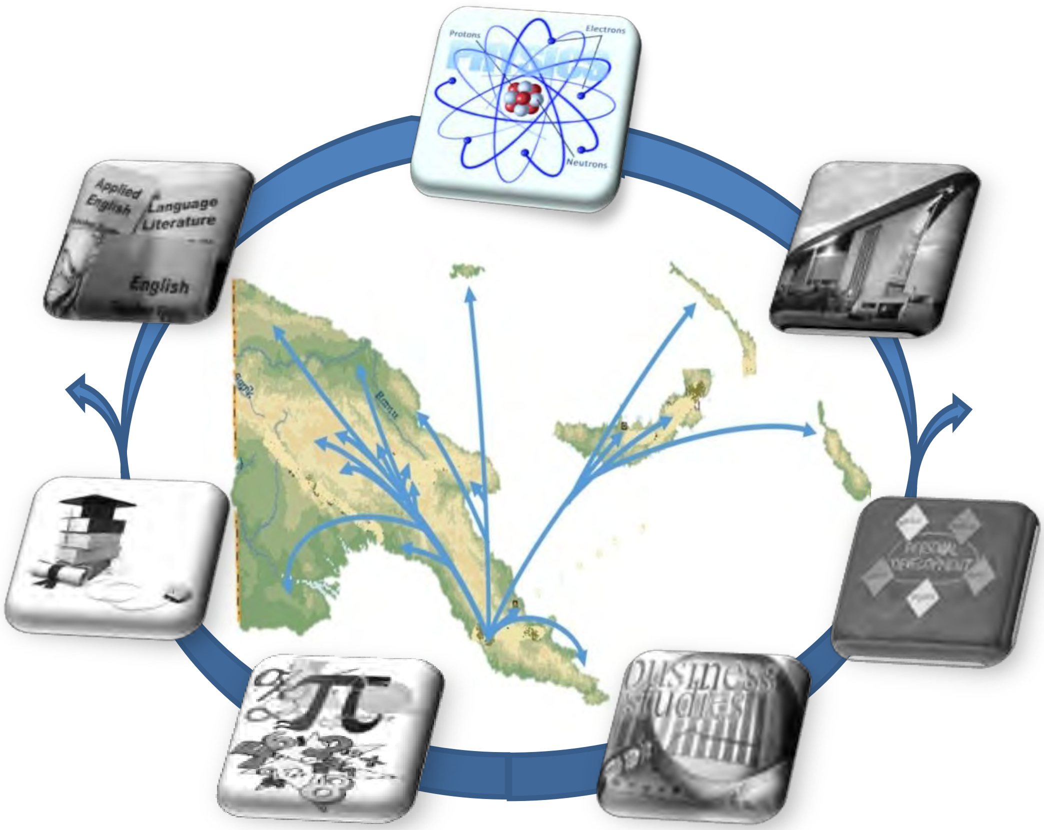
DEPARTMENT OF EDUCATION

GRADE 11

PHYSICS

MODULE 3



FORCE AND MOTION (DYNAMICS)

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 3

FORCE AND MOTION (DYNAMICS)

IN THIS MODULE YOU WILL LEARN ABOUT:

11.3.1: FORCE

11.3.2: NEWTON'S LAWS OF MOTION

11.3.3: MOMENTUM AND IMPULSE

11.3.4: APPLICATIONS OF NEWTON'S LAWS

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 978-9980-89-543-1
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 11.3 Force and Motion (Dynamics)

Introduction

In the previous module on Kinematics, we looked at motion in a straight line without considering what causes it. We will now be looking at the question of why an object initially at rest starts to move, accelerate, decelerate or move around in a circle.

For instance, a game of tug-of-war is the ultimate test of strength between two groups of people. It is also a good example of how forces work in nature. A game of tug-of-war between evenly matched teams often ends up in a stalemate where no one moves. What is the Physics behind a tug-of-war game and its winners and losers? The answers to these and some other similar questions lies in the subject of dynamics, the study of motion and the forces that cause it.

This module will help you to understand what makes an object move the way it does. We will discuss the kinematic quantities displacement, velocity and acceleration along with two new concepts force and mass. The topics will help you to learn motion that involves a change in position at a certain time.

There are four topics in this module. These are Force, Newton's Laws of Motion, Momentum and Impulse and Applications of Newton's Laws. As we go through each topic, you will answer questions in the Learning Activities to help you recall some important concepts and theories. The solutions to all these activities are at the end of the module. Try to answer all the questions on your own without looking at the solutions.

A game of tug-of-war is the ultimate test of strength between two groups of people.

Learning Outcomes

After going through this module, you are expected to:

- demonstrate an understanding of fundamental physics principles and models.
- apply scientific inquiry and reasoning skills to find solutions to problems.
- communicate scientific information and data from investigations and simple experiments in different ways.
- analyze and interpret data and information.
- analyze and evaluate developments in physics from the past and present and its impacts on people and the environment, and use the information to support and make informed decisions.
- define and identify different types of forces that exist in nature.
- recognize that the friction can aid or retard motion.
- use graphical and algebraic methods to analyze motion with a constant acceleration
- qualitatively relate the acceleration of an object to the force acting on its mass.
- explain how the action of forces changes the way an object moves.
- explain movement in terms of Newton's three laws of motion.
- model the effects of forces using Newton's three laws of motion. .
- apply vector addition, subtraction and resolution into components of observable forces such as weight, friction and normal reaction.
- apply mathematical models to data collected to solve problems and movement and the action of forces.
- apply the law of conservation of momentum to predict the outcome of the collisions between two objects.
- apply Newton's Laws to real life situations like the apparent weightlessness and incline planes.

Time Frame

Suggested allotment time: **10 weeks**

This module should be completed within ten (10) 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 module. If you do not get a particular exercise right in the first attempt, you should not get discouraged but instead, go back and try it again. If you do not get the right answer after several attempts, then you should seek help from your friend or even your tutor.

DO NOT LEAVE ANY QUESTION UNANSWERED.

11.3.1. Force

Forces are everywhere, and we experience them every day in our lives. If there are no forces in our universe, our earth would not be held in its orbit around the Sun. There will be no discovery of electricity. And we would not be able to drive a car or even walk. In fact, we would not exist at all, because all objects need forces to keep their shape.

In our everyday experiences, we usually relate forces with our muscular effort or strength. When a weight-lifter lifts a heavy weight, he or she uses the strength of his or her arms to lift the weight above his or her head by applying a force. Another athlete may throw a heavy metal sphere in a shot-put event, while a hunter pulls hard at his or her bow and arrow to kill a wild pig. In all these cases, a force is being applied.

In simple terms, **force is a pull or a push** on an object. It is a physical quantity that describes the interaction between two bodies.

Forces play a major role in the study of physics because they determine how matter interacts with matter. In this section, we will learn about some types of forces that exist in nature and their properties. We will also look at how these forces interact with each other in different ways to influence the motion of objects.

Types and Properties of Forces

Let us start by recalling a physical quantity. A **physical quantity** is anything that can be measured. It includes, mass, temperature, speed, time, length, force and so on.

When an aeroplane takes off from a run way into the air, we would want to know the nature and type of forces responsible for keeping the plane in the air. Which of the forces influence our lives? What other forces exist? These are some typical questions we have to answer as we go through this section.

Force is a product of mass and acceleration. The SI unit for the magnitude or size of the force is called the Newton, abbreviated (**N**). Thus, **one Newton is the force applied to a mass of one kilogram and an acceleration of one metre per second squared. In symbols, 1N = 1kgms^{-2}**.

A force is a push or pull on an object.

Forces are usually measured using an instrument called a spring balance or a dynamometer.

There are different types of forces. The table below lists some examples of the types of forces.

Types of forces

Name of Force	**Definition**
Gravitational	Is the force of gravity that attracts any object with mass.
Action-reaction	Are forces that always act in pairs. Example, the normal force and the weight.
Surface Tension	Is an attraction between the particles of the same material. Example, water molecules.
Upthrust	The difference between the real weight of an object and apparent weight when fully or partially submerged in a fluid, that is, water or air.
Electrostatic	This is the product of two charges and is inversely proportional to the square of the distance between them.
Friction	A force that tries to oppose the motion of an object
Magnetic	A force that exist in the presence of the magnetic field.

Table 1 Table of definitions for different forces.

To minimize confusion with the terms **mass** (m) and **weight** (W), it is important to know their differences.

Mass is made up of matter. Matter is anything that has mass and occupies space. Every matter is made up of very small particles called atoms or molecules. Mass of an object does not change. It remains the same. The SI unit used to measure mass is the kilogram (kg).

Weight on the other hand is the force of gravity acting on an object towards the centre of the earth. It is measured in the SI unit called Newton (N). For example, if you take a stone of mass 1kg to the moon, the same 1kg mass of the stone will remain on the moon.

However, the same 1kg mass of the stone will weigh less or just one-sixth as it did on the Earth. It is because the Earth is much larger and has a greater force of gravity or what we call the gravitational field strength acting on objects.

Therefore, the weight is a force of gravity acting on the mass of an object. It is given by:

$$\mathbf{W = mg}$$

Where W is its weight (**N**), m is the mass (**kg**) of the object and g is the acceleration (**ms^{-2}**) due to gravity or gravitational field strength (**Nkg^{-1}**)

The size of the gravitational field strength (g) on the Earth is $g = 9.8ms^{-2}$ and on the moon is $g = 1.6ms^{-2}$. For simplicity in calculations, the gravitational field strength on the Earth can be rounded off to $10ms^{-2}$.

A force can move objects, stop them, change their speed or direction. It can also spin objects or change their size or shape.

Some forces require objects coming into contact with each other, so that one body can experience an effect of a force from the one applying it. For example, the force that pushes a soccer ball towards the goal requires the contact of the force in your foot with the ball to get it moving. The friction that tries to slow or stop a box being pushed along a table requires contact between the box and the surface of the table.

Some forces do not require contact. For example, the force of gravity pulls you down even when you are not in contact with the object (Earth). A magnet attracts certain materials without being in contact with them.

With the above discussions, we can classify types of forces into two groups, the contact forces and non-contact forces.

1. **Contact forces are forces that require objects to come into contact with each other so that one object can experience a force from the other object applying it, example friction force.**

2. **Non-contact (field) forces are those forces that do not require objects to come into contact with each other so that one object can experience a force. They act from a distance, example, magnetic force.**

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

Learning Activity 1

20 minutes

Answer the following questions on the spaces provided.

1. What is the difference between:

   a) kinematics and dynamics?

b) mass and weight?

____
____
____
____
____
____

---

2. A stone having a mass of 5kg on Earth was taken to the moon. What is likely to change, the mass or the weight of the stone? Explain your answer.

____
____
____

---

3. Find the weight of an object with a mass 4.7kg on the surface of the:

a) Earth.

b) Moon.

---

4. List two things a force can do.

a) ____

b) ____

---

5. Differentiate between contact and non-contact forces.

____
____
____
____

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

Adding Forces

At any time, two or more forces may be acting on an object. A force always acts in a particular direction. They may have different magnitudes or directions. In such cases, how do we add up the two or more forces acting on the object? You will learn how to do this in the next section.

Scalars and vectors

Scalar quantities are physical quantities that have magnitude or size only, like mass and distance. Vector quantities, however, are physical quantities that have both magnitude and direction, like force and velocity. When we refer to a scalar quantity, we consider only its magnitude, example, an object with a mass of 2kg. However, when we refer to a vector quantity, we consider both its magnitude and direction. For example, we say a car travels at a velocity of $20ms^{-1}$east as seen in figure 1 below.

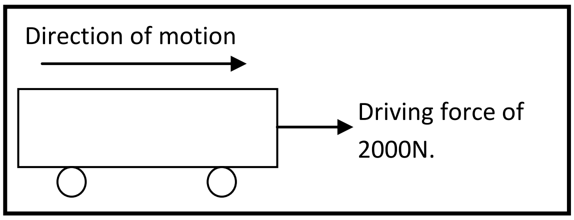


Figure 1 A vector has both size and direction.

A good way to represent a vector quantity is to use a vector diagram. The arrow length represents the magnitude of a vector while the arrow head points the direction of the vector represented by where the arrow head points. For example, to represent a vector with a velocity of 20m/s in the easterly direction, the step-by-step procedure is given below.

- Choose an appropriate scale. In this case, we may choose 1cm to represent 5m/s.
- Use a ruler, draw a straight horizontal line.
- The length of the arrow represents the magnitude of the vector. Hence, the length of the arrow would be 4cm.
- The arrow head represents the direction of the vector.

Scalar is a physical quantity that has size or magnitude only, example, volume. Vector is a physical quantity that has size and direction, example, acceleration.

How do we combine vectors?

Scalar quantities are combined by simply adding vectors that are in the same direction and vectors that are in opposite direction. For example, a mass of 100g added to a mass of 200g gives a total mass of 300g. When we add two vectors, we usually think of both the magnitudes and directions of the vectors. When we combine vectors, we are trying to find a single vector that will produce the same effect called the **resultant** vector.

