ENGINEERING SCIENCE

Energy Calculations

Name ______________________________

Class ______________________________

Teacher ____________________________

Ellon Academy
Technical Faculty

Learning Intentions

- To understand what energy is and how it can be used
- To know how to work out the energy in things
- To learn about energy conservation
- To learn about the transference of energy
- To know about the efficiency of a system
- To know what an energy audit is and why it is used

Success Criteria

- I can solve energy problems using energy formulae for potential, kinetic, heat, and electrical energy.
- Having gained knowledge of how formulae may be used in the context of energy transfer, I can apply them to solve problems, for example in engineering
- I can use Power and Work done formulae.
- I can identify the energy transfers that happen in a system.
- I can carry out and energy audit.
- I can calculate the efficiency of a system.

To access video clips that will help on this course go to www.youtube.com/MacBeathsTech

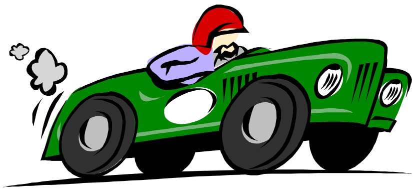
What is Energy?

Energy is what makes things happen, or work. We know to do more work we require more energy. Energy is measured in joules (J)

Types of Energy

Kinetic Energy

Kinetic energy is the energy of movement. It is the name given to the energy that the body possesses due to it moving. This car can be described as having kinetic energy because it is moving



Potential Energy

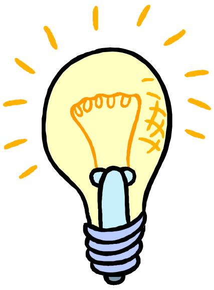
Potential energy is best described as energy stored in a static object. It can be down to how high it is above a starting point (the datum), or that something has been previously done to the object so the energy is already stored e.g. a spring.

The bucket that is supported by the pulley in this diagram would be said to have potential energy

Electric Energy

Electrical energy is one of the most convenient and commonly used forms of energy today. This is because it can be transported easily from place to place along electrical cables and it is easily changed in other forms of energy.

Most electrical energy is generated in power stations, where one type on energy is converted into electrical energy.



Heat energy

Heat energy is the energy transferred to a body that changed its temperature. With a kettle a certain amount of thermal energy is needed to raise the temperature of the water to boiling point.

Task 1

1) Copy and complete the system diagram by adding one main input energy and one main output energy

__________Energy → Hair Straighteners → __________Energy

__________Energy → Stretched Elastic Band → __________Energy

__________Energy → Wind Turbine → __________Energy

2)

a) When an Olympic diver stands on a diving board 10m above the pool, what form of energy do they possess?

b) When the diver jumps on the diving board it will bend. What form of energy does the board now possess?

c) When the diver is jumping up, what form of energy does he now possess?

d) When the diver is at the highest point of his dive why does he not have any kinetic energy?

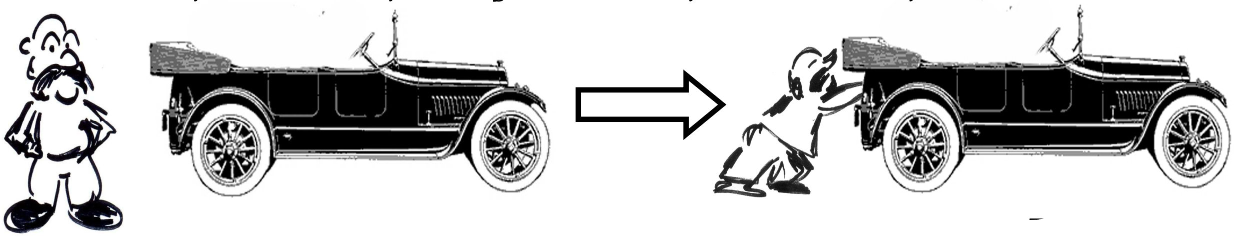
e) A heating element is used to keep the pool to a suitable temperature. Complete the system diagram, showing one input and output that will solve this problem.

→ Heating Element →

Work and Energy

Work done

When a force is used to move an object, 'work' is said to be done.
An example of this is pushing a car from position A to position B.



The amount of work you will do depends on how difficult the car is to push (the size of the force) and how far it has to be pushed (the distance). The amount of work that has to be done can be calculated using the formula:

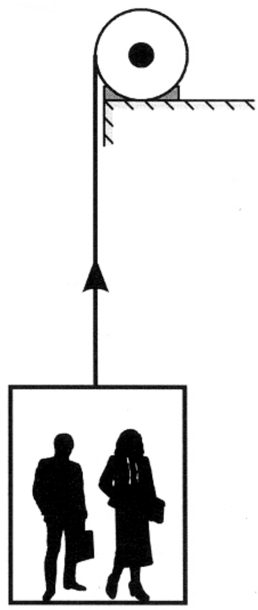
$$W = F \times s$$

(Work Done = force applied x distance moved)

Force is measured in Newtons (N)
Distance is measured in metres (m)
The unit for measuring work is therefore Newton metres (Nm) or joules (J)

Example

A lift raises a mass of 1000kg to the next floor in the Union Square shopping centre, which is 20m up. Calculate the minimum amount of work that must be done by the winch.



