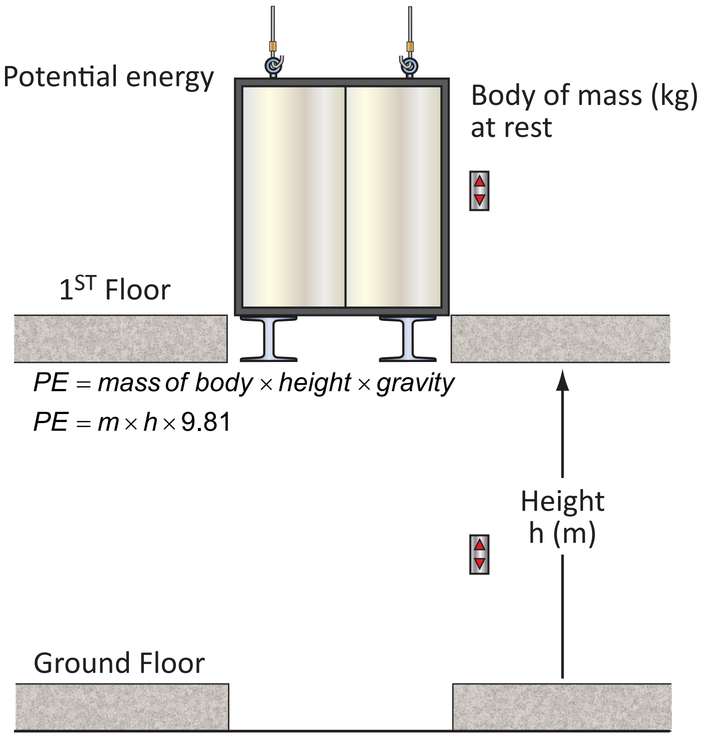
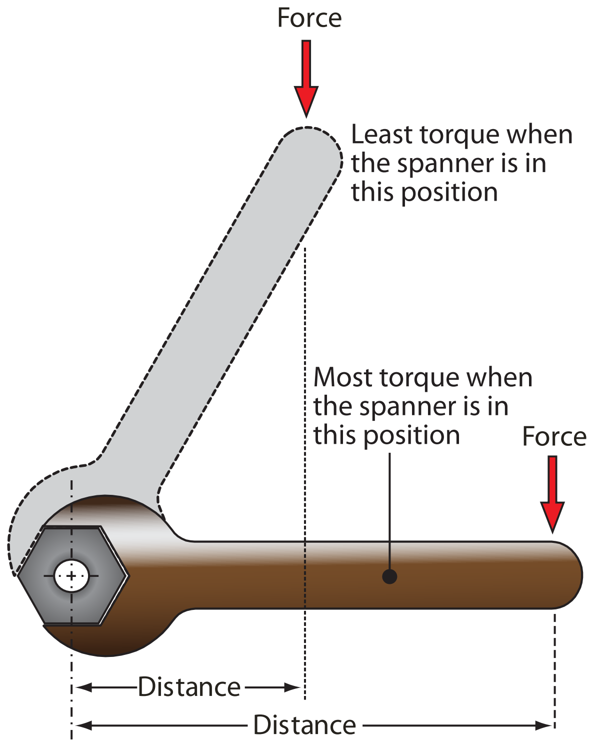
Level 3 Diploma
in
Installing Electrotechnical Systems & Equipment

C&G 2357

Unit 309-3 Basic mechanics and the relationship between force, work, energy and power





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Learning Materials for the Electrical Industry

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Aims and objectives

By the end of this study book you will have had:

- Specify what is meant by mass and weight
- Explain the principles of basic mechanics as they apply to levers, gears and pulleys.
- Describe the main principles and their interrelationships of:
    - Force
    - Work
    - Energy
    - Power
    - efficiency
    - calculate values of electrical energy, power and efficiency

1: Basic mechanics 1

In this session the student will:

- Describe some of the basic terms used in mechanics.
- Carry out simple calculations using force and weight.

In this and the next session we are going to consider some basic mechanics. We will look at force, mass and acceleration. You will need to take you time and just work through the various elements.

Mass

The reason that these have all been lumped together is that they are all very much related to each other.

Mass may be defined as; 'the quantity of matter in a body'.

This is obviously an unchanging quantity, unless I cut great lumps out of the object. So irrespective of where I stand with any particular object it will have a certain mass. This ***mass*** (***m***) is measured in kilograms. This is its standard symbol and unit, as stated earlier.

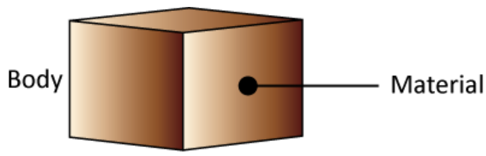
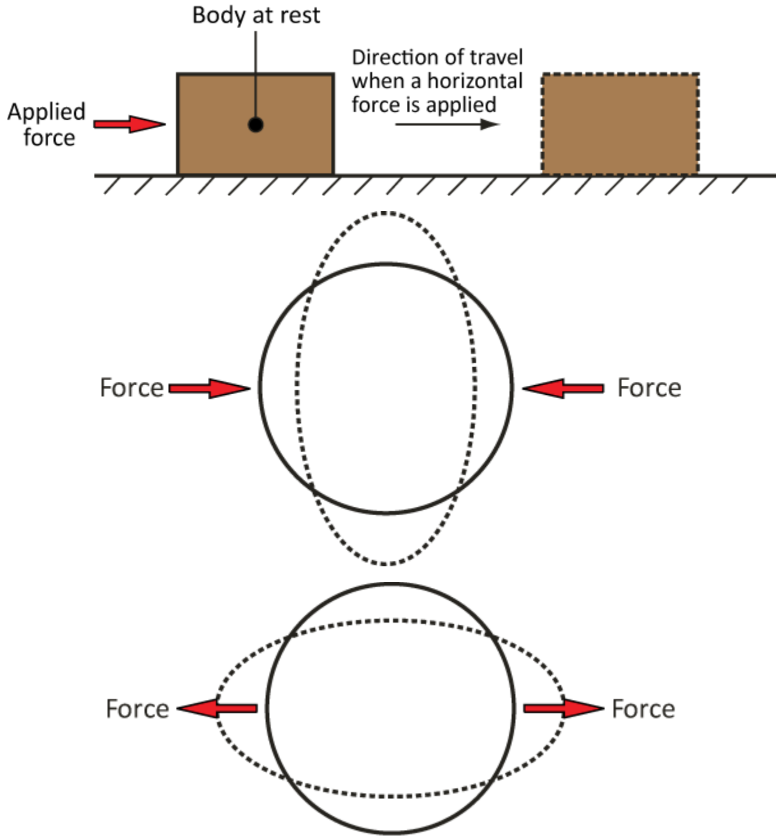


Figure 1 Body of material

Force

Force is generally measured by its effects. If I move an object from one place to another, I must have applied **force** to that object. If I stretch or squeeze an object then I must have applied **force**.



