1 Engineering Materials

(1)

I READING AND COMPREHENSION

[1]Engineers have to know the best and most economical materials to use. [2]Engineers must also understand the properties of these materials and how they can be worked. [3]There are two kinds of materials used in engineering – metals and non-metals. [4]We can divide metals into ferrous and non-ferrous metals. [5]The former contain iron and the latter do not contain iron. [6]Cast iron and steel, which are both alloys, or mixtures of iron and carbon, are the two most important ferrous metals. [7]Steel contains a smaller proportion of carbon than cast iron contains. [8]Certain elements can improve the properties of steel and are therefore added to it. [9]For example, chromium may be included to resist corrosion and tungsten to increase hardness. [10]Aluminium, copper, and the alloys, bronze and brass, are common non-ferrous metals.

Study the following statements carefully and write down whether they are true or not true according to the information expressed above. Then check your answers by referring to solutions at the end of the passage.*

(a) Non-metals are used by engineers.
(b) Cast iron contains more carbon than steel.
(c) Chromium improves the properties of steel.
(1) (d) Copper contains iron.
(e) Bronze is an alloy.

(2) [11]Plastics and ceramics are non-metals; however, plastics may be machined like metals. [12]Plastics are classified into two types – thermoplastics and thermosets. [13]Thermoplastics can be shaped and reshaped by heat and

* The following symbols are used in the solutions:

$=$ equals, means the same as
$\neq$ does not equal, mean the same as
i.e. that is to say
$\therefore$ therefore

pressure but thermosets cannot be reshaped because they undergo chemical changes as they harden. [14]Ceramics are often employed by engineers when materials which can withstand high temperatures are needed.

(f) Thermosets can be machined.
(g) Thermoplastics are metals.
(h) Ceramics can withstand high temperatures.

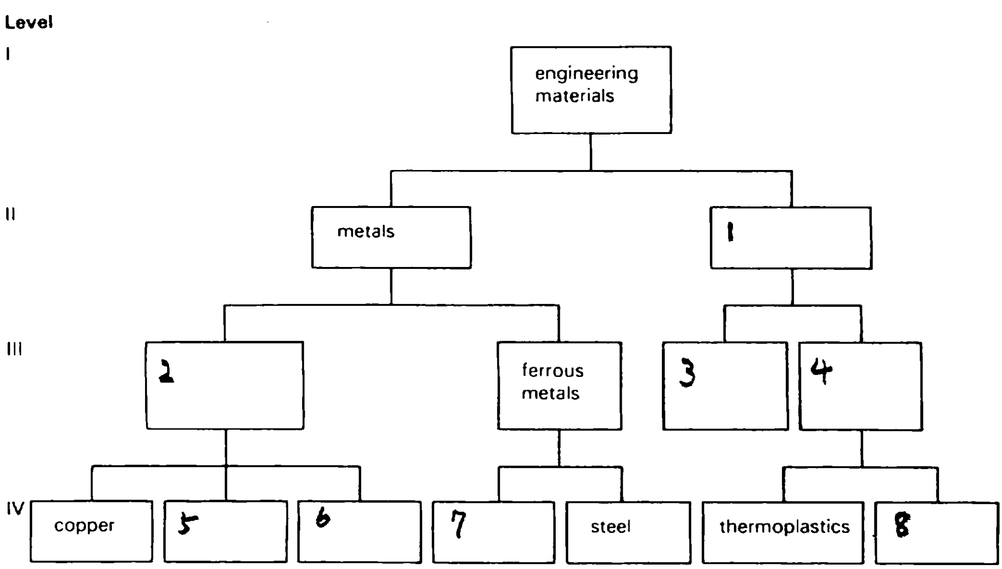
2

3 *Contextual reference*

1. In sentence 2, 'they' refers to
   (a) the engineers
   (b) the materials
2. In sentence 5, 'the former' refers to
   (a) ferrous metals
   (b) non-ferrous metals
3. In sentence 5, 'the latter' refers to
   (a) ferrous metals
   (b) non-ferrous metals
4. In sentence 8, 'it' refers to
   (a) steel
   (b) iron
5. In sentence 13, 'they' refers to
   (a) plastics
   (b) thermosets
   (c) thermoplastics

4 *Classification of engineering materials*

Draw in your notebook the diagram below and complete it, using the information from the reading passage.



5 *Classification (continued)*

Draw diagrams to classify the items in the following lists. Each diagram should have three levels.

1. alloys, copper, brass, pure metals, aluminium, metals.
2. brazing, electric-arc welding, soldering, metal-joining methods, welding, oxy-acetylene welding.
3. measuring instruments, non-precision instruments, micrometer, vernier gauge, metre stick, precision instruments, slip blocks, foot-rule.
4. units of area, cubic metre, metric units, millimetre, square metre, linear units, kilometre, units of volume.
5. milling machines, copy-miller, shaping machines, drilling machines, vertical shaper, radial arm drill, machine tools.

6

6. petrol engines, external-combustion engines, diesel engines, heat engines, steam turbines, internal-combustion engines.
7. grinding, metal cleaning methods, acid cleaning, mechanical methods, grit-blasting, alkali cleaning, chemical methods.
8. regular shapes, square, triangle, oval, irregular shapes, shapes.
9. adhesive joints, inseparable joints, welded joints, nut and bolt joints, joints, riveted joints, separable joints.
10. forging, sand casting, die casting, production processes, rolling, casting.

7 *However, therefore, because*

In this book you will meet many words which can be used to connect statements. Three of the most common are:

(1) however (2) therefore (3) because

Look at these examples:

(1) (a) Copper does not rust.
(b) Copper corrodes.
(a+b) Copper does not rust; however it corrodes.

(2) (a) Cast iron is a brittle metal.
(b) Cast iron is not used to withstand impact loads.
(a+b) Cast iron is a brittle metal, therefore it is not used to withstand impact loads.

(3) (a) Titanium is used for aircraft frames.
(b) Titanium is light and strong.
(a+b) Titanium is used for aircraft frames because it is light and strong.

In (1), statement (b) qualifies statement (a)
In (2), statement (b) is a result of statement (a)
In (3), statement (b) gives the reason why statement (a) is true.

Now join each of the following pairs of statements. Write down your answers in your notebook, using 'however', 'therefore' or 'because' as in the examples.

1. Chromium resists corrosion.
   Chromium is added to steels to make them rust proof.
2. Cutting tools are made from high-speed steels.
   High-speed steels retain their cutting edge at high temperatures.
   (. . . these steels . . . .)
3. Under normal conditions aluminium resists corrosion.
   Serious corrosion occurs in salt water.
   (. . . serious corrosion . . . .)
4. Manganese steel is very hard.
   Manganese steel is used for armour plate.
5. Bronze has a low coefficient of friction.
   Bronze is used to make bearings.
6. Nylon is used to make fibres and gears.
   Nylon is tough and has a low coefficient of friction.
7. Tin is used to coat other metals to protect them.
   Tin resists corrosion.
8. Tin is expensive.
   The coats of tin applied to other metals are very thin.
   (. . . the coats of tin . . . .)
9. Stainless steels require little maintenance and have a high strength.
   Stainless steels are expensive and difficult to machine at high speeds.
10. Nickel, cobalt and chromium improve the properties of metals.
    Nickel, cobalt and chromium are added to steels.

Language of measurement (iii): *Compound metric units*

Look again at the diagrams on pages 6–8 and the language used to describe the diagrams. Copy the following table into your notebook and complete it by filling in the spaces.

physical quantity	typical unit	short form
force	newton	N
time		s
	kilogramme	
length and distance		
	square metre	
		m^3

Compound units are made up of basic and derived units of measurement.

(a) The stroke / means 'per', and indicates that the unit in front of the stroke is divided by the unit after the stroke.

(b) Where there is no stroke between two units, the units are multiplied together.

Now rewrite the following sentences completing them by filling in the spaces.

EXAMPLE

moments The moment of a force is measured in newton metres.
Short form = Nm
The moment of a force is found by multiplying a force by a distance.

1. *velocity* Velocity is measured in metres per second.
   Short form = . . .
   Velocity is found by . . . a . . . by a . . .
2. *pressure* Pressure is measured in . . . per . . .
   Short form = N/m^2
   Pressure is found by . . . a . . . by a . . .
3. *density* Density is measured in kilogrammes . . . cubic metre.
   Short form = . . .
   Density is found by dividing a . . . by . . .
4. *stress* Stress is measured in newtons per . . .
   Short form = N/mm^2
   Stress is found by . . . a . . . by an area
5. *acceleration* Acceleration is measured in metres per second squared.
   Short form = . . .
   Acceleration is found by . . . a . . . by a time.

7 *Sentence building*

Join the following groups of sentences to make eleven longer sentences, using the connecting words printed at the beginning of each group (except group 6). You may omit words and make whatever changes you think are necessary in the word order and punctuation of the sentences.

EXAMPLE

BECAUSE/AND/HOWEVER
Plastics are used widely in engineering.
They are cheap.
They have a resistance to atmospheric corrosion.
Plastics are not particularly strong.

= Plastics are used widely in engineering because they are cheap and have a resistance to atmospheric corrosion; however they are not particularly strong.

1. AND
There are two types of plastics.
Thermoplastics are plastics.
Thermosets are plastics.

2. AND/WHEREAS/AND
Thermoplastics will soften when heated.
Thermoplastics will harden when cooled.
Thermosets set on heating.
Thermosets will not remelt.

3. FROM/TO
Plastics are used to make a great variety of products.
Plastics are used to make textiles.
Plastics are used to make engineering components.

4. SUCH AS
Plastics are available in many forms.
Plastics are available in the form of sheets, tubes, rods, moulding powders and resins.

5. TO
Various methods are used.
These methods convert raw plastic into finished products.

6. Compression moulding is a common method.
Compression moulding is used for shaping thermosets.

7. WITH/WHICH
The equipment consists of a press.
The press has two heated platens.
The two heated platens carry an upper and a lower mould.

8. THEN
Powder is placed in the lower mould.
This is moulding powder.
The upper mould is pressed down on the lower mould.

9. TO/WHICH
The pressure and the heat change the powder.
The powder becomes liquid plastic.
The liquid plastic fills the space between the moulds.

10. WHEN/AND
The chemical changes have taken place.
The mould is opened.
The moulding is extracted.

11. BY
Plastic bowls are made.
The compression moulding method is used,

(10)

V FREE READING

Read the following passage in your own time. If there are any words you do not know, look them up in your dictionary. Try to find additional examples of the points you have studied in this unit.

CORROSION

Corrosion attacks all engineering materials, especially metals. Corrosion is any chemical action which harms the properties of a material. It reduces the life of a material and increases the cost of a structure. For example, a steel bridge must be repainted regularly to protect it from rust. Various metals have therefore been developed to resist corrosion. Among them are the stainless steels. These metals contain from 12 to 35% chromium which forms a very thin layer or film of chromium oxide on the surface of the metal. This film protects the metal from corrosion. Alloys made from copper and nickel are also corrosion-resistant. For example Monel metal, which contains roughly 60% nickel and 30% copper, is resistant to both fresh and salt water corrosion. It is therefore used for marine engine parts, and for other surfaces like ships' propellers which are in contact with sea water. Cupronickels, which contain a smaller proportion of nickel, have a similar resistance to fresh and sea water. They are mainly used to make tubes.

When two different metals touch each other in the presence of moisture, corrosion occurs. This type of corrosion is known as galvanic or electrolytic corrosion because it has an electrical cause. The metals and the moisture act like a weak battery and the chemical action which results corrodes one of the metals. If, for example, aluminium sheets are riveted with copper rivets, the aluminium near the rivets will corrode in damp conditions.

No material can be completely corrosion-resistant. Even stainless steels will corrode. Engineers can, however, fight corrosion. For example, they can use high-purity metals because these metals are more resistant than alloys. They can also make sure that two dissimilar metals are not allowed to touch each other. Finally engineers can protect the surfaces of the metals in many different ways. One of the most common methods is to paint them.

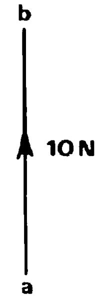
2 Vectors

I READING AND COMPREHENSION

[1]We deal with many different physical quantities in engineering. [2]They can be divided into two groups – scalar and vector quantities. [3]Both have size, or magnitude, but only vector quantities possess direction. [4]Mass, volume and length are scalar quantities. [5]Force, which we measure in newtons, possesses magnitude and direction. [6]Force, then, is a vector quantity. [7]Other examples are acceleration and velocity.

(a) There are two physical quantities in engineering.
(b) Scalar quantities have magnitude.
(c) Acceleration has direction.
(d) There are only three vector quantities in engineering.

