates at 100% efficiency ($\eta = 1$), the output power will be equivalent to the input power. However, in practical applications, energy is often dissipated as waste heat or in other forms, resulting in efficiencies lower than 100%.

FIGURE 6.21 EFFICIENCY OF INCANDESCENT BULB AND FLORESCENT LAMP





UNIT 6

WORK AND ENERGY

Efficiency maximization plays a pivotal role in energy systems as it allows for optimal utilization of resources while minimizing energy wastage.

An incandescent light bulb is designed to provide light energy. Unfortunately, it also produces a lot of thermal energy while in use.

In fact, only about 5% of the electrical energy delivered to the bulb transforms to light energy; the rest becomes waste thermal energy. We say that the incandescent light bulb is only 5% efficient. A fluorescent lamp is about 20% efficient of converting electrical energy into light as shown in the figure 6.21. It is not possible to have a machine with 100% efficiency, because friction lowers the efficiency of a machine. Work output is always less than work input, so an actual machine wasting some of input energy as heat (which is not required) cannot be 100% efficient. Typical efficiencies of energy transformation technologies are given in the table 6.3.

TABLE 6.3 : TYPICAL EFFICIENCIES OF ENERGY TRANSFORMATION TECHNOLOGIES

DEVICE	EFFICIENCY (%)
electric generator	98
hydroelectric power plant	95
large electric motor	95
home gas furnace	85
wind generator	55
fossil fuel power plant	40
automobile engine	25
fluorescent light	20
incandescent light	5

EXAMPLE 6.6: EFFICIENCY

A petrol engine in-takes 400 J of fuel energy and does only 120 J of useful work. How efficient is this petrol engine?

GIVEN

Input energy = Input work $E_{in} = 400 \text{ J}$

Output energy = Output Work $E_{out} = 120 \text{ J}$

REQUIRED

Efficiency = ?



SOLUTION

The efficiency of an engine is given by:

$$\eta = \frac{E_o}{E_i}$$

Putting values: $\eta = \frac{120}{400}$

or

$$\text{efficiency} = 0.3$$

Answer

In percentage: % efficiency = $0.3 \times 100\%$

or

$$\% \text{ efficiency} = 30\%$$



Therefore, such a petrol engine will be 30 % efficient. This means that such an engine will only do about one quarter of useful work of the provided input fuel. Which means that such a petrol engine will be 25 % efficient. It will only do one quarter of useful work of the provided input fuel.

SUMMARY

Work is force multiplied by distance moved in the direction of the force.

Energy is the capacity of a body to do work.

Kinetic Energy is the energy of an object due to its motion and is given by $E_k = \frac{1}{2} m v^2$.

Potential Energy is a form of energy that an object possesses due to its position or state.

Gravitational Potential Energy is a specific type of potential energy associated with an object's position in a gravitational field. It arises because of the gravitational attraction between the object and the Earth (or another massive celestial body) and is given by $E_{p,grav} = mgh$.

Energy Conversion refers to the process of changing one form of energy into another.

Law of Conservation of Energy is a fundamental principle in physics that states that the total energy of an isolated system remains constant over time. In other words, energy cannot be created or destroyed; it can only change forms.

Energy Resources are substances or systems from which we can extract energy for various purposes, such as electricity generation, heating, and powering machinery.

Non-renewable Energy Resources are finite sources of energy that cannot be easily replaced on a human timescale. Examples include fossil fuels (coal, oil, natural gas) and nuclear fuels.

Renewable Energy Resources are sources of energy that are naturally replenished on a human timescale. They include sunlight, wind, rain, tides, waves, geothermal heat, and biomass.

Perpetual Motion Machine is a hypothetical device that can operate indefinitely without an external energy source.

Fossil Fuels are hydrocarbons, primarily coal, fuel oil, or natural gas, formed from the remains of dead plants and animals over millions of years.

Nuclear Fuel is a material that can be used to generate nuclear energy through nuclear reactions, typically involving the release of energy from the nucleus of an atom.

Hydroelectric Resources involve the generation of electricity by harnessing the energy of flowing water, often from rivers or dams.

Power is the rate of doing work or rate of conversion of energy. $P = W/t$.

Efficiency is the ratio of useful energy or work output to the total energy or work input.



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option.