Do you see how force needs to be recognized by the effect it produces?

Force can be seen to involve two quantities, its ***mass*** and its ***acceleration***. This brings us, as always, to an equation. (An equation merely uses letters to describe an idea).

$$F = ma$$

where: $F = \text{force (N)}$

$m = \text{mass (kg)}$

$a = \text{acceleration } (\text{ms}^{-2})$

It is essential that you can begin to memorize these formulae.

This is the first ***derived*** SI unit you will have come across. Its' symbol is '***F***' and its unit is the '***Newton*** (***N***)', named after Sir Isaac Newton.

Follow the following three questions and see how you get along.

1) An object of mass 250 kg is moved at a rate of 4 ms^{-2}. Calculate the force exerted on it.

$$F = ma$$
$$F = 250 \times 4 = \underline{\underline{1000\,\text{N}}} = \underline{\underline{1\text{kN}}}$$

2) It takes a force of 25 N to move an object of mass 12 kg. Calculate the acceleration.

$$F = ma$$
$$a = \frac{F}{m} = \frac{25}{12} = 2.08\,{}^{m}\!/_{s^2} \;\; or\, a = 2.08\,ms^{-2}$$

3) An object is moved at a rate of 8 ms^{-2} with a force of 2 kN. Calculate its mass.

$$F = ma \quad \text{transpose for } m$$
$$\frac{F}{a} = \frac{m\not{a}}{\not{a}} \quad \text{divide both sides by } a \text{ and cancel}$$
$$m = \frac{F}{a}$$
$$m = \frac{2000}{8} = \underline{\underline{250\,\text{kg}}}$$

Again, notice the transposing of the equation. Notice also that we have used base units, i.e. metres, kg, seconds etc. We cannot use prefixes in the equation. So 'kN' (kilo-Newton's) had to be converted to 'N' (Newton's).

Weight

Weight is very much related to force and mass. It can be defined as; 'the gravitational force exerted on a body by the earth.' Unit gravity (g)

What this means is that an object on the earth has a certain gravitational force applied to it. An object on another planet will have a different gravitational force applied to it. This is due to the difference in size and mass of the planet. Someone standing on the moon '***weighs less***' than someone standing on the earth, this is because of the effect described above. We therefore get the term '***weightlessness***' when astronauts travel in space.

Big deal! The thing is that if an object is to be lifted then the effects of gravity have to be overcome. This effect is a ***force,*** a ***weight force***.

The equation that describes this is very similar to that which describes force. Notice that instead of acceleration (***a***), we now have acceleration due to gravity (***g***).

$$F = mg$$

$$\text{where:}\quad F = \text{force } (\text{N})$$

$$m = \text{mass } (\text{kg})$$

$$g = \text{acceleration due to gravity } \left(\text{ms}^{-2}\right)$$

This is a constant, and is usually accepted as $9.81\,ms^{-2}$. So, in any problem involving the lifting or dropping of an object, the acceleration is assumed to be $9.81 ms^{-2}$. The basic working out remains the same as for the last three questions, so one example will suffice for practice.

1). An object of mass 80 kg rests on a table. Calculate the force that the object exerts on the table.

$$F = mg$$

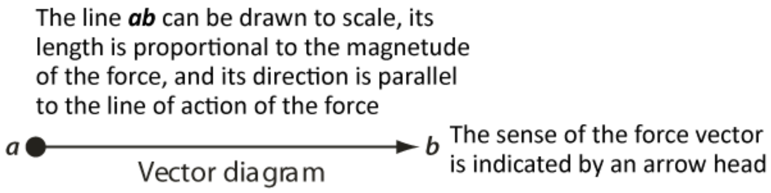
$$F = 80 \times 9.81 = \underline{\underline{784.8\,\text{N}}}$$

It is necessary to note now the difference between two types of quantities. These two types are called ***scalar*** and ***vector*** quantities.

A scalar quantity has magnitude only. Examples of scalar quantities would be ***time***, ***mass*** and ***speed***. They have magnitude but do not have any direction.

A vector quantity has magnitude and direction. Examples of vector quantities would be ***force***, ***weight*** and ***velocity***. There are many other examples of both. It is important to notice the difference.

If a quantity is a vector quantity it can be drawn to scale on paper, as can be seen below.

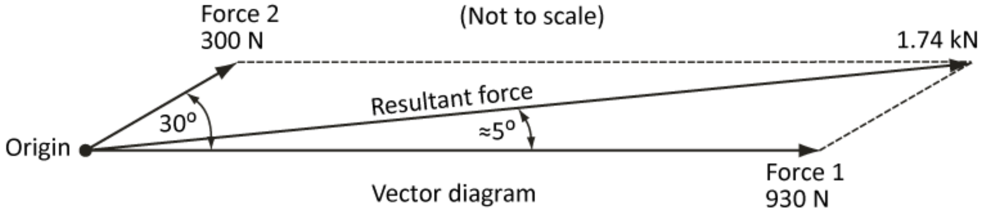


If you look at this line, we can see that the value is expressed by a line of a certain length moving in a direction from left to right or west to east.

The length of the line expresses the amount or quantity, whilst the direction of the quantity is expressed by the direction of the arrow.

Let’s look at this in a little more detail through the use of an example.

There are two forces acting on an object, one is a force of 930 N acting on the horizontal. The other force has a value of 300 N and is acting 30° to the horizontal. Determine the resultant force and its direction.



If we look at this diagram we can see that there is a force of 930 N acting from left to right or west to east. We also have a second force, but this time it is not acting in exactly the same way as the first force. We can see that it is acting at an angle of 30° north of the first force.

There are two ways in which these forces can be dealt with. We can either look at this mathematically by applying Pythagoras' theorem (right-angled triangles), or we can draw it to scale. Because we are dealing with vector quantities we can, more easily, draw the lines to scale. All we need is a protractor (to get the angle) and a decent ruler and pencil (the pencil should ideally be 2H).

We can use the principle of vector quantities in electrical work, and you will look at this when you come to the next level of the course. When we draw an electrical quantity as a vector, it is called a ***phasor diagram***.

