
Energy, work and power

ENERGY:

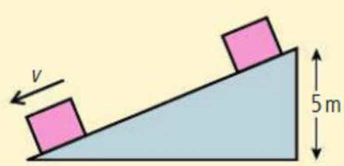
✓ **Different forms of energy:**

- **Internal energy:** The energy of an object due to the internal motion and positions of its molecules is called internal energy. Example: a magnetised object or a hot object has internal energy
- **Gravitational potential energy:** The energy of an object due to its position is called as the gravitational potential energy. Example: Water stored behind a dam.
- **Kinetic energy:** The energy of an object due to its motion is called as kinetic energy. Example: A moving train.
- **Elastic strain energy:** The energy stored in an object when it is stretched or squashed is called as the elastic strain energy. Example: A stretched spring.
- **Nuclear energy:** The energy released when the nucleus of an atom splits or disintegrates is called as the nuclear energy. Examples: nuclear fission, nuclear fusion and radioactive decay.

✓ **Principle of conservation of energy:**

Statement: Energy can neither be created nor destroyed. It can be converted from one form to another. The total amount of energy before and after a change is the same.

A block slides down the frictionless ramp shown in Figure 2.111. Use the law of conservation of energy to find its speed when it gets to the bottom.



As the block slides down the slope it gains KE.

Solution

This time the body loses PE and gains KE so applying the law of conservation of energy:

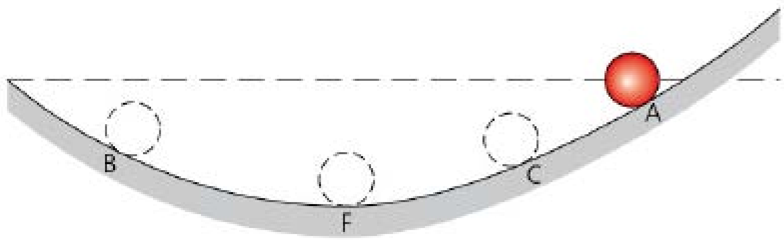
$$\text{loss of PE} = \text{gain of KE}$$

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

So $$v = \sqrt{2gh} = \sqrt{(2 \times 10 \times 5)} = 10\,\text{m}\,\text{s}^{-1}$$

Again, this is a much simpler way of getting the answer than using components of the forces.

Energy transfers:

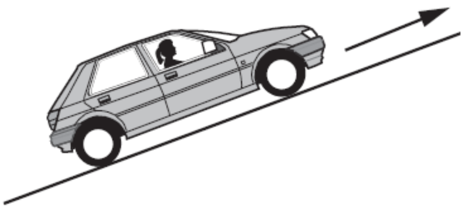


A ball is released from A and rolls back and forth at various positions till it comes to rest at F.

Explaining the energy transfers we have:

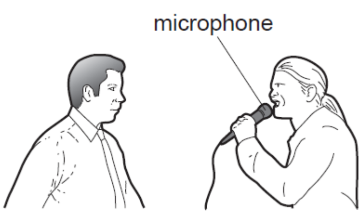
- ✓ As the ball rolls backwards and forwards, there is a continuous transfer of energy between gravitational potential energy and kinetic energy.
- ✓ The ball would only be able to reach the same height as A if there is no force of friction. Because of friction, some kinetic energy is transferred to internal energy in the ball and the slope. So it does not reach the same height. So the ball reaches a max height C on the other side.
- ✓ The ball accelerates as it moves down the slope. When it reaches F, all of the extra gravitational potential that it had because of its position at B has been transferred to the kinetic energy and the ball has its highest speed.
- ✓ The ball decelerates as it moves up to C as the kinetic energy is transferred back to gravitational potential energy.
- ✓ At all times that the ball is moving, some energy is being transferred to internal energy, so the maximum height and the maximum speed of the ball decreases each time, till it finally stops at F.

Conversion of energy from one form to another:



If a car is accelerating while rising uphill, then its gravitational potential energy is increasing and its kinetic energy is also increasing.

In a car engine the energy stored in the fuel is in the form of chemical energy.



