Chapter -11
Work, Energy and Power

In routine life, while performing many activities, we do work by using force e.g.displace an object from one place and put it at another place, push a vehicle, walking, running etc. We need energy to perform work. We and animals get energy from food that we eat while machines gets energy from fuel.Power is also an important concept associated with work. We consider a person (or engine etc) more powerful than the other if that person (or engine) could perform the work faster than the other. In this chapter we shall study work, energy and power.

11.1 Work

When by the application of force the position of an object at rest is changed or velocity of a moving object is changed then it is said that work is done.

Scientifically, work is defined as multiplication of force and displacement of the object in the direction of force.

Work =Force × Displacement in the direction of force

$W = F \times S$

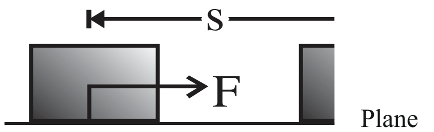


Fig 11.1 Work

If the direction of force is different than the direction of displacement of the object then the component of force along the direction of the displacement is used to calculate work.

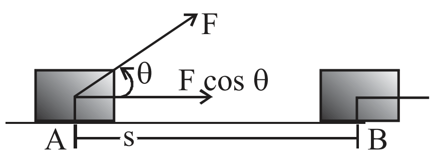


Fig. 11.2 Work when force and displacement are at an angle θ

Let force F is acting at point A in such a way that during the displacement of object till point B the direction of force is making an angle θ with respect to the direction of displacemet. The component of force along the direction of displacement

$= F.\cos\theta$

Thus the work done

W = (Component of force along the direction of displacement) × displacement

$= F\cos\theta \times s$

$= FS\cos\theta$

or $W = \overline{F}.\overline{S}$

Work is a scalar quantity and its value can be positive or negative. If force or component of force is along the direction of displacement then performed work is positive. On the contrary, if force or component of force is opposite to the direction of displacement then the work done is negative.

We shall try to understand this with the help of a few simple examples. For work to be done the force must produce displacement. Let us assume that you try to displace a drum filled with wheat or an almirah filled with books and you apply full force but you could not move them. This means that you did not perform any work even though you got tired because of the labour. Similarly, if you keep standing for some time with weight in your hand and in the process you get tired even then scientifically you did not do any work. When you displace a book kept on a table or you lift pen or you carry a trolley in a mall then you do work. During these activities the object is diplaced because of the force applied by you.

When applied force and resultant displacement are in the same direction then the work done is equal to the mutliplication of force and displacement. Here the displacement 's' is that displacement during which force is acting on the object. The moment force is not in contact with the object there will be no work even if object keep moving. For example, if you pull trolley along the surface (or horizontal) then object is displaced along the direction of displacement. Thus work done is equal to the multiplication of the force applied to pull the trolley and the resultant displacement.

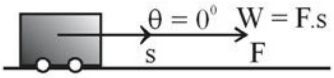


Fig 11.3 (a)

Now we think of a condition where an object with engine is moving with uniform speed.

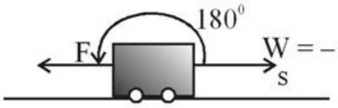


Fig 11.3 (b)

If we apply a force along the direction opposite to the direction of movement of trolley then the trolley shall stop after a certain distance. In this condition the applied force and displacement are opposite to each other making an angle 180°.

Thus work done $W = F.s\cos\theta$

$= -F.s. \quad (\because \cos\theta = \cos 180^o = -1)$

When driver applies break to reduce the speed of a moving car or to stop a moving car then force and displacement are opposite to each other.

If an object of mass m falls towards earth from height of 'h' then because of gravitational acceleration 'g' the force acting on the object will be

$F = mg$

and displacement will be $= h$

As the object is falling downwards and the force is also vertically downwards thus, $\theta = 0$

Hence work done by gravitational force $= mgh$

If the force acting an object is at an angle of 90° from its displacement then $\theta = 90^o$ and work done will be zero $(\because \cos\theta = 90^o)$. When an object is pulled from point A to point B on a plane surface then no work is done by the gravitational force mg $(\because \theta = 90^o)$. In this case we have to work against the friction to displace the object (Fig. 11.4 (a))

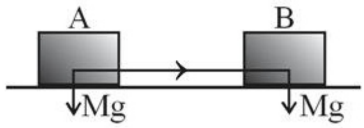


Fig 11.4(a) Work against the friction

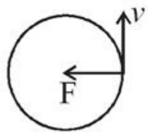


Fig 11.4 (b) Circular motion

Fig 11 Force perpendicular to displacement

Similarly in uniform circular motion the centripetal force on moving object acts perpendicularly and hence no work is done (Fig. 11.1(b)).

11.2. Unit of Work

If force is in Newton and displacement in meters then the unit of work is Joule.

Work = Newton × meter = Joule

Thus if an object is displaced 1 meter by applying a force of 1 Newton then the work done shall be 1 Joule.

J = N × m

If force is in dyne and displacement in centimeters then the work done is in erg.

Work = dyne × cm = erg

1 Joule = 1 Newton × 1 meter

$= 10^5$ dyne × 10^2 cm

$= 10^7$ erg

Example 1 : During a tour you put a bag of 12 kg from ground to your back at 1.5 meter height. Calculate the work done assuming g = 10 m s^{-2})

Solution: Mass of bag m = 12 kg

displacement h = 1.5 m

work W= F s = mgh = 12 kg × 10 m s^{-2} × 1.5 m

= 180 Nm

= 180 J

Work done on bag = 180 Joule

Example 2 . A person is pullig an object with a rope and exerting 5 N force such that the rope is making an angle 30° from the horizontal. Calculate the work done in displacing this object to 20 m (cos 30° = 0.866 or $\cos 30^o = \frac{\sqrt{3}}{2}$)

Solution: Force F = 5 N

Displacement s = 20 m

Angle of displacement & force = 30°

Work $= Fs\cos\theta$

= 5 N × 20 m × cos 30°

= 100 × 0.866 J

= 86.6 J

Thus work done by the person = 86.6 Joule

11.3 Energy

You might have observed that running water carry away with it wooden logs and trees are uprooted in cyclonic wind. When you hammer a nail placed perpendicularly on wooden surface then the nail goes inside the wood. Wind turbine rotates because of wind.

These observations lead us to think that moving objects have the capacity to do work. When we lift an object to a particular height then the object gains capacity to work. When a child wind the key of a toy and put it on a plane surface then the toy starts moving. In that way different objects gain capacity to work by different means.

When work is done by capable object then the object looses its energy and the object on which work is done gains energy. Any object having energy can apply force on other objects and can transfer some or all of its energy to other objects. The other object gains the energy and develops capacity to work and can even move. In that way a part of the energy of the first object is transferred to the other object.