Exercise 1.

1) A motor is being carried along a rail. With what force does the motor of mass 350 kg hit the ground when it falls?

2) Describe the difference between a scalar and a vector quantity.

3) What force is required to hold up an object of mass 20 kg?

4) A car of mass 1.5 tonnes travelling at 20 ms^{-1} is brought to a halt by a tree in 1 s. What force is exerted on the tree?

2: Basic mechanics 2

In this session the student will:

- Explain how to determine turning moments.
- Describe the three classes of levers
- Describe mechanical advantage and velocity ratio.

In the previous session we considered terms used in mechanics, such as mass, weight, force, velocity and acceleration. We determined that force and weight are interchangeable terms, the only difference being that weight is force acting due to gravity. We now need to consider simple machines. Anything that makes a task easier for a human to perform is called a machine. In this section we are going to look at one of the three simplest of machines; the lever. However, firstly, we need to consider what is meant by a turning moment or torque. This will crop up again when you study motors.

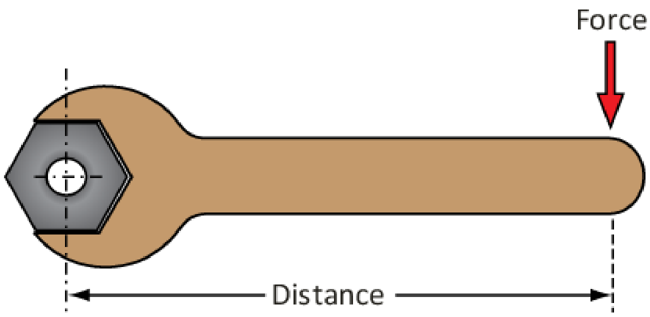
Turning moments

Another word for a turning moment is ***torque***. Torque is the ***turning force*** applied to an object. A steering wheel has a torque applied to it, a car wheel has a torque applied to it, a spanner or wrench has a torque applied to it.

The magnitude of the turning force (from now on called torque) is dependent on two things:

- o force applied
- o distance from the turning point

The diagram below should make it come a little clearer.



Can you see where the force is applied in relation to the force on the object?

Torque can be determined using the following equation.

$$T = Fd$$

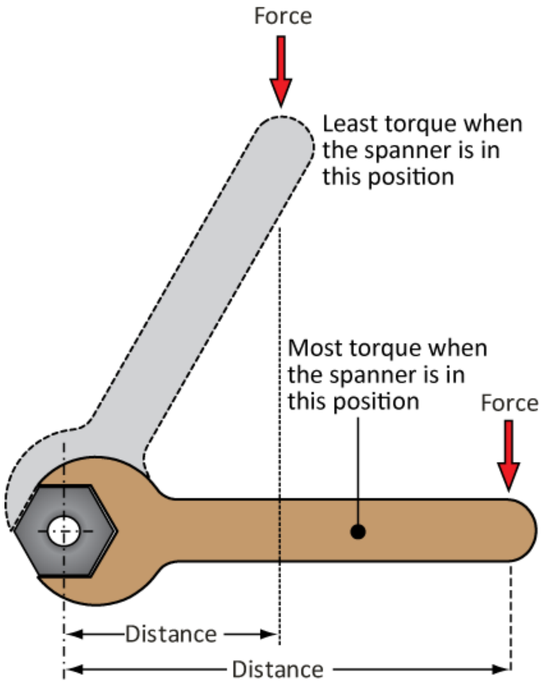
where $T = \text{Torque (Nm)}$

$F = \text{Force (N)}$

$d = \text{Distance (m)}$

The unit used for torque is the Newton-metre (***Nm***). The symbol is ***T***. The main point to realise is that the distance is not just how far away the force is applied, but also takes into account the direction in which the force is applied.

Notice how the torque on the object is applied. It is not just the distance from the turning point but also the '***perpendicular distance***' from the turning point.

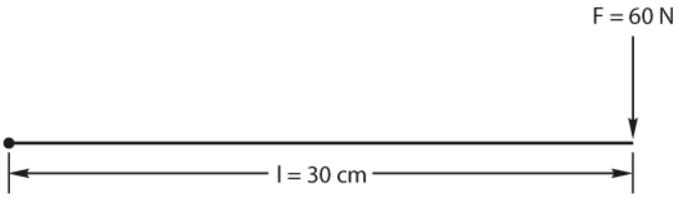


Try following this example.

1). An electrician using a spanner applies a force of 60 N to the end of the spanner, which is 30 cm long. Calculate the torque.

Whenever you are faced with a question like this, it is always worthwhile drawing a little thumbnail sketch. It often enables you to understand something a little better if you can see what is happening.

Never take too long over this. It is only supposed to be a sketch.



Notice that I have converted *cm* into *m*. It is essential that you get into the habit of using base units.

$$T = Fd$$
$$T = 60 \times 0.3 = \underline{\underline{18\,\text{Nm}}}$$

2). An electric motor lifts an object of mass 75 kg by means of a rope wrapped around a drum of diameter 0.75 m. Calculate the torque being applied.

The first thing is to work out what is needed. In this instance, we need force and distance from the turning point. From previous work we know how to calculate force.

$$F = mg$$
$$F = 75 \times 9.81 = \underline{\underline{735.75\,\text{N}}}$$
$$d = \frac{0.75}{2} = \underline{\underline{0.375\,\text{m}}}$$
$$T = Fd$$
$$T = 735.75 \times 0.375 = \underline{\underline{275.91\text{Nm}}}$$

Remember $F = mg$ and $g = 9.81\text{ms}^{-2}$. Notice that two steps are required. Notice also that the torque is applied to the radius of the drum not the total diameter.

It is worthwhile mentioning something called '***mechanical advantage***' here. When we use something (tool or machine) to do some work for us we expect that the task should be made easier.

For example if we wanted to lift something that was too heavy for us, we might use a system of pulleys. If we wanted to lift a car up to change a tyre most people find it quite difficult to physically lift the car without being something of a superman!

The sensible option is to use a jack, and this enables us to lift the car with the minimum of effort.

$$Mechanical\ Advantage\ (MA) = \frac{Force\ acting\ on\ a\ load}{Force\ applied\ as\ an\ effort}$$

As load is measured in Newton's as well as effort, there are no units for mechanical advantage.

The larger the mechanical advantage the easier it is to move the load, or the less effort is required to move the load.