For a microphone, the sound energy is being converted into electrical energy

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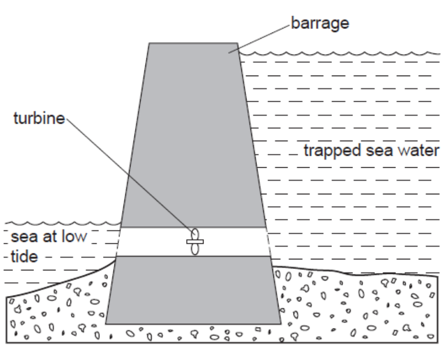

In a tidal power station, the potential energy is being converted to electrical energy

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If a car moving on a leveled ground slows down, then the energy conversion taking place are: kinetic energy⇒heat energy

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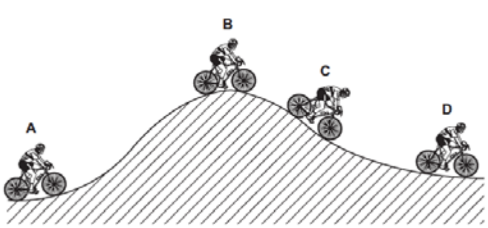
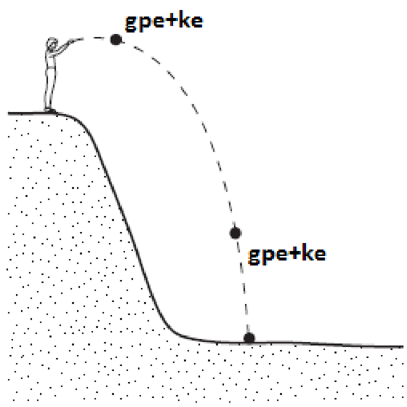


The position A has the least gravitational potential energy.

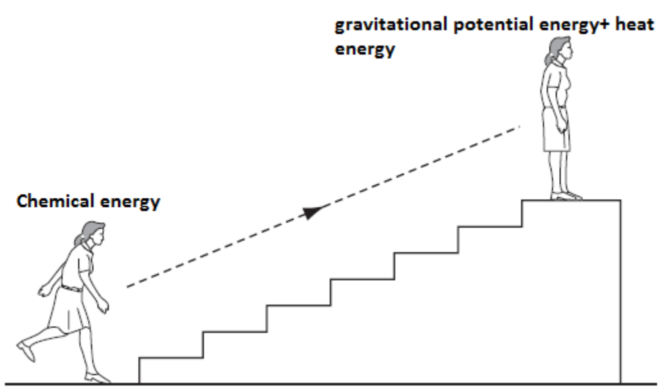


The ball is already in the air so it will possess kinetic and gravitational potential energy while in the air.

The type of power station that does not use steam from boiling water to generate electricity is the hydroelectric power station.

Geothermal, nuclear and oil powered fire stations all use the steam from boiling water to generate electricity.

Coal, natural gas, oil and nuclear energy use their fuel to turn water into steam and use that steam to turn the turbine to generate electricity.



At the top of the stair case , the chemical energy gets changed into gravitational potential energy and heat energy

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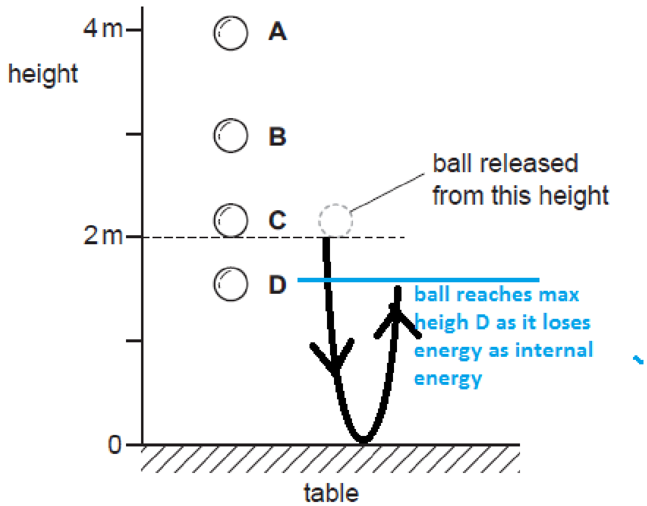
The order of energy transfer in nuclear fission is:

nuclear fuel → reactor and boiler → turbines → generator

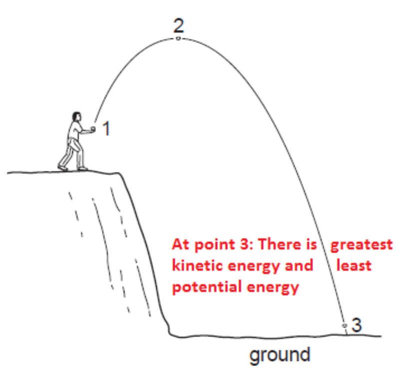
A cyclist travels down a hill from rest at point X without pedalling.