[8]Any vector quantity can be represented by a vector. [9]The straight line *a–b* in the diagram is a vector which represents a force. [10]If we calculate its length we find that it is proportional to the magnitude of the force. [11]The direction of the line indicates the direction of the force. [12]The line is vertical because the direction of the force it represents is vertical. [13]It is important also to know in what sense of direction the force is acting. [14]The arrow-head on the line shows that the sense of direction of the force is upwards.



(e) We can use a vector to represent velocity.
(f) The straight line *a–b* in the diagram is a force.

(g) The arrow-head on line a–b shows that the force is acting in a vertical direction.

2)

(h) The longer the line a–b, the greater the force it represents.

3

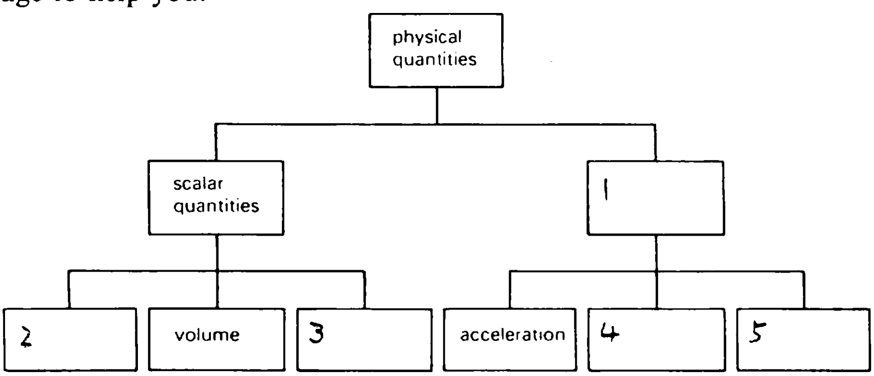
Contextual reference

1. In sentence 2, 'they' refers to (a) physical quantities (b) two groups
2. In sentence 3, 'both' refers to (a) scalar and vector quantities (b) physical quantities
3. In sentence 10, 'it' refers to (a) the length (b) the force
4. In sentence 10, 'its' refers to (a) the force's (b) the line's
5. In sentence 12, 'it' refers to (a) the force (b) the line

4

Classification of physical quantities

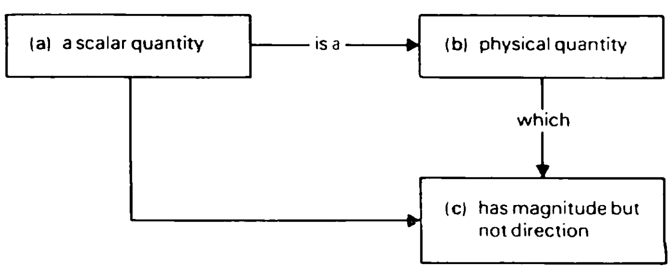
Copy the following diagram into your notebook and complete it to make a classification of physical quantities. Use the information from the reading passage to help you.



5

Making definitions

Study the following diagram:



We can make a classifying sentence about a scalar quantity by joining **(a)** and **(b)**:

A scalar quantity is a physical quantity.

We can then expand the sentence by including **(c)**:

A scalar quantity is a physical quantity which has magnitude but not direction.

The expanded sentence defines a scalar quantity. It is a *definition*. Now write as many definitions as you can using the following table.

a	b	c
a vector quantity a load a tensile force a linear dimension a vector a compressive force a derived unit friction	straight line force unit dimension physical quantity	can extend a body has magnitude and direction represents a vector quantity is a product of basic units can be measured in a straight line can stretch or compress a body can compress a body opposes motion

6 *Making generalizations*

When we join **(a)** and **(c)** only we make a type of statement called a *generalization.*

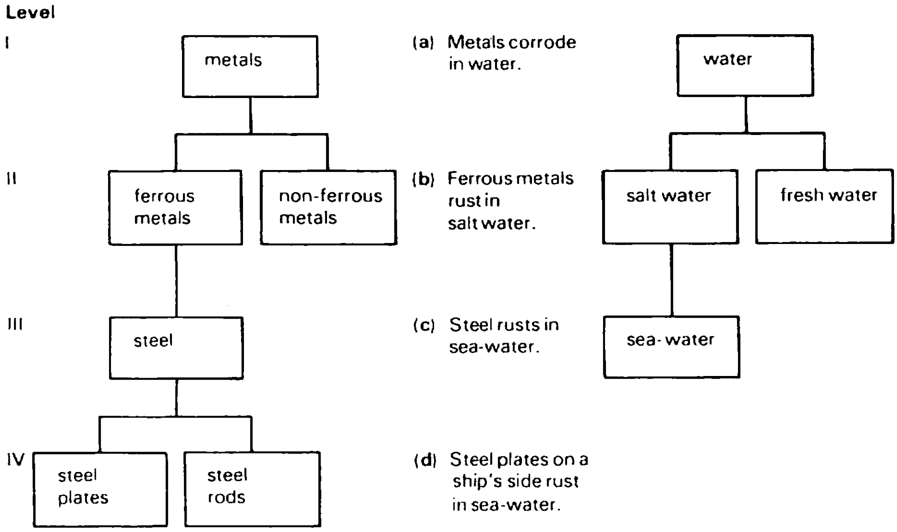
EXAMPLE

A scalar quantity has magnitude but not direction.

Now write as many generalizations as you can based on the table.

7 *Lower-level and higher-level generalizations*

Statements which contain higher-level items are more *general* than statements which contain lower-level items. Look at the following example:



Statement (a) is the most general statement. When statement (a) is true, statements (b), (c) and (d) must also be true.

Study the following sentences. Column (a) contains statements with lower-level items. Column (b) contains more general statements with higher-level items. Write column (a) in your notebook then match each lower-level statement with a general statement from column (b).

a	b
1. Iron rusts.	Engines consume fuel.
2. Bronze contains copper and tin.	Metallic elements are added to steel to improve its properties.
3. A square metre is made by multiplying a metre by a metre.	Compressive forces shorten bodies.
4. Chromium makes steel corrosion-resistant.	Metals corrode.
5. A load of five tonnes compresses a concrete column.	Derived units are products of basic units.
6. Zirconia heat shields withstand temperatures over 2000°C.	Alloys are mixtures of metals.
7. Vinylite can be shaped in a lathe.	Ceramics can resist high temperatures.
8. Railway lines extend in hot weather.	Plastics may be machined.
9. Four-stroke internal-combustion engines burn petrol, diesel oil, and gas.	Metals expand when heated.

(8) *The use of the passive in the description of an experiment*

Look at this sentence:

(a) Bill and I measured the extension in the steel bar.

We would not normally write this type of sentence in a report on an engineering experiment. Instead we would write:

(b) The extension in the steel bar was measured.

Sentence (b) is an example of the passive construction. The passive is common in scientific writing where the action described is felt to be more important than the actors.

Look at the following examples of active and passive sentences:

active	*passive*
We suspend a 1 kg mass from a light bar.	A 1 kg mass is suspended from a light bar.
We measured the distance between the mass and the fulcrum.	The distance between the mass and the fulcrum was measured.
We may calculate the moment of the force in two ways.	The moment of the force may be calculated in two ways.

Now rewrite each of the following sentences in the passive.

1. If we place a smooth roller on an inclined plane, it will run down the plane.
2. Two other forces act on the roller.
3. We can apply this force in any direction providing one component acts up the plane.
4. We call the third force the normal reaction – R.
5. We can therefore draw a triangle of forces for the system.
6. The diagram shows this force – P – acting parallel to the plane. (In the diagram, this force . . . .)
7. To keep the roller in equilibrium we must apply a force to it. (A force . . . .)
8. One is the force due to gravity – F_g – which we can consider to act vertically downwards through the midpoint of the roller.
9. We now find that we have an example of a three-force system. (It . . . now . . . that we . . . .)
10. As we assume the roller and plane to be absolutely smooth, this reaction is at right angles to the surface of the plane.

(9)

SCALES AND GRAPHS

In engineering it is often necessary to describe quantities and relationships. We can give a pictorial representation of vector quantities by using vectors as described in the first reading passage in this unit. Scalar quantities are simply described by giving their magnitude in a suitable unit of measurement. For example, we can describe the mass of a body as a quantity of grammes, the capacity of a container as a number of cubic metres and a period of time as so many seconds. We can also illustrate scalar quantities by points or divisions on a scale. Thus, a clock is a scale for measuring time and the clock hands indicate the passage of time. Similarly a metre stick is a scale for measuring length and a thermometer is a scale for measuring heat.

Scales can also be used to make calculations. For example, engineers use slide-rules for quick multiplication and division. The slide-rule consists of two logarithmic scales.

When there is a relationship between two sets of observations, we can often express this as a mathematical formula. We can also use a graph.

(10)

A graph gives a visual representation of the relationship. This is often more easily understood than a law. For example, if we make a graph to compare the safe working loads of steel ropes with the circumference of the ropes, it is easy to see how the safe working load varies with the circumference. In addition we can use the graph as an information store, rather like a simple computer. In this way a graph can present at a glance the information contained in a law or a collection of tables.

A more complex kind of graph is the nomograph. This can show the relationship between more than two variables. A simple nomograph can consist of a number of scales arranged in a special shape. For example, three scales could be placed parallel to each other or in the form of the letter N, or even in curves. Such a nomograph is read by drawing a straight line to cut through all three scales. With a nomograph of this type an engineer could correlate information on the horse-power of a motor, its speed, and the diameter of driving shaft necessary to transmit the motor's power.

More complex nomographs are made on special graph paper and may even be in three dimensions.

3 Force

I READING AND COMPREHENSION

[1]We can describe a force only by its effects. [2]It cannot be measured directly like a length. [3]A force can start something moving. [4]If we push against a small object it moves. [5]A force can also stop something moving or hinder motion. [6]If we brake a moving car it slows down and will eventually stop. [7]Suspend a heavy mass from a copper wire. [8]The wire extends, showing that a force can stretch a body. [9]Forces may also compress, bend or even break an object.

(a) Length can be measured directly.
(b) A force can slow down a moving object.
(c) A force can cause movement.
(d) A body can be compressed by a force.
(e) A heavy mass can exert a force.

[10]A force can be one of attraction. [11]The force of attraction exerted by the huge mass of the earth is called gravity. [12]If we pick up a stone, then release it, it falls to the ground because of gravitational force. [13]Gravity is an example of a natural force. [14]Whether a force is naturally or deliberately exerted it cannot exist by itself. [15]Forces must always occur in pairs, never in isolation. [16]When a force acts on a rigid body it is balanced by an equal reaction force which acts in the opposite direction. [17]If a man stands on a slippery surface and brings a force to bear on a heavy load, the reaction force makes him slide backwards. [18]Similarly if a man fires a rifle, the force which pushes the bullet forwards will be matched by a force which makes the gun push backwards against his shoulder.

(f) Gravity is a force.
(g) Deliberately exerted forces can exist alone.
(h) Natural forces are forces of attraction.
(i) When a force acts on a rigid body, the magnitude of the reaction force depends on the size of the rigid body.
(j) The force which pushes a gun backwards when it is fired is a reaction force.

3 *Contextual reference*

1. In sentence 2, 'it' refers to (a) an effect (b) a force
2. In sentence 4, 'it' refers to (a) a force (b) a small object
3. In sentence 6, 'it' refers to (a) a moving car (b) a brake
4. In sentence 14, 'it' refers to (a) a force (b) a naturally exerted force
5. In sentence 16, 'it' refers to (a) a force (b) a rigid body

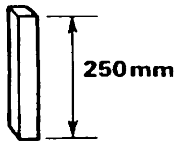
4 *Instructions and results*

Copy the column of instructions below into your notebook. Then write down and complete each sentence in the results column using the information from the reading passage. Sentence 1 has been completed for you.

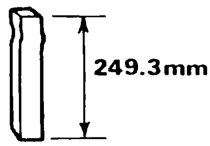
	instruction	*result*
1.	Push against a small object.	The object moves.
2.	Brake a moving car.	The car ....
3.	Suspend a heavy mass from a copper wire.	The wire ....
4.	Release a heavy weight from a height of one metre.	The weight ....
5.	Stand on slippery ground and push against a heavy load.	Our feet ....
6.	Hold a gun against your shoulder and fire it.	The gun ....
7.	Apply a force of 500 N to a thin metal rod.	The rod ....

8.	Apply a force of 2 kN suddenly to an iron casting.	The casting ....

9. Apply a load of 1 kN to the end of a steel upright.



The upright . . . .



10. Apply a force to a rigid body. — The force is balanced . . . .
11. Suspend a brick from a spring balance. — The spring . . . .
12. Strike a piece of glass with a hammer. — The glass . . . .