To get a large mechanical advantage it is necessary to have the effort applied over a longer distance than the load is moved. What this means is that a second term can be used to measure how useful a machine or tool is to us. This second term is called the velocity ratio.

$$Velocity\ ratio\ \left(VR\right) = \frac{distance\ moved\ by\ the\ effort}{distance\ moved\ by\ the\ load}$$

Again, there are no units, however velocity ratio is generally a constant term whereas mechanical advantage may vary with the load.

Just a cautionary note, but do be aware that they are measures of how easy a load can be moved by an effort. What is not being said is that we are getting 100% efficiency!

$$Efficiency\,(\eta) = \frac{Mechanical\ Advantage}{Velocity\ Ratio}$$

Work

Work is done whenever a force moves an object.

The amount of work depends on the amount of force being applied and the distance the object moves. This is obviously so from our own experience. For example, we know that we have done more work if we move a sack of potatoes 200 m rather than 20 m.

Work and energy are very much related terms. Energy is the capacity to do work, and is measured in the same terms as work done.

The equation for work is:

$$W = Fd$$

where:- $W =$ Work done or energy (J)

$F =$ Force (N)

$d =$ Distance (m)

You may notice the similarity between the work done on torque and turning moments. It is preferred to use the joule as the unit but it is also acceptable to use the Newton-metre (***Nm***).

All that is left is to use the equations.

Exercise 2.

1) A force of 50 kN moves an object a distance of 2 m. Calculate the work done.

2) The work done in moving a body 24 m is 750 J. Calculate the value of the force.

3) A mass of 75 kg rests on a horizontal surface. It is moved a distance of 25 m. Calculate the work done.

4) Define mass, force and weight, giving SI units for each.

5) State the earths' gravitational constant with correct units.

6) What is the difference between scalar and vector quantities?

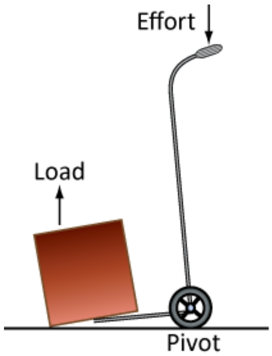
LEVERS

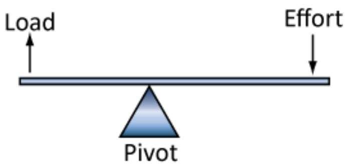
An example of a simple machine is the lever. The point about which the lever rotates is called its fulcrum or pivot. In every case the velocity ratio of a lever is given by;

$$Velocity\ ratio\ (VR) = \frac{distance\ of\ effort\ from the\ fulcrum}{distance\ of\ load\ from the\ fulcrum}$$

Levers fall into three classes; class1, class 2 and class 3.

<u>Class 1</u>

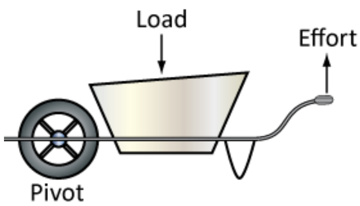


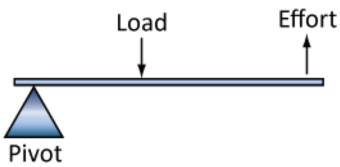


Examples would include, side cutters, pliers, conduit bending machine, crowbars.

Class 1 levers are where the pivot or fulcrum is between the effort and the load.

<u>Class 2</u>

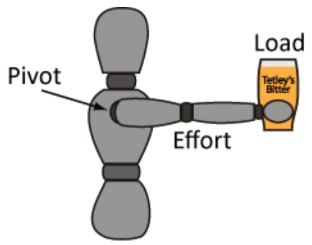


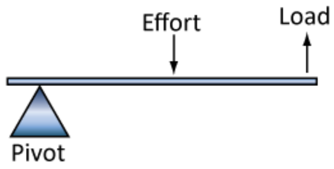


Examples of a class 2 lever are; foot pump, nutcrackers.

Class 2 levers are where the pivot is at the end of the lever and the load is between the effort and the pivot point.

Class 3



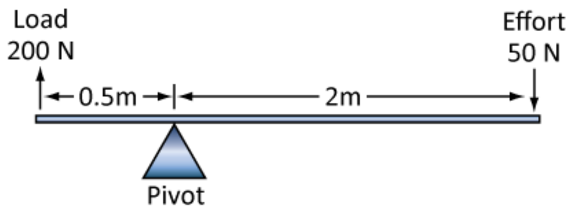


Examples of a class 3 lever are; fishing rod, crane, tweezers, tongs.

Class 3 levers are those where the pivot is at the end of the lever, but the effort is between the load and the pivot.

The total turning moment or torque applied to one end of the lever must be equal and opposite to the torque available at the other end. Balance is achieved.

Consider the example below.



$$Torque_{LHS} = Torque_{RHS}$$
$$Force_{Load} \times distance = Force_{effort} \times distance$$
$$200 \times 0.5 = 100 \times 2$$
$$100 = 100$$

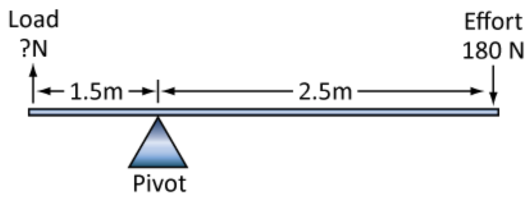
For balance to occur, the torque on each side of the pivot must be the same.

The above example shows that for an effort of 50N, it is possible to balance a torque of 200N, this is made possible by the length of the lever on the right hand side of the pivot being 4 times longer.

Exercise 3.

1) Determine the load force

2) If the load increased by 20%, how much longer should the bar extend past the pivot to allow the same effort to be applied?



3 Gears, and pulleys

In this session the student will:

- Describe the relationship between input and output gears
- Gain an understanding of how pulleys reduce work.

GEARS

Gears are very versatile and many machines use gears to produce a range of movements that can be used to control the speed of action. Just think about when you use the gears on your bicycle, motor bike or car, and the effect that brings.

The amount of teeth each gear wheel has affects the action on the gear wheel it engages or meshes with. The gear wheel being turned is called the input or driver gear and the one it drives is called the output or driven gear. It is also useful to think of the input gear as being the effort and the output gear as being the load.

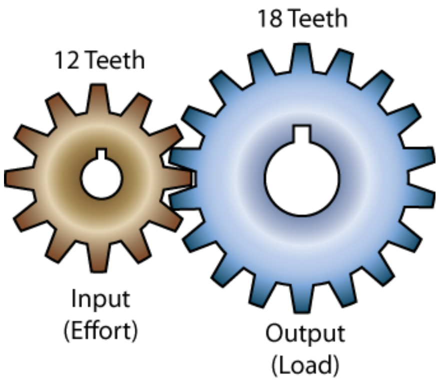


Figure 2 Speed down

Gears also alter the direction of rotation. In Fig. 2, assume the input gear wheel is rotating clock wise but as it turns, the output gear wheel will be turned anti-clockwise.