An object's capacity to work is called energy. Energy of an object is measured by the work that the object is capable to do. Energy is required to do any work. Thus the work done is a measure of energy and hence the unit of energy is same as the unit of work. Energy is also a scalar quntity. If 1 Joule of work is done then the energy required will be 1 joule.

Types of energy

Energy is available in different forms like mechanical energy, light energy, electric energy, thermal energy, nuclear energy, chemical energy etc. Sun is the largest source of natural energy for us. Energy can also be obtained from various natural incidences like tides, flow of rivers, wind etc. A few of the forces of energy are as follows.

Mechanical energy - Energy of an object because of its motion, position or both is called mechanical energy.

Heat energy - Heat energy is because of movement of tiny particles because of heat like in fire chimney. These tiny particles, mostly atoms, molecules or ions in gases, liquid or solids, transfer energy from high temperature to low temperature.

Chemical energy - Energy received through chemical reactions is known as chemical energy. Battery, food, coal, LPG etc have chemical energy.

Electrical energy - Energy produced by electrical charges is called electrical energy. We use electrical appliances at home that are operated with the help of electrical energy.

Gravitational energy - Objects get attracted towards earth because of its gravitational force. Energy produced in objects because of this is called gravitational energy. Generally it is the potential energy held by an object because of its high position compared to a lower position. Water flow from higher level to lower level in waterfalls and rivers because of gravitatioal energy.

Nuclear Energy - Energy released during nuclear fission and nuclear fusion reactions are called nuclear energy.

All types of energies are mostly in two forms-kinetic energy and potential energy.

In this chapter we shall study mehcanical energy, kinetic energy, potential energy and electrical energy.

11.4 Mechanical energy

Mehanical energy of an object is equal to the sum of its kinetic energy and potential energy. For example when we hammer a nail on a wooden object then following actions take place.

1. Hammer has potential energy because of its weight.
2. When we lift the hammer we work on the hammer and thus the potential energy of hammer is increased.
3. When we pound the hammer on nail then because of movement it acquires kinetic energy and helps in driving the nail into the wooden object.

In this process of driving the nail into the wooden object the sum of kinetic energy and potential energy acquired by the hammer is known as mechanical energy. It helped in doing work.

Fig 11.5 (a) Pounding a nail by hammer

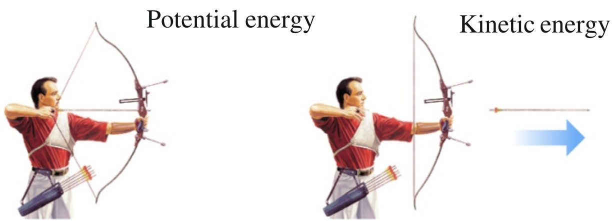


Fig 11.5 (b) Mechanical energy in a bow

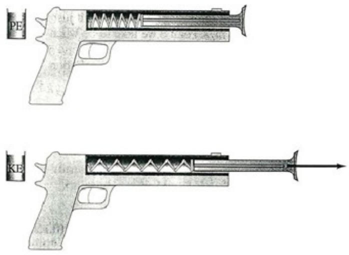


Fig 11.5 (c) Dart out of a toy pistol

Fig 11.5 Mechanical energy

Mechanical energy in a stretched bow is because of its elastic potential energy. Arrow, when released from bow, travels distance because of this energy. A moving car has mechanical energy because of its motion (kinetic energy). Similarly when a dart is pressed in a toy pistol then the spring inside the pistol is compressed and acquires potential energy. When trigger is pressed the spring is released from compression and the dart travels a long distance.

11.5 Kinetic energy

The energy associated with an object because of its motion is known as kinetic energy. A fruit falling from a tree, water flowing in a river, a flying plane, moving car, flying bird, wind etc are able to do work because of the kinetic energy associated with them.

Fig. 11.6 (a) Running Children

Fig 11.6 (b) Galloping horse

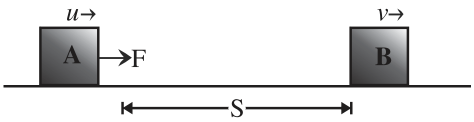


Fig 11.7 Kinetic energy

In order to measure the energy associated with a moving object we calculate the magnitude of the work done to bring that object to rest. Similarly the work done on a body to bring it from rest to a certain speed v is equal to the kinetic energy at speed v.

If an object of mass m is moving with a uniform velocity u and a force F is applied on it in the direction of motion in such a way that the object has displacement 's'. If the velocity of the object changes to v because of the work done and the acceleration is 'a' then from the third law of motion

$$v^2 - u^2 = 2as$$

or acceleration $a = \frac{v^2 - u^2}{2s}$

From the second law of Newton

F=m a

or $F = m.\left(\frac{v^2 - u^2}{2s}\right)$

so $F.s. = \frac{1}{2}m\left(v^2 - u^2\right)$

$W = F.s.$

So $W = \frac{1}{2}m(v^2 - u^2)$

So the work done by the object

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

Thus we see that the work done is equal to the change in kinetic energy of the object.

If the inital velocity of the object is zero i.e. if the object starts from rest and attains velocity v then (Initial kinetic ennergy is zero)

Hence the work done $W = \frac{1}{2}mv^2$

We can say that kinetic energy of an object of mass m moving with uniform velocity v is

$$E_k = \frac{1}{2}mv^2$$

Kinetic energy is always positive and depends upon the mass and the velocity of the object. It does not depend upon the direction of movement of object.

Example 3 An object moving with a uniform velocity and is having kinetic energy 2500 J. If the mass of the object is 50 kg then find the velocity of moving object.

Solution: Kinetic energy of the object $E_k = 2500$ (J)

Mass of the object $m = 50kg$

Velocity of the boject $v = ?$

The Kinetic energy $E_k = \frac{1}{2}mv^2$

or $v^2 = \frac{2E_k}{m} = \frac{2 \times 2500 \text{ J}}{50\ Kg} = 100$

$\therefore \quad v = \pm 10\ m/s$

As kinetic energy does not depend upon the direction of motion of the object and thus velocity of the object is 10 *m/s*

Example 4. A bullet fired from a gun is having a velocity of 500 m/s. If the mass of the bullet is 100 gm then what will be its kinetic energy?

Solution: Mass of the bullet m=100 gm=0.1 kg

Velocity $v = 500\ m/s$

Thus kinetic energy $E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.1kg \times (500\ m/s)^2$

$= \frac{25000}{2} J$

$= 12500\ J$

$= 12.5 \text{ KJ}$

The kinetic energy of the bullet will be 12.5 KJ.

Example 5. A motorcycle of mass 100 *kg* is running with a velocity of 20 km/h. How much work will have to be done to increase the velocity of the motor cycle to 40 km/h?