5

Relative clauses (defining)

Look at the following sentences:

(a) *Loads* cause tensile stresses.
(b) *The loads* tend to pull a body apart.

If the noun phrases in italics refer to the same thing, we can combine the two sentences into one by using a relative clause:

(c) Loads which tend to pull a body apart cause tensile stresses.

Write down a single sentence for each of the following pairs of sentences. Make the second sentence into a relative clause and insert it into the first sentence at the place marked by dots.

EXAMPLE

A lever . . . can be used to compare two masses.
Such a lever has the fulcrum placed between load and effort.
= A lever which has the fulcrum placed between load and effort can be used to compare two masses.

1. A strut is a member . . .
   The member resists a compressive force.
2. The beams . . . are welded together.
   They form the chassis of the truck.
3. Rust may attack certain metals. . . .
   These metals contain some proportion of iron.
4. We can combine information on the size of a force and the distance it moves, in a diagram . . . .
   The diagram is called a work diagram.
5. Sir Isaac Newton put forward a law . . .
   The law states that every action has an equal and opposite reaction.

Relative clauses (non-defining)

Compare the following sentences:

(a) The mill *which produces sheet steel* was made in Scotland but the mill *which produces tube steel* was made in Sweden.
(b) The mill, *which produces sheet steel,* was made in Scotland.

In sentence (a) the relative clauses tell us which mill we are talking about. In sentence (a) we have two *defining* relative clauses. In sentence (b) we already know which mill we are talking about. The clause simply adds some extra information about the mill. In sentence (b) we have a *non-defining* relative clause. Note the use of commas.

In Exercise D you made sentences with defining relative clauses. In this exercise, make the second sentence into a relative clause and insert it into the first sentence at the place marked by dots. You will write sentences with non-defining relative clauses.

EXAMPLE

Brass, . . . , is used to make bolts and screws.
Brass is an alloy of copper and zinc.
Brass, which is an alloy of copper and zinc, is used to make bolts and screws.

1. The rectangular block of steel, . . ., is fixed to the floor.
   The block measures 100 by 200 by 10 mm.
2. The electric motor, . . . , is linked to the driving shaft by a belt.
   The motor has a mass of 400 kg.
3. Polished steel, . . . , is in fact covered with tiny bumps.
   Polished steel is normally described as flat and smooth.
4. Friction, . . . , dissipates mechanical energy by converting it into heat energy.
   Friction is always present in a machine.
5. Stainless steel contains chromium, ...
   The chromium makes the steel corrosion-resistant.

6 *Relative clauses (defining and non-defining)*

Now join the following pairs of sentences and state whether the completed sentences contain defining or non-defining relative clauses.

EXAMPLE

The micrometer screw gauge, . . . , consists of a steel frame carrying a sleeve on which a thimble turns.
The micrometer screw gauge is used by engineers to obtain very accurate measurements.
= The micrometer screw gauge, which is used by engineers to obtain very accurate measurements, consists of a steel frame carrying a sleeve on which a thimble turns. (non-defining)

1. The body is just on the point of sliding at the angle . . . .
   The angle is known as the angle of friction.
2. A railway engine, . . . , draws a train of eight coaches, each of mass 17 tonnes, up a gradient of 1 in 40.
   The engine has a mass of 80 tonnes.
3. The screw-jack is basically a screw running through a fixed nut . . . .
   The nut is incorporated in the jack.
4. As the cord is wound off the wheel, the load cord, . . . , is wound on and thus overcomes the load.
   The load cord is attached to the axle.
5. The gear . . . rotates in an opposite direction to the first.
   The gear is last in an even series of gears in mesh.
6. Intermediate gears, . . . , are often referred to as idlers.
   Intermediate gears do not affect the ratio of the gear train.
7. Hoisting winches of the first group, . . . , are termed single purchase crab winches.
   These winches employ a simple gear train.
8. This diagram means that the tensile force . . . must exceed 3 kN.
   The tensile force will cause permanent distortion.
9. Complicated mechanisms . . . are machines just as simple levers are machines.
   These complicated mechanisms make up an aeroplane engine.
10. Malleable cast iron, ... , is tougher than grey cast iron.
    Malleable cast iron is a ferrous metal.
11. Steels . . . are called tool steels.
    These steels are used to make tools.
12. The Kariba dam, . . . , provides electric power for Zambia.
    The dam is situated on the Zambesi.

7 *Noun modification* (i)

If we want to describe an object in greater detail we may use an adjective:

water – *hot* water
metal – *ferrous* metal
lever – *simple* lever

We can also put a noun in front of a noun:

a cylinder – a *steel* cylinder
a bearing – a *brass* bearing
a filter – an *air* filter

Many grammatical relationships are possible in Noun+Noun constructions, or *noun compounds*. Look at the following examples:

(a) a diesel engine = an engine *which uses* diesel oil
(b) a brass bearing = a bearing *which is made of* brass
(c) carbon steel = steel *which contains* carbon
(d) a capstan lathe = a lathe *which has* a capstan

Find further examples of each type in the following list. Mark each phrase (a), (b), (c) or (d).

EXAMPLE
phosphor bronze (c)

air motor
turret lathe
chromium steel
steel plate
wing nut
electric drill
metal casting
concrete bridge
heat engine
aluminium alloy

8

GRAVITY

A force of attraction exists between every body in the universe. It has been investigated by many scientists including Galileo and Newton. This gravitational force depends on the mass of the bodies involved. Normally it is very small but when one of the bodies is a planet, like the earth, the force is considerable. Everything on or near the surface of the earth is attracted by the mass of the earth. The greater the mass, the greater is the earth's force of attraction on it. We call this force of attraction gravity.

Because of gravity, bodies have weight. We can perceive weight only when a body resists gravity. For example, when we pick up a stone there are two forces involved. One is the lifting force we exert and the other is the force of gravity which attracts the stone downwards and thus gives it weight. When a body escapes from the influence of the earth's gravitational pull, it can become 'weightless'.

9

For example, the centrifugal force of a spacecraft spinning in orbit round the earth cancels the effect of gravity. The crew therefore experience weightlessness. One of the minor disadvantages of weightlessness is that normal pens will not write because the ink is not attracted by gravity to flow out of the pen.

If the space crew land on the surface of the moon, they experience the much weaker force of gravity exerted by the moon. On the moon they weigh less than on the earth. Special training is necessary to help them to walk on the moon's surface.

To simplify engineering calculations, it is assumed that gravity is the same everywhere on the earth's surface, and that for every kilogramme of mass the earth exerts a force of 9·81 newtons on a body. In fact gravity differs slightly from place to place because of the shape of the earth. It is greatest at the poles where the earth is flattest and is least at the Equator.

4 Friction

I READING AND COMPREHENSION

[1]Whenever one surface moves over another, a force is set up which resists the movement. [2]This force, which we call friction, always opposes motion. [3]It exists in every machine. [4]It can be reduced by lubrication but never completely removed. [5]In general, the force opposing motion is slightly greater before one surface starts moving over another surface than after movement has started. [6]This slightly greater force is called static friction. [7]The force which must be overcome to keep one surface moving over another is known as sliding friction. [8]Static friction is greater than sliding friction.

(a) Friction always occurs when there is movement between surfaces.
(b) We can remove all sliding friction by lubricating moving surfaces.
(c) To start a body moving requires a greater force than to keep it moving.
(d) Sliding friction opposes motion.
(e) Friction is a force.

[9]The value of sliding friction depends on the nature of the two surfaces which touch each other. [10]Thus friction between two rough planks can be lessened if they are made smooth. [11]Sliding friction is independent of the area of surface in contact. [12]In theory a small brake pad will exert as much braking force as a large one of greater surface area. [13]In practice a small pad will wear down more quickly and therefore is not used. [14]One other law of friction should be noted. [15]We can make the normal reaction between two surfaces in contact twice as large by doubling the mass carried by one surface. [16]If we do so we find that sliding friction between the surfaces is also doubled. [17]If we halve the mass carried, sliding friction is also halved. [18]This shows that sliding friction is proportional to the reaction between the surfaces in contact.

(f) When the area of surfaces in contact is increased, sliding friction between them is increased.

(g) Large brake pads are used instead of small ones because they exert a greater braking force

(h) Sliding friction between rough planks is greater than between smooth planks.

(i) If the mass of a body sliding over another is increased, the sliding friction force between them will also increase.

2 (j) If we halve the area of surfaces in contact, we will halve the sliding friction between the surfaces.

3

Contextual reference

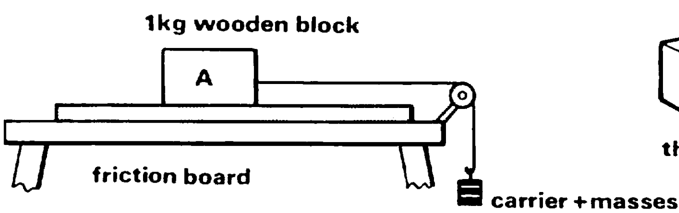
1. In sentence 2, 'this force' refers to
   (a) the force which resists the movement
   (b) the force which moves one surface over another
2. In sentence 3, 'it' refers to
   (a) friction
   (b) motion
3. In sentence 4, 'it' refers to
   (a) a machine
   (b) friction
4. In sentence 10, 'they' refers to
   (a) the two surfaces
   (b) two rough planks
   (c) sliding and static friction
5. In sentence 12, 'one' refers to
   (a) braking force
   (b) brake pad
   (c) a law of friction

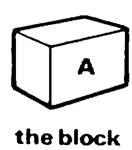
4

Instructions and results

Copy the column of instructions below in your notebook. Then write down and complete the results column using the information from the reading passage. Sentence 1 has been completed for you.

instruction	*result*
1. Place a smooth roller on an inclined plane.	The roller rolls down the plane.
2. Push a table across a rough floor.	A force is set up which .... motion.
3. Double the forces pressing two moving surfaces together.	Sliding friction between the two surfaces is ....
4. Lubricate two moving surfaces.	Sliding friction ....
5. Grease the surface of a shaft rotating in a bearing.	Sliding friction ....





6. Measure the force required to start the block moving *and* measure the force required to keep the block moving.
We find that the force . . . . is greater than the force . . . .

7. Lay the block on side A and measure the force required to keep the block moving.
We find that the force . . . is . . . .

8. Add a 1 kg mass to the block and measure the force required to keep the block moving.
We find that the force . . . is . . . .

9. Substitute a glass sheet for the friction board and measure the force required to keep the block moving.
We find that the force required to keep the block moving . . . .

5 *Short-form relative clauses* (i)

We have seen (Unit 3) that if two sentences each contain a noun phrase, and the noun phrases refer to the same thing, then the sentences can be joined together by a relative pronoun like *which.*

EXAMPLE

The block is resting on a plane.
The plane is inclined at an angle of 30° to the horizontal.
= The block is resting on a plane *which is inclined at an angle of 30° to the horizontal.*

We can make this sentence shorter by omitting *which is*:

The block is resting on a plane *inclined at an angle of 30° to the horizontal.*

In the same way we can omit *which is* from the following sentence:

The plane *which is flying at an altitude of 2,140 metres* is subjected to pressures of 80 kilonewtons per square metre.
= The plane *flying at an altitude of 2,140 metres* is subjected to pressures of 80 kilonewtons per square metre.

Now join the following sentence pairs omitting *which* wherever possible. In each case indicate whether the relative clause is a defining or a non-defining clause.

1. Steels . . . are known as alloy steels.
   These steels are mixed with one or more metallic elements.
2. Tests . . . are of two kinds – tests to destruction and tests within the elastic limit.
   These tests are applied to materials.

3. The power developed by the generator . . . is 20 kW.
   The generator is revolving at 1,000 rev/min.
4. A dockside crane, . . . , has a safe working load of 3×10^3 kg.
   The crane is mounted on a set of rails.
5. The distance . . . is plotted on a graph against time taken.
   The distance is travelled by a moving load.
6. These forces constitute a tensile stress, . . . , which acts around the circumference of the cylinder.
   This stress is known as hoop stress.
7. The force . . . was found to be 1,200 N.
   The force was exerted on the clamps.
8. Bridges, roof trusses and cranes are structures . . . .
   Such structures are designed to resist forces.

6 *Short-form relative clauses* (ii)

Look at this example:

The steel beams are welded together.
The beams form the chassis of the truck.

We can join these two sentences in two ways:

(a) The steel beams *which form the chassis of the truck* are welded together.
or (b) The steel beams *forming the chassis of the truck* are welded together.

In sentence (b) we have made the relative clause shorter by omitting *which* and changing the verb to its *-ing* form. What kind of relative clause does sentence (a) contain – defining or non-defining?