Consider figure 2(a), the two forces of 3N and 4N, pushing a wooden block of mass 2kg on a smooth surface in the same direction cause the block to accelerate at 3.5m/s^2.

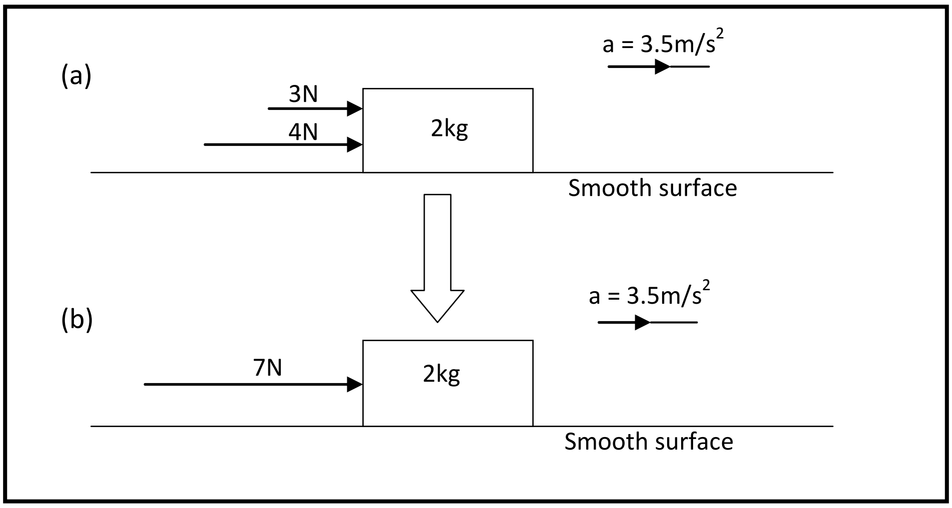


Figure 2 Same acceleration (effect) when a force of 7N replaces the two forces 3 N and 4 N

Figure 2(b) above shows clearly that the two forces are replaced with a single force of 7N, the block will accelerate at 3.5m/s^2.

The effect of pushing the block with 7N is the same as pushing it with 3N and 4N in the same direction, that is, the block accelerates at 3.5m/s^2. In this case, 7N is the resultant force of the combined forces of 3N and 4N.

The resultant force is the result of combining individual forces together.

We will now look at the different methods of adding vectors to find a resultant vector.

Addition and subtraction of parallel vectors

The diagram in figure 3 below will teach us how to obtain a resultant vector by using simple mathematical operations of addition and subtraction.

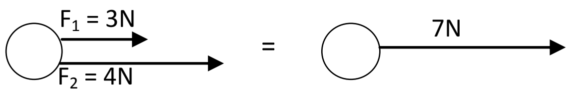
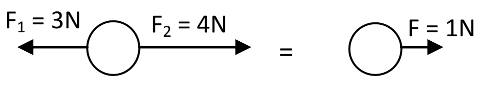
Forces acting in the same direction	Forces acting in the opposite
	
Add the magnitude of the two forces. The resultant force is in the **same direction** as the two forces. Resultant force, $\mathbf{F = F_1 + F_2}$	Subtract the magnitude of the smaller force from the larger one (to find the difference in magnitude between the two forces). The resultant force is in the **direction** of the **larger** force. Resultant force, $\mathbf{F = F_2 - F_1}$

Figure 3 The resultant force is obtained by simple addition and subtraction.

Addition of non-parallel vectors

Simple addition and subtraction cannot be used here to determine the resultant forces when two forces are not parallel to each other. Instead, we can determine the resultant force by drawing scale diagrams using the following three methods.

A. The triangle method (Head-to-tail method)

Figure 4 shows a scaled diagram of the triangle of forces constructed to determine the resultant force of the two forces, F_1 and F_2 acting at an angle θ to each other. First, we will have to choose a scale for the two forces, for example, 1cm : 20kN. Then we will follow the steps to determine the resultant force.

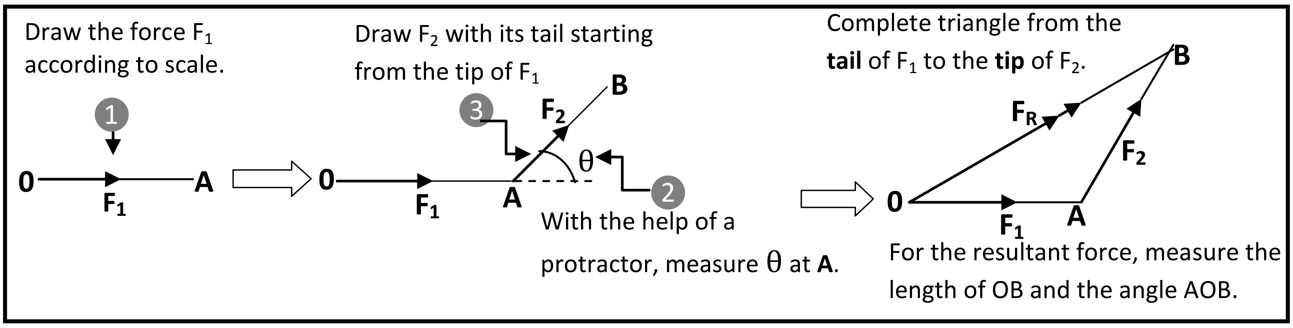


Figure 4 A scaled diagram of the triangle of forces

The resultant force must always be drawn in a straight-line from where the first vector F_1 begin to where the last vector F_2 ends, with a double arrow head at the centre of the line.

B. The parallelogram rule (Parallelogram of forces)

Figure 5 shows a scaled diagram of the parallelogram of forces constructed to determine the resultant force of the two forces, F_1 and F_2 acting at an angle θ to each other. First, we will have to choose a scale for the two forces, for example, 1 cm: 50 N. Then we will follow the steps to determine the resultant force.

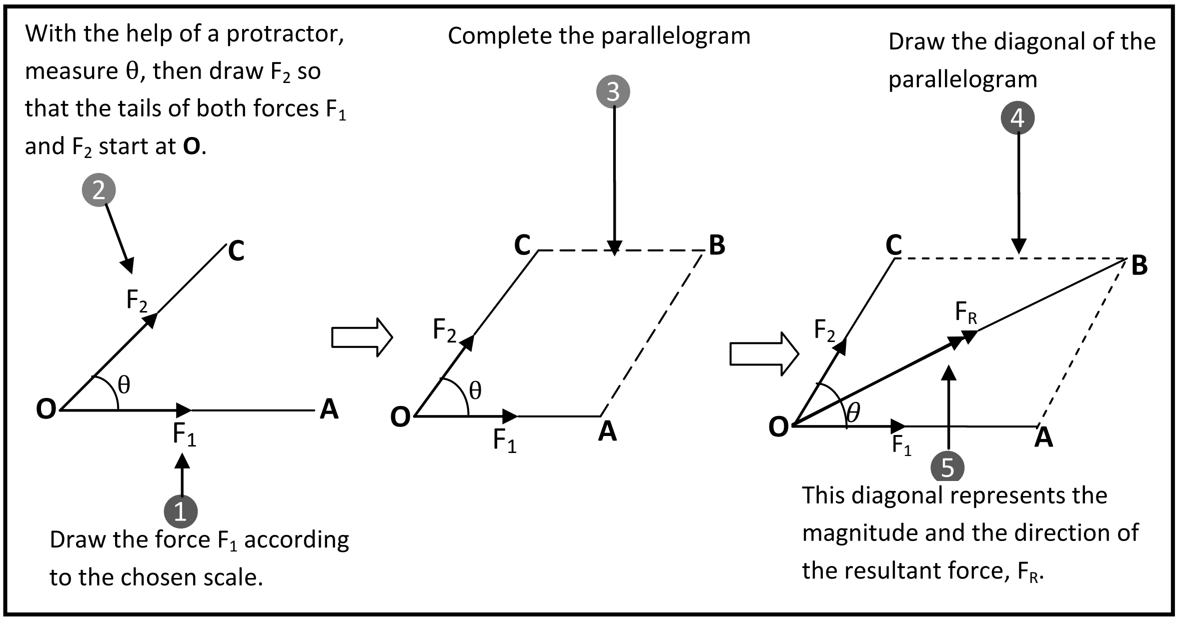
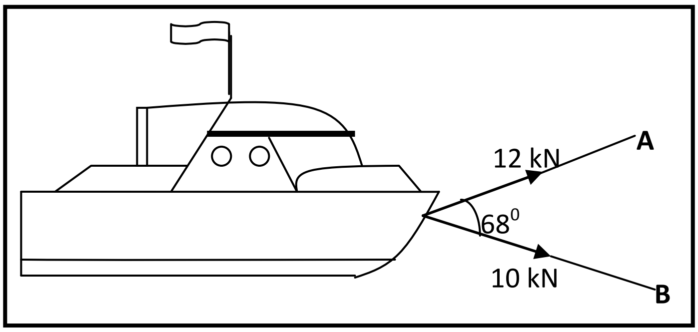


Figure 5 A scaled diagram of the parallelogram of forces

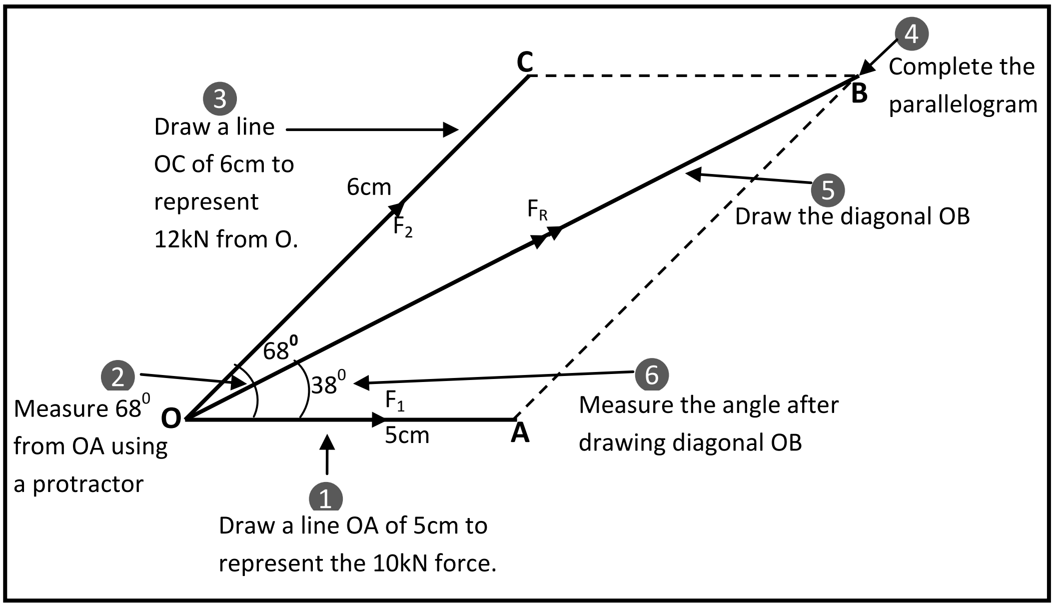
Note that the tails of both forces F_1 and F_2, and the tail of the resultant force, F_R are all at the same point, O and F_R is between F_1 and F_2

Example

A ship is towed into a harbour by two boats, A and B, exerting forces of 12kN and 10kN respectively and the tow-ropes making an angle of 68^0. Find the resultant force acting on the ship.



Solution
Use a scale of 1cm: 2kN (If a scale of 1cm: 1kN is used, the diagram would be too large).



The resultant force, F_R is represented in both magnitude and direction by the diagonal OB. Length OB = 9.2cm. Therefore the magnitude of the resultant force, F_R= 9.2 x 2kN = 18.4kN. The ship is pulled forward by a resultant force of 18.4kN at an angle of 38^0 from the 10kN force.

C. Two perpendicular forces
It is a special case for two non-parallel vectors acting on an object at right angles to each other.

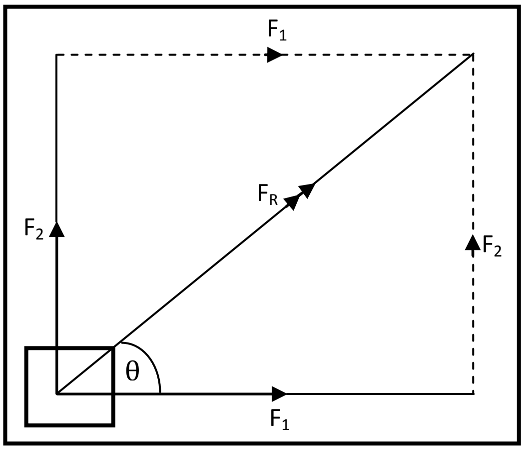


Figure 6 Two forces (F_1 and F_2) together.

Forces acting at right-angles (90^0) to each other can be solved using Pythagoras theorem.