Gears with unequal numbers of teeth alter the speed between the input and output. This is referred to as the Gear Ratio. Consider the two gear wheels in Fig. 2.

The input gear has 12 teeth and the output gear has 18 teeth. This means that for every complete revolution on the input gear, the output gear will only have travelled $\frac{2}{3}$ of one revolution.

$$\text{Gear ratio} = \frac{\textit{number of teeth on output gear}}{\textit{number of teeth on input gear}} = \frac{18}{12} = \frac{1.5}{1} = 1.5{:}1$$

This means the input gear is rotating $1\frac{1}{2}$ times faster than the output gear, hence it is a speed reduction, or in engineering terms, stepping down.

This has the advantage of producing more power, just think why you need to select a lower gear for travelling up a hill.

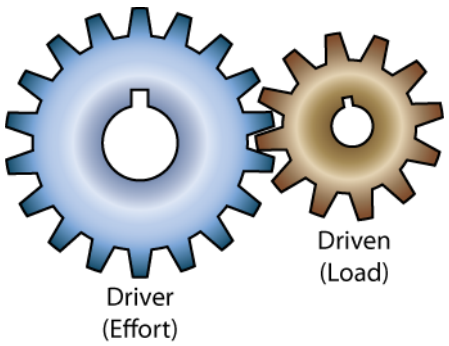
Another way this can be considered is to use velocity ratio V.R. This time, it is usual to consider the largest gear and always set that to one revolution. The number of revolutions on the second gear has to be worked out.

In this example the load gear revolves once, the effort gear revolves $\frac{18}{12} = 1\frac{1}{2}\,times$

$$V.R. = \frac{distance\,moved\,by\,effort}{distance\,moved\,by\,load} = \frac{1.5}{1} = 1.5{:}1\ .$$

Which is of course the same result but thought about in a different way.

Consider what happens when the gear wheels change positions.



Again, set the largest gear to one, this time for every revolution of the driver gear, the driven gear revolves $1\frac{1}{2}$ times.

Hence the velocity ratio is 1:1.5, this is stepping up.

Figure 3 Speed up

Stepping up produces a much faster output speed but delivers less power. Think about the gear you use for motorway driving, that gear couldn't be used to set off from a standing start.

Exercise 4.

1) If an input gear has 60 teeth and an out gear has 20 teeth, determine if it is stepping up or stepping down and the velocity ratio.

2) If an input gear has 30 teeth and an out gear has 120 teeth, determine if it is stepping up or stepping down and the velocity ratio.

A problem with the above arrangement is that the driven gear will revolve in the opposite direction to the input or drive gear. There are a couple of easy solutions to this, one is to use a belt or chain linking the gear together as shown in Fig. 4.

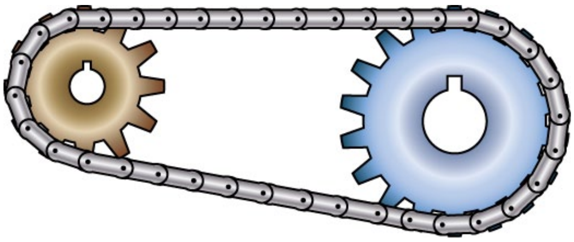


Figure 4 Chain drive

With this arrangement the driven gear will follow the drive gear. The velocity ratio is determined as if the chain wasn't present.

In gear boxes, instead of a chain, the normal solution is to use what is called an idle gear, this sits between the drive gear and the driven gear as shown in Fig. 5.

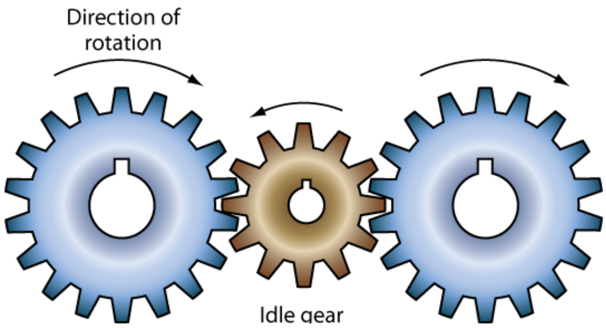


Figure 5 Idle gear used to alter direction of rotation

This arrangement could also be classed as forming a gear train as it is made up of three gears.

To determine the overall velocity ratio of the system above, it is necessary to consider each stage in turn.

For example, let the input gear have 12 teeth, the idle gear have six teeth and the output gear have 24 teeth. What will be the velocity ratio of this drive train?

Consider the first two gears. The idle gear will rotate twice as fast as the input gear.

$$V.R. = \frac{distance\ moved\ by\ input\ gear}{distance\ moved\ by\ idle\ gear} = \frac{1}{2} = 1:2\ ,\ = \frac{1}{2}:1$$

Consider the idle gear and the output gear. This is a stepping down arrangement so you are expecting the answer to reflect this.

The idle gear will rotate 4 times for every 1 revolution of the output gear.

$$V.R. = \frac{distance\,moved\,by\,idle\,gear}{distance\,moved\,by\,output\,gear} = \frac{4}{1} = 4:1,\; = 1:\frac{1}{4}$$

Collecting the ratios, we have $= \frac{1}{2}:1$ and $= 1:\frac{1}{4}$ which gives $= \frac{1}{2}:\frac{1}{4} = 2:1$.

This is telling us that the output or load is revolving half as fast as the input or effort.

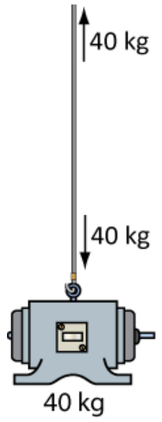
Exercise 5.

1) A gear train is made up of three gears. The first gear revolves ar 60 rpm and has 40 teeth. The intermediate gear has 20 teeth and the third gear has 80 teeth. Determine the overall velocity ratio and the speed of the output gear.

2) A gear train is made up of three gears. The first gear revolves ar 200 rpm and has 120 teeth. The intermediate gear has 80 teeth and the third gear has 40 teeth. Determine the overall velocity ratio and the speed of the output gear.