The cyclist applies his brakes and the cycle stops at point Y.

gravitational potential → kinetic → internal (heat)

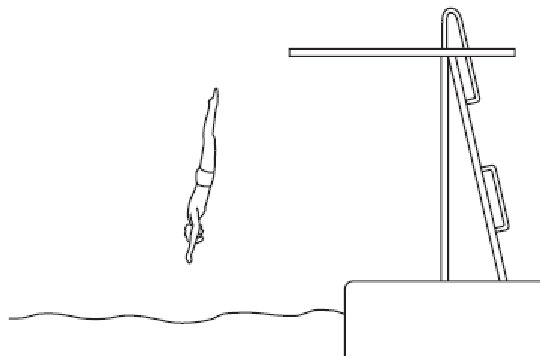


Nuclear fission and geothermal energy is available at all times as against solar energy which is unpredictable



APPLICATION BASED QUESTIONS:

10 The diagram shows a man diving into water. 0625/01



Which form of energy is increasing as he falls?

A chemical

B gravitational

C kinetic

D strain

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9 What is designed to change electrical energy into kinetic energy?

0625/01/M/J/05

A capacitor

B generator

C motor

D transformer

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10 A power station uses nuclear fission to obtain energy. 0625/01/M/J/05

In this process, nuclear energy is **first** changed into

A chemical energy.

B electrical energy.

C gravitational energy.

D internal energy.

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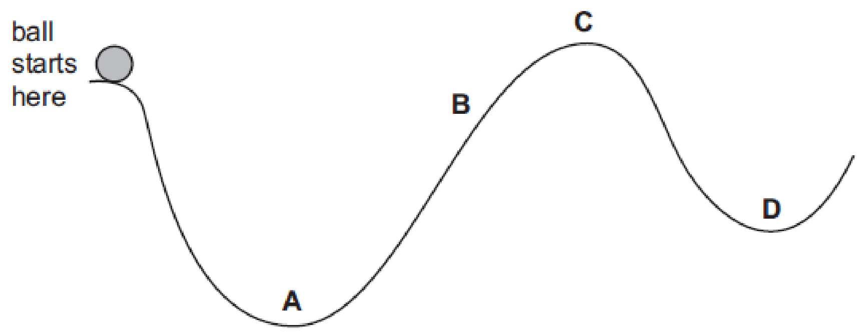
11 A ball is released from rest and rolls down a track from the position shown.

What is the furthest position the ball could reach? 0625/01/M/J/05



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9 Which form of energy do we receive directly from the Sun? 0625/01/M/J/0

A chemical

B light

C nuclear

D sound

0625/01/M/J/07

10 Which form of energy is used to generate electrical energy in a tidal power station?

A chemical energy

B gravitational energy

C internal energy (thermal energy)

D nuclear energy

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11 Which line in the table gives an example of the stated form of energy? 0625/01/M/J/07

	form of energy	example
A	gravitational	the energy due to the movement of a train
B	internal	the energy due to the flow of cathode rays in a cathode ray tube
C	kinetic	the energy due to the position of a swimmer standing on a high diving board
D	strain	the energy due to the compression of springs in a car seat

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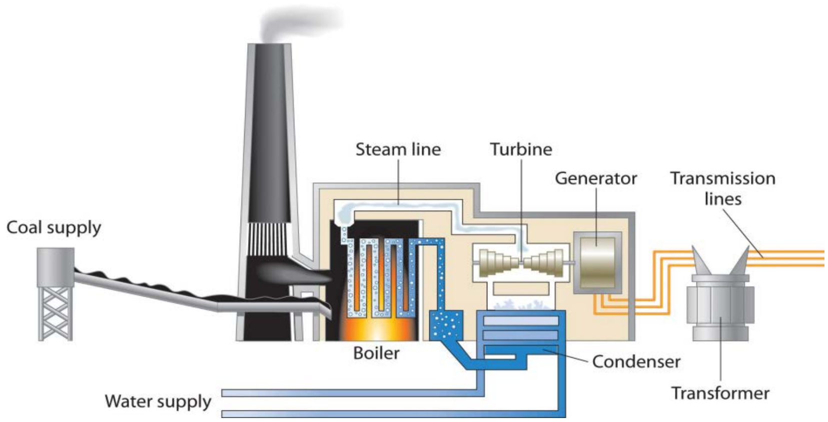
Understanding each type of energy:

Generating electricity in power stations:

Depending on the type of fuel used, the power stations are divided into the following types:

- coal/oil/biofuel fired power stations
- gas fired power station.



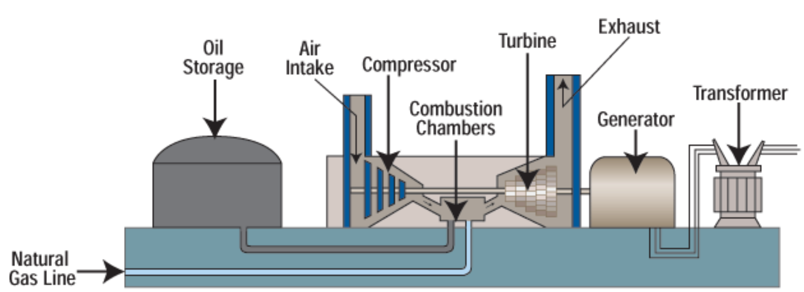
Petrol/coal/oil/biofuel fired power station:

Fuel to be burnt: Petrol, coal or oil or biofuel.