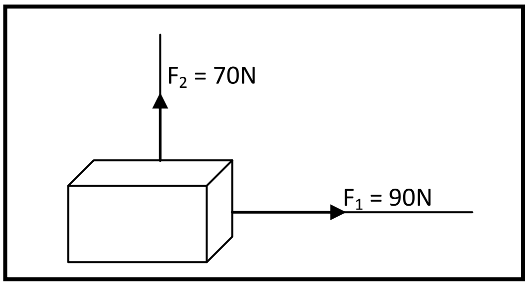
Figure 6 shows the two forces (F_1 and F_2) together with the resultant force F_R using the parallelogram rule.

Unlike the methods in (A) and (B), the resultant force is obtained using Pythagoras Theorem:

- Resultant force $F_R = F_1^2 + F_2^2$
  $F_R = \sqrt{F_1^2 + F_2^2}$

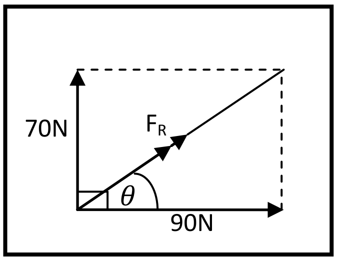
- $\tan\theta = \frac{F_2}{F_1} \rightarrow \theta = \tan^{-1}\left(\frac{F_2}{F_1}\right)$ (Gives the direction of the resultant force)

Example
Tom and Bobby pulled a crate with forces of 70N and 90N respectively.



Find the resultant force on the crate due to these two forces.

Solution
On the right is the sketch of the force.



Therefore resultant force, $F_R = \sqrt{F_1^2 + F_2^2}$

$$= \sqrt{90^2 + 70^2}$$
$$= 114\text{N}$$

$$\tan\theta = \frac{70}{90}$$
$$= 0.778 \rightarrow \theta$$
$$= \tan^{-1}\left(\frac{70}{90}\right)$$
$$= 37.9^0$$

The resultant force is 114N which acts 37.9^0 from the original 90N force.

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

Learning Activity 2

20 minutes

Answer the following questions on the spaces provided.

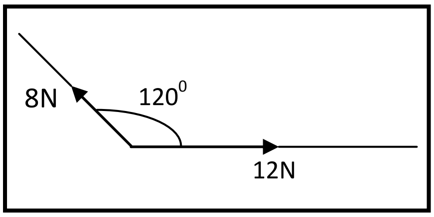
1. Two forces of 60N and 80N acts on an object. Find:

   a) The greatest and the smallest forces that can be exerted if the forces are parallel to each other.

   b) The resultant force if the 80N is acting to the right and is at right angles to the 60N force.

   c) The resultant force if the 80N is acting to the right and is at 120^0 angles to the 60N force.

2. Find the resultant force of the two forces shown in the figure below.



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

Resolution of forces

We have learnt in the previous sections that when two forces combine, a single force can be obtained. This single force is called the **resultant force**. However, if we now reverse the process, the single resultant force can be broken up into its two initial components of forces. This reverse process is known as the **resolution of forces**.

Usually, a force is resolved into components that are at right-angles (perpendicular) to each other. Figure 7(a) shows a single force **F**. If we apply the parallelogram rule, the force **F** can be resolved into a pair of perpendicular components: the vertical force $\mathbf{F_y}$ and the horizontal force $\mathbf{F_x}$.

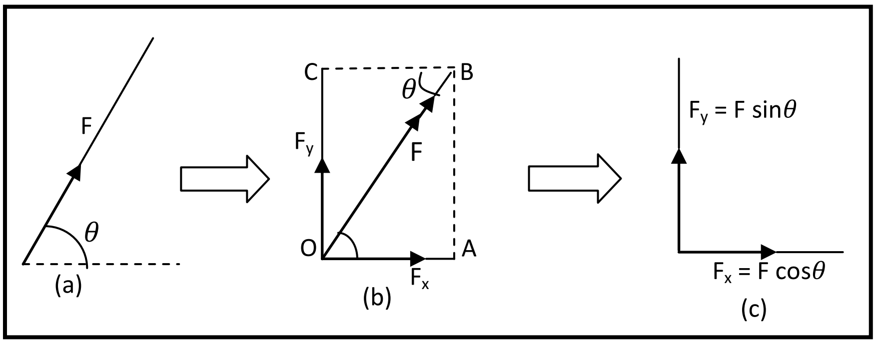


Figure 7 Resolution of a resultant force into its components.

With our knowledge of basic trigonometry, the magnitudes of the vertical and horizontal components can be determined. Since the direction is already known, we need to know the magnitudes only. If we refer to figure 7(b) above we can see that:

For ΔOAB:	For ΔOCB:
$\cos\theta = \dfrac{F_x}{F}$	$\sin\theta = \dfrac{F_y}{F}$
$\therefore F_x = F\cos\theta$	$\therefore F_y = F\sin\theta$

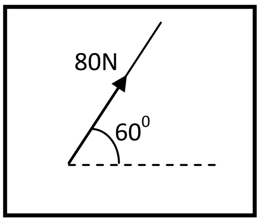
Horizontal component Fx = F cos θ and vertical component$\mathbf{F_y}$ = F sinθ are not fixed formulas. It depends on the position of the angle θ.

Study the example below carefully.

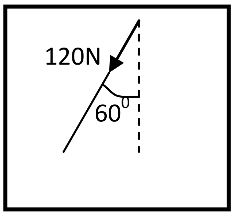
Example

Find the vertical and horizontal components for each of the following forces.

a)

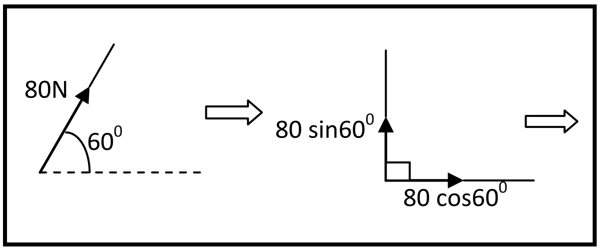


b)



Solution

a)



Here θ is 60^0 from the horizontal line.

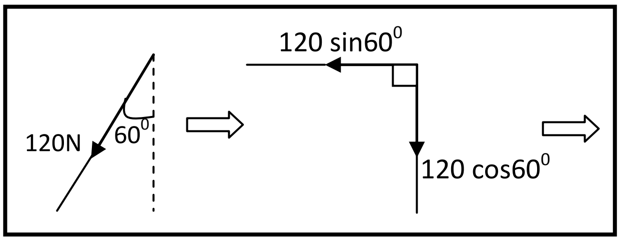
To find the horizontal component:

$F_x = F \cos\theta = 80 \times \cos60^0 = 40N$ right.

To find the vertical component:

$F_y = F \sin\theta = 80 \times \sin60^0 = 69.3N$ up.

b)



Here θ is 60^0 from the vertical line.

To find the horizontal component:

$F_x = F \sin\theta = 120 \times \sin60^0 = 103.9N$ left.

To find vertical component:

$F_y = F \cos\theta = 120 \times \cos60^0 = 60N$ down.

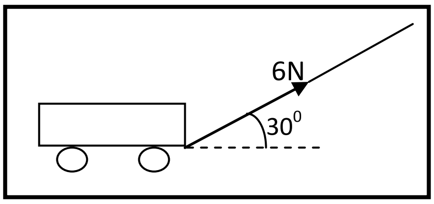
Now check what you have just learnt by trying out the learning activity on the next page!

Learning Activity 3

20 minutes

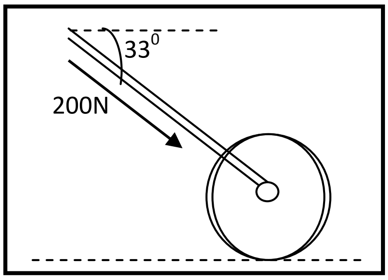
Answer the following questions on the spaces provided.

1. A boy is pulling a toy car with a force of 6N as shown in the figure below.



Find the horizontal and vertical components of the force.

2. Wagi pushes a 250kg roller on the floor with a force of 200N directed from the handle. The handle is at an angle of 33^0 to the horizontal.



a) Find the vertical and horizontal components of the force.

b) What is the weight of the roller?

c) What is the total downward force on the ground?

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

Friction

Whenever one object is pushed or pulled along the surface of another object, there is some resistance to such motion. It is because no two surfaces are perfectly smooth. Hence, the property of the surface that causes this resistance is called **friction**. We can define friction as a force that tries to oppose or resist the motion of an object.

We must take note that friction always acts in parallel to the surfaces that are in contact and in a direction opposite to the motion of the object as shown in figure 8. As we have mentioned earlier, friction depends on the nature of the materials in contact and the smoothness of their surfaces. It does not depend on the area.

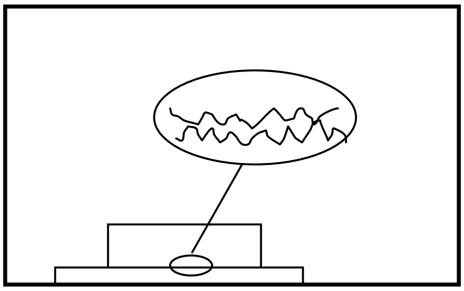


Figure 8 Friction is caused by the interlocking of surface irregularities.

Let us consider a rock moving leftwards over a surface of the road. The resistant force on the rock is upwards as shown in Figure 9(a). It is because the resistant force has two components: The first is the vertical component that is usually called the normal contact or normal reaction force. This component of force is always at right-angles (90°) to the two surfaces in contact. The second is the horizontal component that is the friction force. This force opposes the movement of the rock as shown in figure 9(b).

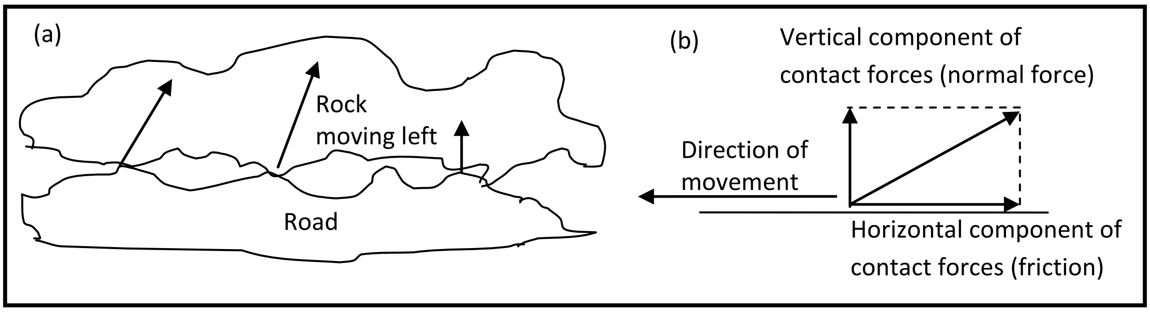


Figure 9 (a) when a rock moves leftwards over a road, the road exerts various upwards forces on the rock. (b) The resultant of these upwards forces is tilted to the right. It has vertical and horizontal components.

We have just seen a situation where a body rests or slides on a surface which exerts forces on the body. We also used the terms normal force and friction forces to describe these forces. These are called **contact forces**. Friction plays a vital role in our everyday life. It has both positive and negative effects. The oil in a car engine reduces friction between moving parts. Also, without friction between the tyres and the road, driving a car would be dangerous. These are positive effects. Friction also reduces the efficiency of cars up to 20% and causes wear and tear of moving parts in engines, motors and machines. These are negative effects.

Consider a box of books on the floor. If you try to push the box across the floor, the box will not move until a certain force is applied. Once the box starts moving, it requires less force than you needed to get it started. If you take some books out, you need less force than before to get it moving or keep it moving. What general statement can we make about this behaviour?

When a body rests or slides on a surface, we can always represent the contact force exerted by the surface on the body in terms of components of forces perpendicular and parallel to the surface. We call the perpendicular component normal force and is denoted by $\mathbf{F_n}$. The component parallel to the surface is the friction force, denoted by $\mathbf{F_r}$. By definition, the F_n and F_r are always perpendicular to each other (i.e. at 90° or at right-angle)

The size and magnitude of the friction force usually increase when the normal force increases. It is because the weight denoted by $\mathbf{F_w}$ of the body acting down and normal force $\mathbf{F_n}$ of the surface acting up are equal and opposite. Therefore, the friction force is proportional to the normal force. In such cases, we can represent the relation by the equation:

$$\text{coefficient of fraction} = \frac{\text{friction force}}{\text{normal contact force}}$$

In symbols:

$$\mu = \frac{F_r}{F_n}$$

Where $\boldsymbol{\mu}$ represent the coefficient of friction, and is unit less. $\mathbf{F_r}$ is the friction force(**N**) and $\mathbf{F_n}$ is the normal force(**N**). You must note that the measures of friction and normal forces are in units of force which is newtons while the coefficient of friction is unit less.
The coefficient of friction for surfaces is found by experiment. The coefficients of all surfaces are usually less than 1.

Friction always opposes motion between two objects in contact.