PULLEYS

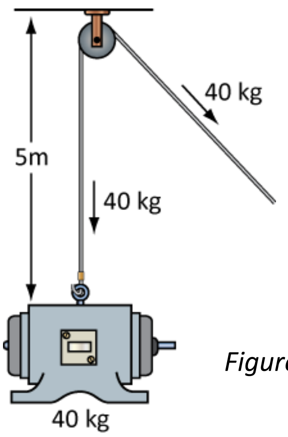
A pulley system is a simple machine used to lift heavy objects. Consider lifting a load such as a motor, and let us assume its weight is 40kg.



To raise this motor off the ground a person would have to be positioned above it and haul upwards on the rope, not an easy task as this load exceeds the 25kg limit of what one male person could lift on their own.

Figure 6; Straight lift

If there was a ceiling available, it would be easier to use a pulley arrangement; this would alter the direction of pull, but the effort required to raise the motor off the ground would be the same as that shown in Fig. 7.

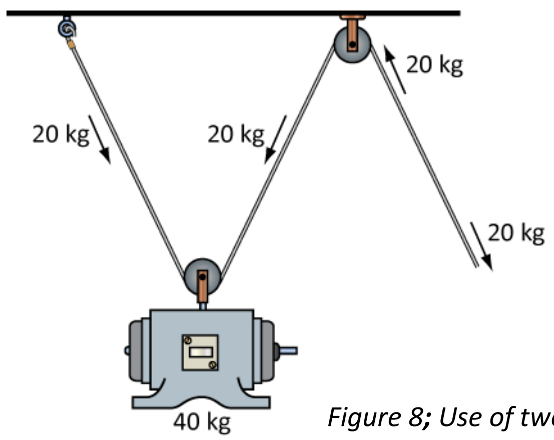


Let us say the motor had to be raised 5m, the person on the end of the rope would have to pull this length to raise the motor.

To determine the velocity ratio of this task;

$$V.R. = \frac{distance\ moved\ by\ the\ effort}{distance\ moved\ by\ the\ load} = 1$$

Figure 7; Use of one pulley



If a second support was used as shown in Fig.8, each of the ropes would share the weight of the load, so that there will now be 20 kg in each rope. A person only needs to effectively pull 20 kg. However, there is a down side. As each pulley holds half the weight, there is twice as much rope to pull on in order to raise the load. The V.R. =2.

Figure 8; Use of two pulleys

If four pulleys were used, the amount of effort required drops to 10 kg, but at the same time more energy is needed because the person lifting the motor would have to pull four times the length of rope. The velocity ratio of a pulley system equals the number of pulleys used. The mechanical advantage would be equal to the velocity ratio if there were no losses, remember; $Efficiency = \frac{M.A.}{V.R.}$.

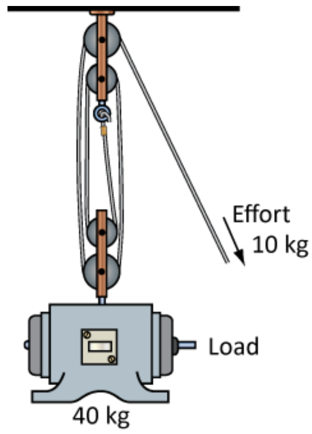


Figure 9 Four pulley system

The arrangement of pulleys and rope is called a 'block and tackle', each pulley would be the same size and they are mounted next to each other.

Exercise 6.

1) A block and tackle of eight pulleys is to be used to lift a cubicle switch panel weighting 240 kg. The lifting system is 80% efficient. Calculate the effort required.

2) A block and tackle set has four pulleys in the top block and three pulleys in the bottom block. It is fixed to ceiling beam in a workshop, where it is to be used to lift a motor weighing 252 kg from its bedplate. If the efficiency of the tackle is 60%, calculate the pull required on the free end of the rope to raise the motor.

3) Why is it incorrect to use kg in the above two questions?

4: Power, energy and efficiency

In this session the student will:

- Describe the relationship between power and energy.
- Gain an understanding of the difference between kinetic energy and potential energy.
- Determine how power and energy might be calculated.

In this session we will consider the nature of power and energy. You will have probably covered both power and energy at GCSE level science; however we need to spend some time clarifying those areas.

Energy

In many ways energy is a difficult concept to grasp hold of, but a simple definition could be the ***ability to do work***.

Energy can be considered in a range of areas including mechanical, thermal and electrical. The common feature is that work is either being done or is capable of being done.

Energy or work done is measured in *Joules (J)*. This unit is named after James P. Joule who carried out work on the relationship between mechanical and thermal energies. The joule itself is defined as:

> The work done when a force of 1 Newton is exerted through a distance of 1 m in the direction of the force.

In effect this makes energy a measure of the work done and can be calculated in a number of ways depending on the nature of the energy.

Thermal energy

Thermal energy is generated and measured by heat of any kind. It is caused by the increased activity or velocity of molecules in a substance, which in turn causes temperature to rise accordingly. There are many natural sources of thermal energy on Earth, making it an important component of alternative energy.

The laws of thermodynamics explain that energy in the form of heat can be exchanged from one physical object to another. For instance, putting fire under a pot of water will cause the water to heat up as a result of the increased molecular movement. In that way, the heat, or thermal energy, of the fire, is partially transmitted to the water.

In a thermal system the energy stored is dependent on the nature of the material. The heat required to raise the temperature of a substance of 1 kg by 1 ^{o}C is called the *specific heat capacity (shc)*.

Thermal energy is calculated using:

$$Q = mc\Delta T$$
$$Q = mc\left(T_2 - T_1\right)$$

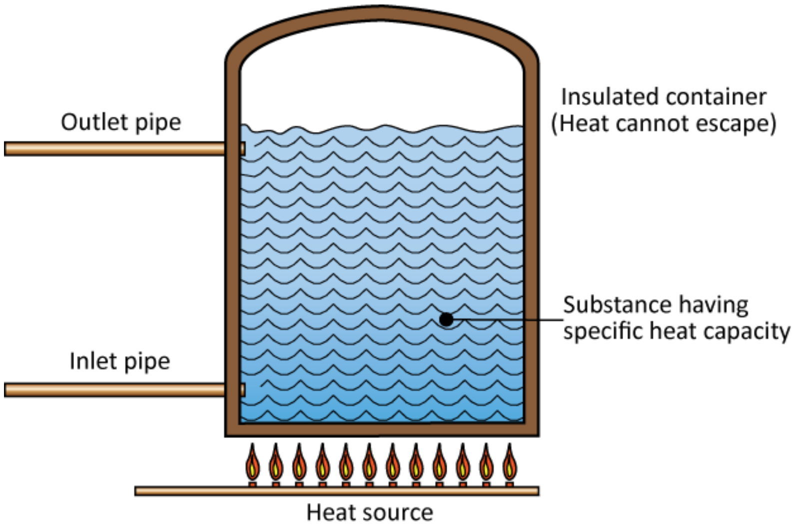
Where:

$Q =$ quantity of heat (energy) in joules
$m =$ mass in kg
$c =$ specific heat capacity of a particular substance in joules/kg^{o}K
$\Delta T =$ change in temperature in K (kelvin)

The table below provides some values of specific heat capacity.