Process:

- Fuel is burnt to heat the water in a boiler.
- Water boils to produce steam.
- The steam drives the turbines,
- The turbines turn an electricity generator.
- The steam is made to condense after it turns the turbines. This condensed steam(water) returns to the boiler. Steam is condensed by passing cold water through the pipes.

Gas fired power station:



Fuel to be burnt: natural gas.

The gas is directly burnt in a gas turbine engine. this produces a powerful jet of hot gases and air that drives the turbines. Such turbines can be switched on very quickly.

Energy conversions taking place in power stations:

chemical ⟹ heat⟹ kinetic⟹ electrical

Energy from nuclear fission:

- Nuclear energy is released in nuclear power station.
- The fuel used is uranium.
- It releases 10 000 times more energy than that released by fossil fuel or biofuel

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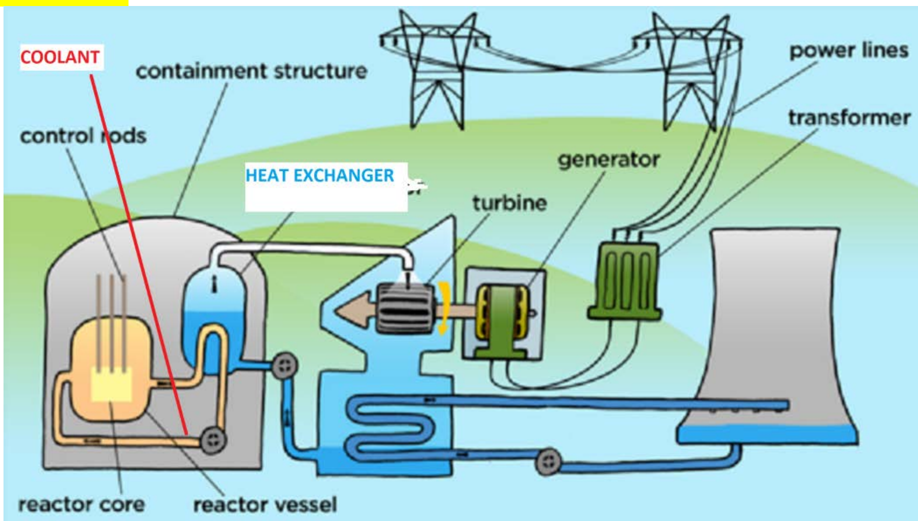
Process:



- A lot of heat is released when the uranium atoms undergo a chain reaction.
- The core of the reactor becomes very hot. The thermal energy of the core is taken away by a liquid called as the coolant. This coolant is pumped through the core to absorb the heat.
- The coolant is very hot when it leaves the core.
- The coolant passes through a heat exchanger where the heat of the coolant is used to change water into steam.
- The steam drives the turbines.
- The turbines are connected to generators that generate electricity.