Friction can be in two parts:

1. Static (non-moving) friction is the frictional force preventing motion until the surfaces begin to slide/move. The above general equation can be written as:

$$\mu_s = \frac{F_s}{F_n}$$

Where $\boldsymbol{\mu_s}$ represents the coefficient of static friction, $\mathbf{F_s}$ is the static friction and $\mathbf{F_n}$ is the normal contact force.

2. Kinetic (moving) friction is the frictional force between objects that are moving across each other. Kinetic friction is usually less than the static friction represented as:

$$\mu_k = \frac{F_k}{F_n}$$

Where μ_k represents the coefficient of kinetic friction, F_k is the kinetic friction and F_n is the normal force.

As we have stated earlier, the size or magnitude of the weight and the normal contact force are equal but opposite in directions. These two forces (weight and normal contact forces) act together and are parallel to each other along the vertical axis(y – axis). On the other hand, the size or magnitude of the frictional force (F_r) and the applied force or tension (T) are equal but opposite in directions. Unlike the weight and the normal force, friction and the tension forces act together along the horizontal axis (x-axis). They also act parallel to each other.

The statements we just made are only true when an object resting on a surface is just about to move in the direction of the applied force. Therefore, we can say that, an object is in a state of equilibrium. This means that the sum of all the forces acting along the vertical and horizontal axes respectively must add up to zero.

We normally represent these mathematically as $\sum F = 0$

Here the sigma notation or the symbol ∑ represents the sum of all variables to be added. More specifically, if we take upwards as positive and downwards as negative along the vertical axis then,

$$\sum_{F_n}^{Fw} F_y. \text{ This means that, } \sum F_y = F_n + (-F_w) = 0$$

Where F_y is the sum of all the forces acting in the vertical axis, F_w is the weight of an object and F_n is the normal contact force.

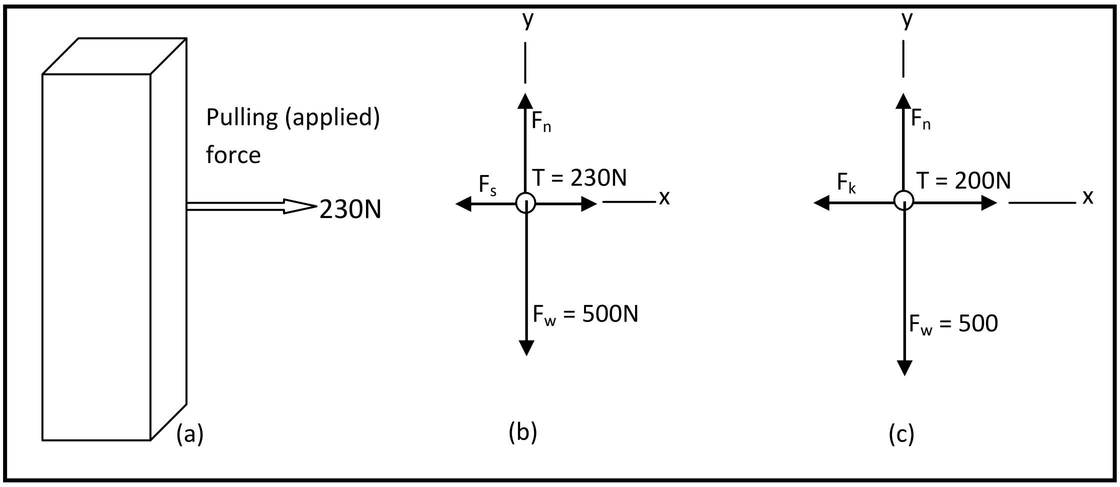
Also, if we take the right as positive and the left as negative along the horizontal axis then:

$$\sum_{T}^{F_r} F_x. \text{ That is, } \sum F_x = T + = (-F_r) = 0$$

Here, F_x is the sum of all the forces acting along the horizontal axis, T is the tension force and F_r is the friction force.

Example 1

A truck has just unloaded a 500N crate full of music equipment on the footpath near your home. A pull with a horizontal force of 230N is needed to move the crate. Once it starts to move, you can keep it moving at a constant velocity with only 200N of force. What are the coefficients of the static and kinetic friction?



Solution

a) Using the equilibrium conditions for the crate before it starts to move as in Figure (b):

$$\begin{aligned}\sum F_y &= F_n + (-F_w)\\ &= F_n + (-500)\\ &= 0\\ F_n &= 500N\end{aligned}$$

$$\begin{aligned}\sum F_x &= T + (-F_s)\\ &= 230 + (-F_s)\\ &= 0\\ F_s &= 230N\end{aligned}$$

Hence, the coefficient of static friction is:

$$\begin{aligned}\mu_s &= \frac{F_s}{F_n}\\ &= \frac{230N}{500N}\\ &= \mathbf{0.46}\end{aligned}$$

b) Using the equilibrium conditions for the crate after it starts to move as in Figure (c):

$$\sum F_y = F_n + (-F_w)$$
$$= F_n + (-500)$$
$$= 0$$
$$F_n = 500N$$

$$\sum F_x = T + (-F_k)$$
$$= 200 + (-F_k)$$
$$= 0$$
$$F_k = 200N$$

Hence, the coefficient of kinetic friction is:

$$\mu_s = \frac{F_k}{F_n}$$
$$= \frac{200N}{500N}$$
$$= \mathbf{0.40}$$

Example 2

a) A wooden crate weighing 240N rests on a horizontal floor. Find the least force to move it if the coefficient of static friction is 0.5.

b) Once the crate is moving, a force of 96N is sufficient to keep the crate sliding at a constant speed. Find the coefficient of kinetic friction.

Solution

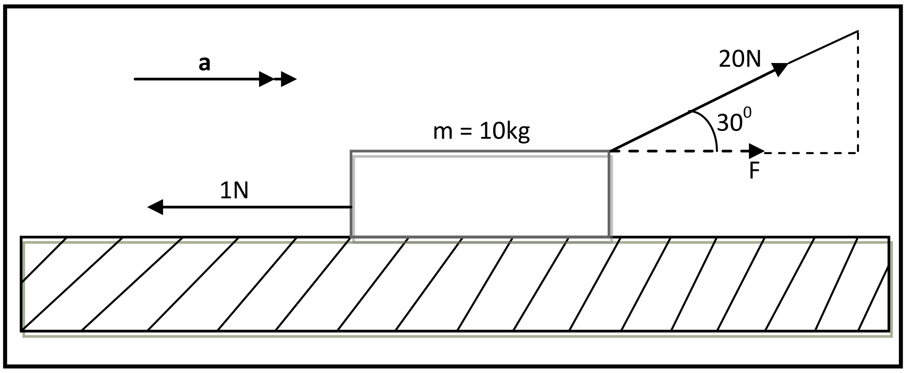
Please recall that the normal force = the weight of the crate:

a)
$$\mu_s = \frac{F_s}{F_n}$$
$$F_s = \mu_s \text{ x } F_n$$
$$= 0.5 \text{ x } 240$$
$$= 120N$$

b)
$$\mu_k = \frac{F_k}{F_n}$$
$$= \frac{96N}{240N}$$
$$= 0.4$$

Example 3

A box of mass 10kg is at rest on a horizontal plane and a force of 20N is applied at 30^0 to the plane as shown in the figure below. If the frictional force amounts to 1N, calculate the acceleration.



Solution

Now we will have to resolve the applied force of 20N into its vertical and horizontal components. It is because the force is acting at an angle as we have discussed earlier. You will notice that, the force that handles the motion of the box is the horizontal component of the initial applied force of 20N. For this case will be $F_x = 20\cos30^0$. Also for the box to move, there must be a net resultant force that will cause an acceleration.

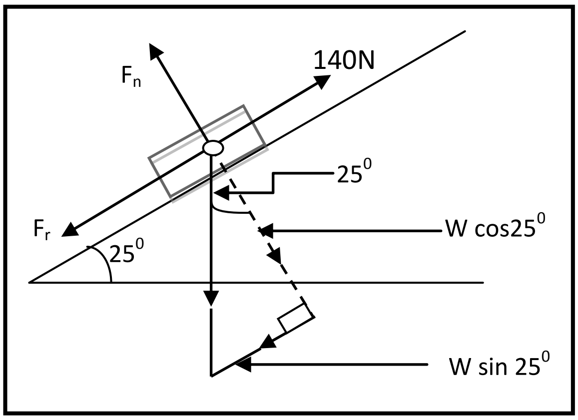
Force causing an acceleration: $F_{net} = (F_x - F_r)$

$$= (20\cos30^0 - 1)N$$
$$= (17.32 - 1)N$$
$$= 16.32N.$$

$$F_{net} = ma$$
$$\therefore a = \frac{F_{net}}{m}$$
$$= \frac{16.32}{10}$$
$$= 1.632 m/s^{-2}$$
$$= 1.6 m/s^{-2}$$

Example 4

A 300N block of ice is being pulled at a constant speed up a steel ramp to a loading truck and requires a force of 140N. The slope inclines at 25^0 to the horizontal. Calculate the coefficient of friction between the ice and the steel.



Solution

According to the state of equilibrium, the upward forces must balance with the downward forces to maintain constant speed. That means the sum of all the forces going up and going down must add to zero. The two forces acting downwards are negative because they are vector quantities and are opposite to the direction of the applied force of 140N.

That is, $\Sigma F = 0 \quad \therefore 140 + (-w \sin 25^0 - F_r) = 0.$

Note: Weight always act vertically down through the centre of an object.

Thus,
$$\begin{aligned} F_r &= 140 - w \sin 25^0 \\ &= 140 - 300 \sin 25^0 \\ &= 140 - 126.78 \\ &= 13.22\text{N} \end{aligned}$$

$$\begin{aligned} \mu &= \frac{F_r}{F_n} \\ &= \frac{F_r}{w \cos 25^0} \\ &= \frac{13.22}{271.9} \\ &= 0.0486 \end{aligned}$$

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

Learning Activity 4

20 minutes

Answer the following questions on the spaces provided.

1. What is friction? What is its unit of measurement?

____

____

____

---

2. Is friction perpendicular or parallel to the motion of an object?

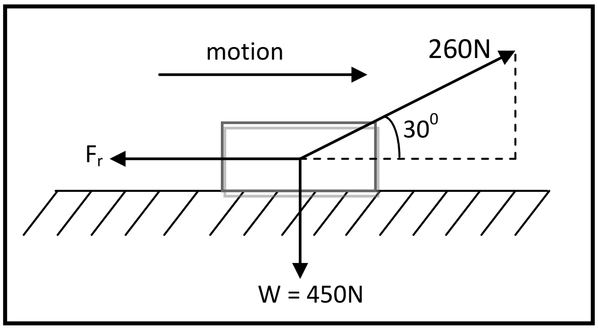
____

____

____

3. A wheelbarrow of mass 24kg at rest on a horizontal floor has a force of 10N applied to it parallel to the floor. If the friction force is 2N, calculate the acceleration of the wheelbarrow.

4. Pulling a box weighing 450N along a level floor at a constant speed by a rope makes an angle of 30^0 with the floor, as shown in the figure below. If the force on the rope is 260N, what is the coefficient of kinetic friction between the surfaces?



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

11.3.2 Newton's Laws of Motion

In our everyday experiences, we may have come across some natural phenomena like earth quakes and shooting stars and massive man-made objects like planes flying in the air. We at times ask questions like why, how and what may have caused these objects to behave the way they do. To answer some of these questions, we can look at Newton's Three Laws of Motion.

Newton's First Law of Motion describes how an object behaves when forces acting on it are balanced or when no forces are acting on it at all. It means that an object can be in constant motion or an object may be at rest. The first law involves the mass and the inertia of an object.
Newton's Second Law of Motion deals with unbalanced forces or sometimes called the net or resultant forces. These unbalanced forces come about as a result of interaction between some physical quantities like force, mass and acceleration that causes a change in the motion of an object.

Finally, Newton's Third Law of Motion talks about action and reaction forces between two bodies. It states that forces never occur individually but always act in pairs.

Newtons First Law of Motion

Newton's First Law of Motion states that, a body at rest or uniform motion will remain at rest or in uniform motion in a straight line.

From Newton's First Law, a body at rest or uniform motion will have zero acceleration.
Does this mean that no force is acting on an object when acceleration is zero? No, there are still forces acting on it but these forces are balanced, that is, they are equal in magnitudes and opposite in directions. This gives us zero acceleration. Therefore, zero acceleration implies that an object could be stationary (Figure 10) or moving with constant velocity (Figure 11).

Figure 10 A car at rest has zero acceleration. It has, however, gravitational pull acting on it.

Figure 11 An ice skater gliding at constant velocity has zero acceleration.

For an object with zero acceleration, the different forces acting on it are balanced or equal to zero, that is, the resultant or net force is zero.

Consider the book in figure 12. The weight of the book acts downwards due to gravity. However, the book does not fall freely (or accelerate) as the table prevents it from doing so. In this case, the table exerts an equal upward force **F** that pushes back on the book, that is, **F** is equal to **W**.