Remember – the gravitational pull is always 9.8

Weight of lift = mg (mass x gravitational pull)
= 1000 x 9.8
= 9800 N

Work = force x distance
= 9800 x 20
= 196,000 Nm

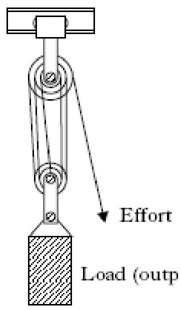
Task 2

Work out these calculations.

a) Calculate the amount of work done when a force of 150 Newtons is used to pull a 50kg bag of sand 20 metres.

b) During the loading process, a forklift truck lifts a pallet of bricks weighing 740kg to a height of 2m.
Calculate the minimum amount of work the truck must do during the lift.
Can you also suggest why the actual work done will be greater than this?

c) A pulley lifting system designed to make it easier for an operator to lift a load onto a lorry is shown below.
The operator applies an effort of 225N and pulls on 4.8 m of rope to raise the load.
Calculate the work done by the operator raising the load.



Calculating Electrical Energy

The formula for calculation electrical energy is:

$$E_e = ItV$$

(Electrical Energy = Current x time x Voltage)

Current is measured in amps
Time is measured in seconds
Voltage is measured in Volts

Example

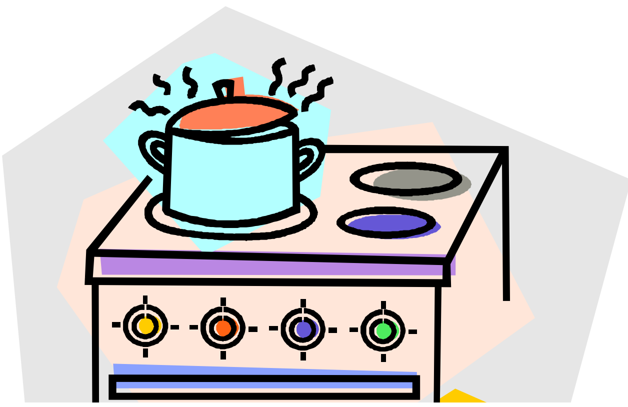
An electric hob in home economics has an operating voltage of 230 volts with a current of 5 amps. Calculate how much electrical energy has been used if the hob takes 5 minutes to heat up a pot of soup.

$E_e = ItV$

$= 5 \times 300 \times 230$

$= 345{,}000$ Joules
$\underline{\underline{= 345 \text{ kJ}}}$

Remember and <u>always</u> convert your time into seconds



Task 3

Work out the following Calculations

a) A hot air hand drier activates for 30 seconds once the switch is pressed. The drier operates from a 230V supply and draws a current of 12A. Calculate the amount of electrical energy used when the drier is operating.

b) A turbine is used to drive a 110v electrical generator. If the output current is 3A, how much electrical energy does the generator produce in 1 hour?

Task 4

A prototype electric sports car is shown.

The car batteries are charged for 30 minutes from a mains supply rated 230V 10A.

(a) Calculate the electrical energy used.

Calculating Kinetic Energy

The kinetic energy of a moving object is dependant on 2 factors – the Mass (m) of the object and its velocity (v)

The object is measured in Kg

Velocity is measured in m/s

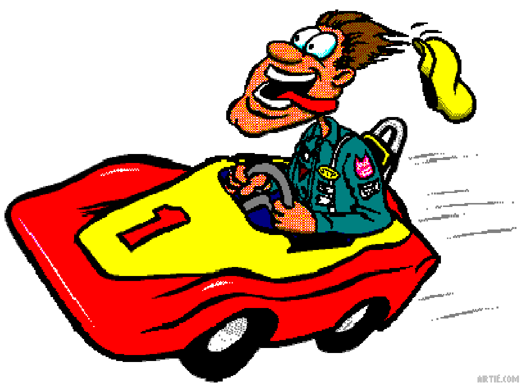
Kinetic energy is calculated using the formula:

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

(Kinetic energy = ½ x mass x velocity^2)

Example

If a 90kg go-kart travels at 40m/s, how much kinetic energy does it possess?



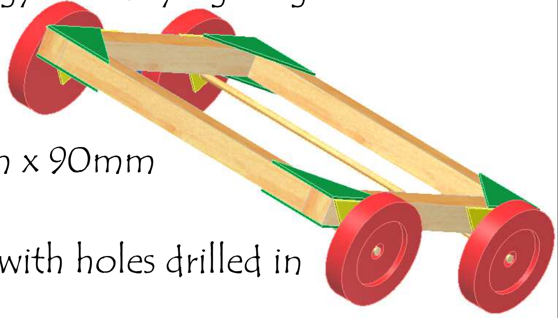
$E_K = \frac{1}{2} mv^2$

$= \frac{1}{2} \times 90 \times 40^2$
$= \frac{1}{2} \times 90 \times 1600$

= 72,000 joules
$\underline{\underline{= 72\ kJ}}$

Task 5

You are now going to create a toy buggy for carrying weights



You will need:

- 4 pieces of pine – 15mm x 25mm x 90mm
- 4 triangular pieces of hardboard
- 4 triangular pieces of hardboard with holes drilled in
- Round dowel
- 4 wheel
- Hot glue gun

Task 6

Add a carrier to your buggies so that it can hold different weights
By using a stopwatch, work out the speed holding the weights inside, and then work out the kinetic energy for the buggy holding…

i) 0.5kg

ii) 1.5 kg

iii) 2 kg

iv) 3kg

Task 7

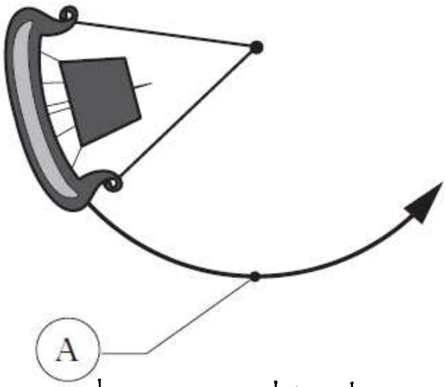
Work out these calculations.

a) A crane raises a load of 200kg to a height of 30m in one minute. Determine the kinetic energy of the load when it's moving.

b) A racing car drives around a circuit at a constant speed of 50m/s. if the car has a kinetic energy of 500kJ, what is the mass of the car?