Solution: Mass of the motorcycle $m = 100\ kg$

Initial velocity $u = 20\ km/h = \dfrac{20 \times 1000}{60 \times 60} m/s$

$= 5.56\ m/s$

Final velocity $v = 40\ km/h = \dfrac{40 \times 1000}{60 \times 60} m/s$

$= 11.11\ m/s$

Work done=Final kinetic energy - initial kinetic energy

$$= \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$= \frac{1}{2}m(v^2 - u^2)$$

$$= \frac{1}{2} \times 100\ kg \times \left[(11.11\ m/s)^2 - (5.56\ m/s)^2\right]$$

$$= \frac{1}{2} \times 100 \times (123.43 - 30.91)\ \text{J}$$

$$= \frac{1}{2} \times 100 \times 92.52\ \text{J}$$

$$= 4626\ \text{J}$$

$$= 4.63\ k\text{J}$$

11.6 Potential energy

We all have experience that when any object is released from any height the object starts falling towards the earth. Similarly, when a spring is released after compressig it then the spring regains its initial state and if we release the spring after stretching it then again it regains its initial state.

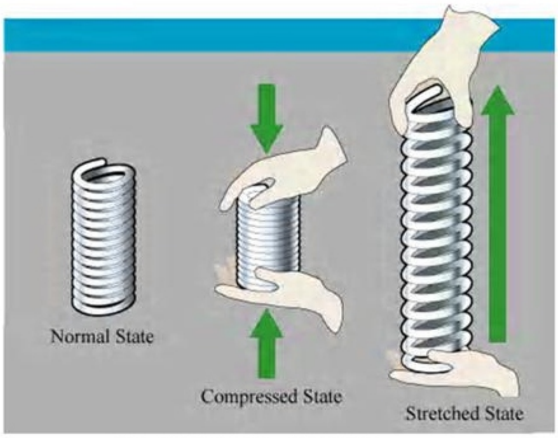


Fig 11.8 Potential Energy

In these examples we observe that some work is done by the object while falling towards earth or by the spring while regaining its initial state. This state is possible only if the object is capable of doing work when it is relesed from one state. When an arrow is released from a stretched bow, the arrow travels a long distannce before coming to rest. Obviously, the stretched bow has sufficient energy to do the work.

Potential energy is that energy of an object that is because of its position. Because of this energy the object attains capability to do the work. Work done to bring object from initial state to new state is a measure of potential energy of the object in new state.

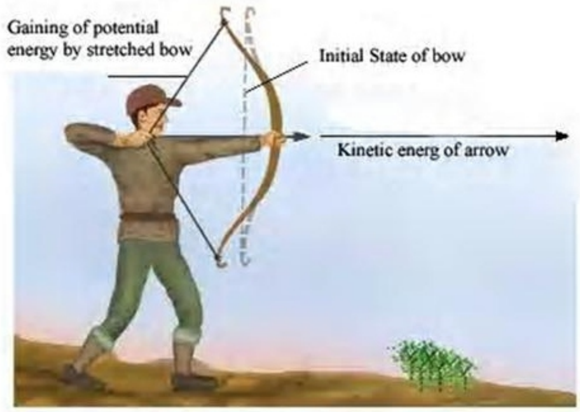


Fig. 11.9 Potetial Energy

We do work to stretch the bow and the corresponding energy will be the potential energy of the stretched bow. In the same manner we do work in stretching a rubber band, compressing or stretching a spring and lifting an object to height. The energy transferred to the object because of this work is stored in the object as potential energy.

Potential energy in gravitational field

When we uplift any object from the surface of the earth then we have to do work against the gravitational acceleration. This work done on the body increases the energy of the object and part of the potential energy of that object.

Maximum force required to uplift the object from the surface of the earth is equal to the weight of the object. If an object of mass m is lifted to a height of h from the surface of the earth then minimum force required is equal to its weight mg.

Potentil energy of the object at height h = work done against the gravitational force

= Force × displacement

= $mg\ h$

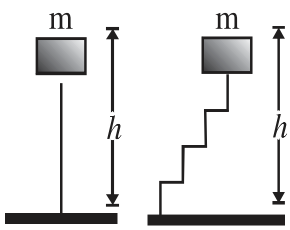


Fig. 11.10 Potential energy

Therefore potential energy of an object of mass m at a height h from the surface of the earth will be mgh. Potetial energy depends upon the height of the object from the earth and does not depend upon the path to reach to that height.

Potential energy of a simple pedulum

When the bob of a simple pedulum is displaced to one side of its equilibrium position then its centre of gravity is lifted up. The work done in the process is stored as potential energy of the pedulum. When bob is released from this position (B in fig 11.11) then it returns towards equilibrium (A in fig. 11.11). Its potential energy decreases during this movement from B to A. At A its potential energy is lowest and because of speed of bob it has highest kinetic energy at point A.

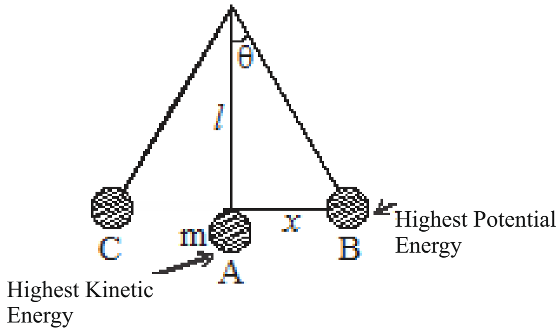


Fig. 11.11 Simple Pendulum

Because of this kinetic energy the pendulum moves towards other side of the equilibrium. During this movement its kinetic energy decreases and again its potential energy increases. At point C the speed of pendulum is zero. At this point the kinetic energy of the pendulum is zero and its potential energy is highest. The pendulum returns to its equilibrium position because of this acquired potential energy.

Let m is the mass of the bob and l is the legth of string to which it is suspended. The potential energy for displacement x of the bob.

$E_p = \frac{1}{2}\frac{mg}{l}.x^2$ (See example 13)

If $k = \frac{mg}{l}$ ($\because$ m, g and l are constant)

then potential energy $E_p = \frac{1}{2}kx^2$

Similarly, when a spring, whose spring constant is k, is displaced by distance x from the equilibrium within the elastic limits, then the potential energy of the spring will be $\frac{1}{2}kx^2$

$$E_p = \frac{1}{2}kx^2$$

Example 6. A student lifts an object of mass 3 kg from the surface of the earth and put it on a table at height of 50 cm. Calculate the potential energy of the object. (Gravitational acceleration $g = 10\ m/s^2$)

Solution: Mass $m = 3\ kg$

Height $h = 50\ cm = 0.50\ m$

Thus potential energy $E_p = mgh = 3 \times 10 \times 0.5 = 15\,J$

Example 7. Spring constant of a spring is $k = 6 \times 10^3 N/m$. Calculate the work done to stretch it by 1 cm.

