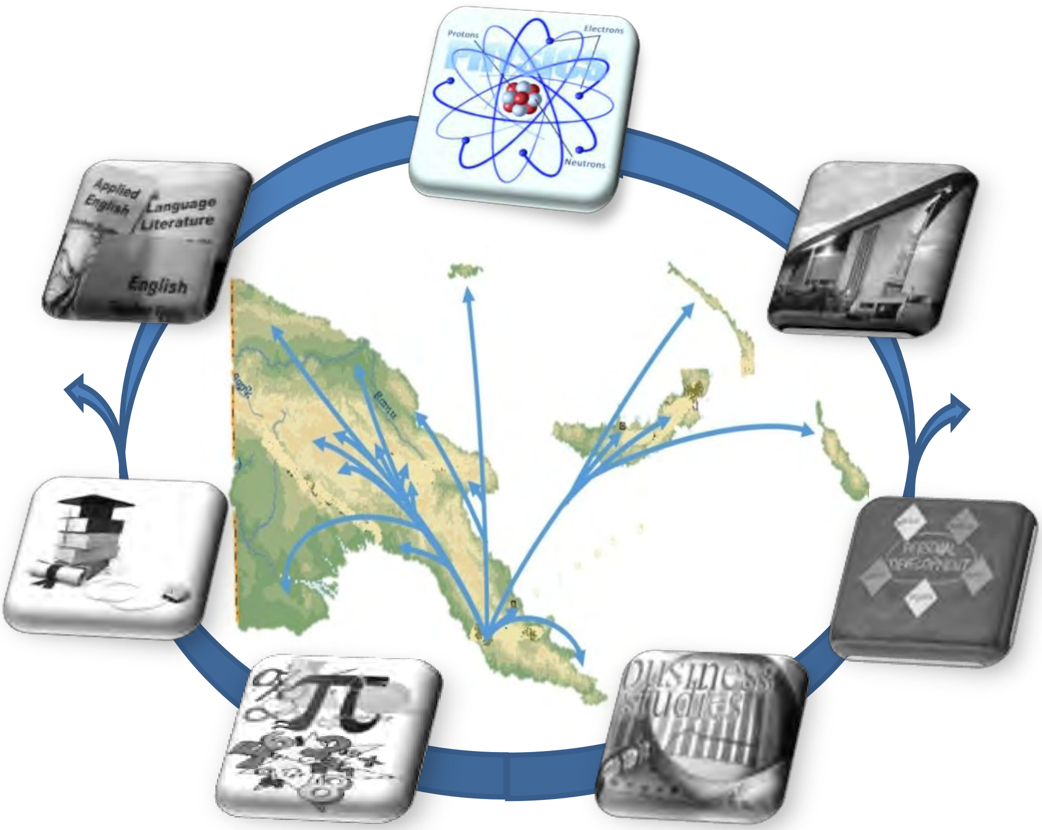
DEPARTMENT OF EDUCATION

GRADE 11

PHYSICS

MODULE 4



WORK, POWER AND ENERGY

PUBLISHED BY FLEXIBLE OPEN AND DISTANCE EDUCATION
PRIVATE MAIL BAG, P.O. WAIGANI, NCD
FOR DEPARTMENT OF EDUCATION
PAPUA NEW GUINEA
2017

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GRADE 11

PHYSICS

MODULE 4

WORK, POWER AND ENERGY

IN THIS MODULE, YOU WILL LEARN ABOUT:

11.5.1:	**WORK**
11.5.2:	**POWER**
11.5.3:	**ENERGY**
11.5.4:	**SIMPLE MACHINES**

Acknowledgement

We acknowledge the contribution of all Lower and Upper Secondary teachers who in one way or another helped to develop this Course.

Our profound gratitude goes to the former Principal of FODE, Mr. Demas Tongogo for leading FODE towards this great achievement.

Special thanks are given to the staff of the Science Department of FODE who played active roles in coordinating writing workshops, outsourcing of module writing and editing processes involving selected teachers of Central Province and NCD.

We also acknowledge the professional guidance and services provided through-out the processes of writing by the members of:

Science Subject Review Committee-FODE
Academic Advisory Committee-FODE
Science Department- CDAD

This book was developed with the invaluable support and co-funding of the GO-PNG and World Bank.

DIANA TEIT AKIS
Principal-FODE

Flexible Open and Distance Education
Papua New Guinea

Published in 2017

Printed by the Flexible, Open and Distance Education
ISBN 978-9980-89-546-2
National Library Services of Papua New Guinea

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SECRETARY'S MESSAGE

Achieving a better future by individual students, their families, communities or the nation as a whole, depends on the kind of curriculum and the way it is delivered.

This course is part of the new Flexible, Open and Distance Education curriculum. The learning outcomes are student-centred and allows for them to be demonstrated and assessed.

It maintains the rationale, goals, aims and principles of the National Curriculum and identifies the knowledge, skills, attitudes and values that students should achieve.

This is a provision by Flexible, Open and Distance Education as an alternative pathway of formal education.

The Course promotes Papua New Guinea values and beliefs which are found in our constitution, Government policies and reports. It is developed in line with the National Education Plan (2005 – 2014) and addresses an increase in the number of school leavers affected by lack of access into secondary and higher educational institutions.

Flexible, Open and Distance Education is guided by the Department of Education's Mission which is fivefold;

- To develop and encourage an education system which satisfies the requirements of Papua New Guinea and its people
- To establish, preserve, and improve standards of education throughout Papua New Guinea
- To make the benefits of such education available as widely as possible to all of the people
- To make education accessible to the physically, mentally and socially handicapped as well as to those who are educationally disadvantaged

The College is enhanced to provide alternative and comparable path ways for students and adults to complete their education, through one system, two path ways and same learning outcomes.

It is our vision that Papua New Guineans harness all appropriate and affordable technologies to pursue this program.

I commend all those teachers, curriculum writers, university lecturers and many others who have contributed so much in developing this course.

UKE KOMBRA, PhD
Secretary for Education

MODULE 11. 4: WORK, POWER AND ENERGY

Introduction

In this module, you will learn the fundamentals of WORK, POWER and ENERGY and their applications in everyday simple machines. The terms work, power and energy are often used in our daily conversations but have different meanings in Physics. This module will give specific scientific meanings and explanations to these terms.

Our daily usage of the term **work** refers to activities like cleaning your room, fetching water, doing household chores or being employed. Imagine a boy pushing against a brick wall. Is he doing any work? You would definitely say yes! However, in Physics the boy is not doing any work, though the contractions and expansions of his muscles can be seen and he may even be sweating. Work done is associated to a constant force applied on an object and the displacement of the object in the direction of the force. Therefore if there is **NO movement** there is **NO work**.

Similarly, imagine mothers carrying bags of vegetables on their heads to the market every day. It may seem that they are doing a lot of work, but again in Physics, they are not doing any work. **There is no work done when the direction of the applied force and the direction in which the object moves are perpendicular to each other**. Work done can be calculated as the product of the applied force and the distance moved by the object in the direction of the applied force ($\mathbf{W = F \times d}$).Work is measured in **joules (J)**.

Power in our everyday language is usually associated with force and authority. When a person is able to get things done quickly and according to his wishes, we say he is powerful. In Physics, power is associated with energy and has a precise meaning. The concept of power is concerned with how rapidly energy is being transferred or transformed when work is done. It is the rate of work done or rate of energy transfer. Power is measured in joules per second (**J/s)** or **watts (W)** and is worked out using the formula:

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

Energy is always associated to strength and strong forces doing work. It is related to activities like the sport of weight lifting, waves crashing against the shores and many others. In Physics, energy is defined as **the ability or capacity to do work.** Work here refers to making a body or machine move to achieve a purpose. In order to do work, energy is transferred or converted from one form to another.

Energy comes in various forms such as light, thermal, sound, electricity, potential energy and kinetic energy. This unit will focus on gravitational potential (stored) energy due to content or position of an object and kinetic energy in moving objects.

Potential energy is the energy of an object due to its position or state. There are different kinds of potential energy such as gravitational potential energy, chemical potential energy, and electrical potential energy.

$$\text{Gravitational Potential energy } (\mathbf{PE}) = \mathbf{mgh}$$

Kinetic energy is the energy of an object due to its motion. This means that any object in motion has kinetic energy. The faster the object moves the more kinetic energy it has. Kinetic energy is therefore dependent in the motion of the object.

$$\text{Kinetic energy } \mathbf{(KE)} = \frac{\mathbf{1}}{\mathbf{2}}\mathbf{mv^2}$$

Potential energy can be converted to kinetic energy and vice versa. When work is done and energy is converted from one form to another, the total amount of energy is the same as before conversion. This leads to the **Law of Conservation of Energy**. The idea is that energy cannot be created nor destroyed but is only transferred or converted from one form to another

Finally, we will study simple machines such as pulley, ramps, wedge, wheel and axle, screw, gear, which multiply force. They are designed and built to do work on objects using less effort compared to the load. A small input force can accomplish a task requiring a large output force. But this small input force as to be applied through a larger distance so that the work input is equal the work output. All machines are typically described by their mechanical advantages and power ratings.

All these will be discussed in detail throughout this module.

Learning Outcomes

After going through this module, you are expected to:

- define work and its equation.
- calculate work done.
- calculate work done by multiple forces.
- define power and its equation.
- calculate power.
- explain how force, energy and work are related.
- calculate electrical power and cost of using electricity.
- define energy and list different types of energy.
- name and describe different forms of energy.
- define and calculate Potential energy.
- define and calculate Kinetic energy.
- define the law of Conservation of Energy.
- list energy changes.
- state and apply the Law of Conservation of Energy in terms of the Energy transformation to practical situations.
- perform calculations relating work done by an object and the changes involved in kinetic energy and potential energy.
- discuss energy application situations at home, in Papua New Guinea and in the world in terms of natural resources; list potential sources of energy.
- define and do calculations on energy transfer through a pendulum, free-fall, up and downhill.
- define simple machines.
- list and define different types of simple machines.
- calculate force using simple machines.
- calculate the mechanical advantage and efficiency of simple machines.

Time Frame

Suggested allotment time: **8 weeks**

This module should be completed within 8 weeks.

If you set an average of 3 hours per day, you should be able to complete the module comfortably by the end of the assigned week.

Try to do all the learning activities and compare your answers with the ones provided at the end of the unit. If you do not get a particular exercise right in the first attempt, you should not get discouraged but instead, go back and attempt it again. If you still do not get it right after several attempts then you should seek help from your friend or even your tutor.

DO NOT LEAVE ANY QUESTION UNANSWERED.

11.4.1 Work

Work is done whenever a force produces movement. The greater the force and the distance moved the more work is done. Therefore, **work is defined as the product of the force applied and the distance moved in the direction of the force**. It is a scalar quantity and can be calculated using the formula:

$$\textbf{Work done (W)} = \textbf{force (F)} \times \textbf{distance moved in the direction of the force (d)}$$

$$\mathbf{W = F \times d}$$

From the definition of work we see that the units are force (**N**) times distance (**m**). Thus, the SI unit for work is **newton-metre** (**Nm**). The newton-metre is also called the **Joule** (**J**).

1 joule (J) of work is done when a force of 1 newton (N) moves a body through a distance of 1 metre (m):

$$\mathbf{1\ J = 1\ Nm = 1\ kgm^2/s^2}$$

Example
If a force of 47N moves an object through a distance of 2m, then the work done is:

Solution

$$\begin{aligned} W &= F \times d \\ &= 47N \times 2m \\ &= \mathbf{94J} \end{aligned}$$

Work done by constant force
Force can be applied horizontally, vertically or at an angle to do work.

(i) Force applied horizontally

When the applied force is parallel to the displacement that means they are in the same direction. If the force acts right, the object will move right and if the force acts left the object will move left.

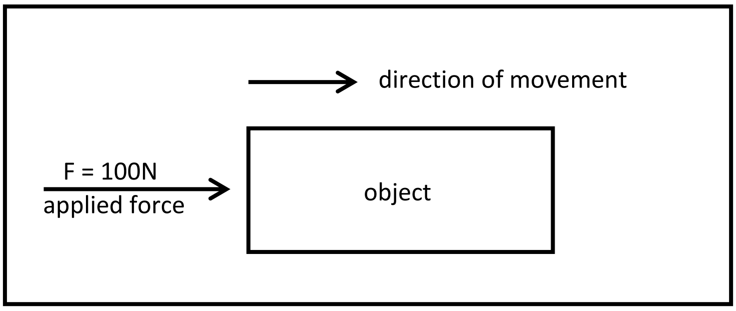
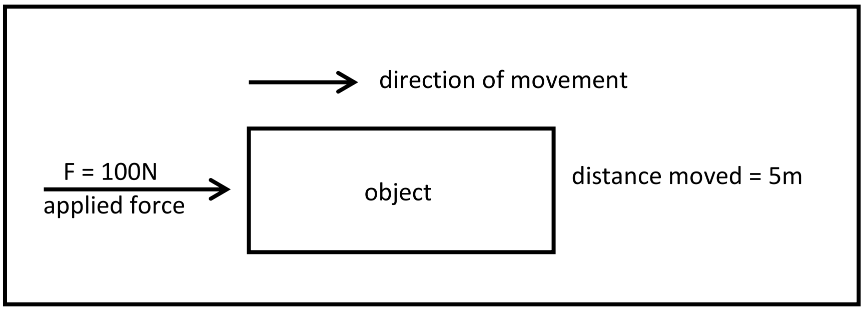


Figure 1 Force in the same direction as the displacement

In f1, the applied force acts to the right on the object and the object moves to the right. Therefore, the **force vector** and the **displacement vector** are in the same direction. So work done will be the product of the applied force (100N) and the distance moved by the object.

Example 1

A 100N force is applied to move an object, a horizontal distance of 5 metres at constant speed neglecting friction. Calculate the work done on the object.



Solution

$$\begin{aligned} W &= F \times d \\ &= 100N \times 5m \\ &= 500Nm \\ &= \mathbf{500J} \end{aligned}$$

Example 2

How much work is done when a force of 5000N moves its point of application 0.6m in the direction of the force.

Solution

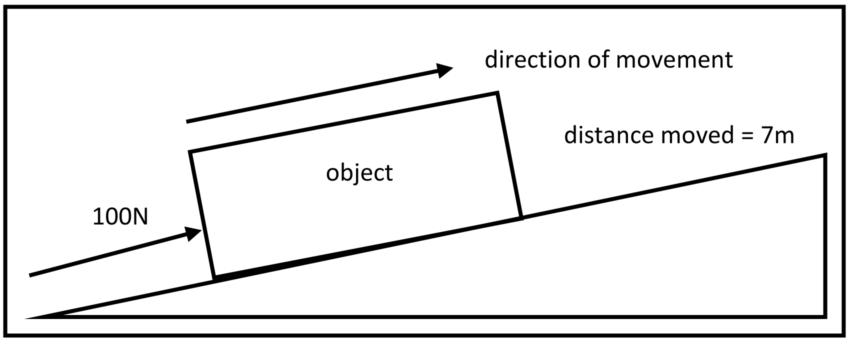
$$\begin{aligned} W &= F \times d \\ &= 5000N \times 0.6m \\ &= 3000Nm \\ &= \mathbf{3000J} \end{aligned}$$

Example 3

Calculate the work done on the object along an inclined plane in the diagram below.

Solution

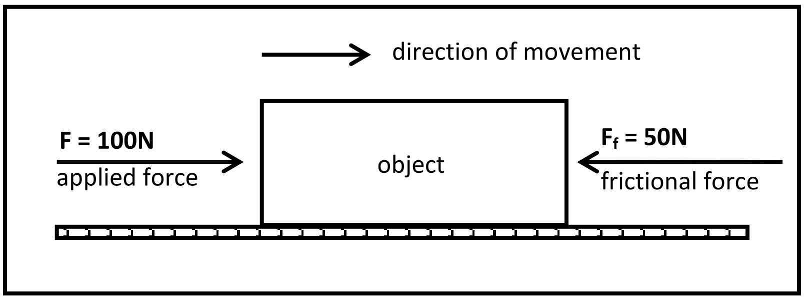
$$\begin{aligned} W &= F \times d \\ &= 100N \times 7m \\ &= \mathbf{700J} \end{aligned}$$



When friction opposes the applied force, an object will always move in the direction of the greater force.

Example 4

A 100N force is applied to move a 15kg object a horizontal distance of 5 meters on a rough surface with a frictional force of 50N.