Task 8

A fairground swing is shown below



The swing and passengers have a combined mass of 2500 kg.

(*a*) Calculate, showing all working and units:

(i) The kinetic energy at its lowest point when the velocity is 15 m/s;

(ii) The maximum height the swing will reach. (Assume no loss of energy).

(*b*) In reality, there will be some loss of energy in the swing.

(i) State **one** possible cause of energy loss.

(ii) State how this energy loss could be reduced.

Calculating Potential Energy

The formula used for calculating potential energy is:

$$E_P = mgh$$

(Potential energy = Mass x gravity x height)

Mass is measured in Kilograms (Kg)
Height is measured in metres (m)

Example

Metal piles are driven into the ground using a Pile Driver. This consists of a 500 kg driver, which is raised by a winch to 3m high, then released.
Calculate the potential Energy stored when the driver is lifted.

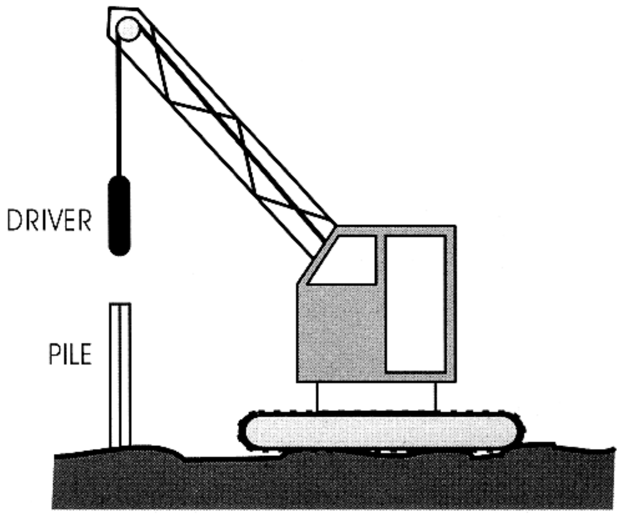
Remember – the gravitational pull is always 9.81

$E_p = mgh$

$= 500 \times 9.8 \times 3$

$= 14,700$ joules

$\underline{\underline{= 14.7 \text{ kJ}}}$



http://www.youtube.com/watch?v=ROeowItLVSc

Task 9

Add 1.5 kg to your toy buggy, set it up to roll down different sized ramps to test its potential energy.

i) 50 cm

ii) 75 cm

iii) 1m

iv) 1.5 m

By adding different weights, work out the potential energy for 2 of these ramps again. Does adding weights to your buggy change its potential energy?

v) 1.5 kg

vi) 2 kg

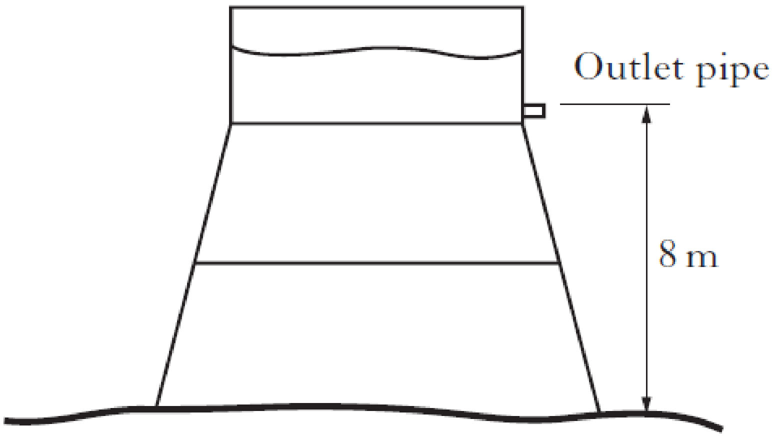
Task 10

Complete these calculations.

A roller coaster has many high and low points on its track. At the top of its largest dip is 50m, and the lowest point is 5m, what is the change in potential energy for a person weighing 80 kg?

Task 11

A crofter uses a wind power system to pump water to a storage tank. A simplified diagram of the storage tank is shown

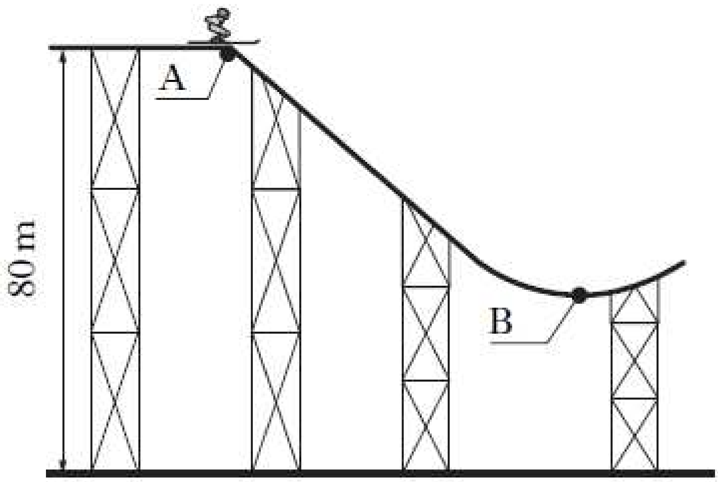


a) Calculate the potential energy of 6L (litres) of water at the outlet pipe.
(1L of water = 1 kg)

b) Describe why not all of the water's potential energy is converted

Task 12

A ski jumper and take-off ramp is shown



The ski jumper has a mass of 65 kg.