Solution: Spring constant $k = 6 \times 10^3 N/m$

$x = 1\,cm = 0.01\,m$

Work done in stretching the spring = acquired potential energy

$$= \frac{1}{2}kx^2$$

$$= \frac{1}{2} \times 6 \times 10^3 \frac{N}{m} \times (0.01m)^2$$

$$= 3 \times 10^3 \times 0.01 \times 0.01\,J$$

$$= 0.3\,J$$

Therefore 0.3 J work will have to be done to stretch the sprign by 1 cm.

11.7 Electrical energy

Energy contained in the charged particles is called electrical energy. When particles are charged then electric field is developed around the charged particles. This electric field exerts force on other nearby charged particles and causes motion in them and energy is transmitted.

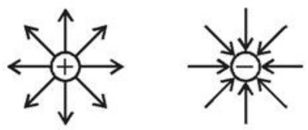


Fig 11.12 (a) Positive and negative electric field

Electric field produced by positively charged particles repel s other positive charges while electric field produced by negatively charged particles attracts other positive charges. According to conventionn the direction of electric field always points towards that direction where a positively charged particle will move in the field. Therefore, electric field because of positively charged particles is shown by outward arrows around a positive point while the electric field because of negatively charged particles is shown as inwards arrows around a negative point.

Because of the position of the charged particles they have potential energy. When force is applied on these particles by electric field then the particles move in certain direction.For example, if a positively charged particle is to be taken away from a negative source then we shall have to apply external force. In this process the potetial energy of positive particle will increase. As soon as external force is removed the particle will move in the electric field from higher potential to lower potential. Similarly, the positively charged particle will naturally move towards negatively charged source. In this process the potential energy of charged particle will covert into kinetic energy. We shall get this energy as electrical energy.

In routine life we use electrical energy at home in the form of electric current and electric potential (voltage). Equipments like bulb, fan, electric iron, hair dryer, geyser, mobile etc require electrical energy to operate. Once electrical energy is converted to other form then we get light, heat, kinetic and other energies. Electricity is produced by different processes. In 1831, Michael Faraday invented electric generator. Even now electricity is mainly, produced in a generator by a wire or copper disk between magnetic poles.

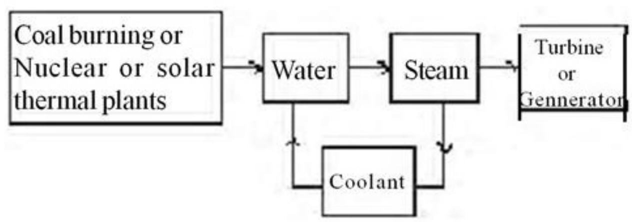


Fig 11. 12(b) Block diagram of power plant

Now-a-days different types of electricity generation plants (Power plants) are used for production of electrical energy. A few of them are as follows.

1. **Coal Power Plant -** In power plants running on coal, the chemical energy of coal is released by

buring it and we get thermal energy. This heat is used to convert highly pure water into steam. The steam then turns the turbine and the generator, attached with the turbine, starts producing electricity.

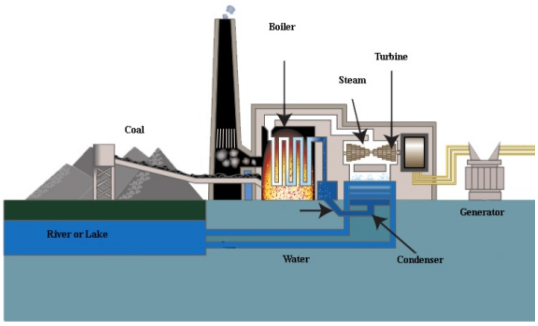


Fig 11.13 (a) Coal power Plant

2. Nuclear Power Plant - In these power plants the nuclear fission is used as fuel and thermal energy is produced. This thermal energy converts water into steam and the steam then propel turbines. Electricity is produced by the generator combined with turbines. The procedure for converting thermal energy to electrical energy remains similar as the coal power plant.

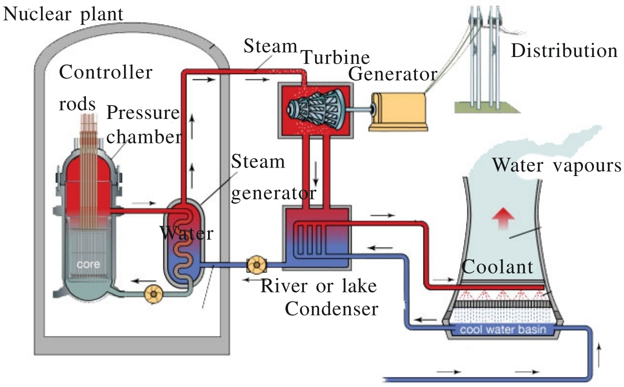


Fig 11.13(b) Nuclear Plant

3. Hydro electric power plant - In hydroelectric plants potential energy of water is increased by increasing the height of water level mostly by forming dams. This energy is converted to kinetic energy by flow of water and is fed to turbine. The turbine rotates and associated generator produces electrical energy.

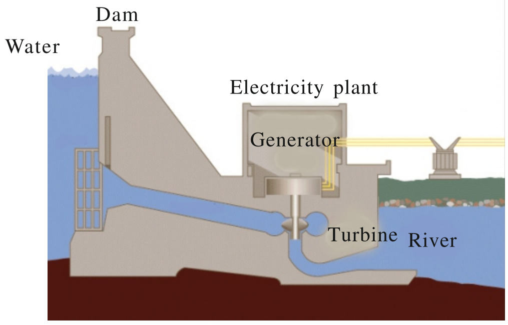


Fig 11.13 (c) Hydro power plant

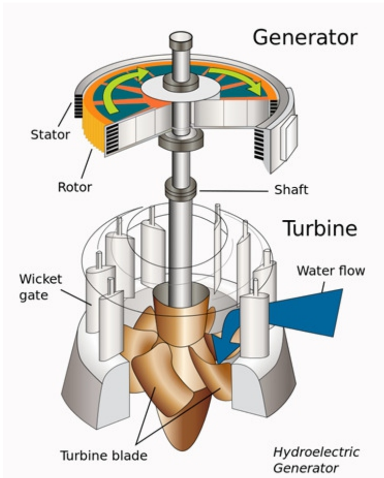


Fig 11.13(d) Turbine & generator

4. Wind power plant - In a wind mill the turbine is rotated by the kinetic energy of wind and generator associated with turbine produces electricity. This renewable energy source is most environment friendly as compared to other power plants.