If the relative clause contains *which*+a verb in the simple present we can omit *which* and change the verb to its *-ing* form. This rule can be applied if

(a) the clause is a defining one
or (b) the verb is a verb of state

Verbs of state describe states not actions like 'work' or 'run'. The most common verbs of state in engineering are

measure	contain
weigh	hold
consist of	form

Now join the following sentence pairs omitting *which* wherever possible. In each case indicate whether the relative clause is defining or non-defining and underline verbs of state.

1. XY is a steel shaft . . . .
   It carries a 300 mm diameter eccentric gear.
2. A flywheel, . . . , has a diameter of 1·6 m.
   The flywheel consists of a cast iron rim which is connected to a boss by spokes.
3. The driving belt, . . . , is 9 mm thick.
   It transmits power to the pulleys.
4. The towers, . . . , support the main section of the bridge.
   The towers weigh a thousand tonnes each.
5. The tapping head has a spring clutch, ...
   The clutch allows the tap to slip without breaking when the load becomes excessive.
6. Grooving tools, . . . , are made of high-speed steel.
   Grooving tools cut slots or keyways.
7. The main shaft of the lathe drives the lubricant pump, ...
   The pump supplies cooling fluid at the tool cutting tip.
8. Bronze . . . is called phosphor bronze.
   This bronze contains 0·8 % phosphorus.

7 *Short-form relative clauses* (iii)

When the relative clause contains *which+have* we can shorten it in two ways. Look at the following examples:

Two steel sheets *which have a thickness of 3 mm each* are joined by rivets.
= (a) Two steel sheets *having a thickness of 3 mm each* are joined by rivets.
or (b) Two steel sheets *with a thickness of 3 mm each* are joined by rivets.

Now join these sentence pairs and omit *which* where possible:

1. Grey cast iron is a soft close-grained cast iron . . . .
   This cast iron has a relatively low melting point.
2. A diesel engine . . . is called a slow-speed diesel.
   This engine has a running speed of 75 to 250 rev/min.
3. A dockside crane . . . is mounted on a set of rails.
   The crane has a safe working load of 2,000 kg.
4. A milling machine . . . is known as a universal milling machine.
   This machine has a swivelling table.

8 *Noun modification* (ii)

In Unit 3 we studied a number of noun compounds. Another common way of modifying a noun can be seen in the following example:

The load is distributed uniformly.
= It is a uniformly distributed load.

Now rewrite the following sentences in the same way:

1. The load was applied suddenly.
2. The forces are perfectly matched.
3. The bar is fixed rigidly.
4. The material corrodes easily.
5. The surface treatment was developed recently.
6. The crane hook is stressed heavily.
7. The salt bath furnace is heated externally.
8. The force was exerted deliberately.
9. We work the forging plastically.
10. The tool drum is controlled automatically.

LUBRICATION

Friction can be useful. For example, the screw-jack depends on friction between the body of the screw and the jack to prevent it running back under heavy loads. Belt drives depend on friction to prevent slipping. Brakes and vices are further examples of useful applications of friction. On the other hand, friction in machines causes loss of power. Twenty per cent of the power of a motor car is wasted in overcoming friction. Engineers try therefore to reduce friction as much as possible by good design. They can also use materials with a low coefficient of friction for devices such as bearings. The third method used for reducing friction is lubrication.

Although the surface of a block of polished steel may seem perfectly flat, when we examine it through a powerful microscope we see that it is covered with tiny 'hills and valleys'. If we bring two steel surfaces together they will touch at only a few points where one set of 'hills' meets another set. Because the total mass of the steel is concentrated at these points, the pressure on them is so great that it causes the points of contact to weld together. When we apply a force to make one block of steel move over another, we must first break these tiny welds before the blocks will move. For this reason, to start a surface moving over another surface requires a force greater than that required to keep the surfaces in motion. This greater force represents static friction whereas the smaller force represents sliding friction. When one block slides over another the two surfaces scrape against each other, breaking off tiny pieces from each surface. However, if we lubricate the two surfaces, oil fills the tiny valleys so that the surfaces do not weld together, and one block can move over the other.

Lubrication, then, reduces friction and because the surfaces do not scrape against each other it reduces wear on the material. Although dry friction can be eliminated in this way, some power will still be lost depending on the thickness of the lubricant used. Thus if the oil is too thick the lubricant itself will offer some resistance to motion. Selection of the correct lubricant depends on many factors, chief among which are the operating speeds of the machinery which is lubricated and the temperature range within which the machine must operate.

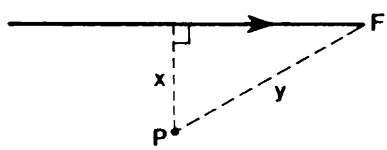
5 Levers

I READING AND COMPREHENSION

(1)

[1]When a force acts on a body it may cause it to move in a straight line or to turn about a point or to do both. [2]A force can make a body rotate around a point which is not in its line of action. [3]If we push against the handle side of a door it will turn on its hinge and open. [4]The size of the turning effect of a force depends on the magnitude of the force and the perpendicular distance between its line of action and the point about which the body turns. [5]We call this point the fulcrum. [6]The turning effect of a force about a fulcrum is known as the moment of the force. [7]It is the product of the force and the distance at right angles between its line of action and its fulcrum.

(a) A hinge is a fulcrum.
(b) A force may make a body rotate about a point and move in a straight line at the same time.
(c) The greater the perpendicular distance between a point and the line of action of a force, the greater the turning effect of the force about that point.
(d) If we multiply length y by force F, we will obtain the moment of the force about point P



(1) **(e)** The moment of a force $= \dfrac{\text{force}}{\text{perpendicular distance between line of action and fulcrum}}$

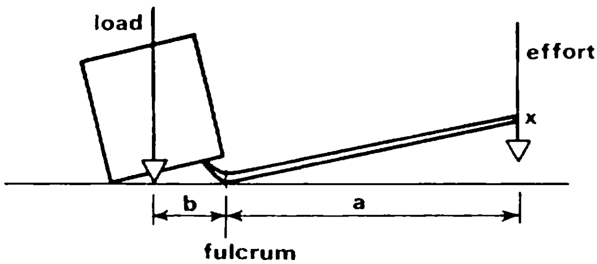
(2) [8]The lever is one application of the principle of the moment of a force about a point. [9]The lever is a simple machine. [10]An example is the crowbar, which is used to move large loads by means of smaller efforts. [11]Diagram 1

shows a crowbar being used to lift a heavy block. [12]The mass of the block is the load, the heel of the crowbar is the fulcrum and the force exerted by the man pressing down at X is the effort. [13]In the diagram a and b represent respectively the perpendicular distance between the effort and the fulcrum and the perpendicular distance between the load and the fulcrum. [14]By the principle of moments we can say that the man will just balance the load when

$$\text{effort} \times a = \text{load} \times b$$

[15]Any increase in the effort will raise the load further and may eventually cause it to overbalance.

1

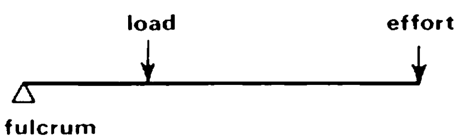


(f) The lever is the only application of the principle of the moment of a force about a point.
(g) The crowbar is a simple machine.
(h) Simple machines can use small efforts to move larger loads.

[16]Levers can be divided into three groups or orders. [17]They are classified according to the relative positions of the load, the effort and the fulcrum. [18] The positions are as follows:

first order: fulcrum between load and effort
second order: load between fulcrum and effort
third order: effort between fulcrum and load.

(i) A crowbar is a lever of the first order.
(j) With a crowbar, effort and load move in the same direction.
(k) All levers belong to a particular order.
(l) This diagram represents a third-order lever.



2

3 *Contextual reference*

1. In sentence 3, 'it' refers to	(a) a handle
	(b) a door
2. In sentence 4, 'its' refers to	(a) the force's
	(b) the turning effect's
3. In sentence 5, 'this point' refers to	(a) the point about which the body turns
	(b) the line of action of the force
4. In sentence 7, 'it' refers to	(a) the moment of a force
	(b) the fulcrum
	(c) the magnitude of the force
5. In sentence 15, 'it' refers to	(a) the effort
	(b) the crowbar
	(c) the load
6. In sentence 17, 'they' refers to	(a) load, effort and fulcrum
	(b) three orders
	(c) levers

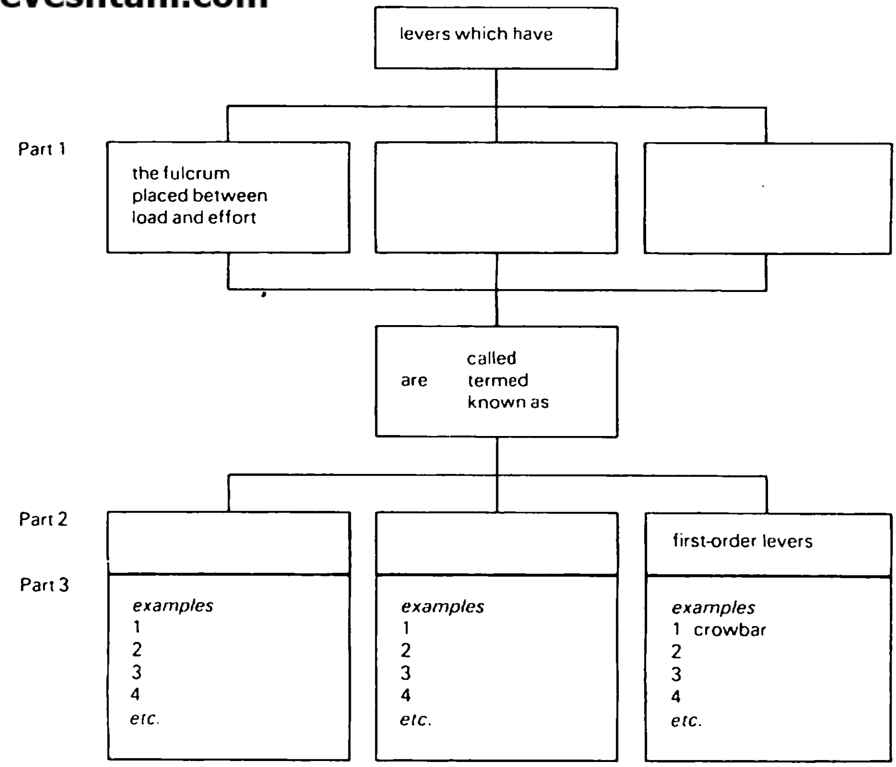
EXERCISE C *Relationships between statements*

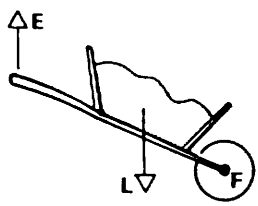
Place the following expressions in the sentences indicated. Replace and re-order the words in the sentences where necessary.

this means that (2)	since (14+15)
thus (2)	it follows that (15)
for example (3)	

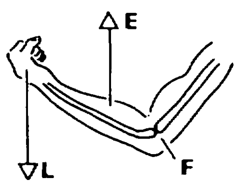
4 *Interpretation of diagrams*

Look at the drawings underneath the table opposite. Decide which kind of lever each drawing represents. Then fill in part 3 of your table, listing as many examples as you can.

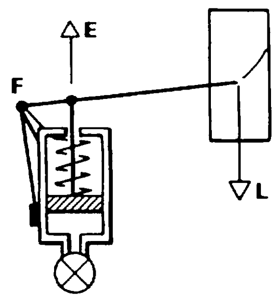




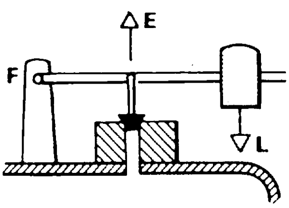
1 wheelbarrow



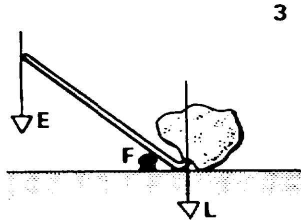
2 human forearm



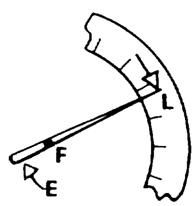
3 engine-indicator tracing point



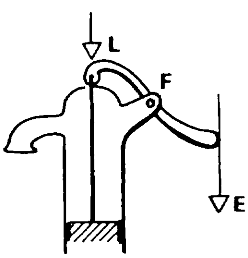
4 steam safety valve



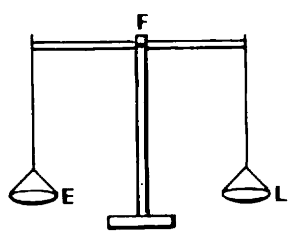
5 crowbar



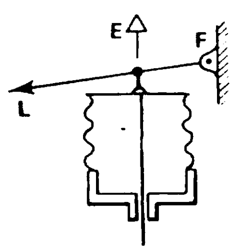
6 meter hand



7 pump handle



8 beam balance



9 aneroid barometer pointer

5 *Combining sentences with an* -ing *clause*

Look at the following sentences:

(a) Belt drives are not so positive as gear drives.
(b) Belts tend to slip on high loads.