(*a*) Calculate, showing all working and units, the potential energy of the ski jumper when stationary at point A.

The ski jumper descends down the ramp and has a potential energy of 31·5 kJ at point B.

(*b*) Calculate:

(i) The kinetic energy of the ski jumper at point B (assume no loss of energy);

(ii) The velocity of the ski jumper at point B.

Calculating Heat Energy

The formula for calculating heat energy is:

$$E_h = mc\Delta T$$

(Heat Energy = mass x heat capacity of material x change in temp.)

mass (m)is measured in Kg

change in temperature (ΔT) is measured in Celsius (°C) or Kelvin (K)

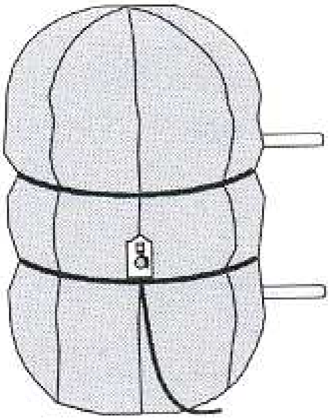
The specific heat capacity (c) of a substance, is the amount of energy required to raise the temperature of 1kg of the material by 1 K

Example

A hot water tank contains 200 litres of water at 18 °C.
Calculate how much energy is required to raise the temperature of the water to 50°C.

The specific heat capacity of water is 4190 Kj/kgK
(THIS SHOULD BE IN YOUR DATA BOOKLET)

Change in temp. = 50-18
= 32



$E_H = mc\Delta T$

= 200 x 4190 x 32

= 26816000J
= 26.8MJ

http://www.youtube.com/watch?v=mUC-1iBt_lk

Task 13

Work out the following calculations

a) Calculate the heat energy required to heat 2kg of water from a temperature of 20°C until it begins to boil.

b) 57kJ of thermal energy is supplied to 17kg of oil having a specific heat capacity of 2.7kJ/kgK.
If the initial temperature of the oil is 3°C, what will be its final temperature?

Task 14

New houses are just getting build outside of Ellon and they have all have solar thermal panels installed to heat cold water.

It was found that 100 kg of water at 10 °C entered the solar panels and absorbed 7 MJ of heat energy.

Calculate the final temperature of the water.

Calculating Power

Power is a measure of the rate of energy transfer. It gives an indication of how quickly the energy is changed from one form to another.

Power is calculated using this equation.

$$P = E/t$$

Power = Energy transfer ÷ time

Power is measure in **watts** (W)
Energy transfer is measured in **joules** (J)
Time is measured in **seconds**(s)

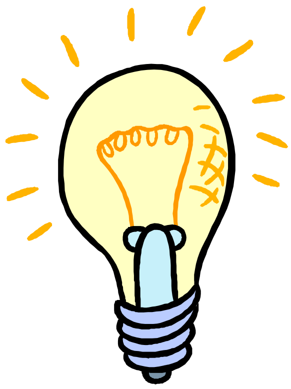
Example

If an electric light bulb uses 60kJ of energy in 10 minutes what is the power rating of the bulb?

P = E/t

= 60Kj / 10 minutes
= 60,000 / 600 (10 minutes x 60 seconds)

= <u>100 watts</u>



Task 15

Using your buggies with 1kg in them, work out the cars kinetic energy used over the set distances

a) 50cm

b) 1m

c) 1.25m

Using the data you will have collected, work out the power that is used in your car each time.

Task 16

Complete these Calculations.

a) A winch lifts a 500 kg pallet of bricks to a height of 10m in a time of 15 seconds. Calculate the minimum output power of the lift.

b) An electric heater is rated at 3kW. Calculate how much heat energy the heater will deliver in 1 hour.

Conservation of Energy

In everyday usage, energy conservation means using less energy to do the same work. Examples of this include improving the heat insulation of buildings and homes, making cars which use fuel more efficiently…etc

In Technological Studies terms 'conservation of energy' has a different meaning. Instead it is looked upon as a rule.
The Rule states that energy cannot be created or destroyed, but can only be changed from one form to another. It is 'transformed' or 'converted'. This rule is also termed a natural law.

The law of conservation of energy

The law of 'conservation of energy' states that for a closed system, where no energy goes in or out, the total energy within the system must always stay the same, although the form of energy may change.
On the other hand, in an open system such as a power station, this rule leads to the conclusion that the total energy input to the system must be exactly equal to the total energy output.

The extent to which the output energy is able to do useful work (of the desired type) is called the efficiency of the system. We can calculate this by comparing the useful output form the system with its energy input.

Energy Transformations

How energy can be transformed or converted is very important to a technologist. Some forms of energy is directly interchangeable (e.g. potential to kinetic), but others need to go through several changed to arrive to the desired form.
Copy and complete these diagrams of simple transformations.