Solution

Work done = Net Force × distance moved in the direction of net force

Net force (F_{net}) = Applied force − Frictional force

$$F_{net} = 100N - 50N$$
$$= \mathbf{50N}$$

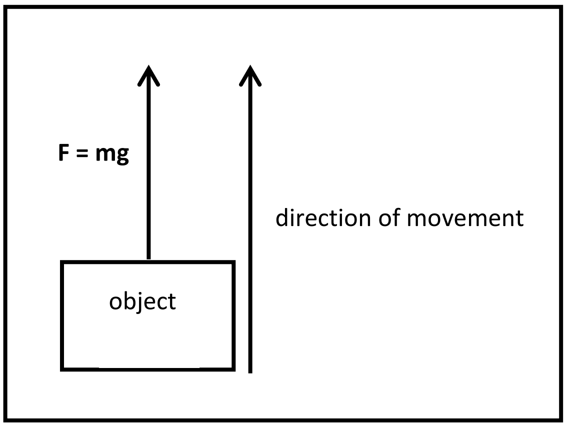
$$W = F_{net} \times d$$
$$= 50N \times 5m$$
$$= \mathbf{250J}$$

(ii) Force parallel to displacement (vertical direction)

When force moves an object vertically; work done is due to gravity.

Example

An upward force is applied to lift a 15kg object to a height of 5m at constant speed.



Solution

Work done due to gravity = Force × height

$$W = f \times d$$
$$= mgh$$
$$= 15kg \times 10ms^{-2} \times 5m$$
$$= 750kgm^2s^{-2}$$
$$= \mathbf{750J}$$

(iii) Force at an angle to displacement

If the direction of the force is not in the direction of the displacement, then the component of the force in the direction of the displacement must be calculated.

Let us consider an applied force acting at an angle to the displacement of an object.

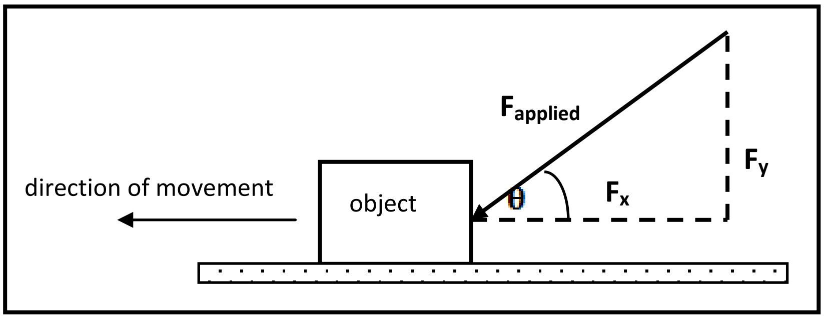


Figure 2 Applied force at an angle to the direction of movement

The components of the applied force can be calculated using the concept of trigonometry.

Vertical component ($\mathbf{F_y}$) $= F_{applied} \times \sin\theta = \mathbf{F\sin\theta}$
Horizontal component ($\mathbf{F_x}$) $= F_{applied} \times \cos\theta = \mathbf{F\cos\theta}$

The direction of the movement of the object is **NOT** in the direction of the vertical component of the applied force. It is perpendicular to the vertical component ($\mathbf{F_y}$). Therefore, there is no work done.

The direction of the movement of the object is in the direction of the horizontal component of the applied force. Therefore, work is done.

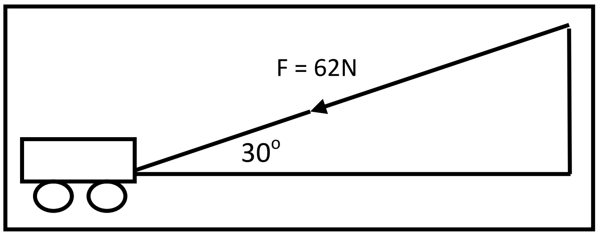
So work done by an applied force acting at an angle to the displacement of an object is given by the formula:

$$\text{Work done} = F_x \times \text{distance moved in the direction of } F_x$$
$$W = \mathbf{Fd\cos\theta}$$

Theta (**θ**) is the angle between the applied force and the movement of an object in the direction of the force.

Example 1

How much work is done when a mother pushes a baby pram a distance of 54.4m, using a force of 62N at an angle of 30^o to the horizontal?



Solution

Work is done by the horizontal component force

$$\begin{aligned} \text{Work} &= Fd\cos\theta \\ &= 62N \times 54.4m \times \cos 30^o \\ &= \mathbf{2920.9J} \quad (1d.p) \end{aligned}$$

Example 2

A 100N force is applied at an angle of 60^o to the horizontal to move a 15kg object at a constant speed for a horizontal distance of 5m.

Solution

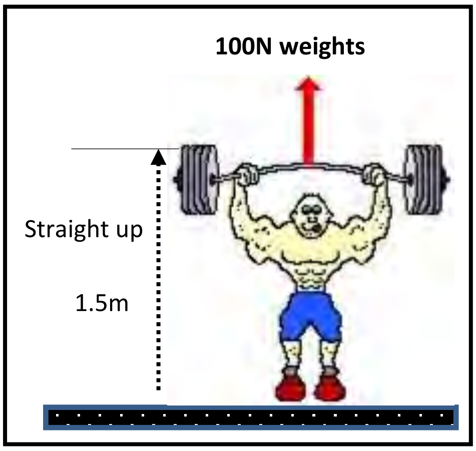
$$\begin{aligned} \text{Work} &= Fd\cos\theta \\ &= 100N \times 5m \times \cos 60^o \\ &= \mathbf{250J} \end{aligned}$$

Positive and negative work

Work can either be positive or negative depending on whether a component of force points in the same direction as the displacement or in the opposite direction.

Example

A weight lifter raises 100N weights vertically to a height 1.5m. The weights were then vertically brought down to the initial position. Work out the work done in (a) raising the weights and (b) bringing the weights down again.

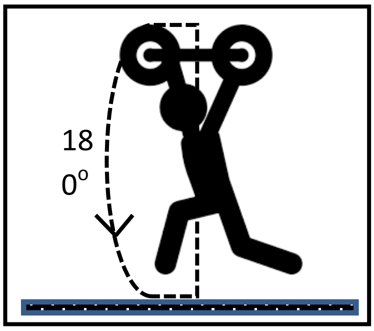


Solution

a) There is no angle between the applied force and direction of movement of the weights. Therefore, the angle is 0^o.

$$
\begin{aligned}
\text{Workdone} &= Fd\cos\theta \\
&= mgh\cos\theta \\
&= 100N \times 1.5m \times \cos 0^{\circ} \\
&= \mathbf{150J}
\end{aligned}
$$

b) When he puts the weights down, he will not place the weights directly straight down. But because of the strain in his arms, he will place the weights at an angle down as illustrated by figure 3.



$$
\begin{aligned}
\text{Workdone} &= Fd\cos\theta \\
&= mgh\cos\theta \\
&= 100N \times 1.5m \times \cos 180^{\circ} \\
&= \mathbf{-150J}
\end{aligned}
$$

Further Challenging Examples

Example 1

Ben Travlun carries a 200N suitcase up three flights of stairs, a height of 10.0m and then pushes it with a horizontal force of 50.0N at a constant speed of 0.5m/s for a horizontal distance of 35.0 metres. How much work does Ben do on his suitcase during this entire motion?

Solution

The motion has two parts: (a) pulling vertically to displace the suitcase vertically and (b) pushing horizontally to displace the suitcase horizontally.

$$
\begin{aligned}
\text{a) } W &= Fd\cos\theta \\
&= 200N \times 10m \times \cos 0^{\circ} \\
&= \mathbf{2000J}
\end{aligned}
$$

$$
\begin{aligned}
\text{b) } W &= Fd\cos\theta \\
&= 50N \times 35m \times \cos 0^{\circ} \\
&= \mathbf{1750J}
\end{aligned}
$$

The total work done is **3750J** (the sum of the two parts).

Example 2
A boy lifts a 40 kilogram bale of rice onto the back of truck two metres above the ground.

(a) How much force is required to lift the bale of rice?

(b) How much work is done by the boy in loading the bale of rice to the back of the truck?

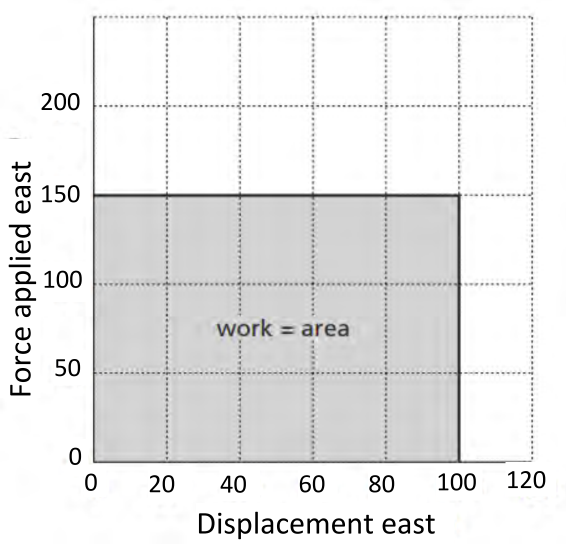
Solution
The force required to lift the bale of rice is equal to force due to gravity. Acceleration due to gravity is $10 m/s^2$.

a) $$\text{Force} = ma = 40kg \times 10ms^{-2} = \mathbf{400N}$$

b) $$W = Fd\cos\theta = 400N \times 2m \times \cos 0^{\circ} = \mathbf{800J}$$

Graphical analysis of work
Work done in a force - distance graph is the area under the graph.

FORCE – DISTANCE GRAPH



Work done = Area under the graph

Example
Calculate the work done in the graph above.

Solution
The shaded area under the graph is a rectangle. Therefore, work done is equal to the area of the rectangle.

$$\begin{aligned}\textbf{Work} &= \text{Area of rectangle}\\ &= \text{Force} \times \text{displacement}\\ &= 150\text{N} \times 100\text{m}\\ &= 15000\text{Nm}\\ &= \mathbf{15000J}\end{aligned}$$

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 1

30 minutes

Read and answer the following questions accordingly in the space provided.

1. You push a table through 3m with a force of 30N. How much work have you done on the table? The table fails to accelerate continuously due to friction.

---

2. In lifting a 20kg bucket of water through 2m from a hole, work has been done and energy transformed. What work have you done? (Use g = $10ms^{-2}$)

---

3. How much work is done when a force of 4000N moves its point of application 0.5m in the direction of the force?

---

4. Find the work done in raising 100kg of water through a vertical distance of 3m. (use g = $10ms^{-2}$)

5. Calculate the work done by a 47N force pushing a pencil 0.26m.

6. Calculate the work done by a 47N force pushing a pencil 0.25m against a force of 23N.

7. How much work is done to lift a 20kg sack of potatoes vertically 6.5m? (use = $10ms^{-2}$)

8. Calculate the work done on an object as illustrated by the graph below.

9. A 75.0kg man pushes on a 500 000 tonne wall for 250s but it does not move. How much work does he do on the wall?

10. A boy on a bicycle drags a wagon full of newspapers at 0.80 m/s for 30 minutes using a force of 40N. How much work has the boy done?

Thank you for completing learning activity 1. Now check your work. Answers are at the end of the module.

11.4.2 Power

The time it takes to do work is as important as the amount of work that is done. So the concept of power is useful. **Power is defined as the rate of doing work** and is given by the formula:

$$\boxed{\begin{aligned}\textbf{Power (P)} &= \frac{\textbf{Work done (W)}}{\textbf{time taken (t)}}\\ \mathbf{P} &= \frac{\mathbf{W}}{\mathbf{t}}\end{aligned}}$$

Now, when work is done, energy is transferred from one form to another. Hence, if power is the rate of doing work, then **power is also defined as the rate of energy transfer** (or energy output). It is given by the formula:

$$\boxed{\begin{aligned}\textbf{Power (P)} &= \frac{\textbf{Enery transfer (E)}}{\textbf{time taken (t)}}\\ \mathbf{P} &= \frac{\mathbf{E}}{\mathbf{t}}\end{aligned}}$$

Power is measured in **joules per second** (**J/s**). It is called **watt** (**W**). If 1 J of work is done every second, the power output is 1W.

Work done = Energy transfer

$$\mathbf{P = \frac{W}{t} = \frac{E}{t} = \frac{J}{s} = watt}$$

$$\mathbf{1W = 1J/s = 1kgm^2/s^3}$$

Conversion factors of power ratings
1 kilowatt (kW) = 1000W (1000 J/s)
1 megawatt (MW) = 1 000 000 W (1 000 000 J/s)

Measuring human power

If you do work by running up the steps of a house, your average power can be calculated from the following measurements:

- your mass
- vertical height from ground to the top of the steps
- time taken to run up the steps

Example 1

A 52kg student runs up a flight of stairs of vertical height 3.0m in 4.7s. Calculate the power output.

Solution

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

$$= \frac{52\,kg \times 10\,ms^2 \times 3\,m}{4.7\,s}$$

$$= \frac{1560\,J}{4.7\,s}$$

$$= \mathbf{331.9\ W}$$

Example 2

What is the power output of a cyclist who transforms 27 000J of energy in 3 minutes?

Solution

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

$$= \frac{27\,000\,J}{180\,s}$$

$$= \mathbf{150\ W}$$

Example 3
What is the rate of work done by a force of 21N on a 3.0kg object through a distance of 4m from rest? (assume no energy is lost to friction)

Solution
The aim of this question is to calculate rate of work which is **power**. However, **time** is missing from the information provided. Therefore, the concepts in the study of force and motion must be applied in this challenging question.

When the object moved a distance of 4m, it **accelerated** from rest.

Step 1 Calculate the **acceleration** of the object in the direction of the force.

$$\begin{aligned} F &= ma \\ a &= \frac{F}{m} \\ &= \frac{21N}{3kg} \\ &= \mathbf{7ms^{-2}} \end{aligned}$$

The object accelerated from rest. That means its initial velocity was zero.

Step 2 Calculate the **velocity** of the mass gained.

$$\begin{aligned} v^2 &= u^2 + 2ad \\ v^2 &= (0ms^{-1})^2 + 2 \times 7ms^{-2} \times 4m \\ v^2 &= 56m^2s^{-2} \\ v &= \sqrt{56m^2s^{-2}} \\ &= \mathbf{7.5ms^{-1}} \end{aligned}$$

Acceleration is the rate of change in velocity. So how long did the change of velocity take place from rest to 7.5 ms^{-1}?

Step 3 Calculate the **time** it took to reach 7.5 ms^{-1}

$$\begin{aligned} a &= \frac{v-u}{t} \\ t &= \frac{v-u}{a} \\ &= \frac{7.5ms^{-1} - 0ms^{-1}}{7ms^{-2}} \\ &= \mathbf{1.1s} \end{aligned}$$

Finally, the time it took for the change of velocity is 1.1s. This is the time it took for the object to accelerate, moving from rest to cover a distance of 4 m. The object moved under the influence of the applied force (21 N) in the direction of the force.

Step 4 You can now be able to find the rate of work done on the object.

$$\begin{aligned} P &= \frac{W}{t} \\ &= \frac{21\,N \times 4\,m}{1.1s} \\ &= \mathbf{76.4\ W} \end{aligned}$$

Therefore, when a machine or a person does work in a given time, we are talking about the power ratings of the person or a machine.

Some typical power ratings

- An electrical light globe 100 W
- A person walking 300 W
- An electric radiator 1000 W
- A small car 60 kW
- A racing car 400 kW

Power and velocity

Power was originally defined as the product of force and velocity. This can be shown mathematically as:

$$\begin{aligned} P &= \frac{W}{t} \\ &= \frac{Fd}{t} \\ \text{but } \frac{d}{t} &= v \end{aligned}$$

$$\boxed{\mathbf{P = Fv}}$$

$$\text{therefore} \quad \mathbf{P = Fv}$$

Example

An upward force of 6kN is required to raise a mine cage vertically at a speed of 2.5 ms^{-1} Calculate the power output of the motor lifting the mine cage.

$$\begin{aligned} P &= Fv \\ &= 6000N \times 2.5ms^{-1} \\ &= \mathbf{15\,000J} \end{aligned}$$

The kilo-watt-hour (kWh)

The kilowatt hour (kWh) is a unit of energy used to measure the amount of energy used in houses or industries. If the formula of power is given by:

$$P = \frac{E}{t} \text{ then } \mathbf{E = Pt}$$

$$\text{Electrical energy} = \text{Power (kW)} \times \text{Time (h)}$$

$$\mathbf{E = kWh}$$

$$1 \text{ kWh} = 1{,}000\text{J/s} \times 3{,}600\text{s}$$

$$= 3{,}600{,}000\text{J}$$

$$= 3{\cdot}6\text{MJ (mega joules)}$$

Example 1

An appliance drawing 1000 Watts (1kW) for 1 hour, is said to have consumed 1kWh of electricity.

$$\begin{aligned} E &= \text{Power} \times \text{Time} \\ &= 1\text{kW} \times 1\text{hour} \\ &= \mathbf{1kWh} \end{aligned}$$

Example 2

An appliance drawing 2kW for a period of 2 hours has consumed 4kWh of electricity.

$$\begin{aligned} E &= \text{Power} \times \text{Time} \\ &= 2\text{kW} \times 2\text{hour} \\ &= \mathbf{4kWh} \end{aligned}$$

Example 3

How long would it take an appliance rated at 2kW draw 48 kWh of electrical energy?

$$\begin{aligned} \text{Time} &= \frac{\text{Energy}}{\text{Power}} \\ &= \frac{48\text{kWh}}{2\text{kW}} \\ &= \mathbf{24\ hours} \end{aligned}$$

Power and efficiency

The efficiency of an engine was originally defined as $\frac{\text{work output}}{\text{energy input}} \times 100\%$; efficiency is also equal to:

$$\mathbf{efficiency} = \frac{\mathbf{power\ output}}{\mathbf{power\ input}} \times \mathbf{100\%}$$

Example

A crane lifts a 100 kg block of concrete through a vertical height of 16 m in 20 seconds. If power supplied to the motor driving the crane is 1 kW, what is the efficiency of the motor?