These can be combined into one sentence:

(c) Belt drives are not so positive as gear drives, belts tending to slip on high loads.

Combine each of the following pairs of sentences into one sentence by using an *-ing* clause in the same way:

1. A chain drive is similar to a belt drive except that the chain passes over sprockets on the chain wheel.
   This arrangement ensures that no slip takes place.
2. When a resultant force acts on a body an acceleration is produced.
   Its value depends on the mass of the body.
3. The length of the steel increases in proportion to the forces applied.
   Its cross-sectional area is unchanged.
4. The screw-jack is a screw revolving in a fixed nut.
   The screw thread provides a means of converting circular motion to motion in a straight line.
5. Work done by a force can be represented by a work diagram in the form of a graph.
   The vertical axis represents the force and the horizontal axis the distance moved.
6. The wheelbarrow is an example of a second-order lever.
   The load is carried between the fulcrum and the effort.
7. When a force is applied to the edge of a door it will turn.
   The hinge forms a fulcrum for the door.
8. Pressure is measured in newtons per square metre.
   The word 'per' implies that the force in newtons is divided by the area in square metres.
9. A crowbar is a first-order lever.
   The fulcrum is the heel of the crowbar.
10. The human forearm is a lever.
    The effort is provided by the muscle joining the upper arm to the forearm.

6 *Relative clauses with prepositions*

In books about engineering we find many relative clauses with a preposition before *which*. Such clauses are formed in the following way:

The shaft runs in brass bushes.
The pulley is mounted *on the shaft*.
= The shaft *on which* the pulley is mounted runs in brass bushes.

Combine each of the following pairs of sentences into one sentence containing a relative clause beginning with a preposition+*which*:

1. The main bearings consist of steel shells lined with aluminium.
   The shaft runs in the bearings.
2. The point is called the fulcrum.
   The body is free to rotate about the point.
3. The piers resist the load by a reaction of 5,000 N each.
   The bridge rests on the piers.
4. The points are 600 mm apart.
   The one kilogramme masses are suspended from the points.
5. The position of the arms of the lever will depend on the angle.
   The forces are required to act at the angle.
6. The rope passes over one pulley in the upper block.
   The lower block is attached to the rope.
7. The distance is double the displacement of the load.
   The effort moves through the distance.
8. Since earliest times man has tried to devise methods.
   A small effort can move a large load by the methods.
9. The efficiency of most machines rises quickly to reach a maximum value near those loads.
   The machine is designed for those loads.
10. A gear box is a unit.
    A compound gear train which can be altered by engaging different gears is housed in this unit.

(7) G *Noun modification* (iii)

Some Noun+Noun combinations used in engineering contain a noun formed from a verb. Often the verb indicates the function of the object described.

EXAMPLE

object: air-compressor
function: to compress air

We can express this information in a sentence:

An air-compressor is used to compress air.

Write similar sentences to indicate the function of the following objects. Note that some of the nouns end in *-er* and some in *-or.*

speed governor	oil cooler
mass carrier	pressure regulator
casing liner	steam condenser
gas generator	shock absorber
air heater	hardness tester

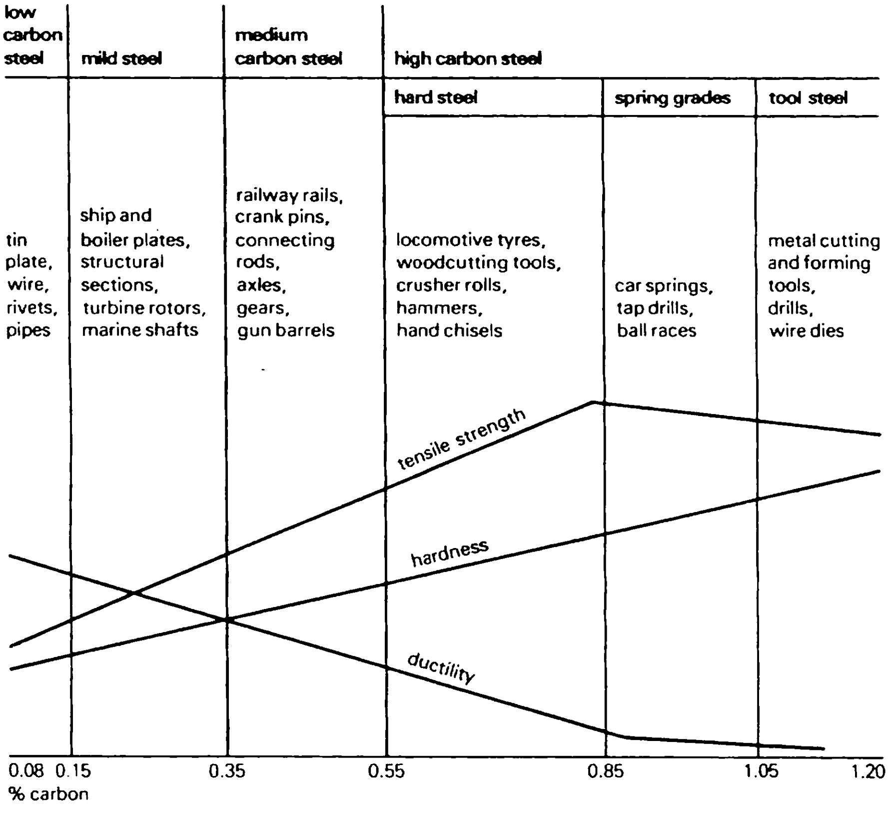
What are the names of the following objects? Check the spelling in your dictionary.

a device used to reduce the speed (of a motor)
a device used to indicate the level of oil (in a gear box)
a device used to grind the surface (of a metal plate)
a device used to inject fuel (into petrol or diesel engines)
a device used to filter oil (for an engine)

The information given in brackets does not form part of the name of the object.

8 *Making comparisons based on a diagram*

Study the following diagram. Then read the comparison of mild steel and low carbon steel which is based on the information contained in the diagram.



Properties and applications of carbon steels

Low carbon steel contains between 0·08 and 0·15% carbon whereas mild steel contains between 0·15% and 0·35% carbon. Mild steel is stronger and harder than low carbon steel but it is less ductile. Low carbon steel is used to make tin plate, wire, rivets and pipes while mild steel is used for structural sections, turbine rotors, marine shafts and for ship and boiler plates.

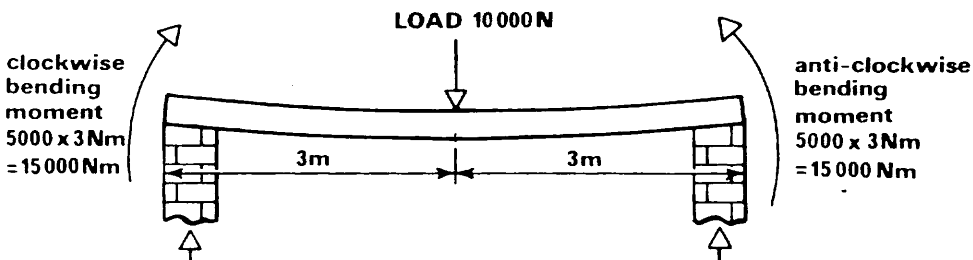
Now write out and complete the following comparison of high and medium carbon steels using the information in the diagram.

High carbon steel contains between . . . and . . . carbon whereas medium carbon steel . . . . High carbon steel is . . . and . . . than . . . steel, but its strength . . . slightly when its carbon content is . . . than 0·83 %. In addition . . . steel is less . . . than . . . steel. Medium carbon steel is used for . . . . High carbon steel with a . . . content up to . . . is used to make woodcutting tools, ... Car springs . . . are made from . . . with between . . . and . . . while metal cutting . . . are made from . . . with between . . . and . . . .

(9) BEAMS

When choosing a beam it is important to know its bending strength. The bending strength of the beam is the beam's resistance to bending moments. Diagram 1 shows a beam supported at both ends and carrying a load at its mid-point. The load makes the beam bend slightly. If we imagine the beam to consist of a number of longitudinal layers we can see that the top layer will be compressed by the load, and the bottom layer will be stretched as the beam bends. At the centre there will be a neutral layer which is neither stretched nor compressed.

The beam is subjected to bending moments because the reaction at the supports causes clockwise and anti-clockwise moments as shown in the sketch. If the beam fails, the top layers will be crushed and the bottom layers torn. This failure will occur at mid-span where the bending moment is greatest.



1

(10)

As most of the stress occurs at the top and bottom of a beam most of the material is concentrated at the top and bottom in the flanges. Material at the neutral layer is wasted as far as bending strength is concerned. In some girders, therefore, material is removed from the web. Diagram 2 shows a castellated girder, which is made by cutting a girder in two as shown, then reversing the ends and welding the two halves together. The result is a stronger beam for equal amounts of steel.

2

The depth of a beam is important in deciding what the resisting moment of the beam will be. The resisting moment of a beam resists the bending moment which tries to destroy the beam. The force produced by the tension of the top layers and the force produced by the compression of the bottom layers form a couple across the depth of the beam to provide a resisting moment. The deeper the beam, the longer the lever arm of the couple and hence the greater the resisting moment. In fact the beam's bending strength increases proportionally to the cube of the depth.

The reasons for the shape of the familiar I-section rolled steel beam now become clear. The flanges contain a lot of steel to resist compression and tension. The web of the beam is thin because it is not subjected to these stresses. The beam is deep compared to its width because its depth gives it a greater moment of resistance to offset bending moments.

6 Stress and Strain

1

I READING AND COMPREHENSION

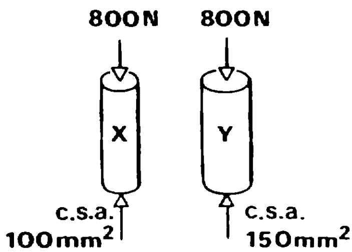
[1]A body is in stress when forces are applied to it which cause its size and shape to change. [2]In other words, stress causes distortion. [3]The intensity of stress depends on the size of the force and the cross-sectional area (c.s.a.) of the body which resists the force. [4]That is,

$$\text{stress} = \frac{\text{applied force}}{\text{c.s.a. of the body}}$$

[5]Distortion due to stress is called strain. [6]Different forces will distort bodies in different ways. [7]A tensile force will lengthen a body. [8]One subjected to a compressive force will contract. [9]If a body has a uniform c.s.a., that is, if it has the same c.s.a. throughout its length, we calculate strain as

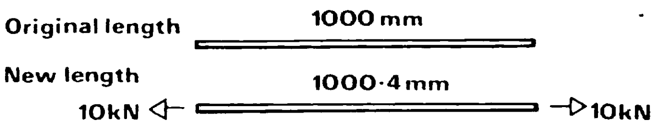
$$\text{strain} = \frac{\text{change of length}}{\text{original length}}$$

(a) Stress on bar x is greater than stress on bar y



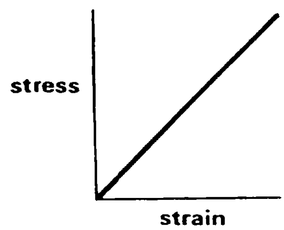
(b) A tensile force can cause distortion.

(c) For this bar of steel, strain is equal to $\frac{1{,}000{\cdot}4}{1{,}000}$



(d) Tensile forces and compressive forces have opposite effects on bodies.
(e) Distortion causes strain.

[10]Most materials used in engineering are elastic. [11]A material which has the property of elasticity will return to its original size and shape when the forces producing strain are removed. [12]However, if these forces go beyond a certain limit, called the elastic limit, an elastic material will not regain its original dimensions. [13]If we take a bar of uniform c.s.a. of an elastic material like mild steel, and apply gradually increasing tensile forces to it, it will extend. [14]If we measure each extension produced by each increase in force, we will find that the bar's increase in length is in proportion to the increase in force.[15]In other words, strain is proportional to stress. [16]A graph of stress against strain would therefore be a straight line like that in Diagram 1:



1

[17]Another way of expressing this is:

$$\frac{\text{stress}}{\text{strain}} = \text{a constant}$$

[18]The value of this constant is different for each elastic material. [19]It is called the Modulus of Elasticity. [20]If we exceed the elastic limit, then strain is no longer proportional to stress and there is permanent deformation. [21]These findings illustrate Hooke's law which states that within the elastic limit, the strain produced is proportional to the stress producing it.