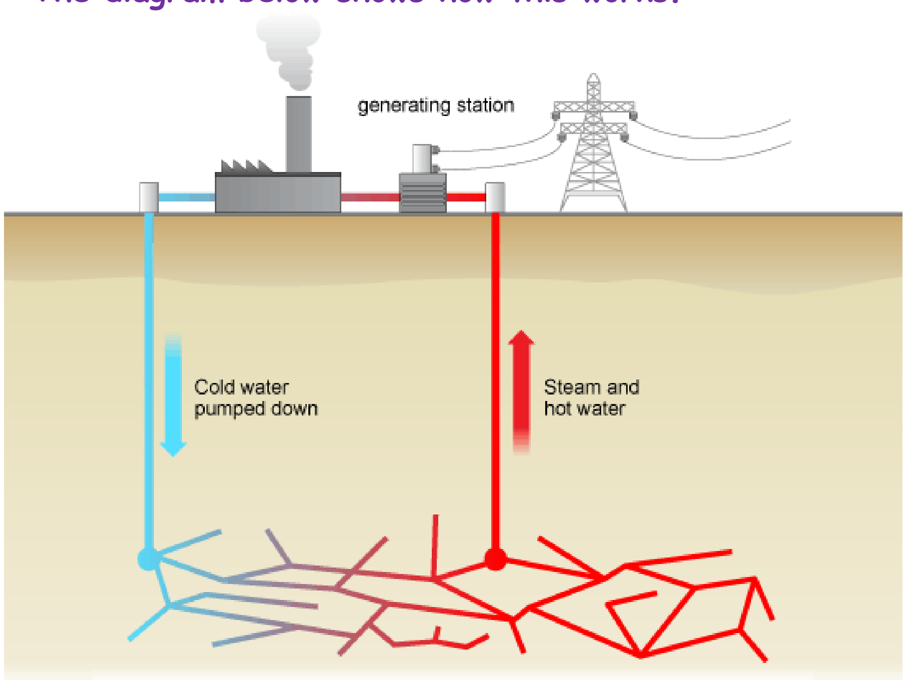
Geothermal resources

Volcanic areas

- Several types of rock contain radioactive substances such as uranium. Radioactive decay of these substances releases heat energy, which warms up the rocks.
- In volcanic areas, the rocks may heat water so that it rises to the surface naturally as hot water and steam.
- Here the steam can be used to drive *turbines* and electricity generators.
- This type of geothermal power station exists in places such as Iceland, California and Italy.

Hot rocks

- In some places, the rocks are hot, but no hot water or steam rises to the surface. In this situation, deep wells can be drilled down to the hot rocks and cold water pumped down.
- The water runs through fractures in the rocks and is heated up. It returns to the surface as hot water and steam, where its energy can be used to drive turbines and electricity generators.
- The diagram below shows how this works.



Solar energy:

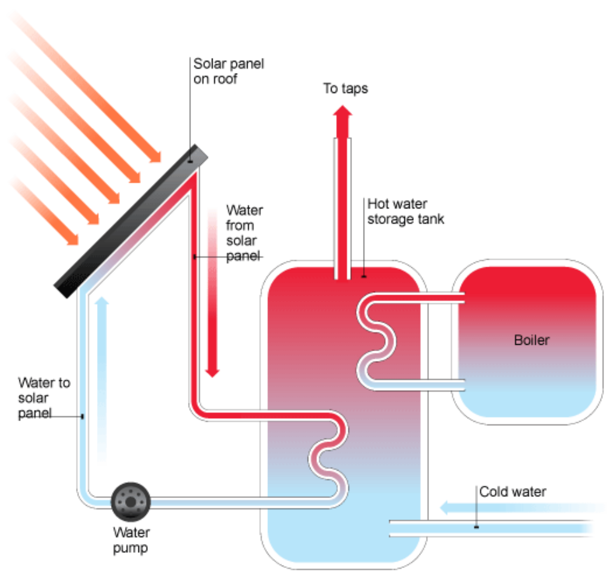
Solar energy is used to work solar cells and solar panels.

Solar cells

- Solar cells are devices that convert light energy directly into electrical energy.
- You may have seen small solar cells in calculators.
- Larger arrays of solar cells are used to power road signs in remote areas, and even larger arrays are used to power satellites in orbit around Earth.

Solar panels

- Solar panels do not generate electricity, but rather they heat up water. They are often located on the roofs of buildings where they can receive heat energy from the sun. The diagram outlines how they work.



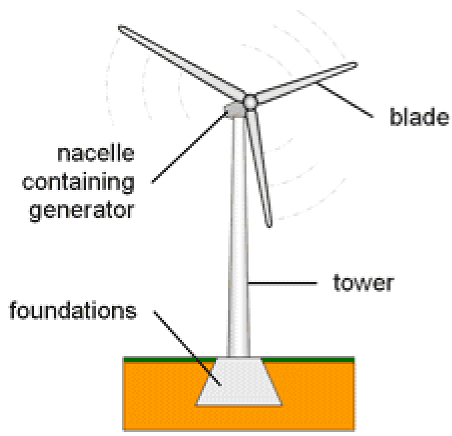
- Cold water is pumped up to the solar panel, there it heats up and is transferred to a storage tank.
- A pump pushes cold water from the storage tank through pipes in the solar panel. The water is heated by heat energy from the sun and returns to the tank. In some systems, a conventional boiler may be used to increase the temperature of the water.

Wind energy:

Big convection currents

The wind is produced as a result of giant *convection* currents in the Earth's atmosphere, which are driven by heat energy from the sun. This means that the kinetic energy in wind is a renewable energy resource: as long as the sun exists, the wind will too.

Wind turbines



Wind turbines have huge blades mounted on a tall tower. The blades are connected to a *nacelle*or housing that contains gears linked to a *generator*. As the wind blows, it transfers some of its kinetic energy to the blades, which turn and drive the generator. A cable between the generator and the shore delivers the electricity to local users or via a network of cables to distant users. Several wind turbines may be grouped together in windy locations to form wind farms.

Note: Nacelleor is a casing in which the generator is enclosed.

Energy from water:

Energy from the water can be harnessed in 3 ways as :

- **Tidal energy**
- **Wave energy**
- **Hydroelectric energy**

Tidal energy:

Huge amounts of water move in and out of river mouths each day because of the tides. A tidal barrage is a barrier built over a river estuary to make use of the kinetic energy in the moving water. The barrage contains electricity generators, which are driven by the water rushing through tubes in the barrage.