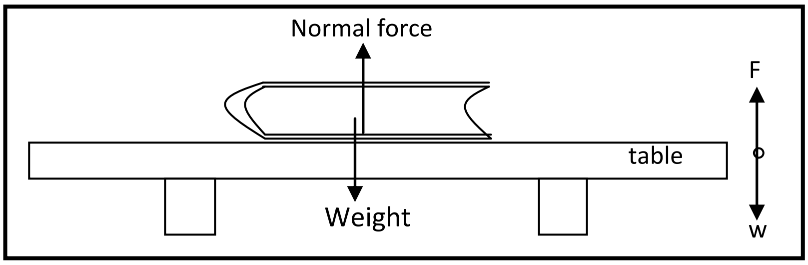


Figure 12 Forces acting show that *F = W.* They act in opposite direction and cancel each other out. We say the forces are balanced.

You will have noticed that these two forces will balance out as they are equal and in opposite directions. Hence, the resultant force is zero and the book is stationary or at rest. Its acceleration is also zero.

What is inertia?

Now, let us consider another example of a book moving at a constant velocity along a frictionless table (Figure 13).

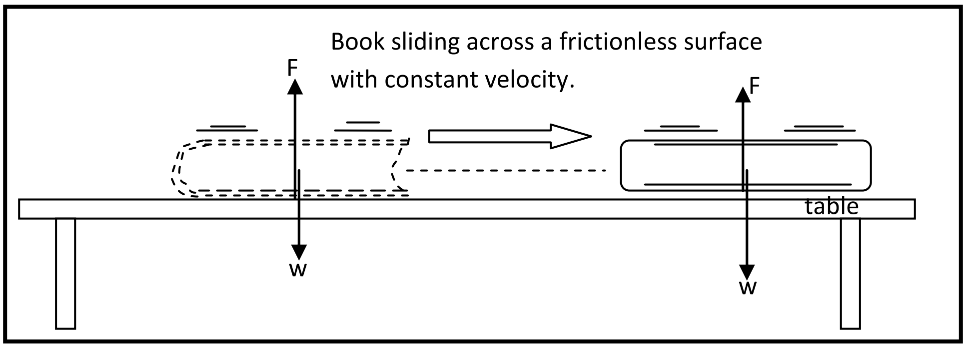


Figure 13 When there is no change in velocity, the acceleration will be zero.

At constant velocity, acceleration is zero. If no other force acts on it to disrupt its motion (e.g. friction), the resultant force on the book will remain zero. Hence, the book will continue to move at this velocity forever.

This brings us to Newton's first Law of Motion also known as the Law of Inertia.

A body will continue to remain at rest or moving with uniform motion in a straight line unless acted upon by an unbalanced force.

We have just learnt how an object behaves if the resultant force acting on it is zero.

Figure 14 summarizes Newton's First Law of Motion.

When forces are balanced

↓

Acceleration = 0m/s

Object in motion will remain in motion at constant velocity.

Object at rest will remain at rest.

Figure 14 Newton's First Law summarized in this simple flow chart.

We stated earlier that Newton's first law is also known as the Law of Inertia. Inertia deals with a physical quantity known as mass. Imagine you are on an open road and suddenly a big elephant comes running straight at you.

Should you run away in a straight line or a zigzag manner to escape from the running elephant?

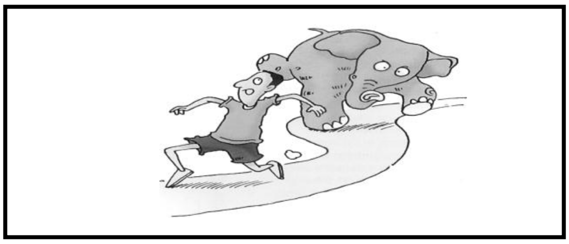


Figure 15 You should run in a zigzag course to escape from an elephant that is running at you.

The answer may look very simple, but what is the reason behind it? To explain it properly, we need to understand inertia and how it is related to mass.

An object that has a huge mass will have a lot of difficulties trying to change its state of rest or motion. This property of an object is known as **inertia**. We can now define inertia as the resistance of an object to change its state of rest or motion.

The inertia of an object is dependent on its mass. Therefore, an object with more mass has greater inertia. In other words, the larger the mass of an object, the harder it is to start moving, or slow down, move faster or change direction.

From this concept it is difficult for an elephant to chase a person in a zigzag manner. Because even if the elephant tries to do that, it will probably trip and fall!

A reason that drivers wear seat belt for safety when driving is because of inertia. Without a seat belt, a driver on applying brakes will continue to move forward due to his inertia and crash into the windscreen (Figure 16). The seatbelt prevents the driver from crashing into the windscreen (Figure 18).

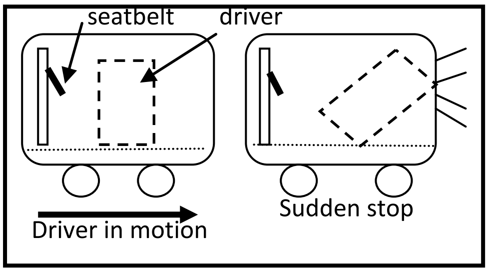


Figure 16 Driver not wearing a seat belt.

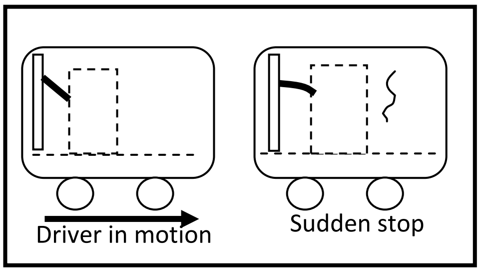


Figure17 Driver wearing a seat belt.

Example 1
Use Newton's First Law of Motion and Inertia to explain the following situation:

A cardboard is placed on the rim of a drinking glass and a coin is placed on top of the cardboard at the centre of the glass. If the cardboard is pulled away quickly, the coin resting on the cardboard drops straight into the glass.

Solution 1
The coin's inertia maintains its state of rest. If the cardboard is pulled away quickly, the coin falls into the glass due to gravity. Note, if the cardboard is pulled away slowly, the frictional force between the coin and the card causes the coin to accelerate so that it moves together with the card. However, quickly pulling the cardboard creates a time too short for the friction to cause any appreciable movement of the coin.

Example 2
A boy riding a bicycle that runs over a stone is thrown forward and off the bicycle.

Solution2
The stone stops the motion of the bicycle but the inertia of the boy move him in the forward motion and throw him forward.

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

Learning Activity 5

20 minutes

Explain the following situations using the Newton First Law and inertia.

1. If a book is pulled out very quickly from the middle of a pile of books, the books at the top will drop instead of moving along with it.

2. When a moving bus stops suddenly, the passengers move forward.

Thank you for completing learning activity 5. Now check your work. Answers are at the end of the module.

Newton's Second Law of Motion

When a body acts on by no force or zero resultant force, it moves with constant velocity. But what happens when the resultant force is not zero? It starts to move. If it is initially moving, the force may speed it up, slow it down or change the direction of its velocity. In each case the body has acceleration. We want to know the relation of the acceleration to the force. This is what Newton's Second Law is all about and it deals with unbalance forces.

In our previous discussions, we learnt that when there is an unbalanced force acting on a body, the body will change its speed. This means that a body can either:

1. Increase its speed or velocity that causes an acceleration or
2. Decrease its speed or velocity to cause deceleration.

This means that, when an unbalanced force acts on an object, it will accelerate in the direction of the applied unbalanced force. The acceleration of any object depends directly on the force applied and indirectly on the mass of the object. Thus, when the size of the unbalanced force increases, the acceleration increases as well.

However, if we keep the force constant and increase the mass of the object, the acceleration will decrease. Newton's Second Law of Motion summarises these facts. It states:

"The acceleration of any object is directly proportional to the unbalanced force applied and inversely proportional to its mass."

We will now analyse two experiments to investigate Newton's second law.

Experiment 1
This shows the relationship between acceleration and force applied on a constant mass.

Situation
Figure 18(a): shows car A and car B of the same mass at the same starting line. Car B is a sports car and it has a much bigger engine capacity than car A. Figure 18(b): shows that car B has built up a higher velocity than car A after 3 seconds.

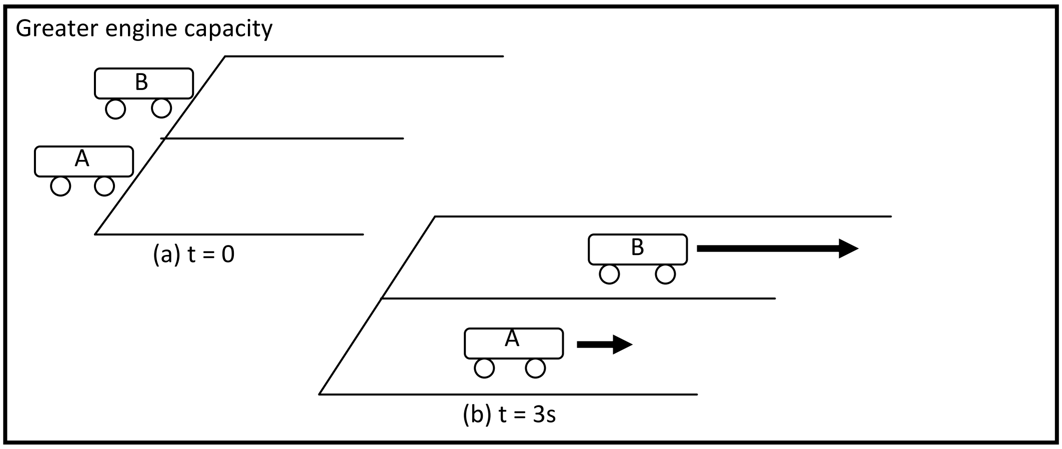


Figure 18 The acceleration of an object depends on the force which acts on it.

Aim
To investigate the relationship between acceleration and the force applied to a constant mass.

Apparatus/ Material
Trolley, three (3) identical elastic chords, runway, ticker-timer, carbonized ticker tape, 12V AC power supply and a wooden block.

Arrangement of apparatus

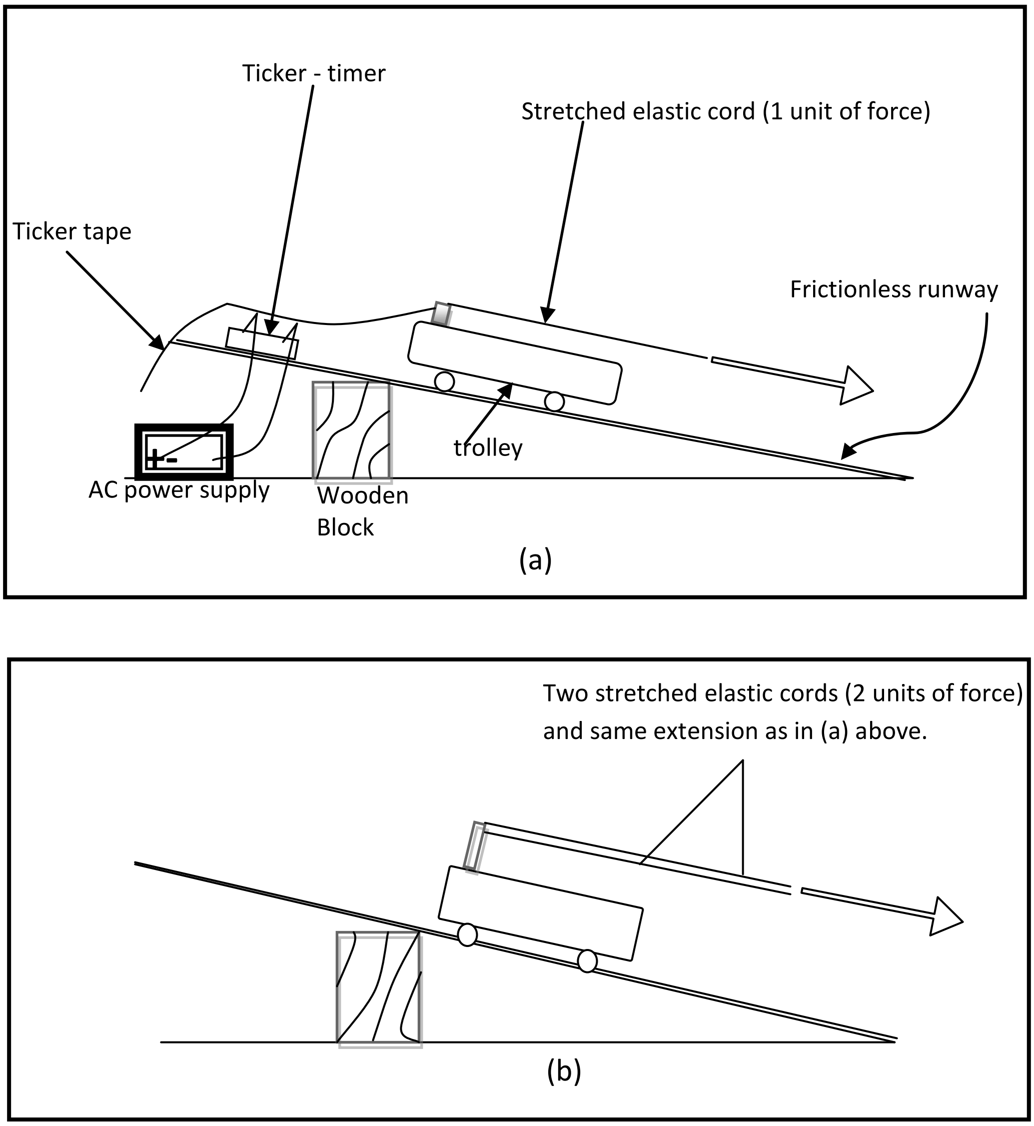


Figure 19 The force in this experiment is the stretching force in an elastic cord used to pull the trolley.