(f) All engineering materials are elastic.
(g) Mild steel is an elastic material.
(h) Elastic materials cannot be in a state of stress.
(i) A mild steel bar will always extend in proportion to the forces which extend it.
(j) Within the elastic limit, if we double the stress on a body we will double the strain produced.
(k) The value of the Modulus of Elasticity varies according to the stress an elastic material is subjected to.
(l) Mild steel has a uniform c.s.a.

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③ *Contextual reference*

1. In sentence 1, 'it' refers to	(a) stress (b) a body
2. In sentence 1, 'its' refers to	(a) the force's (b) the body's
3. In sentence 8, 'one' refers to	(a) a body (b) a tensile force
4. In sentence 9, 'its' refers to	(a) the body's (b) a force's
5. In sentence 12, 'its' refers to	(a) the elastic limit's (b) an elastic material's
6. In sentence 16, 'that' refers to	(a) the graph (b) the straight line
7. In sentence 19, 'it' refers to	(a) a constant (b) an elastic material
8. In sentence 21, 'it' refers to	(a) the strain (b) the stress

④ *Definitions*

Make a definition for each item in column (a)

EXAMPLE

An organic material is a material which is based chemically on carbon.

a	b	c
a stainless steel		can be drawn out into wires
a non-ferrous metal		contains iron
a formable metal		is based chemically on carbon
an abrasive substance	substance	can lengthen a body
a ferrous metal	metal	resists corrosion
a compressive force	steel	does not contain iron
a ductile metal	material	can shorten a body
an organic material	force	can be shaped into forms
a tensile force		can be used to wear away a softer material

5 *Predictions based on the properties of materials*

When we know what the properties of a material are we can predict how it will behave under different conditions. To make predictions of this type, we use an *if*-sentence with *will* in part 2. Look at this example:

If a material is flexible, it will bend easily.

Now write similar predictions for materials which have the properties listed in column (a). Match each property in column (a) with an appropriate expression from column (b).

a	b
elasticity	will not bend easily
plasticity	will resist abrasion, deformation and indentation
toughness	will resist wear
corrosion-resistance	will regain its original dimensions after the forces which have caused deformation are removed
rigidity	will tend to fracture under impact loads
wear-resistance	will bend easily
brittleness	will not return to its original dimensions after the forces producing strain are removed
hardness	will not fracture when indented or scratched
flexibility	will resist fracture when subjected to an impact load
softness	will resist corrosion

6 *Noun modification* (iv)

Here is another common way of modifying a noun in engineering.

(a) a bracket with a pin joint
= (b) a *pin-jointed* bracket

Rewrite each of the following expressions as in example (b):

a metal tube with thin walls
a roller with a flat bottom
a polygon with six sides
a cutting tool with multiple edges
a follower with a knife edge
a rivet with a copper face

Describe each of the following objects as in example (a):

a four-sided indentor
a stellite-tipped cutting tool
a wire-jacketed hose
a square-threaded screw
a round-headed rivet
a stub-nosed tool

7 *Prepositions*

Rewrite the following sentences, filling in the spaces with a preposition from the list. You will have to use some of the prepositions more than once.

away	of
between	on
from	to
in	with
into	

1. The crank gear meshes . . . a second gear to which the winding drum is rigidly fixed.
2. Two masses are suspended . . . the metre stick at points X and Y.
3. A single point tool consists . . . a tip made of high-speed steel and a plain carbon steel shank welded to the tip.
4. The screw runs in a fixed nut incorporated . . . the jack.
5. The worm is prevented . . . axial movements by its bearings.
6. Whether the load extends or compresses the spring depends . . . the type of balance.
7. The calculations necessary in designing gear wheels are based . . . the pitch circle diameter.
8. Vector *a–b* was converted . . . a force of 60 N.
9. Fluid is applied to cutting tools to cool and lubricate them and to wash . . . chips and swarf.
10. Brake linings are often made . . . an asbestos compound.
11. We can distinguish . . . high pressure laminates and low pressure laminates.
12. Vernier calipers are provided . . . a vernier scale to ensure accuracy in measurement.
13. A hammer with one end ball-shaped and the other end slightly domed, is referred . . . as a ball-pein hammer.
14. A single vector quantity can be resolved . . . any number of components in an infinite variety of ways.

8 *Making inductions*

We have seen (Unit 4) that in mechanical engineering it is necessary to make inductions from observations. These observations are often written in the form of *if-* or *when-* sentences.

EXAMPLE

Observation
when we push a table across a rough floor, a force is set up which opposes motion

this shows that

Induction
friction always opposes motion

Write down sentences 2, 7, 8, 11, 15, and 20 from the reading passage in your notebook. Using these sentences to help you, complete in your notebook the inductions which follow each of the observations below.

1. If a bar of iron is subjected to a force of 2 kN, it bends.
   This shows that . . . .
2. When a rod of mild steel has a compressive force of 5 kN applied to it, it contracts by 0·889 mm.
   This demonstrates that . . . .
3. If a weight of 6 kg is attached to a wire of uniform c.s.a., the wire extends by 0·05 mm.
   This shows that . . . .
4. When a load of 30 kN is applied to a steel bar, it lengthens by 0·250 mm. If the load is increased to 60 kN, the bar lengthens by 0·50 mm.
   These findings show that . . . .
5. When the load of 60 kN is removed from the steel bar, it regains its original proportions.
   This demonstrates that . . . .
6. If the load exceeds 60 kN, the bar does not return to its original size and shape when the load is removed.
   This shows that . . . .

9 FACTOR OF SAFETY

Designers of any stress-bearing structure, from a bracket to a suspension bridge, must accurately calculate the stresses they expect the structure to bear. They must also have a good understanding of the properties of materials. In the past, miscalculation of stresses and lack of knowledge of the properties of materials has led to disaster. For example, the first Tay Bridge in Scotland collapsed, killing 77 people, because no allowance was made for wind pressure. Even with today's testing equipment errors are sometimes made in calculating the safe loads a structure can carry. For instance, a number of box girder bridges have collapsed during construction.

To safeguard structures, designers normally work within a factor of safety so that materials are kept within their permitted working stress. Working stress is the greatest stress to which a part of a structure is ever subjected. It is calculated by dividing the ultimate strength of the material by a factor of safety. The former is the stress at which the material fractures. The latter is the product of four main factors.

The first factor is the ratio of ultimate strength to the elastic limit of the material. The elastic limit can be obtained from a tensile test. Normally this ratio is approximately 2.

The second factor depends on the nature of the stress involved. For example, a body may be exposed to one constant stress, or to variable stress, or even to compound stress, that is, where several stresses act on it at the same time. A constant stress of one kind is given a factor of 1. Variable stress is more complex. Under frequently repeated stresses a metal will fracture at a much lower point than its ultimate strength. Metal fracture caused by such stresses is commonly called 'metal fatigue'. For simply repeated stresses ranging from zero to a maximum and back to zero, a factor of 2 is allowed. For alternating stress, which not only varies in size but also in direction, for example from tensile to compressive, a factor of 3 is necessary.

The third factor concerns the application of the load. A factor of 1 may be allowed for a gradually applied load, 2 for a suddenly applied load and greater factors for shock loads.

10

The last factor is the most difficult to determine. Sometimes it is called the 'factor of ignorance'. If all the conditions of service are known, this factor can be low. Where the conditions of service are severe, where there is a danger of an overload or where the materials are imperfect, a factor as high as 10 may be necessary. For example, bridge builders may allow for freak winds and in earthquake zones special allowances must be made when designing tall buildings.

The following example illustrates how the factor of safety for a forged steel connecting rod in a diesel engine is calculated. The first factor is 2. As the rod is subjected alternately to both compressive and tensile stresses, the second factor is 3. When the fuel mixture ignites it imposes a suddenly applied load on the rod, hence the third factor is 2. The conditions of service of an engine are well-known, therefore the last factor is $1\frac{1}{2}$. The factor of safety is thus $2 \times 3 \times 2 \times 1\frac{1}{2}$, which equals 18.

Because of weight restrictions, aircraft are manufactured to much lower factors of safety – between 1·1 and 1·75. These extremely low factors require exacting material and production specifications and highly accurate design calculations.

In advanced design work, especially in designing skyscraper blocks, loadings up to the plastic state of metals are now used. In such design work there can be no 'factor of ignorance' and extreme accuracy in calculating the stresses on the structure is essential.

7 Ideal and Practical Machines

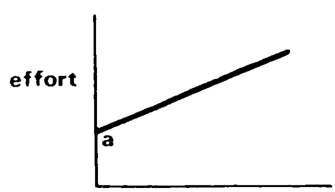
5
1

I READING AND COMPREHENSION

[1]A machine is any device which allows work to be done more conveniently. [2]A machine has an input member to which an effort is applied and an output member which moves a load. [3]The advantage of a machine is that the effort applied can be very much smaller than the load to be overcome. [4]The measure of this advantage is the ratio of load to effort and is known as the Mechanical Advantage (M.A.)

$$\text{M.A.} = \frac{\text{Load}}{\text{Effort}}$$

[5]In a practical machine energy is lost because of friction. [6]The M.A. of a practical machine changes as the load it carries changes because the percentage of effort required to overcome friction depends on the size of the load. [7]For very small loads a large percentage of the effort is needed to work against friction whereas with larger loads the fraction is less. [8]A graph of load against effort has the shape shown in Diagram 1:

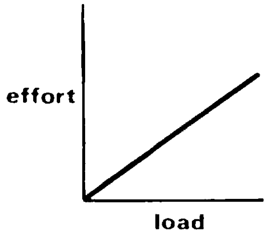


1

[9]In the above diagram, *a* is the effort required to overcome friction.

(a) The M.A. of a practical machine is a constant.
(b) A practical machine requires more effort to move small loads than large loads.
(c) A machine can lift a large load with a smaller effort.

(d) This is a graph of load against effort for a practical machine.



[10]To obtain a high M.A. a machine must be designed so that the distance moved by the effort is much greater than the output displacement of the load. [11]The ratio of the two distances is termed the Velocity Ratio (V.R.) that is:

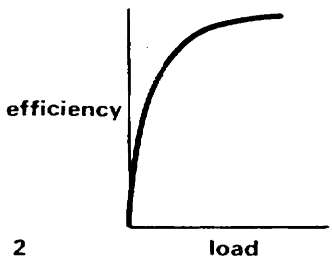
$$\text{V.R.} = \frac{\text{distance moved by the effort}}{\text{distance moved by the load}}$$

[12]The V.R. of a machine depends on its design and has a fixed value for each machine. [13]In other words it is a constant.

[14]We can think of the effort which is applied to the machine as the work input. [15]The work done by the machine on the load is the work output. [16]The efficiency of the machine is then the ratio of the work output to the work input, that is:

$$\text{Efficiency} = \frac{\text{work output}}{\text{work input}}$$

[17]In practice the work output is always less than the work input because some energy is lost inside the machine in overcoming friction. [18]Thus the efficiency of a practical machine can never reach 100%. [19]Efficiency tends to increase sharply with load, then flatten out as it reaches a limiting value as shown in Diagram 2:



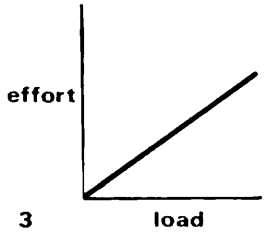
2

(e) The V.R. of a machine varies according to the work output.
(f) The efficiency of a practical machine is not a constant.
(g) The work input of a practical machine is greater than its work output.
(h) Efficiency is proportional to load.

[20]Mathematically it can be shown that

$$\text{Efficiency} = \frac{\text{M.A.}}{\text{V.R.}}$$

[21]An ideal machine has no friction. [22]Since an ideal machine is frictionless, its M.A. would not vary with the load but would be a constant. [23]A graph of load against effort would have the shape shown in Diagram 3:



3

[24]If it were possible to build an ideal machine, there would be no loss of energy within the machine. [25]Thus we could say that

$$\text{work input} = \text{work output}$$

i.e.

$$E \times D_E = L \times D_L$$

where E = effort, D_E = distance moved by effort, L = load, and D_L = distance moved by load. [26]An ideal machine would have an efficiency of 1 or 100%. [27]As efficiency is equal to the ratio M.A./V.R. the M.A. of an ideal machine must equal its V.R.

(i) A machine with an M.A. of 5 and a V.R. of 5 is an ideal machine.
(j) For an ideal machine, efficiency would increase as the load increased.
2 **(k)** The work done by a machine on a load is equal to the load times the distance moved by the load.
(l) Frictionless machines exist.