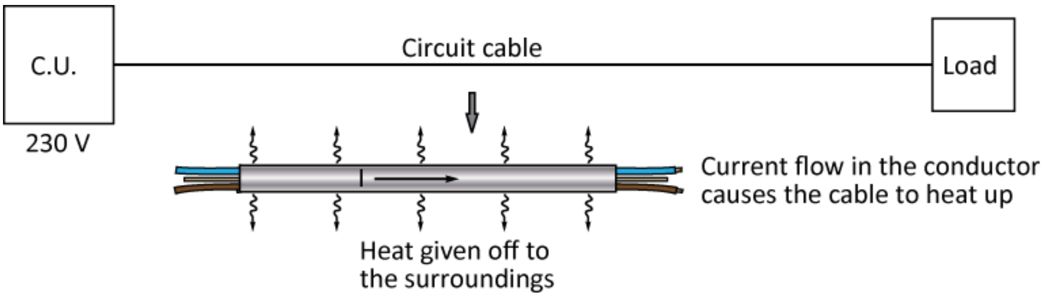
Substance	**Specific heat capacity J/kg^{o}K**
Water	4190
Aluminium	960
Copper	380
Iron	420
Nichrome	430
Silver	230

You can see from the table that water is very good for storing heat as it requires a lot of energy (over 4000 J) to raise the temperature by 1^{o}C; whereas the metals all require less energy to heat.



From the above diagram, heat is delivered to a substance and the temperature of the substance will rise.

Below the current flow in the conductor causes its temperature to rise. When the current causes the temperature of the cable to rise to a greater level than the surrounding air or substance then heat is given off.



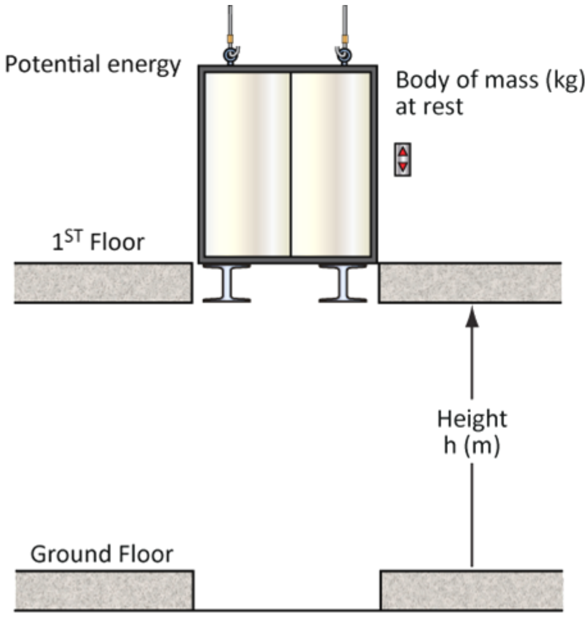
Mechanical energy

With mechanical energy we have to consider two different forms:

- Potential
- Kinetic

Potential energy

Consider the drawing below which shows a lift stationary at the first floor.



The amount of energy available is dependent on the mass of the lift, the height that the lift is going to travel and the acceleration due to gravity.

So: $P.E = mgh$

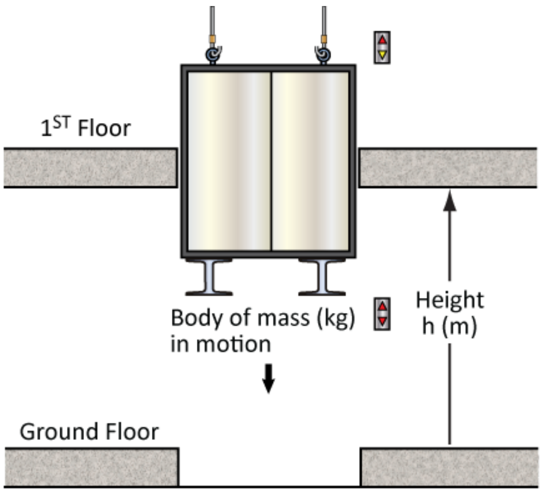
Where:

$P.E. =$ potential energy in J
$m =$ mass in kg
$g =$ acceleration due to gravity in m/s^2
$h =$ height in m

It is assumed that the acceleration due to gravity is constant at 9.81 m/s^2, although this figure does vary at different points on the earth's surface.

Kinetic energy

Kinetic energy is energy related to movement. Now consider the diagram below.



The potential energy of the lift at the first floor is now being converted into kinetic energy as the lift travels to the ground floor.

The kinetic energy can be determined using:- $K.E = \frac{1}{2}mv^2 = \frac{mv^2}{2}$

Where:

$K.E =$ kinetic energy in J
$m =$ mass in kg
$v =$ velocity of the object in m/s

Exercise 7.

1) A builder's hoist is stationary 25m off the ground. It is filled with rubble to be brought to the ground. If the total mass of the hoist with rubble is 380 kg, determine;
   a) the potential energy
   b) the velocity of the hoist as it moves towards the ground if no gearing was fitted.

2) A trolley having a mass of 1 tonne is being pushed at a rate of 2.016 km/hour, what is its kinetic energy?

Electrical energy

As with thermal and mechanical energy, electrical energy is measured in joules (J), and as with the other two forms of energy the work done is dependent on a number of elements. With thermal energy we have to consider the mass, specific heat capacity and the temperature of the substance. With mechanical energy we are dealing with mass, velocity, height and acceleration due to gravity depending on whether we are looking at kinetic or potential energy. With electrical energy the elements that we consider depend on the flow of current and the voltage that is dropped across a particular component.

So: $W = IUt$

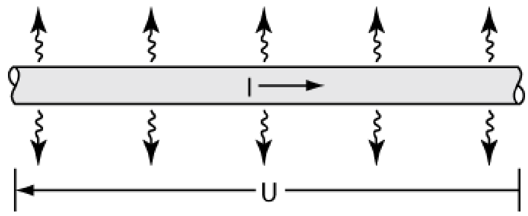
Where:

$W =$ electrical energy in J

$I =$ current in A

$U =$ voltage in V

$t =$ times in s



As the current flows heat is given off, with time the amount of heat given off will increase.