Task 17

__________Energy → Electric Motor → __________Energy

__________Energy → Light Bulb → __________Energy

__________Energy → Generator → __________Energy

More Energy Transformations

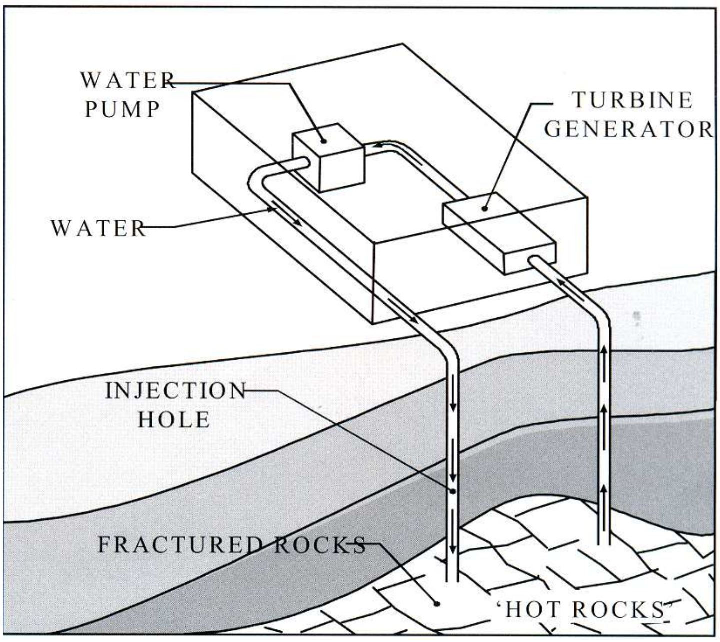
Some systems will require more than one energy conversion to get the desired energy output. An example of this is converting geothermal Energy into electrical energy.

Geothermal Energy

The earth is a massive reservoir of natural heat energy. At its birth the earth was a molten mass at a temperate of 6000°C approx. The earth has been cooling down ever since and will continue to do so for millions of years.
In some places, the natural heat energy reaches close to the surface. Occasionally the molten materials cause the heat escape and this creates volcanoes. It is also known to heat up underwater reservoirs to create hot springs and geysers.

If this geothermal energy could be harnessed at temperatures of 250°C or higher, it could be used to create electricity, the heat being used to turn water into high-pressure steam to drive turbine generators. To achieve these temperatures however it would be necessary to drill deep into the earth's surface to reach "hot-rocks". In Britain it would be necessary to drill as deep as 6000 metres (4 miles approx) to reach useful temperatures.

This is one method of collecting geothermal energy for transformation into electricity.
This system consists of 2 boreholes, which penetrate the earths crust and bore into a region of hot rocks. During construction an explosive charge would be detonated at the bottom of the injection hole to fracture the rocks.



When operating, water would be forced down this hole under pressure. It would then penetrate the hot rocks, pick up the heat, and return to the surface through a second borehole as steam. This stream would then be released through a pressurised system to drive the turbine generators.

The energy conversion could be described as follows:

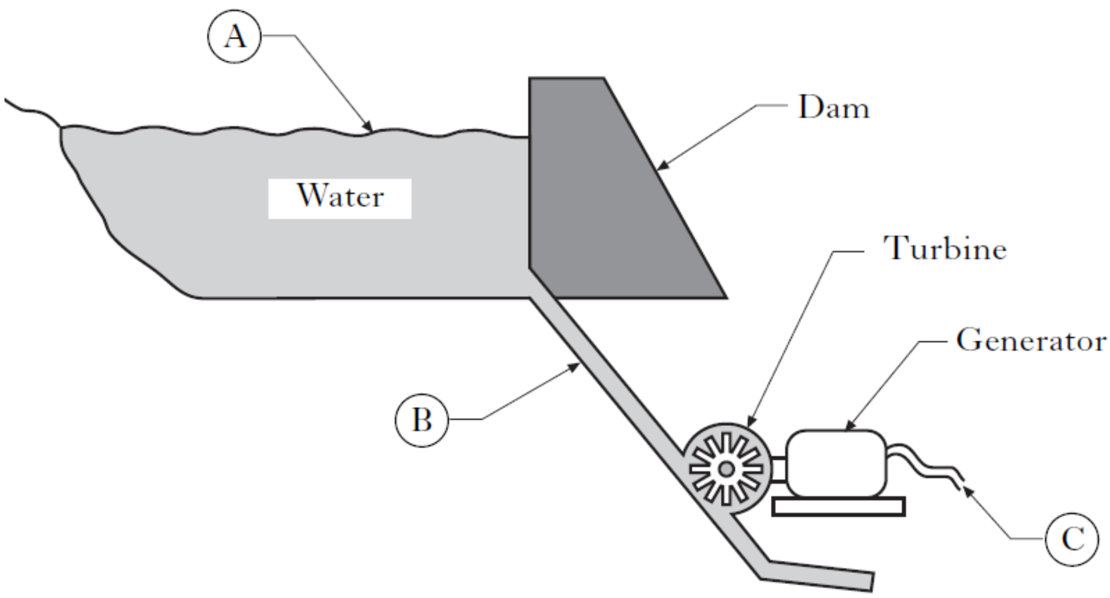
The heat energy in the rocks is transferred to the water in the injection hole pipe. This hot water is changed to high-pressure steam and transported to the surface. The heat energy from the steam is used to turn the blades of a turbine, producing rotational kinetic energy, which is used to create electricity from a generator.

HEAT FROM ROCKS → WATER → STEAM → TURBINE → (KINETIC ENERGY) → GENERATOR → (ELECTRCIAL ENERGY)

Task 18

A simplified hydroelectric power station is shown

State the **main** form of energy changes at positions A B and C.



A:

B:

C:

Energy 'Losses' during transformation

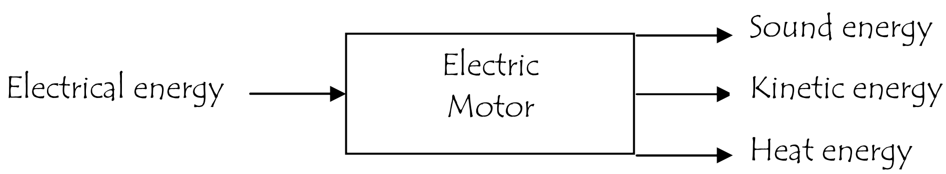
Although we have stated that energy cannot be destroyed, and that the energy output from a system is equal to its input, not all the energy is used efficiently.