Wave energy:

The water in the sea rises and falls because of waves on the surface. . This motion drives the turbines and the kinetic energy of turbines which turns a generator.

Hydroelectric energy

Hydroelectric power stations use the kinetic energy in moving water. This water is stored behind the dam built across a river valley. The water high up behind the dam contains *gravitational potential energy*. This is transferred to kinetic energy as the water rushes down through tubes inside the dam. The moving water drives electrical generators, which may be built inside the dam.

Advantages and disadvantages of generating electricity from various energy sources

Nuclear fuel	Advantages	Disadvantages
Environmental impact	1.Does not produce toxic and acidic gases like CO_2 and SO_2 2. Low greenhouse gas emissions	1. They are non-renewable energy resources 2. If there is an accident, large amounts of radioactive material could be released into the environment. 3.Nuclear waste remains radioactive and is hazardous to health for thousands of years
Reliability	It is reliable	-
Cost	Nuclear power plants are expensive to build but relatively cheap to run	-
Scale	Large scale production of electricity is possible	-
Renewability	It is a non renewable source	-

	Advantages	Disadvantages
Solar energy		
Environmental Impact	1.No harmful polluting gases are produced.	-
Cost	Solar power plants are usually cheaper than new coal, nuclear, or natural gas power plants.	-
Scale	It is possible to install solar power plants in most places in the world.	-
Renewablility	It is a renewable source	-
Reliability	-	When the sun goes down or is heavily shaded, solar PV panels stop producing electricity. If we need electricity at that time, we have to get it from some other source. In other words, we couldn't be 100% powered by solar panels.

	Advantages	Disadvantages
Geothermal energy		
Environmental Impact	1. Geothermal fields produce only about one-sixth of the carbon dioxide that a relatively clean natural-gas-fueled power plant produces.	1. It releases hydrogen sulfide gas that smells like rotten egg at low concentrations. 2.Another concern is the disposal of some geothermal fluids, which may contain low levels of toxic materials.
Reliability	1. Geothermal energy is always available, 365 days a year	Although geothermal sites are capable of providing heat for many decades, eventually specific locations may cool down.
Cost	1.There are no fuel costs. 2. It's also relatively inexpensive; savings from direct use can be as much as 80 percent over fossil fuels. 3.Maintenance cost of geothermal power plants is very less	There is no guarantee that the amount of energy which is produced will justify the capital expenditure and operations costs.
Scale	-	Total generation potential of this source is too small.
Renewablilty	1.It is a renewable energy resource	Most parts of the world do not have suitable areas where geothermal energy can be exploited.

	Advantages	Disadvantages
Water		
Environmental Impact	1. Does not pollute the air.	1.Tidal barrages destroy the habitat of estuary species, including wading birds. 2.Hydroelectricity dams flood farmland and push people from their homes. 3.The rotting vegetation underwater releases methane, which is a greenhouse gas.
Reliability	Tidal barrages and hydroelectric power stations are very reliable and can be turned on quickly to produce electricity on demand.	Hydropower plants can be impacted by drought. When water is not available, the hydropower plants can't produce electricity
Cost	No fuel costs are involved	
Scale	-	It has been difficult to scale up the designs for wave machines to produce large amounts of electricity.
Renewability	Hydropower relies on the water cycle,which is driven by the sun. Thus it is a renewable power source	-

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	Advantages	Disadvantages
Wind		
Environmental Impact	1.No harmful polluting gases are produced	Wind farms are noisy and may spoil the view for people living near them/visual pollution 2. requires large acres of land. 3. turbines kills birds at times
Reliability	It is non-reliable. The amount of electricity generated depends on the strength of the wind. If there is no wind, there is no electricity.	-
Cost	There are no fuel costs	Initial cost of setting up wind farms are high
Scale	Available only locally	-
Renewability	It is renewable	-

Energy efficiency in terms of energy efficiency and power efficiency

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$$\text{Efficiency} = \frac{\textit{Useful energy output}}{\textit{Energy input}}\ x\ 100$$

$$\text{Efficiency} = \frac{\textit{Useful power output}}{\textit{Power input}}\ x\ 100$$

Numerical:

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a In an experiment, energy is provided to an electric motor at a rate of 0.80 W (Figure 2.124). If it raises a 20 g load by 80 cm in 1.3 s, what is its efficiency?

b What happens to all the energy that is not transferred usefully to the load?

a Power used to raise mass, $P = \frac{mg\Delta h}{\Delta t}$

$P = \frac{0.02 \times 9.81 \times 0.80}{1.3}$

$P = 0.12\ \text{W}$

$\text{efficiency} = \frac{\text{useful power output}}{\text{total power output}}$

$\text{efficiency} = \frac{0.12}{0.80} = 0.15$ (or 15%)

b 85% of the energy transferred by electricity to the motor does not go usefully to the increased gravitational energy of the load. The wasted energy goes mostly to internal energy in the motor, which is then transferred as thermal energy to the surroundings. In addition, some energy will have been transferred to sound and some energy was used to stretch the string that connected the load to the motor.