Solution

Step (i) Find the power output of the motor by calculating the work done every second in lifting the concrete block.

$$\text{Work done in lifting the concrete block} = \text{gained in GPE}$$
$$\text{Work} = mgh$$
$$= 100\text{kg} \times 10\text{ms}^{-2} \times 16\text{m}$$
$$= \mathbf{16000J}$$

$$\text{Power} = \frac{\text{work}}{\text{time}}$$
$$= \frac{16000\text{J}}{20\text{s}}$$
$$= \mathbf{800W}$$

Step (ii) Power supplied (power input) to the crane is 1 kW = **1000 W**

Step (iii)

$$\text{Efficiency} = \frac{\text{power output}}{\text{power input}} \times 100\%$$
$$= \frac{800\text{W}}{1000\text{W}} \times 100\%$$
$$= \mathbf{80\%}$$

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 2

30 minutes

Read and answer the following questions accordingly in the space provided.

1. A constant force of 2000N pulls a crate along a level floor a distance of 10m in 50s. What is the power used?

2. A hoist operated by an electric motor raises a load of 300kg vertically at a steady speed of $0.2ms^{-1}$. Frictional resistance can be taken to be constant at 1200N. What is the power required?

3. How long would it take a 500W electric motor to do 1.50×10^{5} J of work?

4. A force of 5.0N moves a 6.0kg object along a rough floor at a constant speed of 2.5m/s.

   a) How much work is done in 25s?

   b) What power is being used?

5. How much electrical energy (in kilowatt hours) would a 60.0W light bulb use in 60.0 days if left on steadily?

6. A 12V car battery is found to be capable of storing 2.0 kWh of electrical energy. For a certain electric car, it is necessary to develop 10kW of power to drive at 20km/h.

   a) Suppose that the car has 10 such batteries which results in 10 times the energy, how long (in hours) could it run if all 10 of them released all of their energy?

   b) How far (in kilometres) can the car go on its 10 batteries if they are fully charged?

---

7. The power output of an engine is 3000W.

   a) How much work does the engine do in 20s?

   b) The efficiency of the engine is 30%. How much energy is supplied to the engine in 20s?

   c) What power is supplied to the engine?

Thank you for completing learning activity 2. Now check your work. Answers are at the end of the module.

11.4.3 Energy

Energy is defined as **the ability or capacity to do work.** In the process of work being done, energy is transferred or converted from one form to another. Therefore, a body which has the capacity to do work is said to possess energy. So when the body does work, the energy it possesses is transferred to other forms. An object that has more energy can do more work than the object that has less energy. The SI unit for energy is the same as work. It is measured in **Joules** (**J**).

Types of Energy

There are different types of energy and all of which measure the ability of work done. The types of energy that exist are combinations of the different forms of energy. For example; solar energy is a type of energy that exists in the form of both light and heat energy. The total energy from the Sun is the sum of the amount of heat energy and light energy.

The following are some examples of different types of energy:

i. **Nuclear energy** is the energy that is comes from the nucleus of an atom. Nuclear energy becomes available when unstable nuclei naturally change by throwing off particles.

ii. **Thermal (heat) energy** is the energy present inside the body. This energy is caused due to motion of the atoms that are present internally. As an object gets heated up, its atoms and molecules move and collide faster.

iii. **Electrical energy**, referred to as electricity by the layman, is energy stored in the back-and-forth motion of electrons in electric utility lines. Lighting is an example of a natural electrical energy. Lightning involves the transformation of electrical energy into thermal and light energy.

iv. **Chemical energy** is the energy that is stored in chemical form, in the bonds of atoms and molecules. Coal, biomass, petroleum products are some examples of stored chemical energy.

v. **Solar energy** is the energy carried by electromagnetic radiation. Radiant energy is present in the form of visible light, x-rays, gamma rays and radio waves etc. Sunlight is a type of radiant energy that supports life on Earth.

vi. **Mechanical energy** is the energy possessed by an object, depending upon its motion or position.

Mechanical energy

Mechanical energy is the energy possessed by an object, depending on its motion or position within a system. Mechanical energy can take the form of **kinetic energy** as in the energy of an object's movement. It can also take the form of **potential energy** by virtue of the stored energy of an object in a particular position.

Mechanical energy is the sum of potential energy and kinetic energy

Potential energy

Potential energy is the energy of a system of particles or objects due to the position of those particles in the system. For example, if you hit an empty tin can the particles in the tin can (system) will vibrate (or move). The effect of their vibrations will result in the sound produced. So when you applied the force on the can, the particles moved out of their initial position. It is for this reason that potential energy is often called **stored energy**. When work is done to change the relative position of parts of a system (by separating or compressing), potential energy is stored in the system by an amount equal to the work done.

$$\textbf{Work done} = \textbf{Potential Energy}$$

Potential energy is a property of a system and not of an individual body or particle. Examples of potential energy include nuclear energy, chemical potential energy, electrical potential energy and gravitational potential energy.

Gravitational Potential Energy

Gravitational potential energy (**GPE**) (or most times it is referred to as potential energy) is the energy that an object has due to its position relative to the Earth's surface. For instance, we are in a system (Earth's atmosphere) where each body exerts force on each other. If there is a change in position with respect to the earth's surface, then there would be a gain in potential energy.

The gravitational force that acts on every kg of mass near the Earth's surface is represented as **g** with an approximate value of **10N/kg** or **10ms^{-2}** so you can think of **g** in two ways.

1. A gravitational force of 10N acts on every kg of mass near the Earth's surface.
2. A free falling object near the Earth's surface will accelerate at 10ms^{-2}.

But you may ask, where did the acceleration, 10ms^{-2} come from? Well you have learnt that 1N = 1kgms^{-2}. So if g = 10N/kg then in place of N we would write 10 kgms^{-2}/kg.

$$\begin{aligned} g &= \frac{10N}{kg} \\ &= \frac{10kgms^{-2}}{kg} \\ &= \frac{10\cancel{kg}ms^{-2}}{\cancel{kg}} \\ &= 10ms^{-2} \end{aligned}$$

Notice that kg cancels out and you are left with $10ms^{-2}$. If greater accuracy is required in a calculation then use **g** = **9.8N/kg** or **9.8ms^{-2}**.

Calculating gravitational potential energy

If you decide to run up the steps of a building, the force of gravity will act on you, thus, there is force between you and the surface of the earth. As you make your way up the steps you are doing work by moving yourself from the ground floor up the steps. As you move up, the force of gravity will act on you so you will carry your own weight up the steps. This results in work being done so you will gain gravitational potential energy.

An object of mass (m) at a vertical height (h) above the ground has a gravitational potential energy (mgh)

Work done = change in gravitational potential energy (GPE)

$$\begin{aligned} \text{Work done} &= \text{change in gravitational potential energy} \\ &= \text{Force} \times \text{distance} \\ &= \text{weight} \times \text{height} \\ &= \text{mass} \times \text{acceleration due to gravity} \times \text{height} \\ &= mgh \\ GPE &= mgh \end{aligned}$$

Example 1

If you weigh 60kg and ran up the building steps covering a distance of 30 metres, then the GPE is calculated as follows:

$$\begin{aligned} GPE &= mgh \\ &= 60kg \times 10ms^{-2} \times 30m \\ &= \mathbf{18\,000J} \end{aligned} \quad \textbf{OR} \quad \begin{aligned} GPE &= mgh \\ &= 60kg \times 9.8ms^{-2} \times 30m \\ &= \mathbf{17\,640J} \end{aligned}$$

If you use g = $10ms^{-2}$ then the answer in example 1 is 18 000J. If you use g = $9.8ms^{-2}$ then the answer is 17640J.

For every calculations dealing with GPE, use g = 10ms^{-2}. But some questions will require you to use g = 9.8ms^{-2} for more accuracy in calculations.

Now, look at the illustration below and study the calculation of their gravitational potential energies. Ball **A** and **B** have the same mass (3kg). Ball **A** and **C** have the same height (4m).

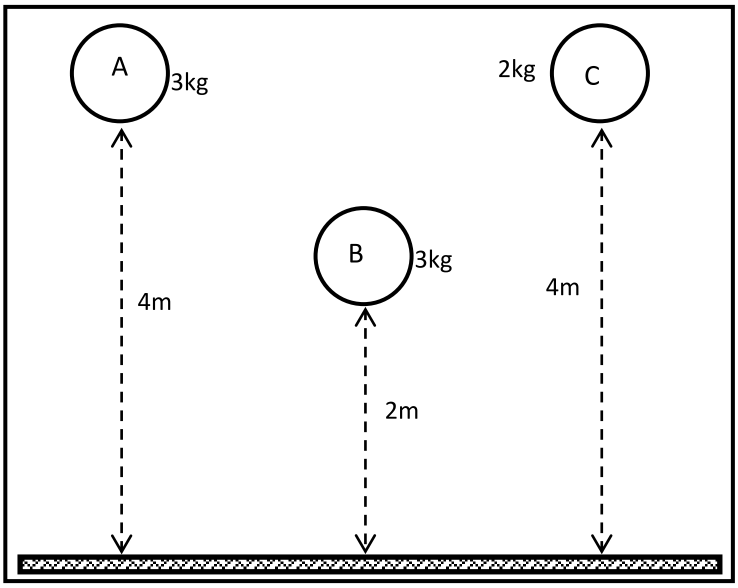


Figure 5 Ball at different heights above ground level

$$\text{Ball } \mathbf{A} \text{ GPE} = mgh$$
$$= 3kg \times 10ms^{-2} \times 4m$$
$$= \mathbf{120J}$$

$$\text{Ball } \mathbf{B} \text{ GPE} = mgh$$
$$= 3kg \times 10ms^{-2} \times 2m$$
$$= \mathbf{60J}$$

$$\text{Ball } \mathbf{C} \text{ GPE} = mgh$$
$$= 2kg \times 10ms^{-2} \times 4m$$
$$= \mathbf{80J}$$

- Ball A and B have the **same weight** but have **different height** above the ground level so Ball A has greater GPE than ball B.
- Ball A and C have the **same height** but have **different weight**. Ball A has more weight than C so it has grater GPE than ball C.
- Ball C weighs less than ball B but it has greater GPE than ball B because it is higher than B.

Therefore, we see that gravitational potential energy depends on the **weight** and **height** of the object.

Example 2

An object has a mass of 6kg. Calculate its GPE

a) 4m above the ground and

b) 8m above the ground

c) At what height above the ground will its GPE be 360J?

Solution

a) $GPE = mgh$

$= 6kg \times 10ms^{-2} \times 4m$

$= \mathbf{240J}$

b) $GPE = mgh$

$= 6kg \times 10ms^{-2} \times 8m$

$= \mathbf{480J}$

c) $h = GPE \div mg$

$= 360J \div (6kg \times 10ms^{-2})$

$= \mathbf{6m}$

Example 3

If you lift a 3kg object from an initial height of 5m to a height of 8m and place it at the top of a shelf, you are doing work on it, since you are applying a force that is in the direction of its displacement (both vertical). In doing work on it, you are also changing its GPE.

Calculate the change in GPE of the above scenario. (use g = $10ms^{-2}$)

(i) At initial height of 5m, the GPE is:

$GPE = mgh$

$= 3kg \times 10ms^{-2} \times 5m$

$= \mathbf{150J}$

(ii) At final height of 8m, the GPE is:

$GPE = mgh$

$= 3kg \times 10ms^{-2} \times 8m$

$= \mathbf{240J}$

(iii) Therefore, the change in GPE is $240\text{J} - 150\text{J} = \mathbf{90J}$

A simpler way to calculate the change in GPE above is by taking the difference in height and then substitute the difference in the formula mgh to find the change in GPE.

(i) Difference in height (is also stated as change in height) is $8\text{m} - 5\text{m} = \mathbf{3m}$. Change in height is represented by **delta h** (Δh).

(ii) Therefore, GPE is:

$$\begin{aligned} \text{GPE} &= \text{mg}\Delta\text{h} \\ &= 3\text{kg} \times 10\text{ms}^{-2} \times (8-5) \\ &= \mathbf{90J} \end{aligned}$$

Energy is a scalar quantity

Mass **A** and **B** have the same magnitude. **A** was moved up the slope with less force but the distance moved was greater. Mass **B** was lifted vertically from the ground. Same amount of work was done in each case so both masses have the same GPE. So to calculate the gravitational potential energy of **A** and **B** you need to know the vertical height only but not the direction taken. Therefore, energy is a scalar quantity because direction is not considered.

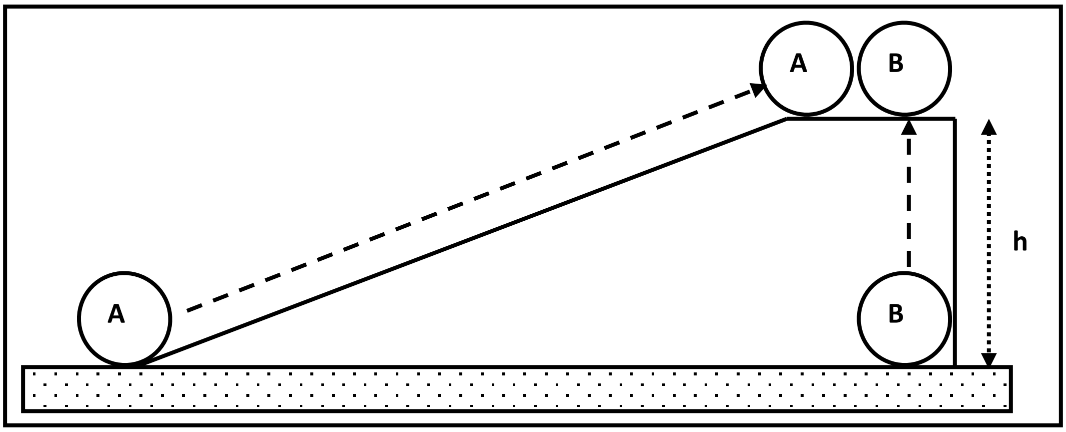


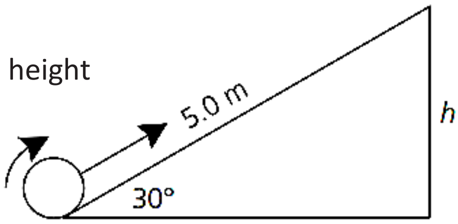
Figure 6 Illustration of energy being a scalar quantity

Example 4

A 35kg beer keg is rolled up a 5m long plank, which makes a 30° incline to the ground. What is the GPE of the keg at the top?

Solution

A 30° incline plane with a hypotenuse of 5m has a vertical height given by: 5.0 × sin 30° = 2.5m.



$$\begin{aligned} GPE &= mgh \\ &= 35kg \times 10ms^{-2} \times 2.5m \\ &= \mathbf{875J} \end{aligned}$$

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 3

20 minutes

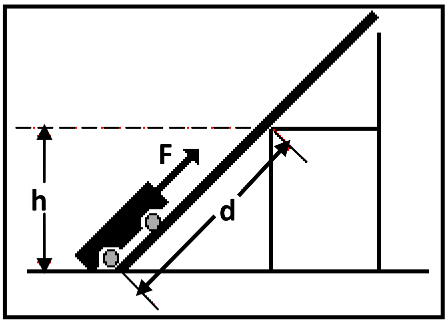
Read and answer the following questions accordingly in the space provided.

1. Richard wants to know how much potential energy his cat has when it climbs to the top of the tree near his house. The tree is 15 metres high and the cat has a mass of 5 kilograms. How much potential energy does the cat have?

2. John has an object suspended in the air. It has a mass of 50 kilograms and is 50 metres above the ground. How much work would the object do if it was dropped?

3. Mrs. Jacobs dropped an object from 10 metres. She knows it did 50 Joules of work. How much did it weigh?

4. A cart is loaded with a brick and pulled at constant speed along an inclined plane to the height of a seat-top. If the mass of the loaded cart is 3.0kg and the height of the seat top is 0.45 metres, then what is the potential energy of the loaded cart at the height of the seat-top?