1. The unit of work or energy joule (J) is equal to:
A. horsepower B. watt metre C. watt second D. newton second
2. A car, an elephant and a cricket ball have same kinetic energies. Which of these will have a greater speed?
A. Car B. Elephant C. Cricket ball D. all have same speed
3. A ball weighing 50 N is lifted to a height of 5 metre. The potential energy stored in it is:
A. 10 J B. 25 J C. 45 J D. 55 J
4. What is the power utilized when 100 J of work is done in 5 s.
A. 10 W B. 20 W C. 105 W D. 500 W
5. The SI unit of power is
A. joule B. watt C. horsepower D. erg
6. A 4 kg body is thrown vertically upward from the ground with a velocity of 5 m/s. If friction is neglected its kinetic energy just before hitting the ground is
A. 25 J B. 50 J C. 75 J D. 100 J
7. A ball is thrown downward with an initial velocity, its
A. E_k increases & E_p decreases B. E_k decreases & E_p increases
C. Both E_k & E_p increases D. Both E_k & E_p decreases
8. The type of energy derived from heated ground water is:
A. tidal energy B. geothermal energy
C. hydroelectric energy D. nuclear energy
9. A weight lifter of power 1960 watt lifts a load of mass 'M' from the ground to a height of 2 m in 3 second. 'M' is:
A. 100 kg B. 200 kg C. 300 kg D. 400 kg
10. Which one is renewable source of:
A. Coal B. Natural gas C. Sunlight D. Uranium
11. One unit of horsepower is equivalent to:
A. 756 watt B. 716 watt C. 736 watt D. 746 watt
12. A practical engine cannot have an efficiency equal or greater than:
A. 0 B. 0.5 C. 0.8 D. 1



13. A heavy and a lighter object have same momenta. The object with greater kinetic energy is:
A. lighter B. heavy C. same kinetic energy D. either a or b
14. A force is acting on body but causes no displacement. The work done on the body is
A. positive B. negative C. zero D. infinite
15. A box is taken to the second floor of a building by doing some work. This work converts to
A. kinetic energy B. potential energy C. heat energy D. sound energy

SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

1. A car is moving with a constant speed along a straight road. Is there any work done on the car?
2. Does the work done in raising a box up in a building depend upon how fast it is raised up? Through which path? To how much height?
3. Work done on the body either speeds it up, slows it down. Keeping it mind, explain how much work is done by centripetal force on an orbiting satellite?
4. A car has Kinetic energy ' E_k '. By what factor its kinetic energy would change, if its velocity is doubled?
5. A bullet is fired from gun, bullet penetrates into sand wall and it stops. Where does its kinetic energy used?
6. An LED light bulb has efficiency of 80%. Does it violate conservation of energy principle?
7. How does using renewable energy sources contribute to reducing environmental impact compared to non-renewable sources?
8. Will we eventually rely entirely on renewable energy sources? Why or why not?
9. How can increasing the power of a machine impact its energy consumption?
10. A perpetual engine has an efficiency equal to 1. Why it will not work?

LONG RESPONSE QUESTIONS

QIII. Give an extended response to the following

1. Define work and its unit. Describe the conditions for maximum and minimum work.
2. What is kinetic energy? Derive its expression by using graphical analysis.
3. What is potential energy? What are its different types? Show that gravitational potential energy is equal to the product of mass ' m ', gravitational field strength ' g ' and height ' h '.
4. What is meant by energy conversion and energy conservation.
5. Describe how useful energy may be obtained from natural resources.
6. Differentiate between renewable and non-renewable energy sources with examples. Write down advantages and disadvantages of each in reference to their availability and environmental impact.



7. Describe the processes by which energy is converted from one form to another with reference to fossil fuel energy, hydroelectric generation, solar energy, nuclear energy, geothermal energy, wind energy and biomass energy.
8. Describe the process of electricity generation by drawing a block diagram of the process from fossil fuel input to electricity output.
9. Define power. What is the relation of its SI unit with horse power?
10. What is efficiency. Why is it important for cars or electronic devices to be designed with high efficiency? Why efficiency of machines can never be unity or 100%?
11. Explain by drawing energy flow diagrams through steady state systems such as Filament lamp, a power station, a vehicle traveling at a constant speed on a level road.

NUMERICAL RESPONSE QUESTIONS

QIV. Solve the following.

1. Calculate the work done in pushing a box with 150 N through distance of 5m.
(Ans. 750 J)
2. A boy weighing 75 N jumps up and gains 300 J of gravitational potential energy. Find the height to which the boy will rise.
(Ans. 4 m)
3. A 5 kg steel ball is dropped from the top of a 12 m high tower. What is kinetic energy of the ball on hitting the ground? With what velocity will it hit the ground? (Neglect air resistance).
(Ans. 588 J and 15.3 m/s)
4. A 2.0 kg rock is dropped from 20 m tall building. What is the Kinetic and gravitational potential energy when the rock has fallen 15 m.
(Ans. $E_k = 294$ J and $E_{p, grav} = 98$ J)
5. A rocket with a mass of 800 g is launched vertically upward with an initial speed of 30 m/s. (a) Assuming no air resistance, calculate the maximum height the rocket would reach. (b) If, due to air friction, the rocket only rises to 25 m, determine the work done against air resistance.
(Ans. (a) 45.92 m, (b) -164 J)
6. A 2 hp electric motor gives energy to a system that lifts a load of 100 kg to height of 10 m in 1.5 s. Calculate (a) Input (work done by motor on system) (b) Output (load lifted by system) and (c) Efficiency of the system.
(Ans. (a) 2238 J, (b) 980 J and (c) 22.8 %)
7. What horsepower (hp) is required to pump up 2500 kg of water to 100 m height in 5 minutes?
(Ans. 95 hp)