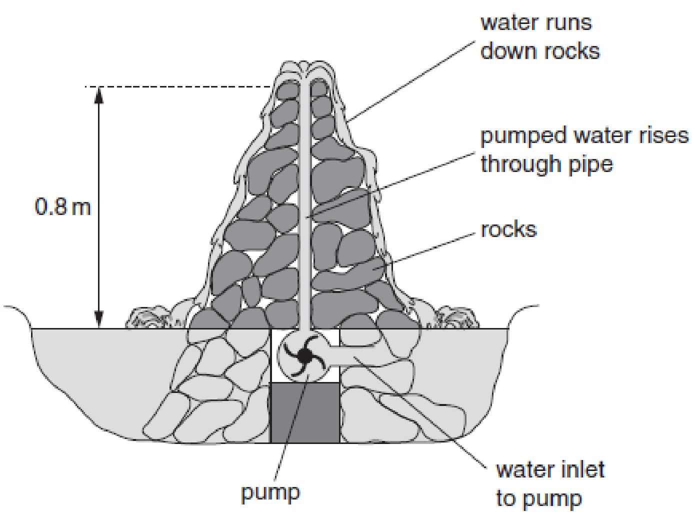
Work:

Work done by a force depends upon the force and the distance moved. Work is defined as:

Work= Force x distance moved in the direction of the force

Units: Joule or Nm

Work done in raising an object above the earth's surface



Suppose we need to calculate the work done while lifting 1 litre[$0.001m^3$] of water up through 0.8m:[density of water=$1000kg/m^3$]

We know that work done= Force x distance in the direction of the force

W=f x d

= (mg) x 0.8

=(dXv)g x 0.8

=1000 x 0.001 x 10 x 0.8

=8J

Thus Work done on an object being lifted upwards= mgh

Note: The gain of gravitational potential energy(change in potential energy)= work done to raise it through a vertical distance. Hence work done=mgh=F x d

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Work done in moving an object horizontally on the earth's surface:

(b) Another athlete using a different spring exerts an **average** force of 400 N to enable her to extend the spring by 0.210 m

M/J/04-P3-Q3

(i) Calculate the work done by this athlete in extending the spring once.

work done = ...

Here the spring is stretched horizontally in the direction of the force. Hence work= force x displacement= 400 x 0.210 =84.0J

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3 Fig. 3.1 shows a skier taking part in a downhill race.

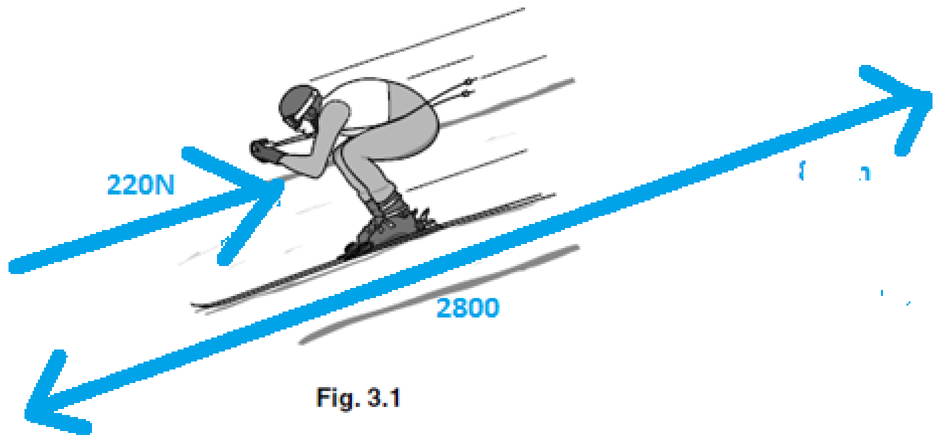

Fig. 3.1

(a) The mass of the skier, including his equipment, is 75 kg. In the ski race, the total vertical change in height is 880 m.

O/N/15-P31-Q3

Calculate the decrease in the gravitational potential energy (g.p.e.) of the skier.

(a) The mass of the skier, including his equipment, is 75 kg. In the ski race, the total vertical change in height is 880 m.

O/N/15-P31-Q3

Calculate the decrease in the gravitational potential energy (g.p.e.) of the skier.

Decrease in the gpe= mgh= 75 x 10 x 880=6.6 x 10^5J.Nm

(b) The skier starts from rest. The total distance travelled by the skier during the descent is 2800 m. The average resistive force on the skier is 220 N.