Thank you for completing learning activity 3. Now check your work. Answers are at the end of the module.

Kinetic Energy

Kinetic energy (**KE**) is the energy of an object due to its motion. This means that any object in motion has kinetic energy. The faster the object moves the more kinetic energy it has. Kinetic energy is therefore dependent on the motion of the object and consequently, the motion of the object depends on its mass and velocity.

There are many forms of kinetic energy - vibrational (the energy due to vibrational motion), rotational (the energy due to rotational motion), and translational (the energy due to motion from one location to another). We will focus on translational kinetic energy.

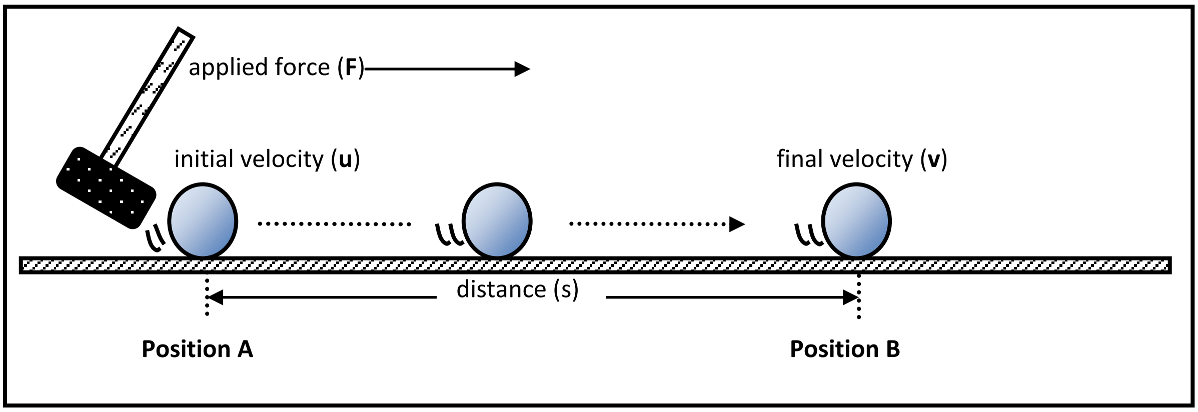


Figure 7 Translational kinetic energy is the kinetic energy due to motion from one location to another.

The diagram above illustrates the kinetic energy of an object. The ball is at rest so its initial velocity (**u**) is zero. Its kinetic energy (KE) at position A is zero.

When an applied force moves the ball in the direction of the force, the ball accelerates from rest to a final velocity (**v**) at position B. Its KE will change from zero to some magnitude because work was done on the ball.

$$\textbf{Work done} = \textbf{Kinetic Energy}$$

An object of mass (m) travelling at a velocity (v) has kinetic energy $\frac{1}{2}mv^2$

The formula for calculating kinetic energy (KE) is derived from Newton's second law (F = ma) and an equation of motion ($v^2 = u^2+2as$)

The force applied to the ball produces accelerated motion and the ball goes from an initial velocity **u** to a final velocity **v**:

$$v^2 = u^2 + 2as$$

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

Newton's second law F = ma

$$\begin{aligned} \text{Work done} &= Fs \\ &= ma \times s \\ &= m\left(\frac{v^2 - u^2}{2s}\right) \times s \\ &= \frac{mv^2 - mu^2}{2} \\ \textbf{Work done} &= \frac{1}{2}mv^2 - \frac{1}{2}mu^2 \end{aligned}$$

Hence, work done is equal to change in kinetic energy. If an object starts from rest, its final kinetic energy is given by:

$$\boxed{KE = \frac{1}{2}mv^2}$$

Example 1

Calculate the kinetic energy of a 6kg bowling ball rolling at $5ms^{-1}$.

$$\begin{aligned} KE &= \frac{1}{2}mv^2 \\ &= \frac{1}{2} \times 6kg \times (5ms^{-1})^2 \\ &= \frac{1}{2} \times 6kg \times 25ms^{-1} \\ &= \mathbf{75J} \end{aligned}$$

What will be its kinetic energy if its velocity is doubled?

$$\begin{aligned} KE &= \frac{1}{2}mv^2 \\ &= \frac{1}{2} \times 6kg \times (10ms^{-1})^2 \\ &= \frac{1}{2} \times 6kg \times 100ms^{-1} \\ &= \mathbf{300J} \end{aligned}$$

Example 2

A ball of mass 0.5kg has 100J of KE. What is the velocity of the ball?

$$\begin{aligned} v &= \sqrt{\frac{2KE}{m}} \\ &= \sqrt{\frac{2 \times 100}{0.5}} \\ &= \mathbf{20\,ms^{-1}} \end{aligned}$$

Example 3

A trolley of mass 2.5kg is pulled along a flat bench by a force of 5N. When the trolley has travelled 4m, find a) how much work has been done on it b) how much kinetic energy it has gained c) its velocity

Solution

a) $$\begin{aligned} Work &= Fs \\ &= 5 \times 4 \\ &= \mathbf{20J} \end{aligned}$$

b) $$\begin{aligned} Work &= Kinetic\ energy \\ &= \mathbf{20J} \end{aligned}$$

c) $$v = \sqrt{\frac{2KE}{m}}$$

$$= \sqrt{\frac{2 \times 20}{2.5}}$$

$$= \mathbf{4ms^{-1}}$$

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 4

30 minutes

Read and answer the following questions accordingly in the space provided.

1. Calculate the kinetic energy of a 45g golf ball travelling at:

    a) 20m/s,

    b) 40m/s,

    c) 60m/s

2. An object of mass 50kg speeds up from 5.0m/s to 10m/s.

    a) What was the total kinetic energy before accelerating?

b) What was the total kinetic energy after accelerating?

c) How much work was done to increase the kinetic energy of the car?

3. At the moment when a shot-putter releases a 5kg shot, the shot is 3m above the ground and travelling at 15m/s. It reaches a maximum height of 8m above the ground and then falls to the ground. (Air resistance is negligible, use $g = 10ms^{-2}$)

a) What was the potential energy of the shot as it left the hand relative to the ground?

b) What was the kinetic energy of the shot as it left the hand?

c) What was the total energy of the shot as it left the hand?

d) What was the total energy of the shot as it reached its maximum height?

e) What was the potential energy of the shot at its maximum height?

f) What was the kinetic energy of the shot at its maximum height?

g) What was the kinetic energy of the shot just as it struck the ground?

Thank you for completing learning activity 4. Now check your work. Answers are at the end of the module.

The Law of Conservation of Energy

The Law of Conservation of Energy states that energy cannot be created nor destroyed but is only transferred from one object to another or transformed from one form to another. That means energy is always conserved when it changes form. In an isolated closed system, energy can never be lost. When work is done in a system, the energy can change from one form to another but the total amount of energy does not change unless work is done on the system from outside.

Energy changes

Energy is constantly changing from one form to another. This is happening all around us and throughout the universe. Energy can be changed from one form to another. For example, as water falls over a waterfall, its gravitational potential energy is first transformed into kinetic energy, then into thermal or heat energy when it hits the ground. Or the kinetic energy of the water stream could be transformed (1) into the rotational kinetic energy of a turbine shaft, then (2) into electricity by turning the shaft of a generator, then (3) into thermal energy by passing the electricity through a resistor, raising its temperature. Finally, heat can be transferred from the resistor to the surrounding air, to warm a house.

Many of the most obvious examples of energy changing from one form into another occur in our homes. Some examples are torches, gas stove, fridge, toaster, TV, radio and washing machine.

Some examples of energy converters are listed below:

Energy Converters	Energy Input	Energy Output
Torch (cell)	Chemical (cell)	Thermal & Light
Guitar String being plucked	Mechanical	Kinetic (Sound)

Petrol Lawn mower	Chemical	Mechanical
Electric jug	Electrical	Thermal
Microwave oven	Electrical	Thermal & Light
Gas stove	Chemical stored	Thermal & Light
Human being running up hill	Chemical & kinetic	GPE & Thermal
Microphone	Electrical	Mechanical
Electric generator	Mechanical	Electrical
Electric motor	Electrical	Mechanical
Steam engine	Thermal	Mechanical
Electric bulb	Electrical	Thermal & Light
Cellular Respiration	Chemical	Thermal & Mechanical
Solar cell	Light	Electrical

The reason we transform through energy converters, from one form to another is because different end users require different forms of energy.

For example, sometimes we want electrical energy to power light bulbs that change electricity into electromagnetic radiation, some of which is visible as light. At other times we want the kinetic energy of a rotating shaft to provide mechanical energy to propel an automobile, so we transform chemical energy from fuel into thermal energy in a car engine, and then into the kinetic energy of the rotating crankshaft that provides power to turn the wheels.

Energy Transfer

As discussed in the preceding concept under conservation of energy:

Energy cannot be made nor destroyed, but it can be changed from one form into another.

For example, if a rock falls from height of 4m, it has only potential energy at the beginning, however, as it falls it gains kinetic energy and its velocity increases. When it hits the ground it has only kinetic energy. Well, where is the potential energy that it has at the beginning? It is totally converted to kinetic energy. As stated above, energy cannot be made nor destroyed, it has changed form. So the potential energy has changed to kinetic energy.

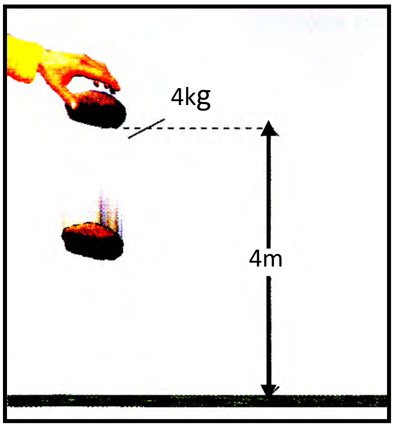


Figure 8 Energy is conserved when it changes form

We will now look at three practical situations to help you understand the concept of energy transformation. During energy transfer, the total energy within a close system is conserved unless work is done externally.

Pendulum

When a pendulum swings backwards and forwards, energy changes from potential to kinetic and back again repeatedly. But the total energy of the system remains the same.

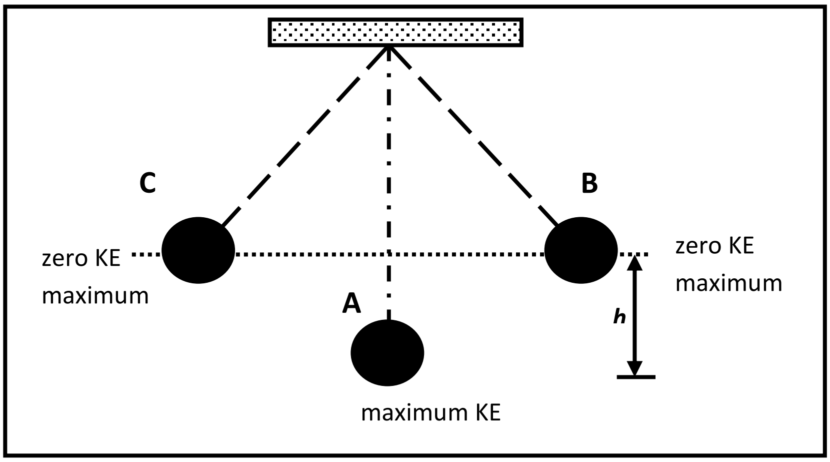


Figure 9 Energy changes in a swinging pendulum

Let us study the diagram of a pendulum on the right

When the pendulum bob is pulled to **position B**, it is raised through a height **h**. At this height, it has maximum GPE equal to mgh and zero KE.

When released, it loses GPE and gains KE. At **position A**, all its GPE is changed to KE. At A it has maximum KE and maximum velocity. Its GPE is zero (since h = 0). As it swings to **position C** to a height on the other side, it gains GPE and loses KE. At position B, it has maximum GPE and no KE (since it is momentarily at rest).

Example

A pendulum bob of mass 0.1kg is raised to a height of 0.4m above its lowest point. It is then released. What is its

a) GPE at this height?

b) KE at its lowest point?

c) maximum velocity?

Solution

a) $GPE = mgh$

$= 0.1 \times 10 \times 0.4$

$= \mathbf{0.4J}$

b) $KE = \text{loss in GPE} = \mathbf{0.4J}$

c)

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

$$0.4 = \frac{0.1v^2}{2}$$

$$0.8 = 0.1v^2$$

$$v^2 = \frac{0.8}{0.1}$$

$$v^2 = 8$$

$$v = \sqrt{8}$$

$$= \mathbf{2.8ms^{-1}}$$

Therefore, the total energy of the system is conserved.

Free fall
When an object falls freely from a height above the ground its gravitational potential energy at that height will be converted to kinetic energy when it hits the ground.

Look at the illustration in figure 10. The block falls at an initial height of 8m above ground level. At that height, its GPE is 160J and its KE is OJ. As it falls its velocity increase to 6m above ground level, its GPE decreases to 120J because 40J is transformed into KE. At 3m above ground level, its GPE is further decreased to 60J because 100J is converted to KE. When it hits the ground all GPE is converted to KE. At ground level the GPE is 0J and KE is 160J.

So you see the energy at 8m above ground level is conserved during the falling process. It is only converted (or transformed) from GPE to KE.

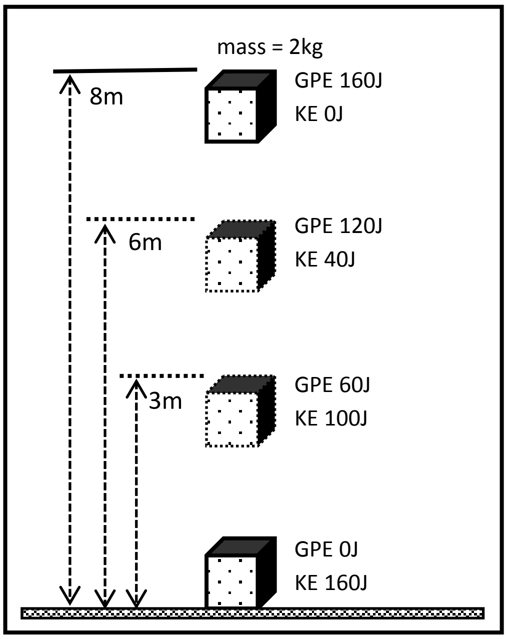
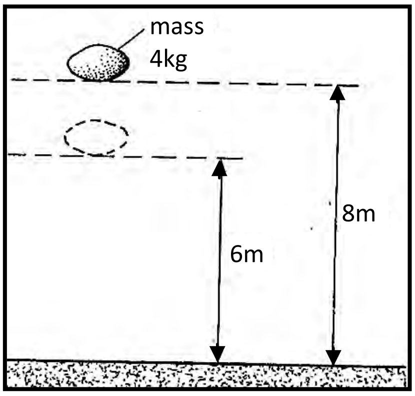


Figure 10 Conversion of GPE to KE

Example

The stone in the left figure has a mass of 4kg. It is at a height of 8m above the ground. (Use g = 10ms^{-2} and assume that air resistance is negligible).



What is its

(a) gravitational potential energy (GPE) at 8m above the ground?

(b) kinetic energy (KE) as it passes a point 6m above the ground?

Solution

(a)
$$\begin{aligned} GPE &= mgh \\ &= 4kg \times 10ms^{-2} \times 8m \\ &= \mathbf{320J} \end{aligned}$$

(b) With such a question, it is not necessary to use KE = ½ mv^2. Just consider the energy change from GPE to KE. That is loss in GPE is equal to gain in KE. There is loss in GPE because there is a change in height.

$$\begin{aligned} \text{loss in GPE} &= \text{gain in KE} \\ &= mgh \\ &= 4kg \times 10ms^{-2} \times 2m \\ &= 80J \end{aligned}$$

Therefore, KE at 6m is **80J**

To confirm your answer for (b) calculate the GPE of the stone at 6m.

$$\begin{aligned} \text{GPE at 6m} &= mgh \\ &= 4kg \times 10ms^{-2} \times 6m \\ &= \mathbf{240J} \end{aligned}$$

Notice that at 8m, the GPE is 320J and at 6m the GPE is 240J. So there is a loss of GPE. The loss is 80J. Where did the 80J gone to? Of course you now know that the 80J of GPE has been transformed into KE. Therefore, loss in GPE is equal to gain in KE.

Motion uphill and downhill

Let us look at the third illustration of energy transfer. A roller coaster ride showing how energy is transformed from GPE to KE and back to GPE.

At **position A** the GPE is at its maximum and KE is at its minimum. As the carrier moves down its velocity increases and so it gains KE from the loss of GPE. The loss of GPE simply means that GPE is transformed to KE as the carrier increases its motion down the trail.

At **position B**, the carrier has more KE than GPE and as it moves up to **position C**, its KE decreases. That means its KE is now transformed to GPE as it gains height, its velocity decreases and so its KE will decrease and its GPE will increase.