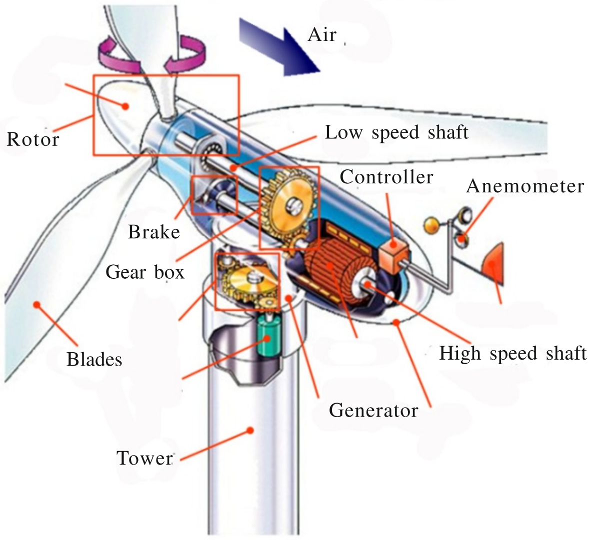


Fig 11.13 (e) Wind power plant

5. **Solar thermal plant -** Energy from Sun is concentrated with the help of lens and mirrors and them it is converted into heat. The heat is used to get steam. This steam rotates turbine and associated generator produces electricity.

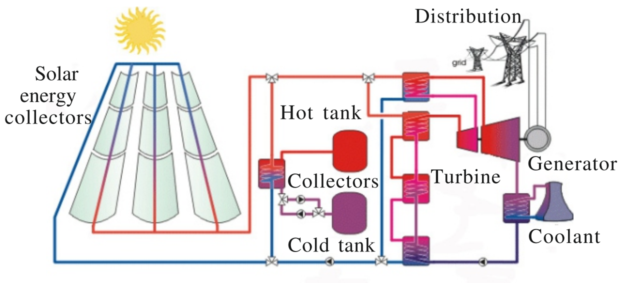


Fig. 11.3(f) Solar thermal generator

6. **Solar photovoltaic electricity plant -** In these plants solar penels, made of solar photo voltaic cells are used at open spaces and roof tops. When Sun light is incident on the photovoltaic cells of solar panel then these cells absorb the light photons and electrons jump to the excited states. These charged particles provide electric current in the circuit. Presently such small solar plants are being installed on roofops of many houses. Government is also providing two way meter for such houses so that excess electricity generated by the home solar plant can be trasferred to electricity board. The electricity board gives money for this electricity at the prescribed rate.

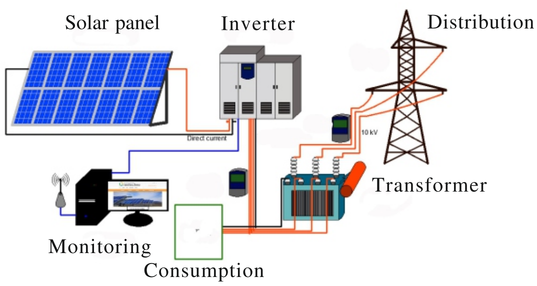


Fig 11.13 (g) Solar Photo Voltaic plant

Generally, we see and use petrol and diesel based generators in many offices and commercial establishments. At home we use inverters that has batteries in

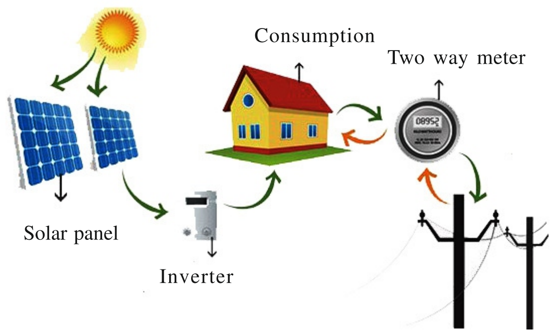


Fig 11.13 (h) Home Solar energy plant

Fig 11 Various electricity plants

it. In batteries chemical energy is transformed into electrical energy. Once discharged, the inverter batteries can be recharged.

A few examples of electrical energy

a. In a car the battery provides electrons as a result of chemical reaction and these electrons move as electric current. These moving charge provides electrical energy to the electrical circuitory of the car.

b. When we switchon a light bulb the electric current reaches to the bulb through electric circuit. In the filament of the bulb the speed of electric charge is slow and temperature of filament increases. When the temperature of the filament reaches a particular value the light energy is emitted.

c. In mobile the chemicl energy of battery is given to electrical charges. The charges move. This electrical energy goes through the circuit of the mobile and electricity flows in the mobile.

d. When electric heater or oven is connected to electric circuit then the moving charge enters the equipment. In filament, this electrical energy is converted to heat and this heat is used for cooking food or other useful work.

e. In our body a part of the energy received from digested food is coverted into electrical energy. This electrical energy reaches to our brain through nervous system. In addition electrical signals are required for heart beats. A signal sent by our brain to any part of the body is in the form of electrical pulses.

11.8 Conservation of energy

According to the theory of conservation of energy the total energy of an isolated system remains constant. Energy can neither be produced nor be destroyed. The energy can only be trasformed from one type to another type.

To understand the concept of energy transformation in a better way we shall analyse the energy transformation process in the compression and stretching of spring. Attach one end of the spring to a wall and fix a rectangular block of mass m to the other end of the spring and place a frictionless horizontal surface below the system.

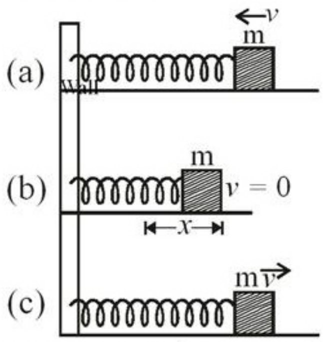


Fig 11.14 Energy transformation in a spring

To compress the spring we push the block towards the wall with velocity v (fig. 11.14 (a)). The kinetic energy of the block is $\frac{1}{2}mv^2$ and because of this energy the block compresses the spring to distance of x from its initial position. If k is spring constant then this compression will generate $\frac{1}{2}kx^2$ potential energy in the spring. Because of this potential energy the spring tries to return to its equilibrium position (initial state) and push the block with velocity v in the opposite direction. Again the kinetic energy of block becomes $\frac{1}{2}mv^2$. The block moves ahead of the equilibrium state (initial state) and stretches the spring because of this knietic energy. This time also kinetic energy and potential energy is transformed as happened during the compression of string. When the block returns to its equilibrium (initial) state after a full cycle then its kinetic energy is same as its initial energy.

When the kinetic energy remains the same as its initial energy after a cycle then such acting forces are called conservative forces. Work done by such conservative forces does not depend on the path and only depends on its initial and final state.

In this complete process the sum of kinetic energy and potential energy remains constant. It is known as mechanical energy. According to the law of conservation of mechanical energy the total mechanical energy of the system remains conserved. If the kinetic energy of the system increases then its potential energy will decreas and vice versa.