Procedure
1. A frictionless inclined runway is prepared.
2. The apparatus is then set up as shown in figure 20(a).
3. The ticker-timer is switched on and the trolley is pulled down the runway by an elastic cord attached to the hind post of the trolley.

4. The elastic cord is stretched until the other end is level with the front end of the trolley. The length is maintained as the trolley moves down the runway.
5. The ticker tape obtained is cut into strips of 10-ticks. A tape chart is constructed and the acceleration, *a* is determined.
6. The experiment is repeated with 2 and 3 elastic cords to double and triple the pulling force to the same constant extension as when one elastic cord is stretched.

Results

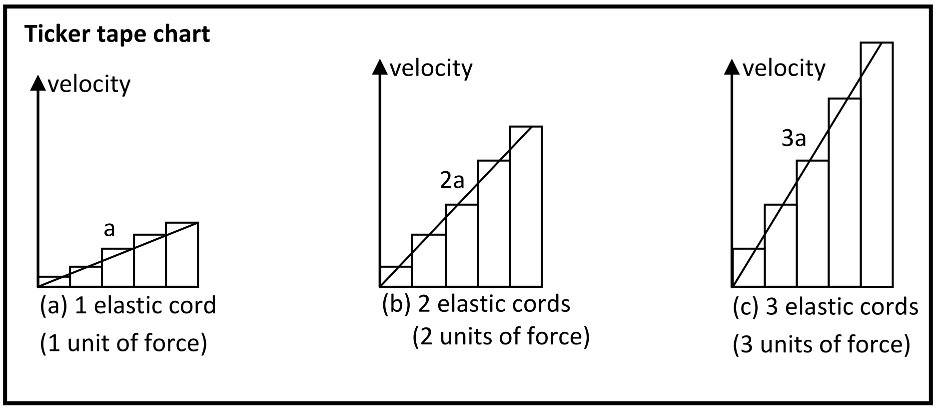


Figure 20 The gradient of each line increases as the number of cords increases. It indicates an increase in acceleration when the force is increased.

Graph

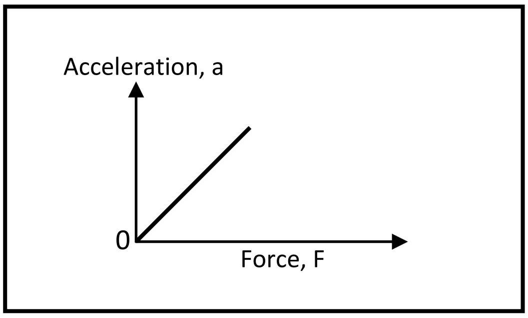


Figure 21 Acceleration is directly proportional to force

Conclusion

The acceleration of an object with constant mass is directly proportional to the force applied.

Experiment 2

This experiment shows the relationship between the acceleration and the mass of an object under constant force.

Situation

Figure 22(a) shows two similar lorries, A and B, in front of a traffic light. When the light turns green, both drivers step on their accelerators simultaneously with the same pressure to provide the same engine thrust, F. Figure 22 (b) shows that within 3 seconds, the empty lorry has built up a higher velocity than the heavier one.

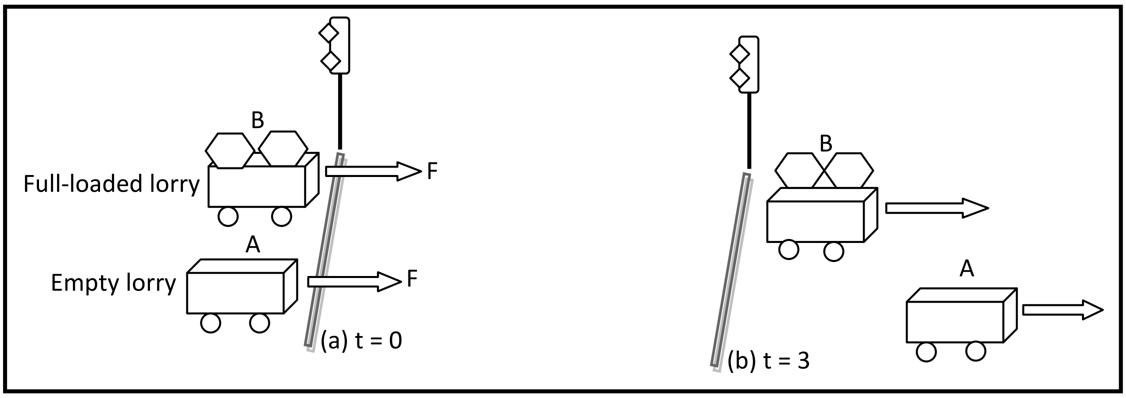


Figure 22 When the force applied on an object is constant, the greater the mass of the object, the smaller its acceleration.

Aim

To investigate the relationship between the acceleration and the mass of an object under a constant force.

Apparatus/Material

Ticker-timer, 12 V AC power supply, 3 trolleys, elastic cord, friction compensated runway, wooden block and ticker tape.

Arrangement of apparatus

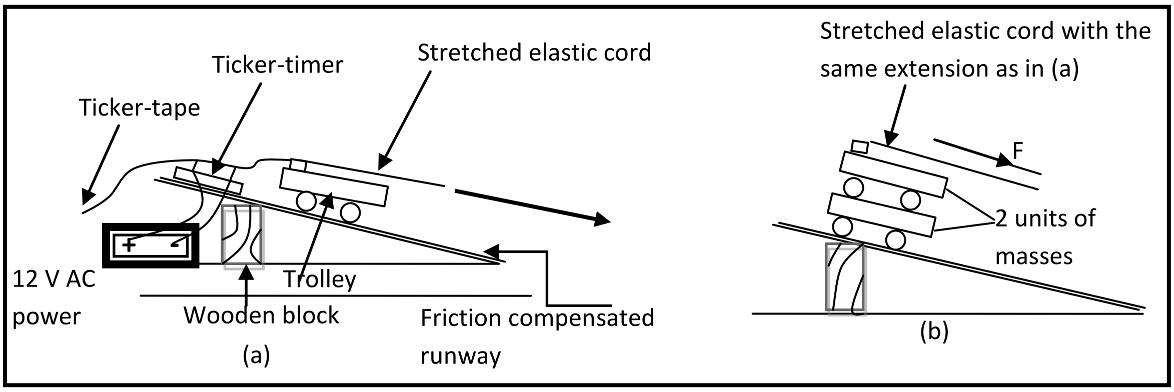


Figure 23 The mass in this experiment is represented by the number of identical trolleys.

Procedure

1. A friction-compensated runway is prepared.
2. Set up the apparatus as seen in the Figure 23(a)
3. Attach a ticker tape to the trolley and pass through the ticker-timer.
4. The ticker-timer is switched on, and the trolley is pulled down the inclined runway by an elastic cord.
5. A ticker tape obtained is cut into strips of 10 ticks. A tape is constructed and the acceleration a, is determined.
6. The experiment is repeated using 2 trolleys and 3 trolleys. The elastic cord is stretched to the same fixed length.

Results

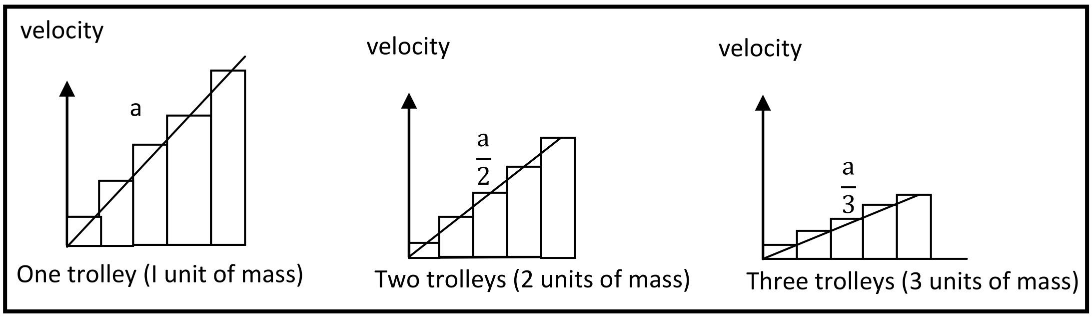


Figure 24 The gradients of the lines joining the strips decreases as the number of trolleys increases. This indicates that the acceleration decreases as mass increases.

Graph

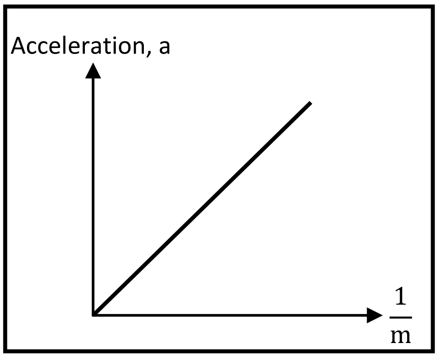


Figure 25 The graph of *a* against 1/m shows a straight line passing through the origin.

Conclusion

The acceleration of an object is inversely proportional to its mass when the force acting on it is constant.

The above experiments show the relationships between the resultant forces, mass and acceleration. Thus we derive the formula:

$$\mathbf{F = ma}$$

where F = resultant force (N or kgm/s^2), m =mass of object (kg) and a = acceleration (m/s^2) of an object.

This equation tells us that,

1. **A resultant force on an object will produce an acceleration.**
2. **Doubling the resultant force on an object will double the acceleration.**
3. **With the same resultant force, doubling the mass will half the acceleration.**

The SI unit of force is newton (N). It is defined as:

One newton (1N) is the force that will produce an acceleration of 1m/s^2 on a mass of 1kg.

If m=1kg and a=1m/s^2, using the formula, F = ma,

$$\mathbf{F = (1\ kg)(1\ m/s^2) = 1\ kg\ m/s^2 = 1N.}$$

Example 1
An unbalanced force of 48N west is applied to a 4kg box. Calculate the acceleration of the box.

Solution

$$a = \frac{F_{un}}{m} = \frac{48N}{4.0kg} = 12 m/s^2 \text{ west}$$

Example 2
A car 2200kg, travelling at 25m/s south comes to a stop in 10 seconds.

Calculate the:

a) car's acceleration and

b) unbalanced force required to cause the acceleration.

Solution
a) Using the equation of motion in Kinematics, where v= final velocity, u = initial velocity and t = time taken.

$$a = \frac{v-u}{t} = \frac{0-25}{10} = -2.5 m/s^2 \text{ south}$$

Thus, the car's acceleration is 2.5ms^{-2} south, which is the same as 2.5ms^{-2} north.

b) F = ma

$= 2200kg \times 2.5m/s^2$ north

= 5500N north.

Therefore the unbalanced force is 5.5×10^3N north.

Example 3
A car of 1200kg mass travelling at 15m/s comes to rest over a distance of 30m.

Find the average:

a) retardation (braking acceleration or decelaration).
b) braking force.

Solutions
a) Using the formula $v^2 = u^2 + 2as$:

Data: $v = 0ms^{-1}$, $u = 15ms^{-1}$, a = ?

Solution:

$V^2 = u^2 + 2as$

Make 'a' the subject

$$a = \frac{v^2 - u^2}{2s}$$
$$0 = 15 + 2a(30)$$
$$a = \frac{(0)^2 - (15)^2}{2 \times 30}$$
$$= \frac{-225}{60}$$
$$= -3.75m/s^2$$

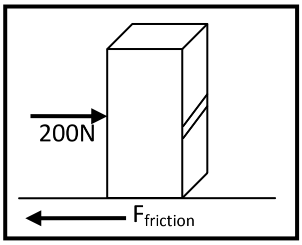
Therefore, retardation $=3.75m/s^2$. Note that retardation is the same as deceleration. Deceleration is the opposite of acceleration which means decreasing in speed or velocity.

b) F = ma
= 1200 x (- 3.75)
= - 4500N

Negative sign indicates retardation force or opposing force. Hence, average braking force = 4500N.

Example 4
Mimoke pushes a heavy cupboard with a force of 200N, but the cupboard does not move.

Find the friction force acting on the cupboard.



Solution

Using $F_{un} = ma$:

a = 0 because the cupboard does not

Data:
F_{un} = 0N since, a = 0
F_a = 200N
F_r = ?