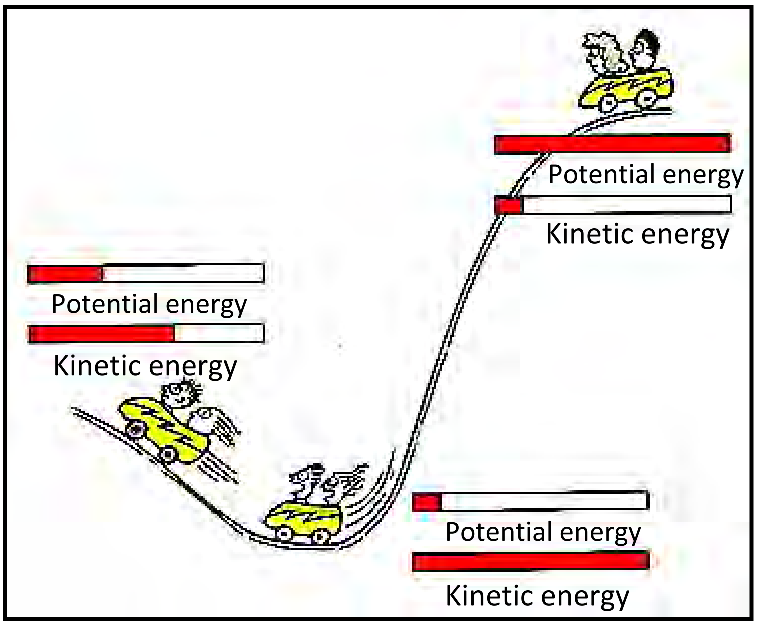


Figure 11 Energy conversion uphill downhill motion

Importance of energy resources

Moving vehicles, electricity in our houses, running of heavy machineries and many other activities of life depend on the use of energy. Most energy resources like water, coal and crude oil are being used at a rate that need careful management and conservation for future use.

Crude oil and gas are the two most used natural resources in the world today. There is a greater need to conserve and limit their use because such resources are non-renewable. Imagine the problems the world would face if crude oil and gas run out next year, it would be chaotic. Crude oil is a valuable source of plastics.

A cup of petrol can move a car several kilometres than putting a large windmill in the car's engine or having a coal engine that is not environmentally friendly. Although water is not included with the other two, many water ways and natural sources of water are now being polluted.

Therefore, we need to conserve and manage our natural energy resources because in PNG, we do not have the capacity to build and sustain nuclear power stations, giant windmills as other alternative energy sources.

Energy sources available in PNG

The following are alternate energy sources:

- **Tidal energy**: harnessing the energy from the movement of sea tides
- **Geothermal energy**: energy from hot rocks beneath the earth's surface is used to produce steam to power generators.
- **Solar energy**: sun's radiation is trapped using solar cells
- **Biomass** : use of plants and animal waste to produce fuel and gas
- **Windmills**: the use of wind energy
- **Natural crude oil** and **gas**: the use of crude oil and gas to produce energy

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 5

20 minutes

Read and answer the following questions accordingly in the space provided.

1. What is the gravitational potential energy of a 61.2kg person standing on the roof of a 10-storey building (Each storey is 2.50m high.) relative to the

   a) tenth floor?

   b) sixth floor?

   c) first floor?

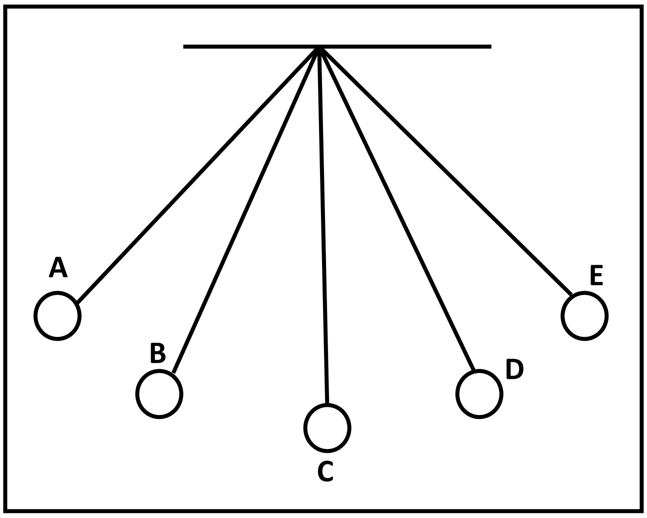
2. Shown is a swinging pendulum of mass 0.3kg. Positions **A** to **E** have different heights above ground level. Positions **A** and **E** are both 1.5m above ground level, positions **B** and **D** are 1m above ground level and position **C** is 0.5m above ground level.

Calculate the GPE and KE at positions

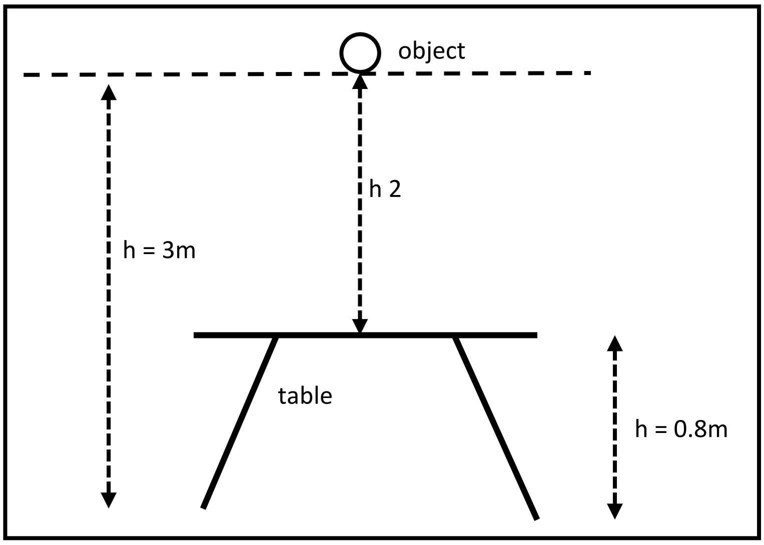
a) C

b) E

c) B



3. An object of mass 2kg is held 3m above the floor of a room. Find the gravitational potential energy (GPE) and kinetic energy (KE) of the object relative to a table surface 0.8m above the floor as shown.



4. In PNG, why is it necessary to conserve and limit the use of crude oil and gas?
____
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Thank you for completing learning activity 5. Now check your work. Answers are at the end of the module.

11.4.4 Simple Machines

A **simple machine** is a device that does work easily for human beings by increasing our ability to do work. A simple machine can change the size, the direction, or the distance over which a force acts.

It basically transmits and modifies forces to lift a heavy load by accomplishing one or more of the following functions:

- transferring a force from one place to another,
- changing the direction of a force,
- increasing the magnitude of a force, or
- increasing the distance or speed of a force.

There are six (6) major types of simple machines. They are levers, ramps (or inclined planes), wheel and axles, screws, wedges and pulleys.

Illustration with a lever

The lever below is a simple machine. You can lift a **load** on the far end of the lever by applying a force called the **effort**, at the near end. The lever turns about a point called the **fulcrum** or **pivot**.

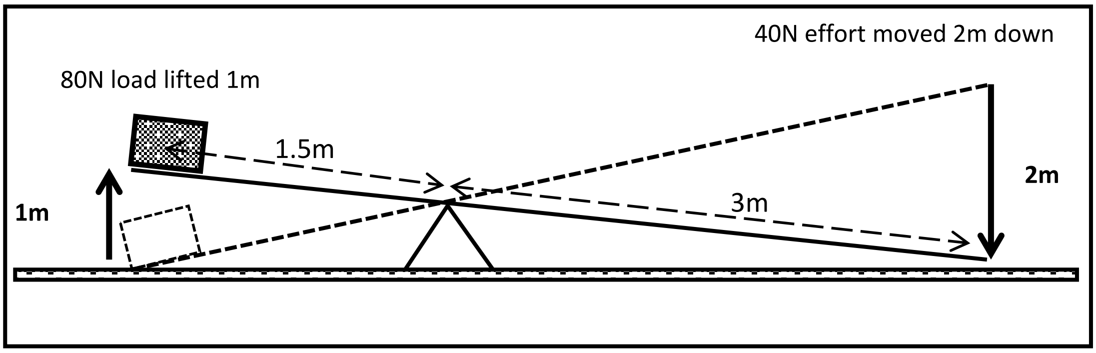


Figure 12 A simple machine in operation. The effort is smaller than the load but same amount of work done

A 40N effort applied to the lever moved 2m to lift a load of 80N for 1m. The distance of the effort from the pivot is 3m while the distance of the load from the pivot is 1.5m. If work is calculated, each has the same amount of work done.

Work done in lifting load

$$\begin{aligned} W &= \text{force} \times \text{distance} \\ &= 80\,\text{N} \times 1\,\text{m} \\ &= \mathbf{80J} \end{aligned}$$

Work done by effort

$$\begin{aligned} W &= \text{force} \times \text{distance} \\ &= 40\,\text{N} \times 2\,\text{m} \\ &= \mathbf{80J} \end{aligned}$$

Therefore the following can be concluded:

1. the load is twice the effort
2. the effort moved twice the distance as the load
3. work done by effort is the same as work done by load so the lever is 100% efficient.

Mechanical advantage

Mechanical advantage (**M.A.**) is the **force-amplifying effectiveness** of a simple machine. It defines the efficiency of a machine. A machine will have a high mechanical advantage if the load lifted is large compared to the effort. It is calculated as:

$$\mathbf{M.A.} = \frac{\mathbf{load}}{\mathbf{effort}}$$

Example 1

The mechanical advantage for the lever in figure 1 is:

$$\begin{aligned} \text{M.A.} &= \frac{\text{load}}{\text{effort}} \\ &= \frac{80\,\text{N}}{40\,\text{N}} \\ &= \mathbf{2} \end{aligned}$$

Velocity ratio

Velocity ratio (**V.R.**) defines the **motion-amplifying effectiveness** of a simple machine. It compares the distance moved by the effort with the distance moved by the load. It is calculated as:

$$\mathbf{V.R.} = \frac{\textbf{distance moved by effort}}{\textbf{distance moved by load}} \quad \textbf{or} \quad \mathbf{V.R.} = \frac{\textbf{distance of effort from pivot}}{\textbf{distance of load from pivot}}$$

Example 2
The velocity ratio for the lever in figure 1 is:

$$\begin{aligned} \text{V.R.} &= \frac{\text{distance moved by effort}}{\text{distance moved by load}} \\ &= \frac{2\,\text{m}}{1\,\text{m}} \\ &= \mathbf{2} \end{aligned}$$

or

$$\begin{aligned} \text{V.R.} &= \frac{\text{distance of effort from pivot}}{\text{distance of load from pivot}} \\ &= \frac{3\,\text{m}}{1.5\,\text{m}} \\ &= \mathbf{2} \end{aligned}$$

A machine with a high mechanical advantage also has a high velocity ratio. If the value of the mechanical advantage is equal to the value of the velocity ratio then this is true for any machine with an efficiency of 100%.

The efficiency of a machine is calculated by:

$$\textbf{Efficiency} = \frac{\textbf{mechanical advantage (M.A.)}}{\textbf{velocity ratio (V.R.)}} \times \mathbf{100\,\%}$$

or

$$\textbf{Efficiency} = \frac{\textbf{work output}}{\textbf{energy input}} \times \mathbf{100\,\%}$$

Example 3
The efficiency of the lever in figure 1 is:

$$\begin{aligned} \text{Efficiency} &= \frac{\text{M.A.}}{\text{V.R.}} \times 100\,\% \\ &= \frac{2}{2} \times 100\,\% \\ &= \mathbf{100\,\%} \end{aligned}$$

OR

$$\begin{aligned} \text{Efficiency} &= \frac{\text{work output}}{\text{energy input}} \times 100\,\% \\ &= \frac{80}{80} \times 100\,\% \\ &= \mathbf{100\,\%} \end{aligned}$$

Levers, Ramps and Wheel and Axle

Levers

A lever is a bar that is free to spin around, or move about a fixed point when an input force is applied. The point at which the lever starts to spin is called the **pivotal point** of a lever and is commonly known as the **fulcrum**.

There are three classes of levers based on the positioning of the effort force, resistance force (load) and fulcrum (or pivot). These three are known as **first class levers**, **second class levers** and **third class levers**.

First class levers

The position of the fulcrum identifies a first-class lever. The fulcrum of a first-class lever is always located between the input force (effort) and the output force (load). Depending on position of fulcrum, the mechanical advantage (M.A.) of first-class lever can be greater than 1, equal to 1 or less than 1.

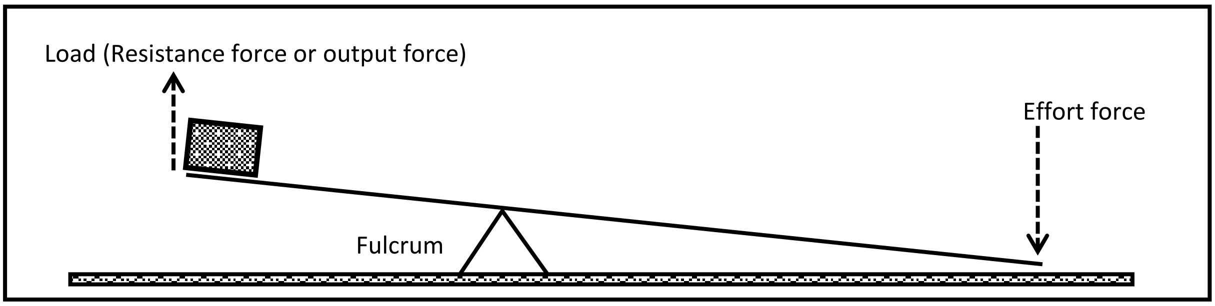


Figure 13 First class lever

Second class levers

In the second class levers the output force or resistance force (load) is located between the input force (effort) and the fulcrum. **Effort moves farther than Resistance Force (load)**. The mechanical advantage (M.A.) of second class lever is always greater than 1. For example, the wheel barrow is a second class lever. When you lift the handles of a wheelbarrow, it rotates around its fulcrum. Input distance is greater than output distance. Increased input distance means it takes LESS force from you to lift the load.

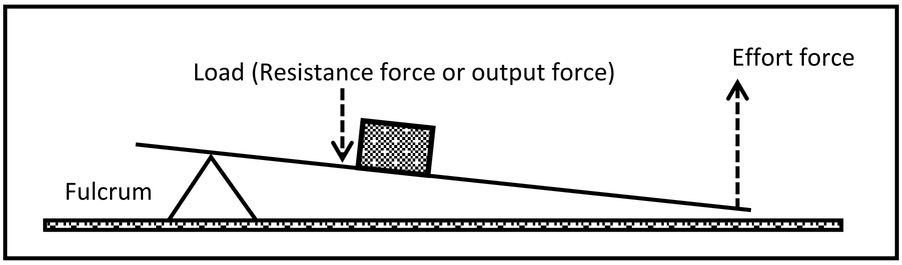


Figure 14 Second class lever

Third class levers

For the third class levers the input force (effort) is located between the fulcrum and the output force (load). The output distance over which the lever exerts its force is always larger than the input distance moved through the lever. Therefore M.A. for third-class levers is always less than 1.