If the change in the potential energy and kinetic energy is ΔE_p and ΔE_k respectively then

$$\Delta E_p = -\Delta E_k$$

or $$\Delta E_p + \Delta E_k = 0$$

Total mechanical energy $E_m = E_p + E_k$

In reality the mechanical energy of the system decreases in one cycle. This decrease is because of the non-conservative forces like frictiong viscosity etc. Non conservative forces transform a part of the energy into sound, heat or other dissipative energy form. Thus the form of the energy of the system changes but the total energy of the system remains conserved.

$$E = E_M + E_{heat} + E_{friction} + Other = Constant$$

11.9 Dissipation of energy

When one type of energy is transformed to another type then a part of the energy is dissipated as heat, sound, light etc. From dissipation of energy we mean that during the process of transformation or transmission, a part of the energy is converted in such form that is either not required or not usable by us. Though total energy is conserved but because of this unproductive dissipation we are not able to make one hundred percent efficient system. Energy dissipation occurs mainly through following ways.

(a) Heat Energy -Whenever any work is done then because of friction, resistance by air and other resistances the capability of doing work is reduced. Generally the body, on which work is being done, is heated. Alarge and significant part of dissipated energy becomes unusable as heat energy. In an incandescent bulb most of the energy is lost as heat energy.

(b) Light energy - In most of the combustion and burning processes a part of energy becomes unusable and is lost as light energy.

(c) Sound energy - During collision, friction and other processes a part of energy is dissipated as sound energy. Because of friction the vibration of molecules convert into pressure wave that creates sound.

To understand energy dissipation the best example is electricity that we use at home. Initially electricity is produced where energy is dissipated in different processes. In nuclear power plants, coal power plants, hydro electricity plants, wind wills and other mediums of electricity production heat energy or mechanical energy is produced by different processes. A part of energy is lost during these processes. Steam is produced from the heat energy to rotate the turbine. Mechanical energy of turbine, as kinetic energy, is used to operate the generator. In this process also a part of energy is lost. Turbine helps in electricity production in the generator. Efficiency of a coal plant is around 40%. Electric energy produced by the generator is converted into kinetic energy of electric charges. With the help of conductors this electrical energy is trasmitted to our houses. During the process a part of electrical energy is lost during transmission, distribution and storage. When we switch on a light bulb at home then electric current carry the electric energy to the bulb. The electrical charges give their kinetic energy to the filament of the bulb and heat is produced in the filament. At above certain critical heat of the filament we get light energy. In this process a large part of energy is lost as heat energy. Out of the total chemical energy available in coal a very small fraction is converted as light energy.

In the same manner when diesel or petrol is used in internal combustion engine of vechicles then the chemical energy of diesel or petrol is converted into heat energy. This heat energy creates pressure on the piston and piston starts rotating. This mechanical energy provides kinetic energy to the wheels of vechicles. In this process a part of energy is dissipated as the sound of the engine, as light produced during combustion of fuel, as friction between wheels and road and many such unproductive works. Around one fourth of the efficiency of the fuel is available as usuable energy for engine in vechicles at present.

11.10 Reducing energy dissipation

Energy is very important for our lives and using it properly is the responsibility of all of us. For a developing country like India it is even more important that we fulfil our energy needs with maximum possible efficiency and reduce the energy dissipation.

The more we reduce the energy dissipation as heat, sound, light, friction etc during the process of work, the more energy will be available for productive work. If there are more than one option to complete a task then we shall choose that option that is more energy efficient.

Some energy is dissipated in common household equipmenet like TV, microwave, washing machine etc when they are put on stand by mode when not is use. To save this energy loss we should switch off these equipments when not in use.

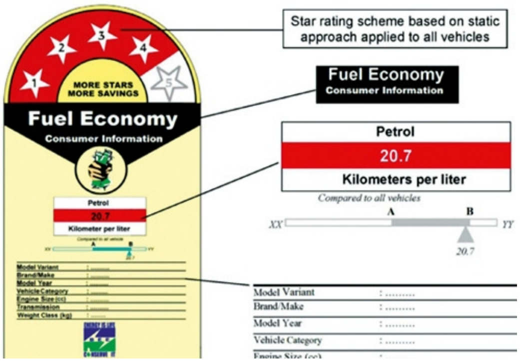


Fig. 11.15 Star rating

Presently many fuel and electric appliances like vehicle, fan, refrigerator, washing machine, air conditioners etc, are coming with star rating. More star rating means more energy efficiency. Energy efficient appliannces use around 30% less electricity. In addition we must purchase the appliance with appropriate capacity. Unncessarily purchasing a high capacity or high power equipment will cost more and will consume more energy.

In order to lower the consumption of electricity at homes we should use CFL and LED lights. A common incandescent bulb has an avergae life of around 1200 hours while average life of CFL is 8000 hours and usable life of an LED is around 50000 hours. A 60 W bulb, a 15W CFL and a 8 W LED gives almost equal light energy but CFL and LED consume very less electricity in comparison to a common incandescent bulb. Using LED will lead to low consumption of electricity and that, in turn, will reduce the emission of carbon dioxide, Sulfur dioxide and other harmful emitters during the electricity production.

In summers and winters a large amount of energy is lost in heat exchange during air conditioning and heating. To reduce this loss due to heat exchange the walls and roofs of houses should have insulators in them. This will also reduce the cost of air conditioning. Now-a- days new technology hollow bricks are being made that reduces the total weight of the building and acts as insulator medium between outer environment and inside atmosphere of building. This reduces the overall cost of air-conditing.

We must also preserve natural energy sources and should use them with maximum possible efficiency. We can use water for different purposes by collecting water during rainy season. Rest of the unused water should be used to recharge the ground water levels so that we can get water with minimum energy through-out the year.

More efficient systems should be used to produce electricity so that emission of harmful and unusable greenhouse gases could be lowered. More and more renewable energy should be for electricity production.

In this way wherever possible we must help in reducing dissipation of energy and increasing efficiency so that we could keep our environment better and could provide quality life to all.

11.11 Power

Till now we have read that the work does not depend upon the way it has been done. Work done in going from point A to point B shall remain same irrespective of the path. Whe one person cover this distance by running in certain time and other person covers the same path in lesser time by runinng faster then we say that the other person is more powerful. Scientifically rate of doing work or work per unit time is called power. Power is a scalar quantity like work. If time t is required to finish a work W then

$$\text{Power } p = \frac{W}{t} = \frac{Work}{Time} = \frac{Joule}{Second}$$

$$\text{Work} = \text{Force} \times \text{displacement}$$

$$\text{So Power } \quad p = \frac{W}{t} = \frac{F \times s}{t}$$

$$\text{But} \quad v = \frac{s}{t}$$

$$\text{Therefore} \quad P = F\,v$$

$$= m\,a\,v$$

Fig 11.16 Examples of Power

Unit of power

In the honour of the inventor of steam engine 'James Watt' the unit of power is given by watt.

$$Watt = \frac{Joule}{second}$$

$$1W = 1\ J/s$$

Sometimes horse power is also taken as unit of power. It is equal to 746 Watt

11.12 Electric power

Just like mechanical power, electrical power is also measured as the rate of doing work. Its unit is watt but most of the time 'Wattage' is also used for electric power in many popular common languages. If a charge Q coulomb passes through a V volt electric potential in time t then

$$\text{Power P} = \frac{\text{Work}}{\text{Time}} = \frac{\text{VQ}}{\text{t}}$$

But Current $I = \frac{Q}{t}\ Ampere$

$\therefore$ Power = V.I Watt

Rate of transportation of electrical energy in eletric circuit is called electrical power. Electric power is mostly produced in electricity generator in different types of power plants. Some times, battery is also used to get electric power.