3 *Contextual reference*

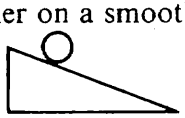
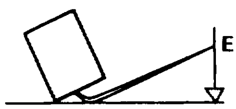
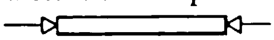
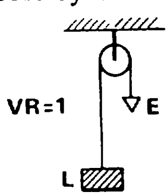
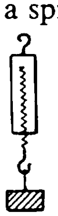
1. In sentence 2, 'which' in the phrase 'to which' refers to
   (a) a machine
   (b) an input member
   (c) an output member
2. In sentence 6, 'it' refers to
   (a) the Mechanical Advantage
   (b) the load
   (c) a practical machine
3. In sentence 12, 'its' refers to
   (a) the Velocity Ratio's
   (b) a machine's
   (c) a value's
4. In sentence 13, 'it' refers to
   (a) the Velocity Ratio
   (b) each machine
   (c) a machine
5. In sentence 19, 'it' refers to
   (a) a practical machine
   (b) an ideal machine
   (c) a load
   (d) efficiency
6. In sentence 27, 'its' refers to
   (a) an ideal machine's
   (b) efficiency's
   (c) a machine's

4 *Predictions based on laws, generalizations and proven facts*

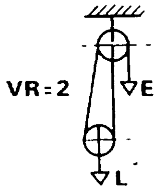
In Unit 6 we practised '*if*-sentences' which were predictions. These predictions were based on the properties of different materials and the sentences contained *will* in column (b). We can also make predictions based on laws, generalizations and proven facts.

EXAMPLE (based on the law 'Friction always opposes motion')
We push a table across a rough floor.
The motion will be opposed by friction.
= If we push a table across a rough floor, the motion will be opposed by friction.

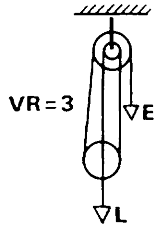
Now write in your notebook predictions based on the sentences in column (a). The sketches will help you to complete column (b) of each prediction.

a	b
1. We subject a steel bar to tensile forces. 	The bar . . . .
2. We place a roller on a smooth inclined plane. 	The roller . . . .
3. We apply an effort at E. 	The block . . . .
4. We subject a strut to compressive forces. 	The strut . . . .
5. We move the effort by 1 metre. 	The load . . . .
6. We attach a load to a spring balance. 	The spring . . . .

7. We move the effort by 50 centimetres. The load . . . .



8. We move the effort by 1·80 metres. The load . . . .



Now use the facts given in the table to write predictions based on the following suppositions:

COEFFICIENT OF FRICTION

surfaces	μ
bronze on bronze dry	0·20
bronze on bronze lubricated	0·05
steel on brass dry	0·35
steel on cast iron dry	0·40
leather on cast iron	0·55
plastic on cast iron	0·18
rubber on asphalt	0·65
rubber on concrete	0·70

9. We lubricate two bronze moving surfaces in contact. Friction . . . .
10. We replace the brass bushes in which a steel shaft is running with cast iron bushes. Friction between shaft and bushes . . . .
11. We compare braking distances for a car on asphalt roads and on concrete roads. We will find . . . .
12. We replace a leather belt driving a cast iron pulley with a plastic belt. The plastic belt will . . . . . under heavy loads.

5 *Predictions based on unlikely suppositions*

Another kind of *if*-sentence is used to make predictions where the supposition is unlikely to happen.

EXAMPLE

we build an ideal machine

it will have no energy loss due to friction

= *If we built* an ideal machine, *it would have* no energy loss due to friction.

Now make predictions based on the following suppositions. First you will have to match each supposition to the appropriate sentence in column (b). Remember to change the verb in the supposition to the past tense form, and *will* in column (b) to *would.*

a	b
1. We compare work output to work input for an ideal machine.	It will be a constant.
2. We make a perfectly smooth surface.	It will be a straight line passing through the origin.
3. We measure the efficiency of an ideal machine.	We will find they are equal.
4. We draw a graph of load against effort for an ideal machine.	It will be frictionless.
5. We prepare two perfectly smooth surfaces.	We will find it is 100%.
6. We calculate the M.A. of an ideal machine.	We will find they are equal.
7. We compare the M.A. and the V.R. of an ideal machine.	It will require an effort of 20 N to raise a load of 200 N.
8. It requires an effort of 10 N to raise a load of 100 N with an ideal machine.	They will have a zero coefficient of friction with each other.

2

6 *toughen, harden, soften, etc.*

Rewrite the following sentences using the verbs from the list.

roughen	lengthen	sharpen
harden	loosen	strengthen
soften	ensure	shorten
enlarge	weaken	lessen
tighten	lighten	widen

EXAMPLE

Drills can be made sharp with grinding stone.

= Drills can be *sharpened* with grinding stone.

1. The 5 kg mass was removed to make the load on the test piece lighter.
2. A reamer can be used to make drill holes larger.
3. Repeatedly flexing copper wire makes it hard and thus makes it easy to break.
4. A torque wrench should be used to make the bolts tight on a cylinder head.
5. A tensile force will make a body longer.
6. Wing nuts can be made loose easily by hand.
7. A compressive force will tend to make a body shorter.
8. The surface should first be made rough using a coarse file.
9. Solvents can be used to make coatings soft.
10. The gap between tailstock and spindle nose can be made wider by rotating the hand wheel.
11. Friction between two rough planks can be made less if they are planed.
12. Piston rings make sure that the piston makes a gas-tight seal with the cylinder wall.
13. Extra struts will make the framework stronger.
14. Dirty materials may make reinforced concrete weak.

Sentence and paragraph building

Join the following groups of sentences to make eleven longer sentences describing a screw-jack. You may add or omit words where you think it is necessary, and you should provide appropriate punctuation and paragraph divisions.

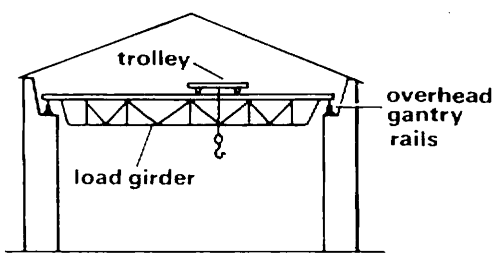
1. The wheel and axle, the lever, and the inclined plane are simple machines.
   Man has used simple machines for over 2,000 years.
2. Most machines are based on simple machines.
   The screw-jack is based on the inclined plane.
3. Cut a triangle out of paper.
   The triangle is right-angled.
   The purpose of the triangle is to represent an inclined plane.
4. Wrap the paper triangle round a cylinder.
   The inclined edge of the paper makes a spiralling line round the cylinder.
5. The spiralling line becomes the thread of the screw.
   The spiralling line is known as a helix.
6. A screw forms the main component of the screw-jack.
   The screw has a square thread.
7. Square threads are used for power transmission.
   Square threads offer less frictional resistance than vee-threads.

8. The screw is free to rotate.
The screw rotates in a fixed nut.
The fixed nut forms part of the body of the jack.
9. The screw rotates.
This raises the load.
An effort is applied to the effort bar.
10. The screw makes a full revolution.
The load is raised by a distance.
The load is lowered by a distance.
The distance is equal to the pitch of the screw.
11. The pitch is a distance.
The distance is between the same points.
The points are on adjacent threads.

(8) CRANES

We can define a crane as a machine which lifts heavy loads and displaces them horizontally. In other words, a crane can lift loads and move them to a different position in the horizontal plane, unlike a hoist which is only a lifting device. We can divide cranes into two main classes. These are jib cranes and overhead travelling cranes. Jib cranes have a jib, or arm, from which the load is suspended. The jib allows the load to be raised or lowered and then deposited at any point within the radius of the jib. Movement of the jib in the vertical plane is known as derricking. The rotation of the jib in the horizontal plane is called slewing.

The commonest kind of non-revolving crane is the overhead travelling crane. Such a crane is illustrated in the diagram below. It consists of a



horizontal section called a load girder, made up of a number of steel beams, resting on end carriages which run on overhead gantry rails. A trolley to carry the crane hook in turn runs on top of the load girder. Cranes like this are found in workshops where heavy machinery has to be transported from place to place on the shop floor for different stages in its manufacture.

The three movements of the overhead travelling crane are as follows. It can lift a load to the height of the load girder, it can traverse the width of the shop floor with it, and it can move the load along the length of the workshop. As the body of the crane is mounted overhead it does not affect work on the shop floor as it moves. Cranes with a span of 40 metres and a maximum lifting capacity of 400 tonnes are made.

9 For use outside a factory, for example in timber yards, a similar crane, termed a goliath crane, is used. The load girder of a goliath crane is supported not on gantry rails but on legs running on rails mounted on the ground.

There are many varieties of cranes for special purposes. They may be fixed, portable or mobile. A portable crane must be transported, whereas a mobile crane is either self-propelled or mounted on a truck chassis or a railway wagon. Cranes use different forms of power, for example electric power, diesel power, hydraulic power, steam power and even hand power are used depending on the type of crane and its application.

An example of a crane with a particular application is the shipyard crane. This is a heavy, fixed crane with a slewing cantilever mounted on a latticed tower which is firmly anchored in concrete. In addition to the main load trolley the crane may be fitted with a small jib crane running on the cantilever. Such cranes are necessary in shipbuilding because when a ship is being fitted out, heavy machinery, such as the engines, has to be lowered into the vessel. These cranes must be capable of placing the loads inside the ship with great accuracy. For this reason some form of fine electrical control is normally employed.

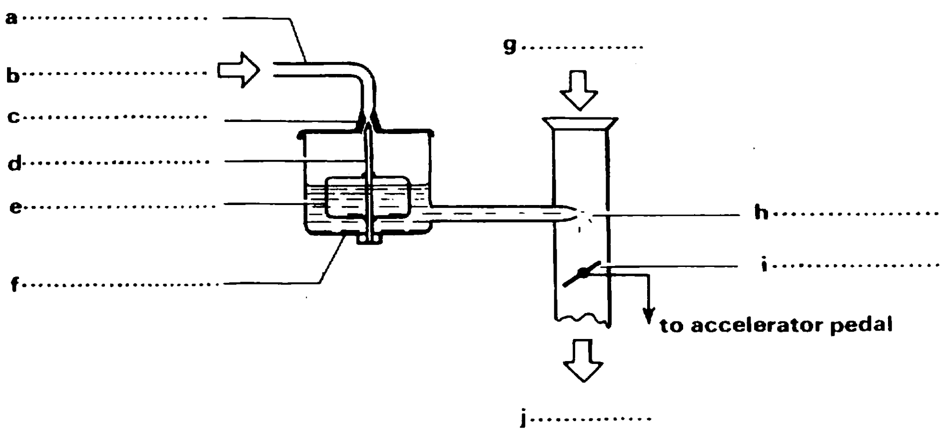
Another example is the dockside crane which is used to unload and load ships. It is usually mounted on rails which run the length of the quay and is often fitted with a grab instead of a hook. A grab has two jaws which open and close like a clamshell. It is designed to handle bulk cargoes like iron ore and gravel. One variety of dockside crane, known as a kangaroo crane, feeds bulk cargoes directly into a hopper at its base. From the hopper the cargo is weighed and discharged into trucks and railway wagons.

8 The Four-Stroke Petrol Engine

I READING

(1) PART 1 *The carburettor*

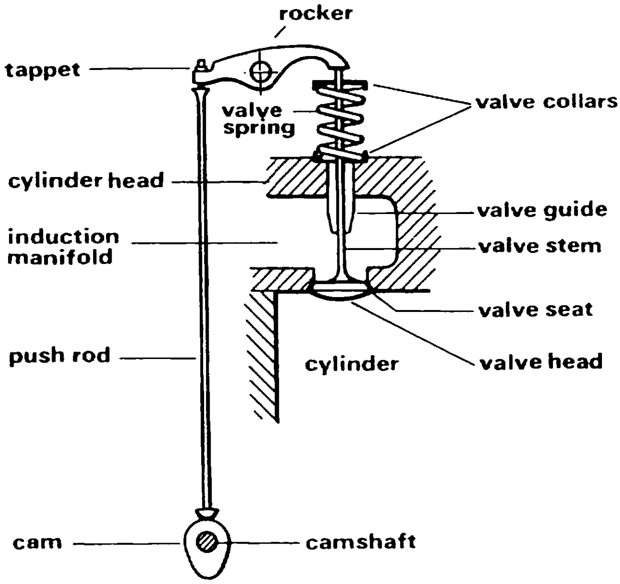
Complete the labelling of the diagram using the words in italics in the passage. Write down the labels in your notebook against the letters a–j.



[1]The carburettor is a device which provides the engine with an air and petrol mixture in the correct proportions for all running conditions. [2]This simplified diagram shows how it operates. [3]*Petrol* enters the *float chamber* via the *feed pipe* and the *fuel inlet*. [4]When the chamber is filled to the correct level, the *float* and *needle-valve* rise, cutting off the fuel supply. [5]When the piston moves down the cylinder it reduces the pressure within the cylinder. [6]The pressure of the atmosphere then pushes *air* in through the carburettor where it mixes with a fine *jet of petrol* from the float chamber to produce finely divided fuel droplets. [7]The quantity of this *atomized fuel* which enters the cylinder is controlled by a *throttle valve*. [8]In a motor car the throttle valve is opened and closed by operating the accelerator pedal.