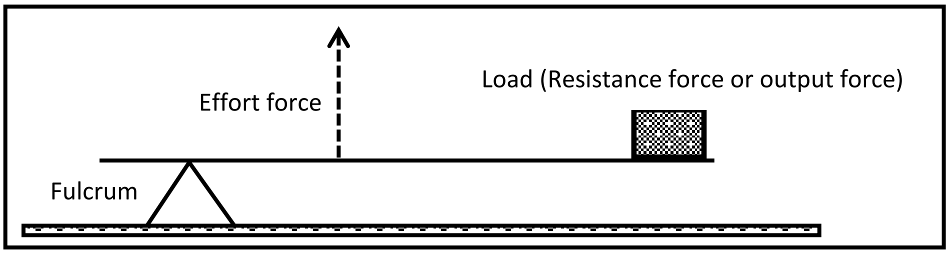


Figure 15 Third class lever

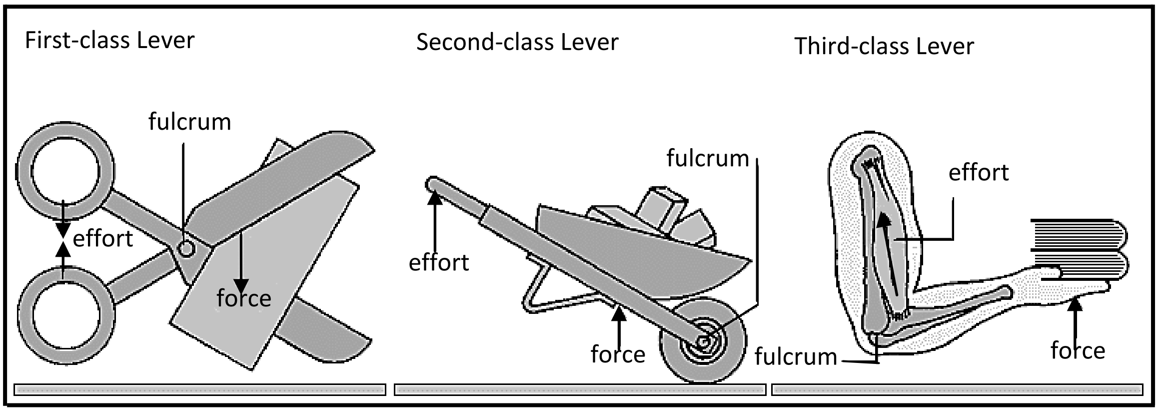


Figure 16 Examples of the three different types of levers

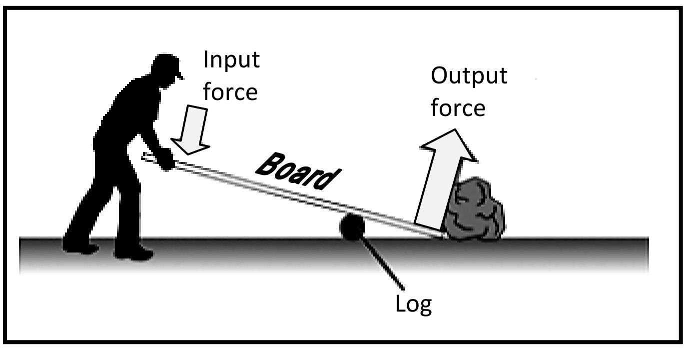
The velocity ratio (V.R.) of any lever can be calculated as follows:

$$\textbf{V.R.} = \frac{\textbf{distance of effort from fulcrum (pivot)}}{\textbf{distance of load from fulcrum (pivot)}}$$

The mechanical advantage (MA) of a lever is the same as its VR provided friction at the pivot is negligible.

Example 1

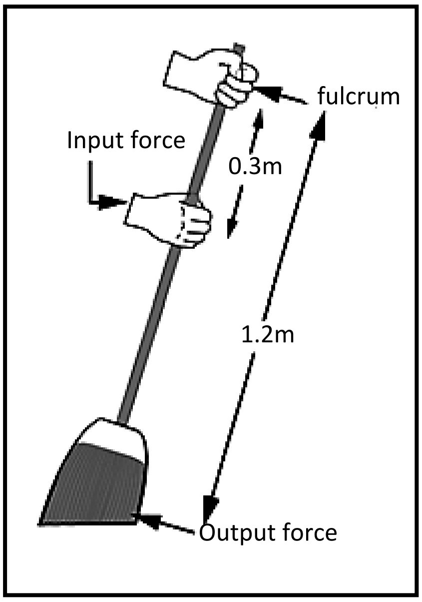
A construction worker uses a board and log as a lever to lift a heavy rock. If the input arm is 3 meters long and the output arm is 0.75 meters long, what is the mechanical advantage of the lever? (Assume friction at the log is negligible)



$$\begin{aligned} \text{M.A.} &= \text{V.R.} \\ &= \frac{3}{0.75} \\ &= \mathbf{4} \end{aligned}$$

Example 2

Sometimes levers are used to multiply distance. For a broom, your upper hand is the fulcrum and your lower hand provides the input force (effort): Notice the input arm is shorter than the output arm. The mechanical advantage of this broom is:



$$\begin{aligned} \text{M.A.} &= \text{V.R.} \\ &= \frac{0.3}{1.2} \\ &= \mathbf{0.25} \end{aligned}$$

A mechanical advantage less than one do not mean a machine is not useful. It just means that instead of multiplying force, the machine multiplies distance. A broom does not push the dust with as much force as you use to push the broom, but a small movement of your arm pushes the dust a large distance.

Ramp

A ramp is also known as an **inclined plane**. It is a simple machine that allows a load to be lifted by using an effort that is less than that of the load. It relies on components of the weight force. So you can pull a load up a ramp using less force than you would need to lift it vertically.

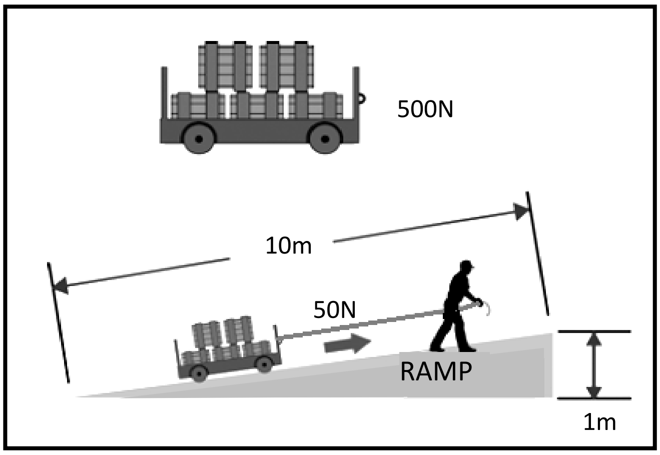


Figure 17 An inclined plane or ramp

$$\textbf{V.R. of ramp} = \frac{\textbf{distance moved by effort}}{\textbf{vertical distance moved by load}} \quad \textbf{or} \quad \frac{\textbf{length of ramp}}{\textbf{height of ramp}}$$

The mechanical advantage (**M.A.**) of the ramp is equal to its VR if friction is negligible.

Example 1

In figure 17, A 500-newton cart is lifted to a height of 1 metre using a 10 metre long ramp. Calculate the MA of the ramp if friction is negligible.

Solution

$$\begin{aligned}
M.A. &= \frac{\text{ramp length}}{\text{ramp height}} \\
&= \frac{10}{1} \\
&= \mathbf{10}
\end{aligned}$$

$$\begin{aligned}
M.A. &= \frac{\text{output force}}{\text{input force}} \\
&= \frac{500N}{50N} \\
&= \mathbf{10}
\end{aligned}$$

The ratio $\frac{\text{ramp length}}{\text{ramp height}}$ is equal to $\frac{1}{\sin\theta}$, where θ is the angle of the ramp.

Example 2

Calculate the angle of the ramp in figure 17.

Solution

$$\begin{aligned}
\frac{\text{ramp length}}{\text{ramp height}} &= \frac{1}{\sin\theta} \\
\frac{10m}{1m} &= \frac{1}{\sin\theta} \\
\sin\theta &= \frac{1}{10} \\
\theta &= \sin^{-1}(0.1) \\
&= \mathbf{5.7^\circ}
\end{aligned}$$

Wheel and axle

Wheel and axles are usually circular objects, often a big wheel and a smaller axle; rigidly secured to one another as shown Figure 18. When one is turned the other must turn. In this simple machine you are making work easier by trading force for distance.

The force is **decreased** when transferred from the axle to the wheel, and **magnified** when transferred from the wheel to the axle.

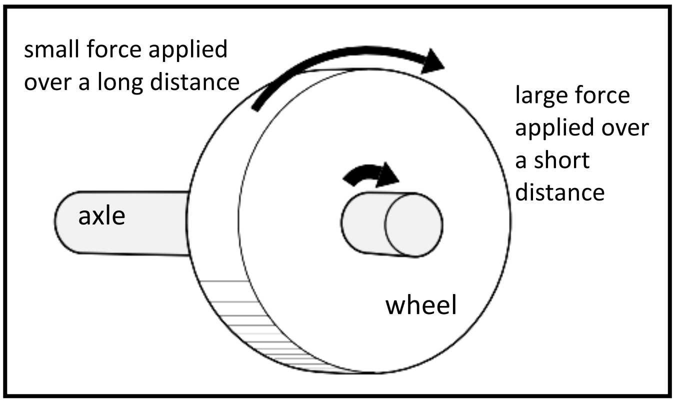


Figure 18 Like all simple machines, wheel and axle transmits and magnifies force.

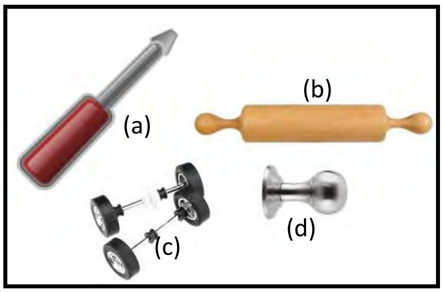


Figure 19 Examples of wheel and axle. (a) screw driver, (b) rolling pin, (c) car wheel and axle (d) door knob

The mechanical advantage (MA) of wheels and axles describe the ratio of rotation between the wheel and axle.

Mechanical advantage is calculated by the following formula.

$$\text{M.A.} = \frac{\text{diameter of wheel}}{\text{diameter of axle}} = \frac{\text{radius of wheel}}{\text{radius of axle}}$$

$$\boxed{\textbf{M.A.} = \frac{\mathbf{D_w}}{\mathbf{Da}} = \frac{\mathbf{r_w}}{\mathbf{r_a}}}$$

Example

Calculate the mechanical advantage (M.A.) of a wheel and axle where the diameter of the wheel is 0.4m and the diameter of the axle is 0.1m.

Solution

$$\begin{aligned} \text{M.A.} &= \frac{D_w}{D_a} \\ &= \frac{0.4\text{m}}{0.1\text{m}} \\ &= \mathbf{4} \end{aligned}$$

Modified wheel and axle - Gears

Gears are like wheels with teeth on them, attached to a rotating shaft. They can be used to change the direction of effort, slow or speed things up, or turn many things at once. Gears are used on ten speed bikes, cars, in watches or clocks and among other things.

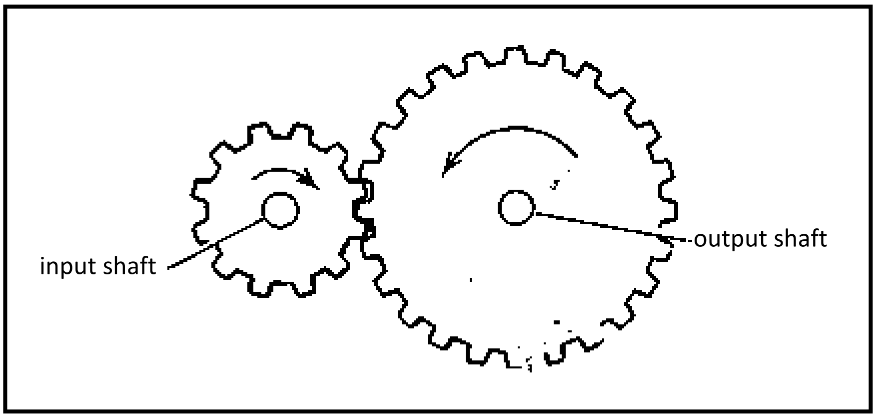


Figure 20 Gears are modified wheels with teeth.

Gears do for couples what levers do for forces. They magnify or reduce their size. The velocity ratio (V.R.) of a gear is calculated by the ratio of the bigger wheel and smaller wheel with respect to the number of notches on each gear.

$$\textbf{V.R.} = \frac{\textbf{number of teeth on big wheel}}{\textbf{number of teeth on small wheel}}$$

Example

Calculate the V.R. of the gear in figure 20.

Solution

The smaller wheel has 12 teeth while the bigger wheel has 24 teeth.

$$\text{V.R.} = \frac{24}{12}$$
$$= \mathbf{2}$$

Now check what you have just learnt by trying out the learning activity on the next page.

Learning Activity 6

60 minutes

Read and answer the following questions accordingly in the space provided.

1. A lever used to lift a heavy box has an input arm of 4 metres and an output arm of 0.8 metres. What is the mechanical advantage of the lever?

2. What is the mechanical advantage of a lever that has an input arm of 3 metres and an output arm of 2 metres?

3. A rake is held so that its input arm is 0.4 meters and its output arm is 1.0 metres. What is the mechanical advantage of the rake?

4. A 5-metre ramp lifts objects to a height of 0.75 metres.

   What is the velocity ratio of the ramp?

5. a) A ramp with a velocity ratio of 8 lifts objects to a height of 1.5 metres. How long is the ramp?

   b) What is the angle of the ramp?

6. The diameter of a wheel is 0.3m and the diameter of its axle is 0.2m.

   Calculate the M.A. of the wheel and axle.

7. Find the M.A. of a couple where the smaller gear has 14 teeth and the bigger gear has 26 teeth.

Thank you for completing learning activity 6. Now check your work. Answers are at the end of the module.

Screws, Wedges and Pulleys

Screw

A screw is an inclined plane wound around a central cylinder. They have continuous spiraling ridges called **threads**. Threads are equally spaced and the distance between each ridge is called the **pitch** of the screw. On turn of the handle on a screw, results in the motion of the screw equal to the distance of one pitch. The friction provided by the threads stops the screw from unwinding when the handle is let go.

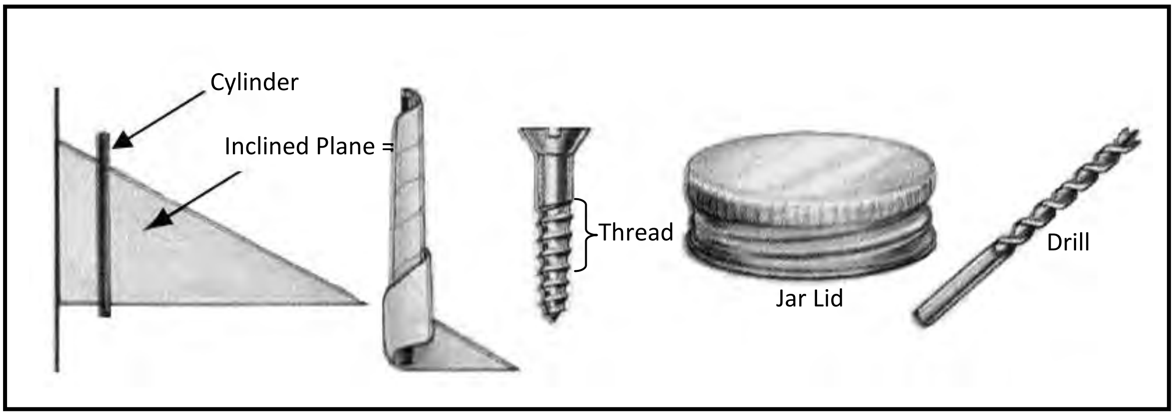


Figure 21 Examples of screws.

An example of a screw that is used most often by car owners is the screw jack. It is used to jack up the side of a car. The handle is winded at the top and the nut gets carried up the thread of the screw and the car is lifted upwards.

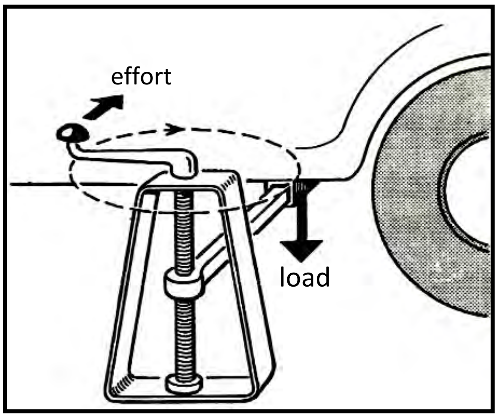


Figure 22 A car jack is likely to have a VR of 500 and a MA of 200.

The velocity ratio of a screw is found by:

$$\textbf{V.R.} = \frac{\textbf{circumference of the face of screw}}{\textbf{pitch of screw}}$$

As stated in figure 22, a car jack is likely to have a V.R. of 500 and a M.A. of 200. Friction is usually considerable in screws and very useful, as it stops the screw unwinding.

Wedge

A Wedge is a V-shaped object whose sides are two inclined planes sloped toward each other. They are moving inclined planes that are driven under loads to lift or into a load to split or separate. Examples of wedges include knife, axe blade, sword, and razor blade.