Commercially, the electric power providing companies charge the electric energy consumption as kilowatt hour. One kilowatt hour is called one 'unit' that can be read in electric meter.

1 unit = 1 Kilowatt hour = 1000 Wh

1 kWh = 1000 W × 60 × 60 s

$$= 3600000\ Ws = 3.6 \times 10^6 \frac{J}{s}.s$$

$$= 3.6 \times 10^6\ J$$

If 1kilowatt (1000 W) bulb is used for one hour then one unit of electricity will be used or if 100 w bulb is used for 10 hours than one unit of electricity will be used.

Example 8 A person of mass 60 kg reaches a height of 5m in 30 seconds. Find the power used by the person $(g = 10\ m/s^2)$

Solution:- Mass of the person $h = 5\ m$

Distance travelled

Time taken t = 30 s

$$\text{Power} \quad p = \frac{W}{t} = \frac{F \times s}{t}$$

$$= \frac{60 \times 10 \times 5}{30}$$

$$= 100\ W$$

Person used 100 W of power

Example 9 Suresh and Ramesh climb a 15 m high hill. Ramesh does the work in 19 seconds while suresh complete this work in 15 seconds. If both of them has mass 38 kg each then find the power used by both of them $(g = 10\ m/s^2)$

Solutio: (i) Power consumed by Suresh

Weight of Suresh = mg= 38 kg × 10 m/s^2

$$= 380\ N$$

height $h = 15\ m$

time $t = 15\ s$

Power $P = \frac{W}{t} = \frac{mgh}{t} = \frac{[380 \times 15]}{15} W$

$= 380\ W$

(ii) Power consumed by Ramesh

Mass of Ramesh $= mg = 38kg \times 10\ m/s^2$

$= 380\ N$

height $h = 15\ m$

time $t = 19\ s$

Power $P = \frac{W}{t} = \frac{380 \times 15}{19} W$

$= 300\ W$

Exampel 10 A lift reaches 300 meter height in 5 minutes. If the combined mass of the lift and the material inside the lift is 1000 kg then find the work done by the lift and power of the lift $(g = 10\ m/s^2)$

Solution: Mass of the lift $m = 1000\ kg$

height $h = 300\ m$

Time $t = 5m = 5 \times 60 = 300\ s$

Work done $= W = mgh = 1000kg \times 10\ m/s^2 \times 300\ m$

$= 3.0 \times 10^6 J$

and Power $P = \frac{W}{t} = \frac{3.0 \times 10^6 J}{300\ s} = 10 \times 10^3 W$

$= 10\ kW$

Example 11 A horse pulls a cart by 7.2 km/hour speed while applying 30 N force at an angle of 60° from the horizontal for one minute. Calculate the work done by the horse and the power used by the horse $\left(\cos 60^o = \frac{1}{2}\right)$

Solution: Force $F = 30\ N$

Speed $v = 7.2 km/h = \frac{7200 m}{60 \times 60 s}$

time $t = 1\ m = 60\ s$

Angle between force and displacemennt $= 60^o$

Distance travelled in 1 minutes =

$= v \times t = \frac{7200\ m}{60 \times 60\ s} \times 60\ s = 120m$

Work done by the horse= $W = F.s\cos\theta$

$= 30 \times 120 \times \cos 60$

$= 30 \times 120 \times \frac{1}{2}$

$= 1800\ J$

Thus power $P = \frac{1800\ J}{60s} = 30\ W$

Example 12 If average power of a refrigerator is 100 W then find the energy used by a refrigerator in a day in electrical unit.

Solution: Power $P = 100\ W = 0.1\ kW$

Time t = 24 h

Energy $= p \times t = 0.1\ kW \times 24\ h$

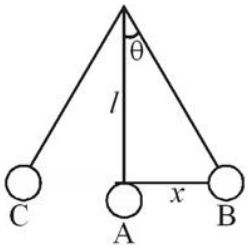
$= 2.4$ kwh

$= 2.4$ unit

Thus the refrigerator will consume 2.4 units of electricity in a day

Example 13 Calculate the potential energy of a simple pendulum of mass m when it is displaced slightly by x from the mean position.

Solutio: At any moment if the pendulum is at a displacement x from meann position then restoration force will be $F = mg\sin\theta$



If the bob is at a distance *l* from the point of suspension and displacement x is negligible in comparison to l then

$$\sin\theta \quad \theta = \frac{x}{l}$$

or $$F = mg.\frac{x}{l}$$

If $\frac{mg}{l} = k$ (as m, g o l are constant)

then $F = kx$

If the bob further slightly displaced by dx then the work done will be

$$dW = F\ dx = kxdx$$

Therefore the work done in displacing the pendulum from its mean position will be given by

$$W = \Sigma kxdx = \int_0^x kxdx$$

or $$W = \Sigma kxdx = \int_0^x kxdx$$

or $$W = \frac{1}{2}kx^2$$

where $k = \frac{mg}{l}$

$$\therefore \quad W = \frac{1}{2}\frac{mg}{l}x^2$$

The work done W will be equal to the change in the potential energy

or $W = \Delta E_p = E_p - E_{p_0}$

Where E_{p_0} is the potetial energy at mean position. For calculation we have assumed it zero.

$$\therefore \quad W = E_p = \frac{1}{2}\frac{mg}{l}x^2$$

or $$E_p = \frac{1}{2}kx^2$$

Important Point

1. Work is defined as displacement of an object by applying force.
   Work = Force × displacement in the direction of force.
2. When force F is applied and displacement is S and the angle between the direction of force and displacement is θ then the work will be given as W=FScosθ
3. Work is a scalar quantity and its unit is Joule.
4. Capacity to perform work is called energy.
5. Mechanical energy has two forms (a) kinetic energy (b) potential energy.
6. If an object of mass m is moving with velocity v then the kinetic energy is given as $\frac{1}{2}mv^2$.
7. Energy of an object because of its position or state is called potential energy.
8. Potential energy of an object of mass m at height h will be mgh. Where g is gravitational acceleration.
9. The work done by the conservative forces does not depend upon the path.
10. Mechanical energy of a system is conserved in the presence of conservative forces i.e.the sum of the kinetic energy and potential energy of the system remains constant.
11. According to the law of conservation of energy the total energy of an isolated system is always constant. Energy can neither be produced nor be destroyed. Energy can only be transformed from one form to another form.
12. When energy transformation takes place a part of energy is dissipated as heat, sound, light etc.
13. Energy associated with charged particles is called electrical energy.
14. Rate of of performing the work is called power.