When an energy conversion takes place there is always an energy change that we do not desire – usually in the form of heat sound or friction from the moving parts of the mechanism.

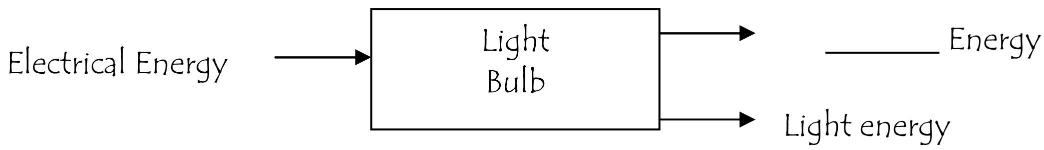
If we look at the simple energy conversions from earlier we can expand these to show the waste energy, or energy losses.

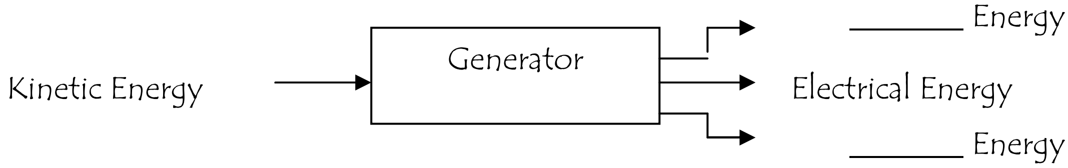
Example

An electric motor converts electrical energy to kinetic energy, but while doing so also creates sound energy and heat energy.



Task 16
Complete these diagrams showing all the energy losses.

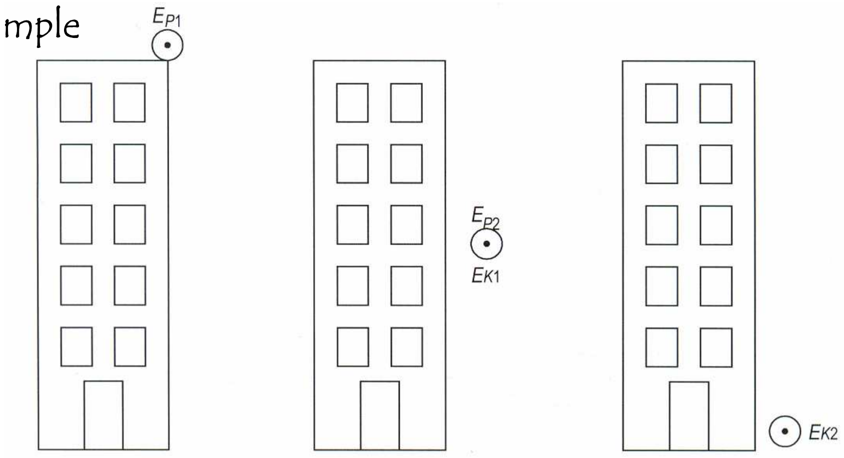




Calculating Energy transfers

It has already been stated that energy cannot be created or destroyed – it can only be made to change form.
During an energy transformation, therefore, the total energy contained within any closed system must remain constant.
Knowing the total amount of energy at the start (or end) of any energy transformation tells us the total energy at any given time during the transformation.

Example



Consider a ball that is released from a high building

When the ball is at the top of the building, it has gravitational potential energy (E_{P1})

$$\text{The total energy, } E= E_{P1}$$

When the ball is released, it falls and some of the potential energy (E_{P2}) is converted into kinetic energy (E_{K1}). The total amount of energy (E) the ball possesses at this time is equal to the potential energy plus the kinetic energy.

$$\text{The total energy } E_T = (E_{P\,2} + E_{K1}) = E_{P1}$$

Just as the ball hits the ground, it no longer has any potential energy – all the potential energy E_{P1} has been converted into kinetic energy E_{K1}. The total amount of energy now consists of the kinetic energy alone.

$$\text{Total energy } E = E_{K1} = (E_{P2} + E_{K1}) = E_{P1}$$

Example

A body of mass weighing 30 kg falls freely from a height of 20 metres. Find its final velocity and kinetic energy at impact.

First – Calculate the initial potential energy

E_p = mgh

= 30 x 9.81 x 20

= 5886

= 5.88 kJ

This potential energy is then transferred into kinetic energy, which means the kinetic energy at impact is equal to 5.9kJ.

To calculate the final velocity of the body we begin by taking

E_K = 5.88kJ

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

5.88kJ = $\frac{1}{2} \times 30 \times v^2$

5.886×10^3 =

5886 = $15 \times v^2$

$v^2 = 5886 \div 15$

$v^2 = 392.4$

<u>v = 19.8 m/s</u>

This type of calculation can be completed for any type of energy conversion: knowing the total amount of energy at any given time (beginning/middle/end) is <u>the same</u> at any other given time

Task 19

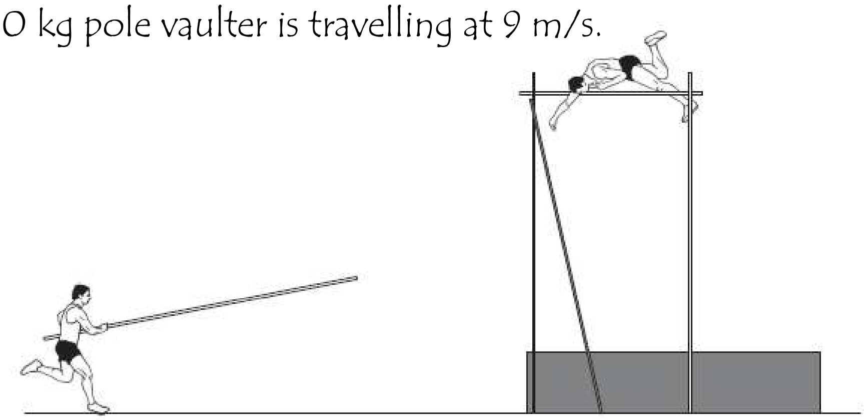
Calculate the transfer of energy

a) A 5kg mass is raised steadily through a height of 2m. What work is done and what is the body's potential energy relative to the start?

b) An electric kettle takes 5 min to boil water. The original temperature of the water is 20°C and the kettle contains 2 litres of water. Calculate how much electrical current is used by the kettle from a 230 volt main supply.