Calculate

(i) the work done against the resistive force,

Work done against the resistive force= Force x distance = 220 x 2800 =6.2 x 10^5Nm [This is equal to the loss of gpe]

(ii) the kinetic energy of the skier as he crosses the finishing line at the end of the race.

As he crosses the finishing line all the gpe gets changed into his kinetic energy=6.6 x 10^5J.Nm-6.2 x 10^5J/Nm= 4 x 10^4J

Note that the skier bends his body to reduce the air resistance.

Kinetic energy:

If an object of mass v moves with a velocity of v , then the kinetic energy is given by:

$K.E = \frac{1}{2}mv^2$

m- mass object in kg

v= velocity in m/s

In a roller coaster type of motion.

Assume that all the loss of g.p.e gets transformed into the k.e of the train; then;

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

where;

h=distance between the highest point of the track and the bottom of the descent.

v= speed at the bottom of the descent.

The woman in Figure 2.100 walks along with a constant velocity holding a suitcase.
How much work is done by the force holding the case?

Solution

In this example the force is acting perpendicular to the direction of motion, so there is no movement in the direction of the force.

Work done = zero

Power:

The output power of a machine is the rate at which it does work.
Power is also the rate at which the machine transfers the useful energy.
Hence:

Power (Watts)= $\frac{Work\ done(J)}{Time\ taken\ (s)}$

or

Power(Watts)= $\frac{useful\ energy\ transferred\ (J)}{Time\ taken\ (s)}$

Hence: 1W= 1J/s

Making some interpretations:
If a torch has a power of 5W it means that it transfers 5J of energy per second

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Whenever a machine does work on an object, energy is transferred to the object.

Numerical:

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9 The table shows the times taken for four children to run up a set of stairs.

Which child's power is greatest?

0625/12/O/N/09

	mass of child / kg	time / s
A	40	10
B	40	20
C	60	10
D	60	20

The answer here is obviously C. Explanation:

Power (Watts)= $\frac{Work\ done(J)}{Time\ taken\ (s)} = \frac{mgh}{t}$

Let's assume that the vertical height=10m for each child. Substituting we get the highest value of power for child C

0625/01/M/J/03

11 A labourer on a building site lifts heavy concrete blocks onto a lorry. Lighter blocks are now lifted the same distance in the same time.

What happens to the work done in lifting each block and the power exerted by the labourer?

	work done in lifting each block	power exerted by labourer
A	decreases	decreases
B	decreases	remains the same
C	increases	increases
D	remains the same	increases

Power (Watts)= $\frac{Work\ done(J)}{Time\ taken\ (s)} = \frac{mgh}{t}$

Obviously if bricks become lighter, then numerator decreases but denominator stays the same, so the power decreases. Also work = mgh, so work too decreases.

Application based questions:

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11 A worker is lifting boxes of identical weight from the ground onto a moving belt.

0625/01/M/J/08

At first, it takes him 2 s to lift each box. Later in the day, it takes him 3 s.

Which statement is correct?

A Later in the day, less work is done in lifting each box.

B Later in the day, more work is done in lifting each box.

C Later in the day, less power is developed in lifting each box.

D Later in the day, more power is developed in lifting each box.

(b) Another athlete using a different spring exerts an **average** force of 400 N to enable her to extend the spring by 0.210 m

M/J/04-P3-Q3

(i) Calculate the work done by this athlete in extending the spring once.

work done = ...

(ii) She is able to extend the spring by this amount and to release it 24 times in 60 s. Calculate the power used by this athlete while doing this exercise.

power = ...

(b) A road is covered with a layer of snow. The temperature of the snow is 0 °C. The specific latent heat of fusion of snow is 3.3×10^5 J / kg.

O/N/16-p43

The snow forms a layer of uniform thickness on the road surface.

(i) Calculate the power needed to melt 0.12 kg of the snow in 220 s.

power = ... [4]

4 **(a)** The source of solar energy is the Sun.

Tick the box next to those resources for which the Sun is also the source of energy.

F/M/16-P42

☐ coal

☐ geothermal

☐ hydroelectric

☐ nuclear

☐ wind [2]

O/N/14-P33-Q6

6 (a) Explain why

(i) metals are good conductors of electricity,

....

....

(ii) insulators do not conduct electricity.

....

....
[3]

(b) The battery of an electric car supplies a current of 96 A at 120 V to the motor which drives the car.

(i) State the useful energy change that takes place in the battery.

....[1]

(ii) Calculate the energy delivered to the motor in 10 minutes.

energy = ... [2]

(iii) The motor operates with an efficiency of 88 %.

Calculate the power output of the motor.

power = ... [2]

[Total: 8]