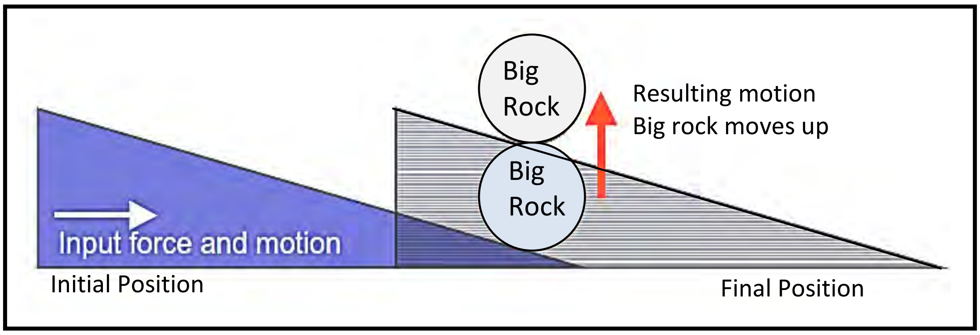


Figure 23a Wedge driven under load to lift

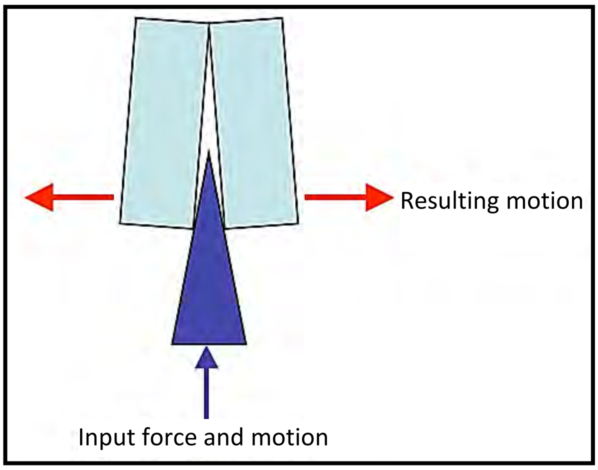


Figure 23b Wedge driven into load to split or separate

A thin wedge of a given length has greater MA than thick wedge of the same length.
The Japanese Samurais feel it was so important to keep their blade of their swords so sharp because sharpening increases the mechanical advantage (MA) of their swords. They want to have the highest MA as possible.

Figure 24a A Samurai maintains his sword at a highest MA as possible.

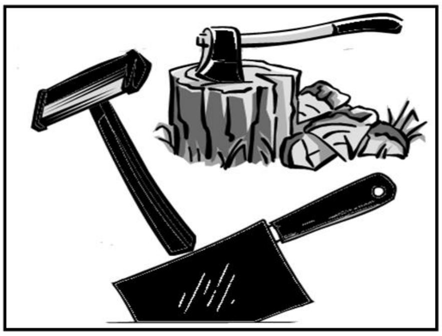
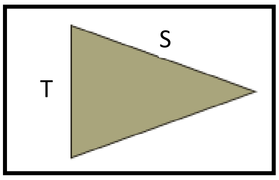


Figure 24b Examples of wedges.

The mechanical advantage (MA) of a wedge can be found by dividing the length of either slope (S) by the thickness (T) of the big end.

$$\mathbf{M.A.} = \frac{\textbf{slope length (S)}}{\textbf{thickness of big end (T)}}$$



Example

Find the MA of a wedge whose slope length is 25cm and the thickness at the bigger end is 10cm.

Solution

$$\begin{aligned} \text{M.A.} &= \frac{\text{slopelength}}{\text{thickness}} \\ &= \frac{25\text{cm}}{10\text{cm}} \\ &= \mathbf{2.5} \end{aligned}$$

Pulley

A pulley is a wheel that carries a rope, string or chain on its rim. Pulling on one end of the rope allows the force to be transmitted resulting in the rise of a load to a certain height.

Study figure 25 on how pulleys can make work easy for us.

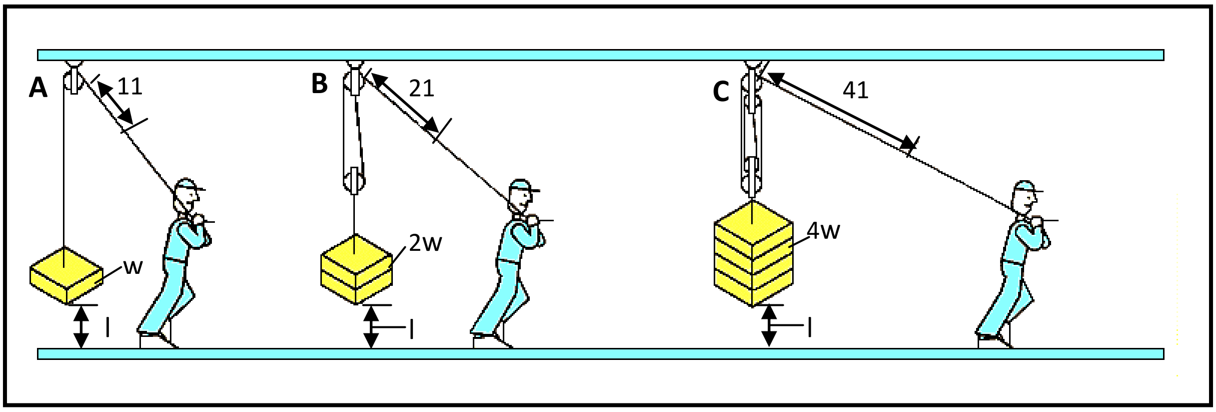


Figure 25 Pulley also helps make hard work become easy

- Pulling a rope that passes over a single pulley (**A**) lifts a weight (w) a distance (l). The applied force must equal the weight. ($F_A = F_W$)

- If a second pulley is added (**B**), the same force can lift twice the weight the same distance (l). The force must be exerted over twice the distance the weight is lifted. It can also lift the same weight a distance l with half the effort.

- If a pulley system is rigged with four strands of rope (**C**), the same force can lift four times the weight, but the force must be exerted over four times the distance. It can also lift the same weight a distance (l) with a quarter of the effort.

Two types of pulleys

The two different types of pulleys are:

(i) **Fixed pulleys**

They can only change the direction of a force and have a Mechanical Advantage of one.

MA = 1

(ii) **Movable pulleys**

Can multiply an effort force, but cannot change direction. They have a mechanical advantage greater than one. MA > 1

The velocity ratio (V.R.) of a pulley system is determined by counting the number of ropes between the pulleys or by counting the number of pulleys.

The mechanical advantage (M.A.) is equal to the VR provided that friction is negligible.

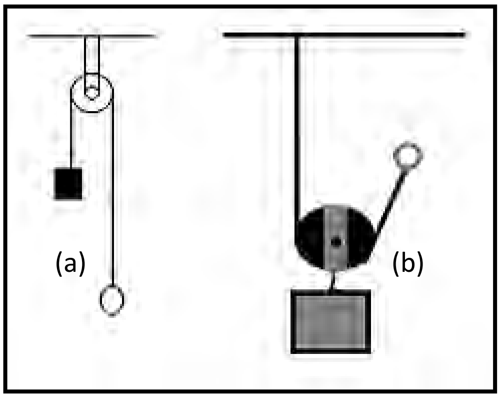


Figure 26 (a) Fixed pulley (b) movable pulley

Figure 27 show that the VR of the pulley system is 4. There are four pulleys and also there are four ropes between the pulleys. Therefore, the VR is 4.

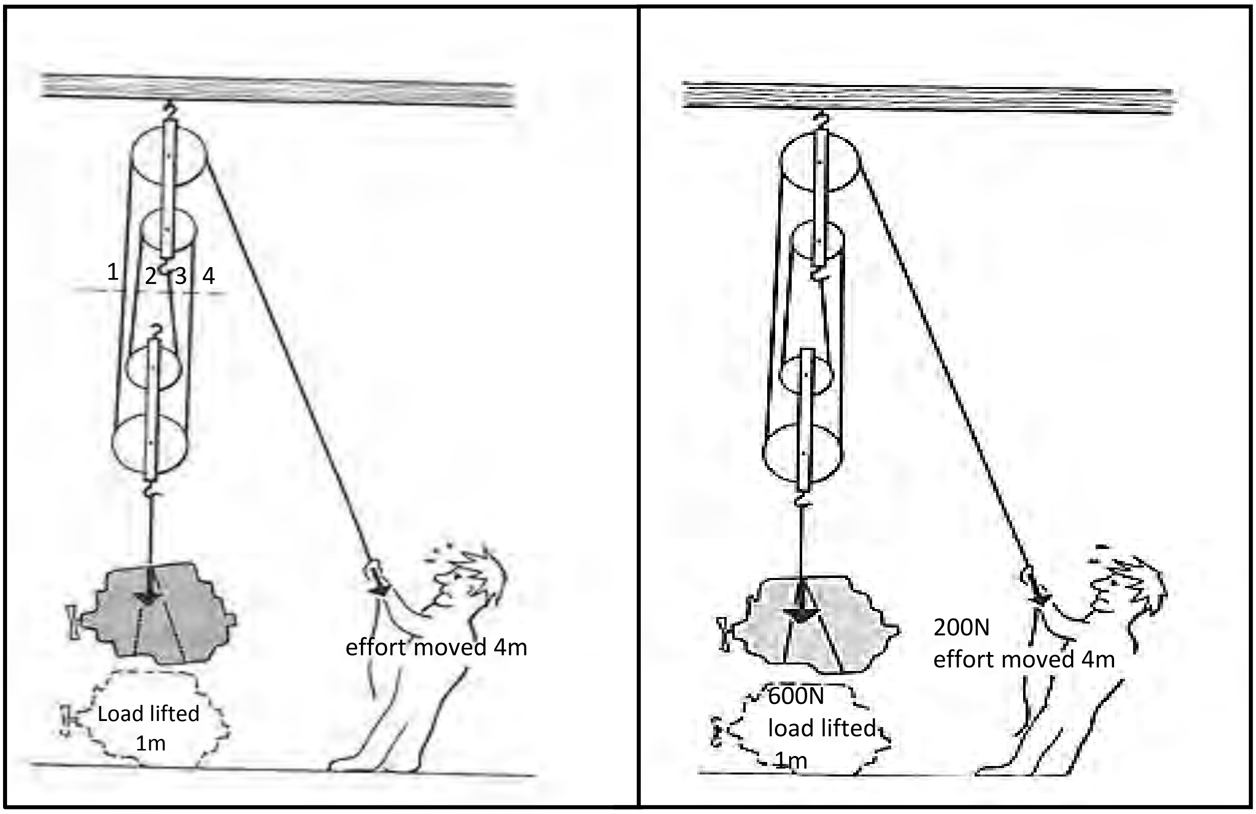


Figure 27a In this system, the effort moves four times as far as the load

Figure 27b The VR is four (4) but the MA is 3

If friction is considered then the MA would not be equal to the VR.

Example 1

In figure 27, the load is 600N and the effort is 200N. The distance moved by the load is 1m while the distance moved by the effort is 4m. Find the M.A. and V.R..

Solution

$$\text{M.A.} = \frac{\text{load}}{\text{effort}} = \frac{600\text{N}}{200\text{N}} = \mathbf{3}$$

$$\text{V.R.} = \frac{\text{distance moved by effort}}{\text{distance moved by load}} = \frac{4\text{m}}{1\text{m}} = \mathbf{4}$$

Example 2
Calculate the work done by the load and effort in figure 27.

Solution

Work done by load

$$\begin{aligned} \text{Work} &= \text{force} \times \text{distance} \\ &= 600\text{N} \times 1\text{m} \\ &= \mathbf{600J} \end{aligned}$$

Work done by effort

$$\begin{aligned} \text{Work} &= \text{force} \times \text{distance} \\ &= 200\text{N} \times 4\text{m} \\ &= \mathbf{800J} \end{aligned}$$

Example 3
Calculate the efficiency for the pulley system in figure 27.

Solution
The efficiency can be calculated with the ratio of the M.A. and V.R. or with the ratio of work done by the load and effort respectively.

i)

$$\begin{aligned} \text{efficiency} &= \frac{\text{mechanical advantage}}{\text{velocity ratio}} \times 100\% \\ &= \frac{3}{4} \times 100\% \\ &= \mathbf{75\%} \end{aligned}$$

ii)

$$\begin{aligned} \text{efficiency} &= \frac{\text{work output (work done by the load)}}{\text{work input (work done by the effort)}} \times 100\% \\ &= \frac{600\text{J}}{800\text{J}} \times 100\% \\ &= \mathbf{75\%} \end{aligned}$$

Therefore, you will still have the same answer if you use any two of the equations based on the given information.

Now check what you have just learnt by trying out the learning activity on the next page!

Learning Activity 7

30 minutes

Read and answer the following questions accordingly in the space provided.

1. Calculate the mechanical advantage (MA) of a wedge whose slope length is 0.6m with a thickness of 0.05m

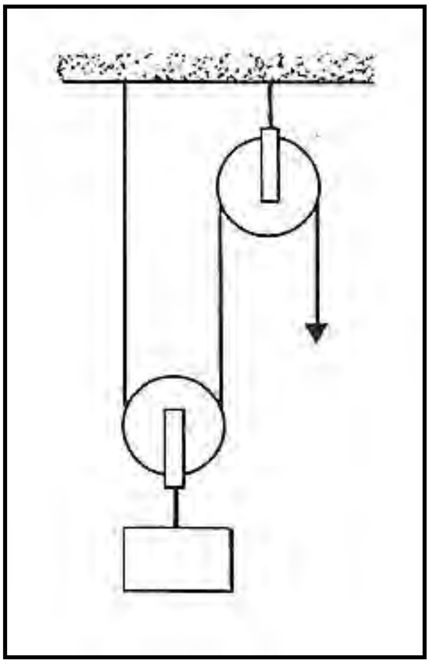
2. Calculate the velocity ratio of a screw whose pitch is 0.5cm with a circumference of 10cm

3. Study the two-pulley system shown in the figure on the right.

   a) What is the velocity ratio (VR) of the pulley system?

   b) Through what distance must the string at P be pulled to lift the mass 0.2m?

   c) If the efficiency of the pulley system is 75%, what is its mechanical advantage?



d) What is the force at P required to lift the 3kg mass slowly?

e) How much work is done on the pulley to lift the 3kg mass 5m?

Thank you for completing learning activity 7. Now check your work. Answers are at the end of the module.

NOW REVISE WELL USING THE MAIN POINTS ON THE NEXT PAGE.

Summary

You will now revise this module before doing **ASSESSMENT 4**.
Here are the main points to help you revise. Refer to the module topics if you need more information.

- Work is defined as the product of the force applied and the distance moved in the direction of the force. The SI unit for work is newton-metre (Nm). The newton-metre is also called the **Joule** (**J**). $W = Fd$
- Force can be applied horizontally, vertically or at an angle to do work. When force is applied at an angle, the following equation is used to calculate work.

$$W = F\cos\theta d$$

- The area under a force – distance graph is equal to work done.
- Work can either be positive or negative depending on the angle between the applied force and displacement.
- Power is defined as the

(i) rate of doing work

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

(ii) rate of energy transfer.

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

(ii) product of force and velocity

$$P = Fv$$

- Power is measures in joules per second (J/s). It is called watts (W).
- The kilowatt-hour (kWh) is a unit of energy used to measure the amount of energy used in houses or industries.

$$E = Pt$$

- Efficiency of an engine is defined as:

$$\text{efficiency} = \frac{\text{work output}}{\text{energy input}} \times 100\% \quad \text{or} \quad \text{efficiency} = \frac{\text{power output}}{\text{power input}} \times 100\%$$

- Energy is defined as the ability or capacity to do work. It is measured in Joules.
- The Law of Conservation of Energy states that energy can neither be created nor destroyed but can only be converted from one form to another or transferred from one body to another. There are different types of energy existing in different forms and combinations.
- The different types of energy includes

i) nuclear energy
ii) thermal (or heat) energy
iii) electrical energy
iv) chemical energy
v) solar energy
vi) mechanical energy

- There are two forms of mechanical energy. They are Potential and kinetic energy. Potential energy is stored energy relative to position and kinetic energy is energy due to motion.
- Gravitational potential energy (GPE) (or most times it is referred to as potential energy) is the energy that an object has due to its position relative to the Earth's surface. It is calculated by:

$$GPE = mgh$$

- An object of mass (m) at a vertical height (h) above the ground has a gravitational potential energy (mgh)
- In every calculation concerning acceleration due to gravity use $10ms^{-2}$ unless otherwise stated. For more accuracy $9.8ms^{-2}$ is used instead.
- Kinetic energy (KE) is the energy of an object due to its motion. This means that any object in motion has kinetic energy. The faster the object moves the more kinetic energy it has. Kinetic energy is therefore dependent on the motion of the object and consequently, the motion of the object depends on its mass and velocity. It is calculated using the formula

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

- It is important to conserve natural energy resources here in PNG because the natural energy resources like crude oil and gas are non-renewable. Also PNG does not have the capacity to build and maintain alternate energy sources like nuclear power station, geothermal energy, tidal energy or large scale windmills.
- A simple machine is a device that does work easily for human beings by increasing our ability to do work. A simple machine can change the size, the direction, or the distance over which a force acts. It basically transmits and modifies forces to lift a heavy load by accomplishing one or more of the following functions:

  i) transferring a force from one place to another,
  ii) changing the direction of a force,
  iii) increasing the magnitude of a force, or
  iv) increasing the distance or speed of a force.