Task 20

An 80 kg pole vaulter is travelling at 9 m/s.



(*a*) Calculate the kinetic energy of the pole vaulter.

The vaulter must be raised 4 m to clear the bar.

(*b*) Determine if the vaulter can clear the bar when travelling at 9 m/s immediately before take off. (Apply the law of conservation of energy and assume no energy losses).

(*c*) Describe why, in reality, not all of the kinetic energy of the vaulter is converted to potential energy during the vault.

Energy Efficiency

It is possible to look at how well an energy system is operating by calculating its efficiency. The efficiency of an energy transformation is a measure of how much the input energy appears as useful as the output energy.
This can be calculated using the following equation:

$$\eta = \frac{E_{out}}{E_{in}}$$

$$\left(\text{Efficiency} = \frac{\text{Useful energy output}}{\text{Total energy input}} \right)$$

Note – η is the ratio of output to input energy.
This can never be greater than 1.

In order to convert η to a percentage, it has to be multiplied by 100

Example
An electric lift rated at 110V, 30A raises a 700kg load to a height of 20m in 2 minutes.
By considering the electrical energy input and the potential energy gained by the mass, determine the percentage efficiency of this energy transformation.

Remember – translate the time into seconds!

The energy into the system is electrical, so…

$E_E = ItV$
$= 30 \times 120 \times 110$
$= 396kJ$

The output Energy is potential so…

$E_P = mgh$
$= 700 \times 9.8 \times 20$
$= 137200$

$$\eta = \frac{E\ out}{E\ in} = \frac{\text{potential energy}}{\text{electrical energy}} = \frac{137.2}{396} = 0.346$$

Percentage efficiency = 0.347 x 100% = 34.6%

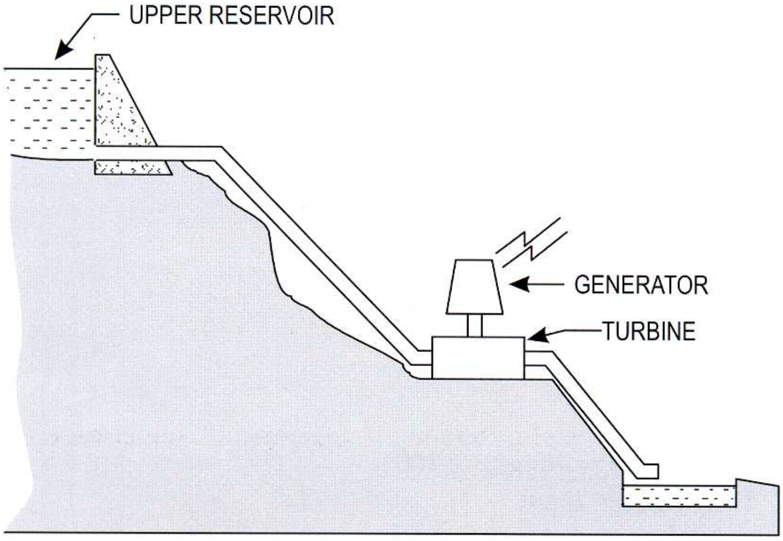
Task 21

Work out the efficiency of your buggies.
What is the energy in? And what is the most suitable form of energy to use as the energy out?

Where is the most likely source of energy loss in your car?

Task 22

In a hydroelectric electricity generating station, water is allowed to flow downhill through a turbine, which is connected to a generator.



The water falls through a vertical height of 500m at a rate of 5,000kg/s. If the energy transfer is 65% efficient, determine the amount of electrical energy produced per second.

Task 23

An environmentally friendly racing car has a mass of 600 kg.

(*a*) Calculate, showing all working and units, the velocity of the car when it has 925 kJ of kinetic energy.

When the car uses 150 MJ of fuel it produces 63 MJ of useful energy.

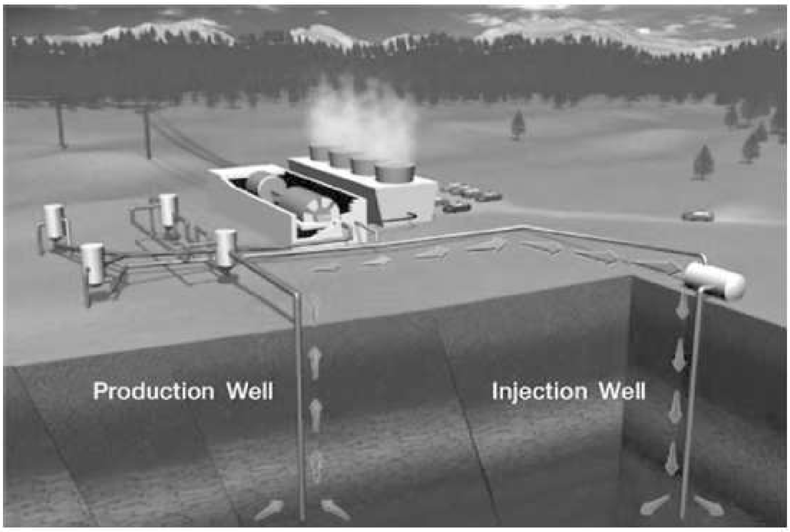
(*b*) Calculate the efficiency of the car.