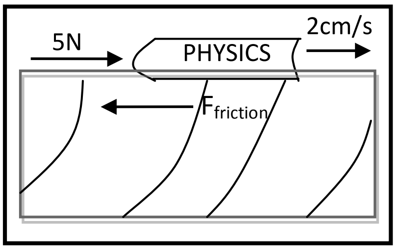
Solution: From the state of equilibrium

$$\sum F_u = F_a - F_r$$
$$0 = 200 - F_r$$
$$F_r = 200N$$

Therefore, the frictional force (F_r) = 200N

Example 5
A girl pushes a book on a table with a force of 5N. The book moves with a uniform velocity of 2cm/s.

Find the frictional force acting on the book.



Solution
Using $F_{un} = ma$:

a = 0 because the book moves with a uniform velocity.

Data:
F_{un} = 0N since, a = 0
F_a = 200N
F_r = ?

Solution: From the state of equilibrium

$$\sum F_u = F_a - F_r$$
$$0 = 200 - F_r$$
$$F_r = 200N$$

Therefore, the frictional force (F_r) = 200N

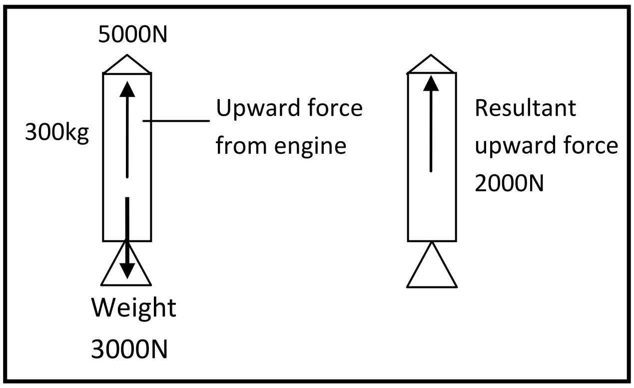
Now check what you have just learnt by trying out the learning activity on the next page!

Learning Activity 6

20 minutes

Attempt the following questions on your own and check your solutions at the end of the unit.

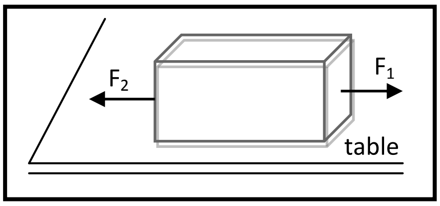
1. The figure below shows a small rocket of mass 300kg at the point of take-off. Find its initial acceleration.



2. John pushes a 12kg carton with a force of 50N. If the carton moves with an acceleration of $2 m/s^2$, what is the frictional force acting on the carton?

3. A 1.6m long barrel propels an object of mass 70kg. If the object is propelled in barrel for 1.2 seconds, find the average net force exerted on it.

4. Two forces $F_1$and F_2 act on a wooden block which is placed on the table. The friction between the block and the table is 3N. Which pair of forces F_1 and F_2 will accelerate the block?



	F_1(N)	F_2(N)
A	4	7
B	8	5
C	6	4
D	9	5

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

Newton's Third Law of Motion – Action Reaction

Do you sometimes push your feet against the wall to propel yourself forward when you are swimming in a pool? Doing so, you are already using Newton's Third Law of Motion! The law states:

> **For every action force, there is an equal and opposite reaction force and these forces act on different bodies.**

It means that if body A exerts a force F on body B, body B will exert an equal and opposite force F (or–F) on body A.

Newton's third law of motion tells us the four (4) characteristics of forces:

1. Forces always occur in pairs, an action force and a reaction force.
2. Action and reaction forces are equal in magnitude.
3. Action and reaction forces act in opposite direction
4. Action and reaction forces act on different bodies.

With this understanding, if a force **F** produced by the boy's leg against a wall produces a reaction. This reaction force **R** exerted by the wall propels the boy forward as seen in figure 27. Thus, we can see that *R* and *F* occur as a pair and are equal in magnitude, but opposite in direction. They also act on different bodies.

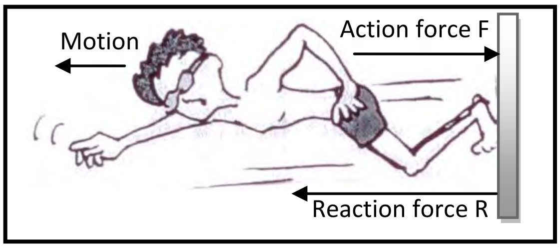


Figure 26 A simple demonstration of Newton's Third Law

Below are some examples of action and reaction forces.

Action	Reaction
• Gas is pushed out behind a rocket.	• The rocket moves forward.
• A car hits a tree.	• The tree pushes the car.
• A foot pushes on the ground.	• The ground pushes on the foot.
• A tyre pushes on the ground.	• The road pushes back on the tyre.
• A hand pushes a brick.	• The brick pushes back on the hand.
• A sprinter pushes on the starting blocks.	• The block pushes on the sprinter.

Table 2 Action and reaction apply when forces are exerted on different bodies.

Let us consider a box resting on a table. The two forces can be labeled as $\mathbf{F_W}$ the weight of the box and $\mathbf{F_N}$ the normal reaction force that the table pushes up normal to the surface.

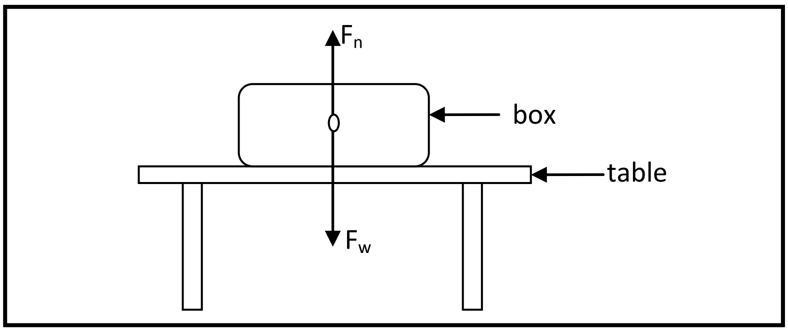


Figure 27 A simple demonstration of action and reaction forces.

In this case, the forces are equal and oppositely directed because no acceleration is occurring. If the mass of the box was 125g, then the weight would be 1.25N down and the normal reaction force would be 1.25N upward.

Example1

1. What are the reactions to the following action?
   a) A man jumping out of a canoe in still water.
   b) A soft-ball hit by a bat.

2. A book of mass 1.5kg exerts a downward force on a table.
   a) What is the size of the force exerted by the table on the book?
   b) Is this an example of action- reaction forces? Explain.

3. A tractor is pulling a heavy load. If, according to Newton's third law of motion, the load is pulling as hard as the tractor is pulling forward, then why does the tractor move?

Solutions

1. a) The canoe moves forward.
   b) The bat slows down as the ball pushes back.

2. a) The size of the force is $F_N = mg = 1.5 \times 10 = 15N$ upwards.
   b) Yes, because the book has a weight of 15 N acting downwards on the table. The table in turn exerts an upward force of 15 N on the book. The forces act in pairs and on two different bodies, the book and the table.

3. There are two forces, and they have the same magnitude and opposite direction, but are both exerted on the same object. Action and reaction apply when forces are exerted on different objects.

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

Learning Activity 7

20 minutes

Answer the following questions on the spaces provided.

1. What are the reactions to the following action?

   (a) A tennis ball is hit by a racket.

   (b) A grasshopper jumps into the air.

2. A school bag of mass 2.5kg rests on a desk top. What is the normal reaction force exerted by the table on the school bag?

3. Explain why a shopping trolley still moves even if two people apply forces on both sides of the trolley.

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

11.3.3 Momentum and Impulse

How difficult is it to stop a moving object? How difficult is it to make a stationary object move? The answer to both of these questions depends on two physical characteristics of an object. The mass and how fast the object is moving.

All objects in motion have momentum. It is the product of mass and the velocity. Momentum is one of the greatest achievements in physics. It is the concept that explains much of the behaviour of matter.

In this section, we will look at momentum and the law of conservation of momentum. We will also look at impulse which is the change in momentum of an object. Finally, we will look at the collisions between objects. Collisions are something we experience every day. This involves force, mass, velocity and time.

Momentum

Our everyday experience, tells us that it is more difficult to stop a heavier object than a lighter object moving at the same speed. Let us consider figure 28 below of a loaded truck and a car moving at the same speed.

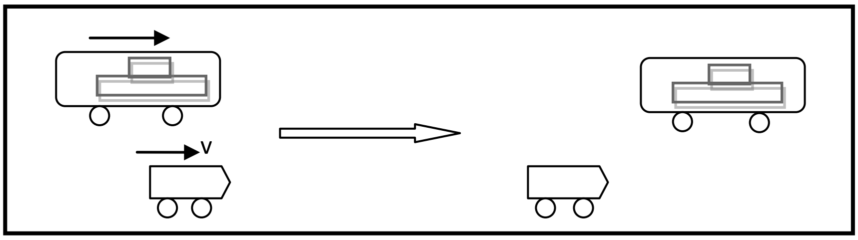


Figure 28 A heavier truck and a lighter car moving at the same speed.

Two factors considered here are mass and velocity. The product of mass and velocity is called **momentum.** Momentum is a useful physical quantity that is used to describe the motion of an object. The formula for momentum is

Momentum = Mass x Velocity

$$P = mv$$

Where **P** is the momentum in kg ms^{-1}, **m** is the mass in kg and **v** is the velocity in ms^{-1}.

Momentum is a vector quantity, being the product of a scalar (mass) and a vector (velocity). The unit of the momentum does not have a particular name. The unit for momentum, $Kgms^{-1}$, is the same as Ns, which is often used. The direction of momentum is the same as the direction of velocity.

Take note that when we calculate momentum problems, we must take direction to the right as positive and to the left as negative. It means that the right direction of action possesses positive momentum and the left direction of action possesses negative momentum.

Example 1
Calculate the momentum of a car of mass 2000kg travelling at 5m/s.

Solution
P = mv = 2000 x 5 = 10 000kg m/s.

Example 2
A bicycle and rider of total mass 100 kg travelling west at 6m/s increases speed to 10m/s in 8 seconds.

Find the change in momentum.

Solution
Change in momentum = final momentum – initial momentum

Final momentum = mv
= 100 x 10
= 1000kg m/s.

Initial momentum = mu
= 100 x 6
= 600kg m/s.

Change in momentum = 1000 – 600
= 600kg m/s.

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

Learning Activity 8

20 minutes

Answer the following questions on the spaces provided.

1. Calculate the momentum of the following objects:

   a) A 0.1kg golf ball travelling at $16ms^{-1}$.

b) A 40kg rock falling at constant speed $30ms^{-1}$.

---

2. A motor vehicle of mass 1200kg has a momentum of $8400kg\ ms^{-1}$. Find its velocity.

---

3. Which object has the greater momentum: an object of 100kg mass travelling at $2ms^{-1}$ or an object of mass 2 kg travelling $100ms^{-1}$?

---

4. A person throws a 0.1kg ball at a brick wall. The ball hits the wall perpendicularly with the speed of $5ms^{-1}$. Then it bounces back with a speed of $4ms^{-1}$.

   Which of the following is the change in the momentum of the ball?

   a) $0.1kg\ ms^{-1}$ b) 0.9kg m/s

   c) 0.4kg m/s d) 0.5kg m/s

Thank you for completing learning activity 8. Now check your work. Answers are at the end of the module.

Conservation of momentum

When two bodies collide, each exerts a force on the other; Newton's Third Law of Motion calls these two forces 'action' and 'reaction'. That is, $F_A = - F_B$.

In our previous discussions, we have learnt that Newton's Second Law of Motion as F = ma and the acceleration is $a = \frac{v-u}{t}$. If we now combine these two equations, then we will get:

$$F = m \times \frac{(v-u)}{t} = \frac{mv - mu}{t} = \frac{\text{change in momentum}}{\text{time}}$$

So the rate of change of momentum is equal to the external force causing the change. This is Newton's Second Law in terms of momentum.

We have seen earlier that $F = \frac{m(v-u)}{t}$ so we can write:

$$\frac{m_1 v_1 - m_1 u_1}{t} = \frac{m_2 v_2 - m_2 u_2}{t}$$

Multiplying both sides by t and rearranging this we get:

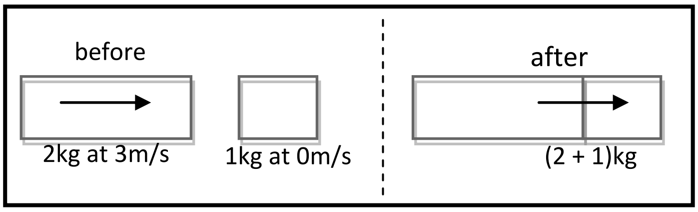
$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

That is, the total momentum before a collision equals the total momentum after collision, this is the **law of conservation of momentum**. The conversation of momentum is a consequence of Newton's Third Law of Motion. Here m_1 = mass of body one, u_1= initial velocity of body one, m_2= mass of body two, u_2= initial velocity of body two, v_1= final velocity of body one and v_2= final velocity of body two.