- There are six (6) types of simple machines. They are levers, ramps (or inclined planes), wheel and axles, screws, wedges and pulleys.
- Mechanical advantage (MA) is the force-amplifying effectiveness of a simple machine. It defines the efficiency of a machine. A machine will have a high mechanical advantage if the load lifted is large compared to the effort. It is calculated as:

$$MA = \frac{load}{effort}$$

- Velocity ratio (VR) defines the motion-amplifying effectiveness of a simple machine. It compares the distance moved by the effort with the distance moved by the load. It is calculated as:

$$VR = \frac{\text{distance moved by effort}}{\text{distance moved by load}} \qquad VR = \frac{\text{distance of effort from pivot}}{\text{distance of load from pivot}}$$

- A machine with a high mechanical advantage also has a high velocity ratio. If the value of the mechanical advantage is equal to the value of the velocity ratio then this is true for any machine with an efficiency of 100%.
- The efficiency of a machine is calculated by:

$$\text{Efficiency} = \frac{\text{mechanical advantage (M.A.)}}{\text{velocity ratio (V.R.)}} \times 100\%$$

- A lever is a bar that is free to spin around, or move about a fixed point when an input force is applied. The point at which the lever starts to spin is called the **pivotal point** of a lever and is commonly known as the **fulcrum**.
- There are three classes of levers. They are the First class levers, Second class levers and Third class levers.
- A ramp is also known as an **inclined plane**. It is a simple machine that allows a load to be lifted by using an effort that is less than that of the load.

$$\text{VR of ramp} = \frac{\text{distance moved by effort}}{\text{vertical distance moved by load}} \text{ or } \frac{\text{length of ramp}}{\text{height of ramp}}$$

- The mechanical advantage (MA) of the ramp is equal to its Velocity ratio (VR) if friction is negligible
- Wheel and axles are usually circular objects, often a big wheel and a smaller axle; rigidly secured to one another. When one is turned the other must turn. In this simple machine you are making work easier by trading force for distance. The force is decreased when transferred from the axle to the wheel, and magnified when transferred from the wheel to the axle.

$$MA = \frac{D_w}{D_a} = \frac{r_w}{r_a}$$

- Gears do for couples what levers do for forces. They magnify or reduce their size.

$$VR = \frac{\text{number of teeth on big wheel}}{\text{number of teeth on small wheel}}$$

- A screw is an inclined plane wound around a central cylinder. They have continuous spiralling ridges called threads. Threads are equally spaced and the distance between each ridge is called the pitch of the screw. On turn of the handle on a screw, results in the motion of the screw equal to the distance of one pitch.

$$VR = \frac{\text{circumference of the face of screw}}{\text{pitch of screw}}$$

- Wedge is a V-shaped object whose sides are two inclined planes sloped toward each other. They are moving inclined planes that are driven under loads to lift or into a load to split or separate.

$$MA = \frac{\text{slope length(S)}}{\text{thickness of big end(T)}}$$

- A pulley is a wheel that carries a rope, string or chain on its rim. Pulling on one end of the rope allows the force to be transmitted resulting in the rise of a load to a certain height.

$$MA = \frac{\text{load}}{\text{effort}}$$

$$VR = \frac{\text{distance moved by effort}}{\text{distance moved by load}}$$

We hope you have enjoyed studying this module. We encourage you to revise well and complete assessment 4.

NOW YOU MUST COMPLETE ASSESSMENT TASK 4 AND RETURN IT TO THE PROVINCIAL CENTRE CO-ORDINATOR.

Answers to Learning Activities 1 - 7

Learning Activity 1

1. $$\begin{aligned} W &= Fd \\ &= 30N \times 3m \\ &= 90J \end{aligned}$$

2. $$\begin{aligned} W &= mgh \\ &= 20kg \times 10ms^{-1} \times 2m \\ &= 400J \end{aligned}$$

3. $$\begin{aligned} W &= Fd \\ &= 4000N \times 0.5m \\ &= 2000J \end{aligned}$$

4. $$\begin{aligned} W &= mgh \\ &= 100kg \times 10ms^{-1} \times 3m \\ &= 3000J \end{aligned}$$

5. $$\begin{aligned} W &= Fd \\ &= 47N \times 0.26m \\ &= 12.22J \end{aligned}$$

6. $$\begin{aligned} W &= Fd \\ &= (47 - 23)N \times 0.25m \\ &= 6J \end{aligned}$$

7. $$\begin{aligned} W &= mgh \\ &= 20kg \times 10ms^{-1} \times 6.5m \\ &= 1300J \end{aligned}$$

8. $$\begin{aligned} W &= \text{area of triangle} + \text{area of rectangle} \\ &= (\frac{1}{2} \times 100N \times 60m) + (100N \times 100m) \\ &= 3000J + 10000J \\ &= 13000J \end{aligned}$$

9. No work is done there was no movement.

10. $W = Fd$

$= Fvt$

$= 40N \times 0.8ms^{-1} \times 1800s$

$= 57600J$

Learning Activity 2

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

$= \frac{2000N \times 10m}{50s}$

$= 400W$

2. $P = Fv$

$= (mg - friction)v$

$= (300kg \times 10ms^{-2} - 1200N) \times 0.2ms^{-1}$

$= 360W$

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

$= \frac{1.5 \times 10^5 J}{500W}$

$= 300s$

4. a) $W = Fd$

$= Fvt$

$= 5N \times 2.5ms^{-1} \times 25s$

$= 312.5J$

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

$= \frac{312.5J}{25s}$

$= 12.5W$

5. $E = Pt$

$= 60W \times 24h \times 60$

$= 8.64kWh$

6. a) $t = \frac{E}{P}$

$= \frac{20kWh}{10kW}$

$= 2 hours$

b) $d = st$

$= 20kmh^{-1} \times 2h$

$= 40km$

7. a) $W = Pt$

$= 3000W \times 20s$

$= 60000J$

b) $energy input = \frac{100\% \times work output}{efficiency}$

$= \frac{100\% \times 60000J}{30\%}$

$= 200\,000J$

c) $power input = \frac{100\% \times power output}{efficiency}$

$= \frac{100\% \times 3000W}{30\%}$

$= 10000W$

Learning Activity 3

1. $E = mgh$

$= 5kg \times 10ms^{-2} \times 15m$

$= 750J$

2. $E = mgh$

$= 50kg \times 10ms^{-2} \times 50m$

$= 750J$

3. $m = \frac{E}{gh}$

$= \frac{50J}{10ms^{-2} \times 10m}$

$= 0.5kg$

4. $E = mgh$

$= 3kg \times 10ms^{-2} \times 0.45m$

$= 13.5J$

Learning Activity 4

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

$= \frac{1}{2} \times 0.45kg \times (20ms^{-1})^2$

$= 9J$

b) $K = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 0.45kg \times (40ms^{-1})^2$

$= 36J$

c) $K = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 0.45kg \times (60ms^{-1})^2$

$= 81J$

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

$= \frac{1}{2} \times 50kg \times (5ms^{-1})^2$

$= 625J$

b) $K = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 50kg \times (10ms^{-1})^2$

$= 2500J$

c) $W = \text{change in KE}$

$= 2500J - 625J$

$= 1875J$

3. a) $E = mgh$

$= 5kg \times 10ms^{-2} \times 3m$

$= 150J$

b) $K = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 5kg \times \left(15ms^{-1}\right)^2$

$= 562.5J$

c) $\text{Total energy} = PE + KE$

$= 150J + 562.5J$

$= 712.5J$

d) $\text{Total energy} = PE + KE$

$= 150J + 562.5J$

$= 712.5J$

e) $E = mgh$

$= 5kg \times 10ms^{-2} \times 8m$

$= 400J$

f) $KE = \text{Total energy} - PE$

$= 712.5J - 400J$

$= 312.5J$

g) 712.J

Learning Activity 5

1. a) $GPE = mgh$

$= 61.2kg \times 10ms^{-2} \times 2.5m$

$= 1530J$

b) $GPE = mgh$

$= 61.2kg \times 10ms^{-2} \times (4 \times 2.5m)$

$= 6120J$

c) $GPE = mgh$

$= 61.2kg \times 10ms^{-2} \times (9 \times 2.5m)$

$= 13770J$

2. a) $$\begin{aligned} GPE &= mgh \\ &= 0.3kg \times 10ms^{-2} \times 0.5m \\ &= 1.5J \end{aligned}$$

$$\begin{aligned} KE &= \Delta GPE \\ &= mgh - mgh \\ &= (0.3kg \times 10ms^{-2} \times 1.5m) - (0.3kg \times 10ms^{-2} \times 0.5m) \\ &= 3J \end{aligned}$$

b) $$\begin{aligned} GPE &= mgh \\ &= 0.3kg \times 10ms^{-2} \times 1.5m \\ &= 4.5J \end{aligned}$$

$$KE = 0J$$

c) $$\begin{aligned} GPE &= mgh \\ &= 0.3kg \times 10ms^{-2} \times 1m \\ &= 3J \end{aligned}$$

$$\begin{aligned} KE &= \Delta GPE \\ &= mgh - mgh \\ &= (0.3kg \times 10ms^{-2} \times 1.5m) - (0.3kg \times 10ms^{-2} \times 1m) \\ &= 1.5J \end{aligned}$$

3. $$\begin{aligned} GPE &= mgh \\ &= 2kg \times 10ms^{-2} \times (3m - 0.8m) \\ &= 44J \end{aligned}$$

$$\begin{aligned} KE &= \Delta GPE \\ &= mgh - mgh \\ &= (2kg \times 10ms^{-2} \times 3m) - (0.3kg \times 10ms^{-2} \times 2.2m) \\ &= 16J \end{aligned}$$

4. It is necessary because crude oil and gas are non-renewable resources and if they run out, PNG do not have the capacity to build and maintain other alternate energy sources.

Learning Activity 6

1. $$\text{M.A.} = \frac{\text{input arm}}{\text{output arm}}$$
$$= \frac{4}{0.8}$$
$$= 5$$

2. $$\text{M.A.} = \frac{\text{input arm}}{\text{output arm}}$$
$$= \frac{3}{2}$$
$$= 1.5$$

3. $$\text{M.A.} = \frac{\text{input arm}}{\text{output arm}}$$
$$= \frac{0.4}{0.1}$$
$$= 4$$

4. $$\text{V.R.} = \frac{\text{length of ramp}}{\text{height of ramp}}$$
$$= \frac{5}{0.75}$$
$$= 6.7$$

5. a) $$\text{length of ramp} = \text{V.R.} \times \text{height of ramp}$$
$$= 8 \times 1.5\text{m}$$
$$= 12\text{m}$$

b) $$\sin\theta = \frac{12\text{m}}{1.5\text{m}}$$
$$= 0.125$$
$$= \sin^{-1}(0.125)$$
$$= 7.18^{\circ}$$

6. $$\text{M.A.} = \frac{D_w}{D_a}$$
$$= \frac{0.3\text{m}}{0.2\text{m}}$$
$$= 1.5$$

7. $$\begin{aligned} M.A. &= \frac{\text{teeth on big wheel}}{\text{teeth on small wheel}} \\ &= \frac{26}{14} \\ &= 1.9 \end{aligned}$$

Learning Activity 7

1. $$\begin{aligned} M.A. &= \frac{\text{slope}}{\text{thickness}} \\ &= \frac{0.6\text{m}}{0.05\text{m}} \\ &= 12 \end{aligned}$$

2. $$\begin{aligned} V.R. &= \frac{\text{circumference}}{\text{pitch}} \\ &= \frac{10\text{cm}}{0.5\text{cm}} \\ &= 20 \end{aligned}$$

3. a) $V.R. = 2$

b) $$\begin{aligned} d_{effort} &= V.R. \times d_{load} \\ &= 2 \times 0.2\text{m} \\ &= 0.4\text{m} \end{aligned}$$

c) $$\begin{aligned} M.A. &= \text{efficiency} \times V.R. \\ &= 0.75 \times 2 \\ &= 1.5 \end{aligned}$$

d) $$\begin{aligned} \text{Effort} &= \frac{\text{load}}{M.A.} \\ &= \frac{30\text{N}}{1.5} \\ &= 20\text{N} \end{aligned}$$

e) $$\begin{aligned} W &= F_{effort} \times d_{effort} \\ &= F_{effort} \times V.R. \times d_{load} \\ &= 20\text{N} \times 2 \times 10\text{m} \\ &= 200\text{J} \end{aligned}$$

If you have queries regarding the answers, then please visit your nearest FODE Provincial Centre and ask a distance tutor to assist you.

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FODE PROVINCIAL CENTRES CONTACTS

PC NO.	FODE PROVINCIAL CENTRE	ADDRESS	PHONE/FAX	CUG PHONES	CONTACT PERSON		CUG PHONE
1	DARU	P. O. Box 68, Daru	6459033	72228146	The Coordinator	Senior Clerk	72229047
2	KEREMA	P. O. Box 86, Kerema	6481303	72228124	The Coordinator	Senior Clerk	72229049
3	CENTRAL	C/- FODE HQ	3419228	72228110	The Coordinator	Senior Clerk	72229050
4	ALOTAU	P. O. Box 822, Alotau	6411343 / 6419195	72228130	The Coordinator	Senior Clerk	72229051
5	POPONDETTA	P. O. Box 71, Popondetta	6297160 / 6297678	72228138	The Coordinator	Senior Clerk	72229052
6	MENDI	P. O. Box 237, Mendi	5491264 / 72895095	72228142	The Coordinator	Senior Clerk	72229053
7	GOROKA	P. O. Box 990, Goroka	5322085 / 5322321	72228116	The Coordinator	Senior Clerk	72229054
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10	VANIMO	P. O. Box 38, Vanimo	4571175 / 4571438	72228140	The Coordinator	Senior Clerk	72229060
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13	LAE	P. O. Box 4969, Lae	4725508 / 4721162	72228132	The Coordinator	Senior Clerk	72229064
14	KIMBE	P. O. Box 328, Kimbe	9835110	72228150	The Coordinator	Senior Clerk	72229065
15	RABAUL	P. O. Box 83, Kokopo	9400314	72228118	The Coordinator	Senior Clerk	72229067
16	KAVIENG	P. O. Box 284, Kavieng	9842183	72228136	The Coordinator	Senior Clerk	72229069
17	BUKA	P. O. Box 154, Buka	9739838	72228108	The Coordinator	Senior Clerk	72229073
18	MANUS	P. O. Box 41, Lorengau	9709251	72228128	The Coordinator	Senior Clerk	72229080
19	NCD	C/- FODE HQ	3230299 Ext 26	72228134	The Coordinator	Senior Clerk	72229081
20	WABAG	P. O. Box 259, Wabag	5471114	72228120	The Coordinator	Senior Clerk	72229082
21	HELA	P. O. Box 63, Tari	73197115	72228141	The Coordinator	Senior Clerk	72229083
22	JIWAKA	c/- FODE Hagen		72228143	The Coordinator	Senior Clerk	72229085

FODE SUBJECTS AND COURSE PROGRAMMES

GRADE LEVELS	SUBJECTS/COURSES
Grades 7 and 8	1. English
	2. Mathematics
	3. Personal Development
	4. Social Science
	5. Science
	6. Making a Living
Grades 9 and 10	1. English
	2. Mathematics
	3. Personal Development
	4. Science
	5. Social Science
	6. Business Studies
	7. Design and Technology- Computing
Grades 11 and 12	1. English – Applied English/Language& Literature
	2. Mathematics - Mathematics A / Mathematics B
	3. Science – Biology/Chemistry/Physics
	4. Social Science – History/Geography/Economics
	5. Personal Development
	6. Business Studies
	7. Information & Communication Technology

REMEMBER:

- For Grades 7 and 8, you are required to do all six (6) subjects.
- For Grades 9 and 10, you must complete five (5) subjects and one (1) optional to be certified. Business Studies and Design & Technology – Computing are optional.
- For Grades 11 and 12, you are required to complete seven (7) out of thirteen (13) subjects to be certified.

Your Provincial Coordinator or Supervisor will give you more information regarding each subject and course.

GRADES 11 & 12 COURSE PROGRAMMES

No	Science	Humanities	Business
1	Applied English	Language & Literature	Language & Literature/Applied English
2	Mathematics A/B	Mathematics A/B	Mathematics A/B
3	Personal Development	Personal Development	Personal Development
4	Biology	Biology/Physics/Chemistry	Biology/Physics/Chemistry
5	Chemistry/ Physics	Geography	Economics/Geography/History
6	Geography/History/Economics	History / Economics	Business Studies
7	ICT	ICT	ICT

Notes: You must seek advice from your Provincial Coordinator regarding the recommended courses in each stream. Options should be discussed carefully before choosing the stream when enrolling into Grade 11. FODE will certify for the successful completion of seven subjects in Grade 12.

CERTIFICATE IN MATRICULATION STUDIES		
No	**Compulsory Courses**	**Optional Courses**
1	English 1	**Science Stream:** Biology, Chemistry, Physics
2	English 2	**Social Science Stream:** Geography, Intro to Economics and Asia and the Modern World
3	Mathematics 1	
4	Mathematics 2	
5	History of Science & Technology	

REMEMBER:
You must successfully complete 8 courses: 5 compulsory and 3 optional.