As the car slows its kinetic energy reduces.

(*c*) Explain what happens to this kinetic energy.

Task 24

A Geothermal power plant uses the heat in the earth to help produce electricity.



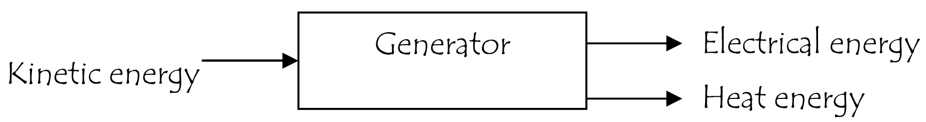
(*a*) Calculate the heat energy absorbed by 100 litres of water which is pumped into the earth at 10 °C and comes out as steam at 240 °C.
(1 litre of water has a mass of 1 kg.)

(*b*) For every 15 MJ of heat energy that comes from the ground, the power plant produces 5.34 MJ of electricity.
Calculate the efficiency of the power plant.

Energy Audits

During energy transformations all the energy that goes IN the system must come OUT. It is not possible to 'destroy' energy – it must go somewhere.
Not all energy going into a system comes out as useful energy – this is called *waste energy*, or *lost energy*. An example of this is that a light bulb turns electric energy into light energy, but it also creates heat – heat is the lost energy.

Since we know that the total energy in any closed system must be constant, we can carry out meaningful calculations if we remember to take all types of input and output energy into account.



In the generator example above:

- the input energy is in the form of kinetic energy
- the total output energy will be electrical energy, plus heat energy

Hence, through conservation of energy $E_K = Ee + Eh$

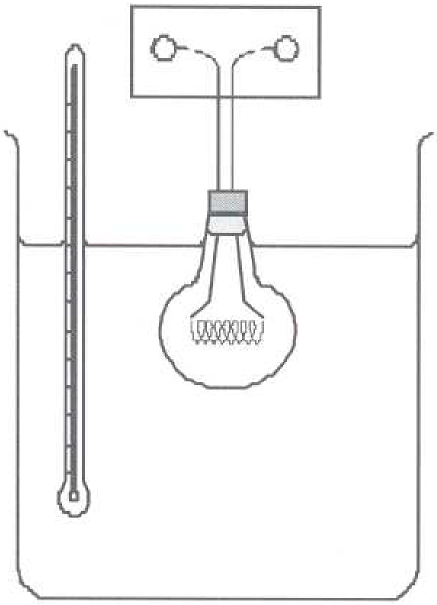
In order to ensure that we have taken all energies into account, it is useful to carry out an energy audit.

An energy audit is a list of all energies coming IN and going OUT of a system.

The total for the energies IN <u>must</u> be the same as the totals for the energies OUT.

http://www.youtube.com/watch?v=O9RD9-G5Bb4

Example



In order to estimate the efficiency of an electric light bulb, the bulb is immersed into a beaker of water as shown.
Assuming all the heat energy is transferred to the water, it is possible to work out the efficiency of the bulb as a light producer.

Data: Power supply = 12 V
Current Drawn by the bulb = 5 A
Volume of water in beaker = 0.5L
Initial temperature of water = 18°C
Temperature of water after 10 minutes = 30°C

Energy IN the system is electrical (E_e)

E_e = ItV
= 5 x 600 (10 mins is 600 secs) x 12
= 36,000 J = 36 kJ

Energy OUT of the system is light (E_L) and heat (E_h)

E = mcΔT
= 0.5 x 4190 x 12 (30-18) The specific heat capacity for water is 4190
= 25,140 J = 25.1 kJ (This is also in the data booklet)

Energy OUT = Energy IN
Energy IN = 36 kJ
Energy Out = E_h + E_L = 25.1 KJ + E_L

Therefore… 25.2 + E = 36 kJ
E = 36 – 25.1 = 10.9 kJ

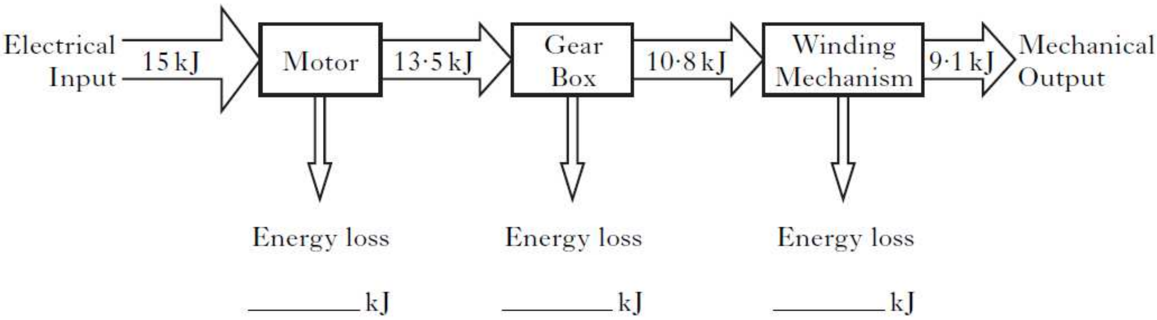
Efficiency = $\frac{\text{Energy out}}{\text{Energy in}} = \frac{10.9}{36} \times 100\%$ = 30%

Waste energy (heat energy) is 70% of output (25.2 kJ)

Task 24

An electric motor is used to drive a ski tow.

(a) Complete the energy audit below



b) Calculate the total energy loss in the ski tow.

Total energy loss = kJ

c) How efficient is the ski tow?