There are other forms of electrical energy related to capacitance and inductance, however for the present we will simply consider resistive loads.

Power

If I were to carry a sack of potatoes 50 m in 25 seconds, I would have expended more power than if I carried the same sack the same distance in more time.

The symbol for power is (***P***), not surprisingly, and its SI unit is the Watt.

$$P = \frac{W}{t}$$

where:- $P =$ Power (W)

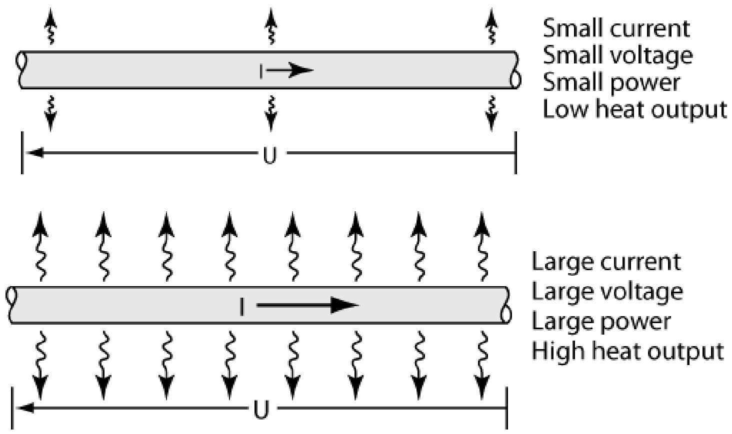
$W =$ Work done or energy (J)

$t =$ Time (s)

Notice that the watt is joules/second.

Power is closely related to energy. If energy is the work done on a system, an object or a substance, then power is defined as ***the rate at which work is done*** or ***the rate at which energy is converted***.

In effect, with power we are more concerned with how quickly the heat is given off by the load.



The larger the voltage and current, the greater will be the power output and this can be demonstrated by: $P = IU$

Where:

$P =$ power in W
$I =$ current in A
$U =$ voltage in V

Power, in whatever system we deal with is measured in watts (W) and:

$$1 \text{ watt} = 1 \text{ Joule/second}\left(J/s \right)$$

When we look at the power formula above we can see that it makes use of both voltage and current. We can apply elements of Ohm's law to provide ourselves with some variations on a theme.

$$P = IU \; (W)$$

$$P = IU \quad \text{and} \quad U = IR$$
$$P = I(IR) = I^2R \; (W)$$

$$P = IU \quad \text{and} \quad I = \frac{U}{R}$$
$$P = \left(\frac{U}{R}\right)U = \frac{U^2}{R} \; (W)$$

Calculations using power formulae will be practised in Outcome 4 of Unit 309.

Efficiency

Efficiency is simply a ratio. It compares what goes in with what comes out and gives us some idea of the losses that are inherent within a system.

Efficiency can therefore be a ratio of power in to power out or energy in to energy out. So at its most basic we get:

$$\text{Efficiency }(\eta)=\frac{\text{energy output}}{\text{energy input}}\times 100\%$$

$$\text{Efficiency }(\eta)=\frac{\text{power output}}{\text{power input}}\times 100\%$$

1). A motor has an output power of 10 kW and an input power of 12 kW. What is its efficiency?

$$\text{Efficiency }(\eta)=\frac{P_{out}}{P_{in}}\times 100\%$$

$$\eta=\frac{10}{12}\times 100=\underline{\underline{83.33\%}}$$

2). A heater has an input power of 6 kW and a stated efficiency of 92 %. What will be its maximum output power available?

$$\text{Efficiency }(\eta)=\frac{P_{out}}{P_{in}}\times 100\%$$

$$92=\frac{P_{out}}{6}\times 100$$

$$P_{out}=\frac{92\times 6}{100}=\underline{\underline{5.52kW}}$$

If we didn't multiply our answer by 100 we would get a *per unit* (p.u.) value rather than a *per centage* (%) one. Calculating efficiency should be familiar to you and so a couple of examples should be adequate in the final exercise.

Exercise 8.

1) The power developed by the shaft of a motor is 25 kW. If the input power is 32 kW what is the overall efficiency of the motor?

2) A motor has an efficiency of 78%. If the input power is 39 kW, what will be the output power available?

3) If the output power of a generator is 250 kW and the efficiency is 83%, what is the required input power?

4) The mass of water in a tank is 50 litres, if its initial temperature is 18°C, what heat energy is required to bring the temperature of the water up to 85°C?

5) If a 3kW heating element was used, how long would the process in Q4 take?

6) If electricity costs 10p per kWh, what will be the cost of heating the 50 litres of water?

B&B Training Associates

Engineering Learning Materials

Attempt all questions.

All marks are shown in the right-hand margin.

You should aim to pass with a 85 % minimum mark.

Anything less than this mark should lead you to re-read the text.

1) A spanner with a handle of length 20 cm applies a turning force (torque) of 20 N. How much work is being done? 2
2) A force of 70 N is applied at a point 250 mm from the centre of a pulley. Calculate the torque applied. 4
3) A pulley has a radius of 0.225 m. A force of 2.5 kN is applied. What is the turning force being applied? 2
4) An object of mass 25 kg falls from a scaffold 10 m high. With what force will it hit the ground? 2
5) A block and tackle set of 8 pulleys, four in the top and four in the bottom is used to raise a load of 200 kg, what effort is required? 2
6) Two gear wheels are meshed together, the drive gear has 48 teeth and the driven gear has 96 teeth. If the input speed is 20 mph what is the output speed? 2
7) A gear train is made up of three gears. The drive gear has 128 teeth and rotates at 10 mph. The idle gear has 32 teeth and the output gear has 16 teeth. What is the output speed? 4
8) A machine has an output of 200 kW and demands 275 kW of electrical energy. What is the overall efficiency? 2
9) A tank measuring 1.2 x 0.3 x 0.2 m is used to hold water. The initial temperature of the water is 15°C and the final temperature is to be 85°C. If a 3kW element is used to heat the water;
   i) how long will be the process take? 6
   ii) what will be the cost if the unit rate is 10p per kWh? 2
10) What is the potential energy of 100m roll of $1.5mm^2$ twin & E if the cable has a mass of 8kg, and sits on a shelf 2.5m high? 2

Total 30