The unit of the power is watt.

15. Commercial unit of measuring consumption of electric power is unit. 1 kilowatt hour is equal to one electrical unit.

16. One horse power is equal to 746 watt.

Practice questios

Ojbective type questions

1. Unit of work is

(a) Newton (b) Joule

(c) Watt (d) None of these

2. If the angle between the force F and displacement S is θ then the work done will be given by

(a) $FS \sin\theta$ (b) $FS\,\theta$

(c) $FS \cos\theta$ (d) $FS \tan\theta$

3. If an object of mass m is moving with v velocity then its kinetic energy will be given as

(a) mv (b) mgv

(c) mv^2 (d) $\frac{1}{2}mv^2$

4. What will be the potential energy of an object of mass m at a height of h?

(a) mgh (b) $\frac{mg}{h}$

(c) $\frac{mh}{g}$ (d) $\frac{1}{2}mgh^2$

5. Unit of power is

(a) Newton (b) Watt

(c) Joule (d) Newton meter

6. Calculate the work done in taking object of 1 kg mass at 4 m height? (g = 10 m/s^2)

(a) 1 Joule (b) 4 Joule

(c) 20 Joule (d) 40 Joule

7. Total energy of an object falling freely towards earth will

(a) keep on increasing

(b) keep on decreasing

(c) remains constant (b) be zero

8. If the velocity of an object is doubled then what will be its kinetic energy?

(a) one fourth (b) half

(c) double (d) four-time

9. What is the commerical unit of electrical energy

(a) Joule (b) Watt-second

(c) Kilowatt hour (d) kilowatt per hour

10. If a spring is compressed under elastic limit to x distance then what will be the acquired potential energy (spring constant = k)

(a) kx (b) $\frac{1}{2}kx^2$

(c) kx^2 (d) None of these

Very short type questions

1. Define work and write its unit.
2. What is energy? Write the unit of energy.
3. What do you understand by kinetic energy?
4. What is potential energy?
5. Write the law of conservation of energy.
6. What are the common forms in which dissipation of energy takes place?
7. Can you make a hundred precent efficient system?
8. What do you mean by electrical energy?
9. Write name of any three types of electricity plants.
10. What is power? Write unit of the power.
11. Which light will be useful in reducing consumption of electric energy at home?
12. Which important point we should remember while purchasing new electrical home appliances.
13. An object displaces 10 m when 20 N force is applied on it. Calculate the work done. (200 Joule)
14. It takes one minute to uplift a 30 kg object to

the height of 2m. Calculate the power used (10 W)

15. A 60 W bulb is used 8 hour per day for 30 dys then what will be the energy consumption in electic uint? (14.4 units)

Short type questions

1. What do you mean by work? If the direction of displacement is differennt from the direction of the force then how the work is calculated? Explain with example.
2. When force F is applied on an object moving with velocity u then its velocity increases to v. If the distance travelled by the object during this change of velocity is S then calculate the increase in the kinetic energy.
3. What is potential energy? An ideal spring having spring constant k is compressed by x distance derive the formula of acquired potential energy of the spring.
4. An object is moving with a uniform velocity v. If the mass of the object is m then find how much work will have to be done to bring this object to rest?
5. What do you mean by conservation of mechanical energy.
6. An object falls freely from a height and its potential energy is continuously decreasing. Explain how mechanical energy is conserved in this process?
7. How energy dissipaution takes place?
8. From the production of electrical energy to its cosumption at home how does energy dissipation takes place?
9. How work, energy and power are related to each other?
10. What do you mean by electrical energy? How does electrical energy is obtained from a coal power plant?
11. How electrical energy is produced from hydro electric plants?
12. How can we reduce the dissipation of electrical energy?
13. What improvements can be done to make air conditioning more efficient in homes.
14. What is electric power? How the consumption of electric power is calculated? Explain by giving an example.
15. When we switch on a bulb to get light then what energy trasformations take place?

Essay type questions

1. What is energy? Prove that the work performed by an object is equal to the difference between kinetic enegy of the objects in two different states.
2. What is electrical energy? How electrical energy is produced in following of the plants? Explain.
   (a) Hydroelectric plant
   (b) Wind electric plant
   (c) Solar energy plant
3. Total energy of an ideal simple pendulum is conserved. Prove this statement by calculating its energy in differet states of its oscillations.
4. Explain various energy dissipations during transformation of energy. What can be done to reduce the dissipation of energy.
5. Prove that the mechanical energy of a freely falling object remains constant at all points of its path under gravitational field.

Numerical Questions

1. An electron is moving with a velocity of 1.2×10^{6} m/s. If the mass of the electron is 9.1×10^{-31} kg then find its kinetic energy. (6.55×10^{-19} J).

3. A machine takes an object of 40 kg mass to a height of 10 m. Calculate the work done ($g = 9.8\ m/s^2$) (3.92 kJ)

3. An object of mass 6 kg falls from a height of

5 m. Calculate the change in potential energy. ($g = 10\ m/s^2$) (300 J)

4. Spring constant of a spring is 4×10^3 N/m. How much work will have to be done to compress it by 0.04 m? (3.2 J)

5. 0.4 J work is required to be done on a spring to stretch it by 0.02 m. Calculate the spring constant (2×10^3 N/m)

6. Calculate the power used by an engine taking 200 kg mass at 50 m height in 10 seconds. ($g = 10\ m/s^2$) (10 kW)

7. In a house 5 electrical appliaces are used for 10 hours per day. Out of these two appliace are of 200 W and three appliances are of 400 W. Calculate the energy consumed in one day in terms of electrical units. (16 units)

8. An object of 40 kg mass is moving with 2 m/s velocity. Now force is applied on the object such that its velocity increases to 5 m/s. Calculate the work done by the force (420 J).

9. If an object of 50 kg is lifted to 3 m height then calculate its potential energy. Now let it freely fall and find its kinetic energy when it is just at middle of its path ($g = 10\ m/s^2$) (1.5 kJ, 750 kJ)

10. A block of 8 kg is moving with 4 m/s on a frictionless surface. This block compresses a spring and comes to rest. If spring constant is 2×10^4 N/m then find the compression in the spring. (0.08 m)

Answer key

1. (b) 2. (c) 3. (d) 4. (a) 5. (b)
6. (d) 7. (c) 8. (d) 9. (c) 10. (b)