(2) PART 2 *The valves*

Complete the passage using the information in the diagram. Write down a list of the missing words against their sentence numbers.



[9]The function of the valves is to open and close at the correct time when the engine is running so that fuel can enter the cylinder and the exhaust gases escape. [10]The valve illustrated is an inlet valve. [11]It is fitted into the . . . . [12]Fuel from the . . . enters the . . . through it. [13]The . . . is ground so that it fits the . . . exactly, forming a gas-tight seal. [14]The . . . slides through a . . . , which is a sleeve of bronze tapered at one end so that it can be driven tightly into the cylinder-head.

[15]The inlet valve is kept closed by means of a . . . . [16]The ends of the spring are held between two . . . . [17]One collar is set in the cylinder head while the upper collar is attached to the valve stem.

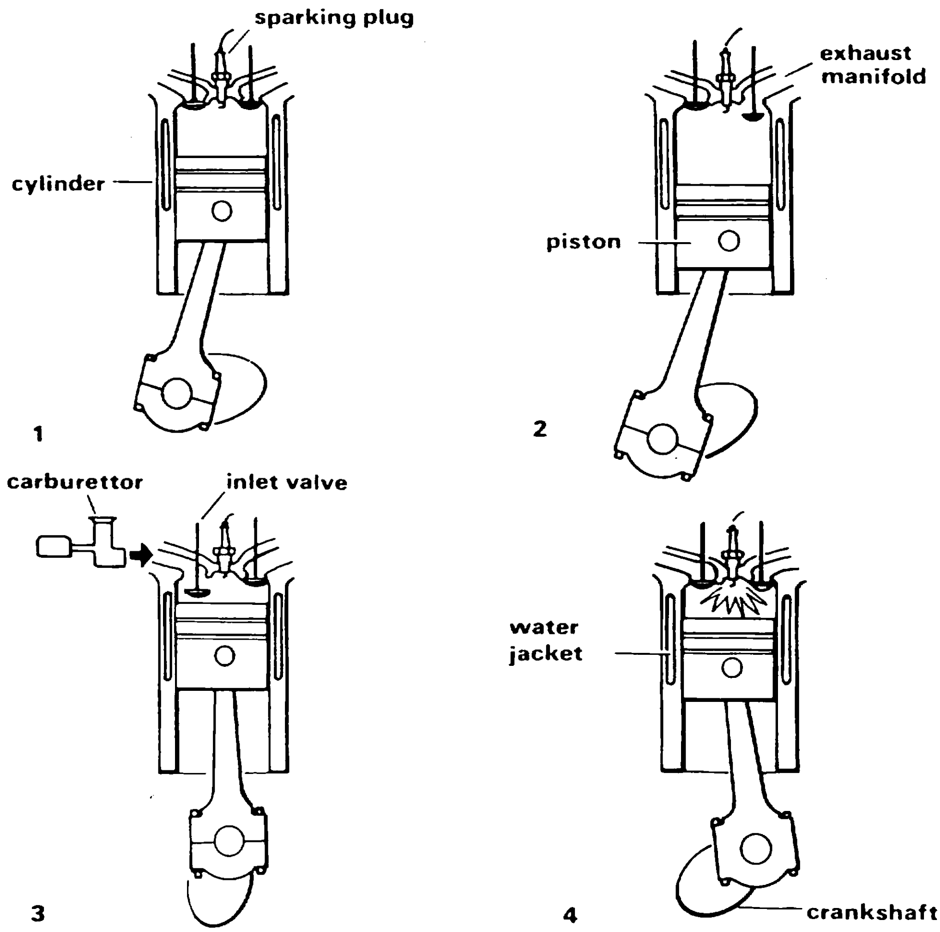
[18]The valve is opened at the right moment by means of a . . . mounted on a . . . . [19]This shaft is driven by the engine crankshaft. [20]As the cam turns it pushes up the . . . which in turn raises one end of the . . . . [21]The other end presses down on the valve stem and the valve opens. [22]A small screw, called the . . . , is provided at one end of the rocker to allow slight adjustments to be made in the proportion of the lift from the cam being imparted to the valve.

(3) PART 3 *The four-stroke cycle*

Read the following passage carefully and write down a list of the missing words against their sentence numbers. Use the diagrams on page 94 to help you. These diagrams represent the four strokes in the cycle. They are not in the correct order and they are not named. Write down the names of each of the strokes represented.

[23]In the four-stroke petrol engine there is a sequence, or cycle of events which is completed in four strokes of the piston. [24]The events which take place in each stroke are as follows:

induction stroke [25]With the . . . open and the exhaust valve shut, the piston moves down the cylinder creating a partial vacuum. [26]This partial vacuum draws in the atomized fuel from the . . . into the cylinder.
compression stroke [27]With both the inlet and exhaust valves closed, the . . . moves up the cylinder, compressing the fuel mixture. [28]Just before the end of the stroke, an electric spark across the points of the . . . ignites the petrol and air mixture.
power stroke [29]Both valves remain closed. [30]During the tiny interval of time required for the flame to establish itself, the piston has reached its highest position in the . . . . [31]The gas generated by the burning fuel now expands rapidly, driving the piston down the cylinder. [32]This downward push is converted into a rotary movement by the connecting rod and . . . . [33]A . . . contained within the cylinder wall helps to conduct away the heat generated during this burning and thus keeps the engine cool.
exhaust stroke [34]The exhaust valve opens but the inlet valve remains shut. [35]The piston moves up the cylinder, pushing the exhaust gas out through the . . . . [36]With the completion of the exhaust stroke the cycle begins again.



(4) *Cause and effect*

We can sometimes use an *-ing* clause to link a 'cause' and an 'effect'.

EXAMPLES

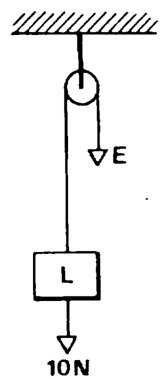
cause: The piston travels up the cylinder.
effect: The piston compresses the mixture.
The piston travels up the cylinder, compressing the mixture.

cause: The gas expands suddenly.
effect: This drives the piston down the cylinder.
The gas expands suddenly, driving the piston down the cylinder.

Now join the following cause and effect pairs in the same way:

	cause	*effect*
1.	The piston moves down the cylinder.	This creates a partial vacuum.
2.	The inlet valve opens.	This allows the fuel mixture to enter the cylinder.
3.	The rocker tilts to the right.	It pushes the valve down.
4.	A poppet valve drops after two milliseconds.	The valve shuts off the fuel supply.
5.	The worm-gear revolves once.	This turns the wheel a distance equal to the lead of the worm.
6.	A tensile force is applied to the bar.	It stretches the bar by 0·09 mm.
7.	The screw revolves once.	It raises the load by 30 mm.
8.	The drum unwinds 100 metres in 20 seconds.	It lowers the pit-cage at a velocity of 5 m/s.
9.	The brakes are applied when the car has a speed of 54 km/h.	They reduce its speed to 20 km/h.
10.	As the governor spins, the weights pull outwards.	This raises the shaft collar and reduces the fuel supply to the engine.

(5) *Problems and solutions*



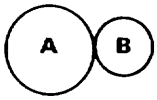
Look at this example:

problem	*solution*
Raise the load.	Apply a force at E greater than 10 N.

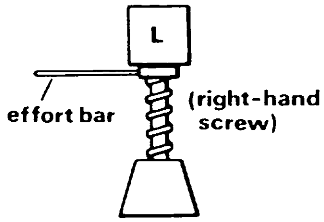
We can join the 'problem' and the 'solution' in various ways:

(a) To raise the load, apply a force at E greater than 10 N.
(b) We raise the load by applying a force at E greater than 10 N.
(c) The load is raised by applying a force at E greater than 10 N.

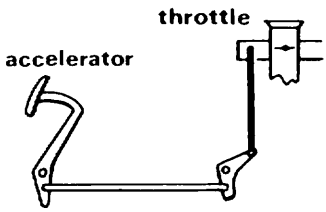
Now write down a solution for each of the following problems. Then combine problem and solution in a sentence, using pattern (a), (b) or (c).

1. 

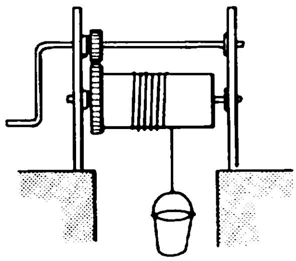
Rotate gear B clockwise.

2. 

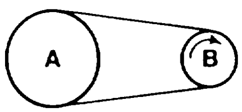
Lower the load.

3. 

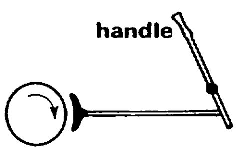
Open the throttle.

4. 

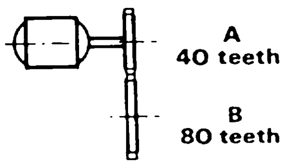
Raise the bucket in the well.

5. 

Reverse the direction of rotation of pulley B.

6. 

Apply the brake.

7. 

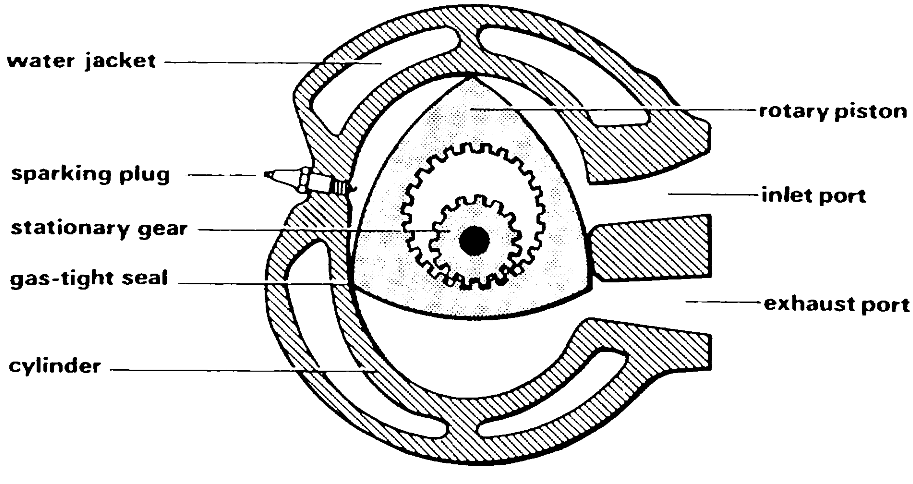
Rotate gear B at 40 rev/min.

The oil lubricates the rings and the pistons.
The bottom ring clears surplus oil from the cylinder walls.
A hole through the piston holds the gudgeon pin.
The gudgeon pin connects the piston and the connecting rod.
The gudgeon pin should be of the floating type.
The gudgeon pin should be hollow.
The piston must be well designed.
The piston is subjected to compressive stress.
The piston must withstand repeated impact loads.
The piston must withstand heat.
The piston must move up and down at an average speed of 13 m/s in automobile engines.

9 THE WANKEL ENGINE

The Wankel engine is a form of heat engine which has a rotary piston. In other words, instead of going up and down the Wankel piston rotates in the cylinder. Both cylinder and piston are quite different in shape from those of conventional engines. The Wankel piston is triangular with curved sides and the cylinder is roughly oval in shape. The piston has an inner bore which is linked through an eccentric gear to the output shaft. The other end of the bore is toothed and engages with a stationary gear fixed to the cylinder end. This arrangement ensures that the piston follows an elliptical path round the cylinder so that the apexes of the piston, which carry gas-tight seals, are always in contact with the inside surface of the cylinder.

The piston thus forms three crescent-shaped spaces between itself and the cylinder wall, which vary in size as the piston rotates. Fuel enters the cylinder through the inlet port when one of these spaces is increasing in size. The fuel trapped in this section is then compressed by the turning piston and ignited by the sparking plug. The expanding gases subject the



piston to a twisting moment which makes the piston revolve further until the exhaust gases escape through the exhaust port. A fresh charge is then induced into the cylinder. Meanwhile the same process is being repeated in the other two spaces between the piston and the cylinder.

The Wankel engine has many advantages over the reciprocating piston engine. Fewer moving parts are necessary because it produces a rotary movement without using a connecting rod and a crankshaft. Because of this rotary movement it has no vibration. In addition it has no valves, it is smaller and lighter than conventional engines of the same power, and it runs economically on diesel and several other fuels.

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