Example 1

A trolley of mass 2kg travelling at $3ms^{-1}$ collides with a stationary trolley of mass 1kg. The two trolleys stick together after the collision. Find their common velocity.

Solution



Total momentum before impact = total momentum after impact

$$m_1u_2 + m_2u_2 = m_1v_1 + m_2v_2$$

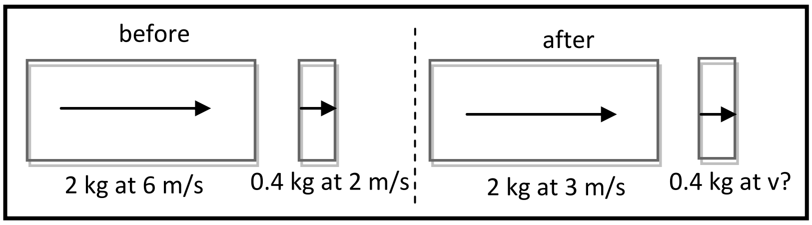
$$3 \times 2 + 0 = 3 \times v \text{ (since } v_1 = v_2)$$

$$6 = 3v$$

$$v = 2ms^{-1}$$

Example 2
A trolley of mass 2kg travelling at $6ms^{-1}$ collides with another trolley of mass 0.4kg travelling in the same direction at $2ms^{-1}$. After impact, the 2kg trolley travels at $3ms^{-1}$ in the same direction. Find the velocity of the 0.4kg trolley after the collision.

Solution



Using : $m_1u_2 + m_2u_2 = m_1v_1 + m_2v_2$

$$2 \times 6 + 0.4 \times 2 = 3 \times 2 + 0.4 \times v$$

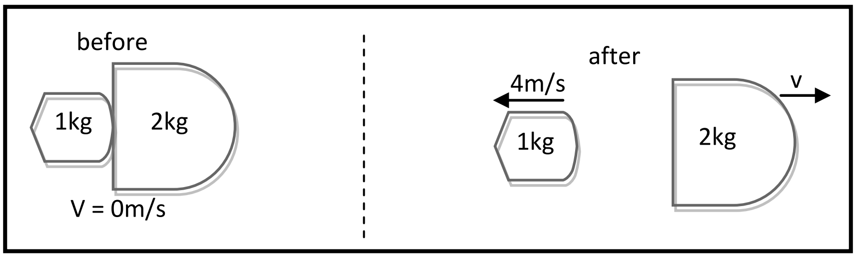
$$12.8 = 6 + 0.4v_2$$

$$12.8 - 6 = 0.4v_2$$

$$v_2 = 17ms^{-1}$$

Example 3
Two stationary rocks with masses 1kg and 2kg are held together. An explosion occurs between the rocks. They are pushed apart with no loss of mass. The velocity of the 1kg rock after the explosion is $4ms^{-1}$. Find the velocity of the 2kg rock after the explosion.

Solution



Using : $m_1u_2 + m_2u_2 = m_1v_1 + m_2v_2$

$$0 = 1 \times (-4) + 2 \times v_2$$

$$V_2 = 2m/s$$

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

Learning Activity 9

20 minutes

Answer the following questions on the spaces provided.

1. An object of mass 5kg moving at a velocity of 16ms^{-1} strikes another object of mass 3kg at rest. The two masses continue in motion together.

   Find their common velocity.

2. A body of mass 5kg travels at 6ms^{-1}. It collides with a 2kg mass travelling at 3ms^{-1} in the same direction. After the collision, the 5kg mass has a velocity of 2m $^{-1}$.

   Find the velocity of the 2kg mass after the collision.

Thank you for completing learning activity 9. Now check your work. Answers are at the end of the module.

Impulse

The equation for Newton's Second Law is F = ma, and the equation for acceleration is $a = \frac{v-u}{t}$. When you combine these two equations by substituting $a = \frac{v-u}{t}$ for acceleration in F = ma, it gives:

$$F = m\frac{v-u}{t}$$

Multiplying by t on both sides of the equation results in:

$$Ft = m(v - u) = mv.$$

However, the above relationship can also be written as: Ft = mv – mu i.e. Ft = ΔP. The product Ft is called the **impulse** of the motion. The impulse measures how hard and for how long a force is exerted. The result of an impulse (Ft) is equal to the change in momentum (ΔP) of the object upon which the force is applied. The SI unit for impulse is **Ns** or **kgm/s**.

Example 1

A ball of mass 0.03kg hits a wall horizontally at a speed of 15m/s and bounces back in the opposite direction at a speed of 12m/s. It is in contact with the wall for an interval of 0.0015 seconds.

a) What is the change in momentum of the ball?

b) What is the impulse on the ball?

c) What is the magnitude of the force exerted by the wall on the ball?

Solution

Let us take initial direction of the ball as positive.

a) ΔP = mv – mu

= m(v – u) 0.03(-12 – 15)

= 0.03(- 27) = - 0.81Ns

b) Impulse = change in momentum.

Ft = ΔP = - 0.81Ns

c) Using the equation

$$F = m\frac{(v-u)}{t} = \frac{mv - mu}{t}$$

$$= \frac{\text{changeinmomentum}}{\text{time}}$$

$$= \frac{-0.81}{0.0015}$$

$$= -540N$$

The negative sign tells us that both the change in momentum (impulse) and the force act in the opposite direction since they are vectors. The magnitude of the force is 540N.

We can summarise the above discussions using the flowchart below.

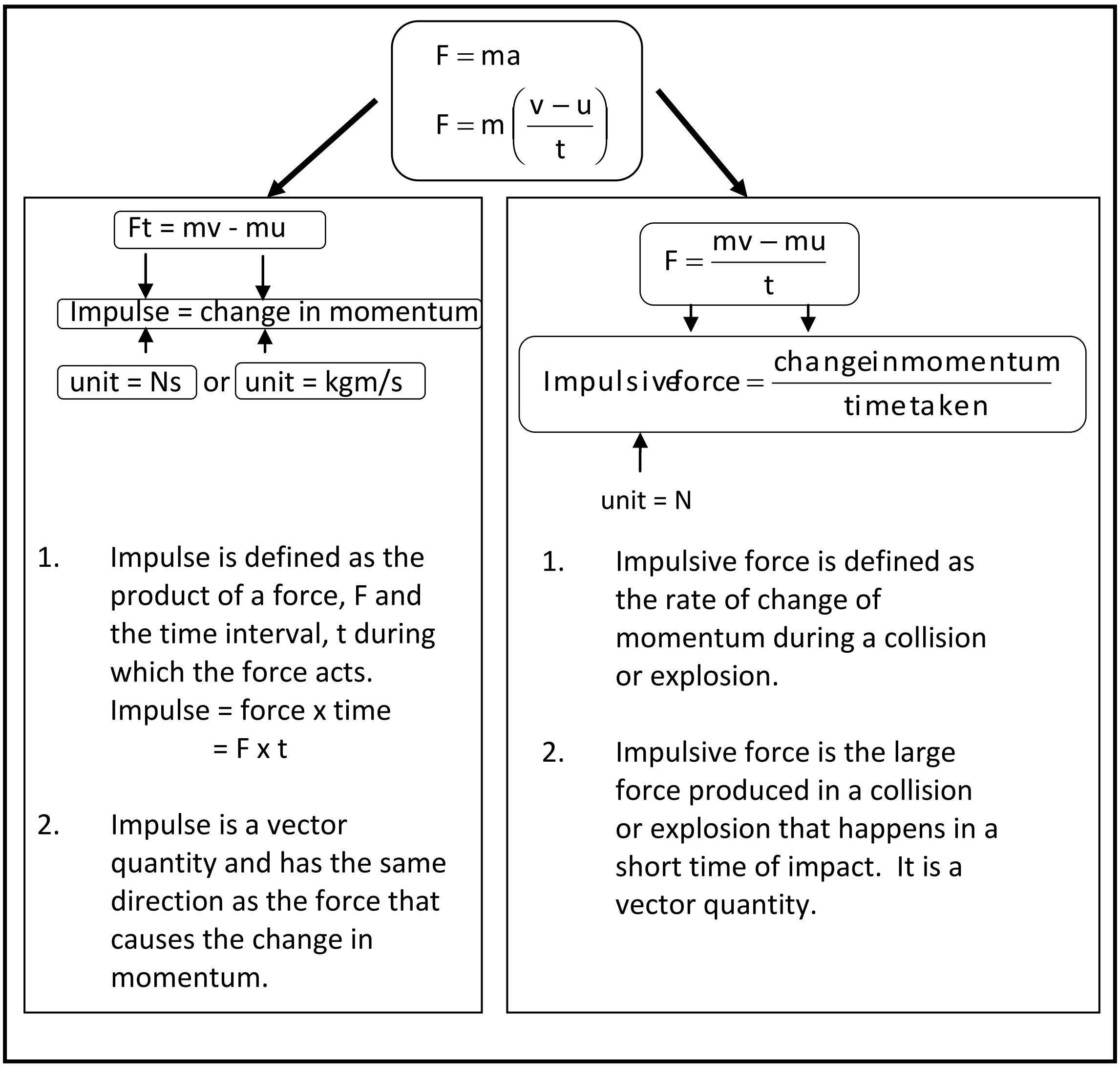
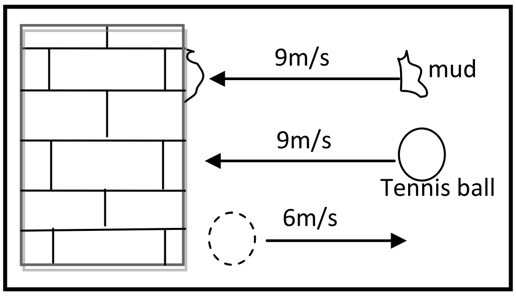


Figure 29 The relationship between the impulse and the impulsive force.

Example 2

A tennis ball and a piece of mud with the same mass (0.06kg) which are moving at 9m/s strike a wall. The mud sticks to the wall while the ball rebounds at 6m/s. Find the impulse on each object.



Solution

Take the right as positive.

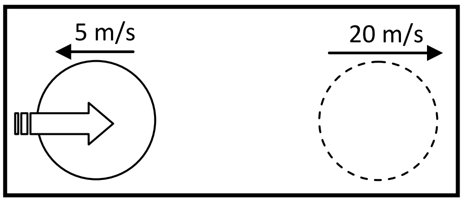
For the mud:
Impulse
= change in momentum
=mv – mu
= 0 – 0.06 x (-9)
= 0 + 0.54
= 0.54Ns

For the ball:
Impulse
= change in momentum
=mv – mu
= 0.06 x 6 – 0.06 x (-9)
= 0.36 + 0.54
= 0.9Ns

You will now see from our example here that, a greater impulse is exerted on an object if it rebounds after collision.

Example 3

A player spikes a volleyball coming towards him at a speed of 5m/s. The ball reverses its direction at a speed of 20m/s. The mass of the ball is 0.36kg. Find the impulse on the ball.



Solution

Take the direction away from the hand as positive.

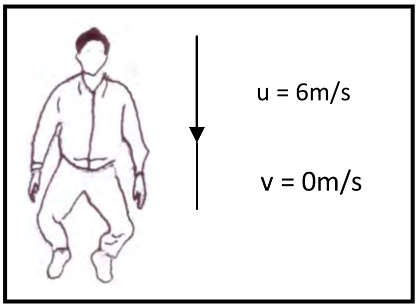
Impulse = Change in momentum = mv – mu = 0.36 x 20 – 0.36 x (-5) = 0.36 x 20 + 0.36 x 5
= 9Ns

The next example will make us understand how time affects collisions.

Example 4

A person of mass 50kg jumps down from a wall. He lands on a cement floor with a velocity of 6m/s.

He bends his knees upon landing. The time taken to stop his motion is 1.0 s.



Solution

Take the downward direction as positive.

m = 50kg, u = 6m/s, v = 0 m/s, t = 1.0s

$$F = \frac{mv - mu}{t}$$

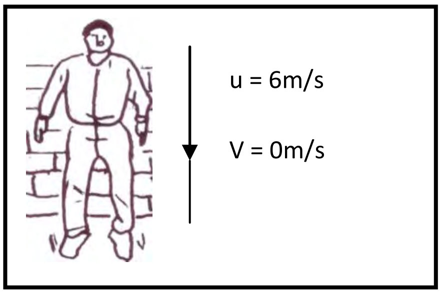
$$F = \frac{50 \times 0 - 50 \times 6}{1}$$

$$= -300N$$

The negative sign indicates an opposing force that reduces momentum.

The impulsive force that acts on his legs is 300N.

He did not bend his knees upon landing. The time taken to stop his motion is 0.05 s.



Solution

Take the downward direction as positive.

m = 50kg, u = 6 m/s, v = 0 m/s, t = 0.05s

$$F = \frac{mv - mu}{t}$$

$$F = \frac{50 \times 0 - 50 \times 6}{0.05}$$

$$F = 6000N$$

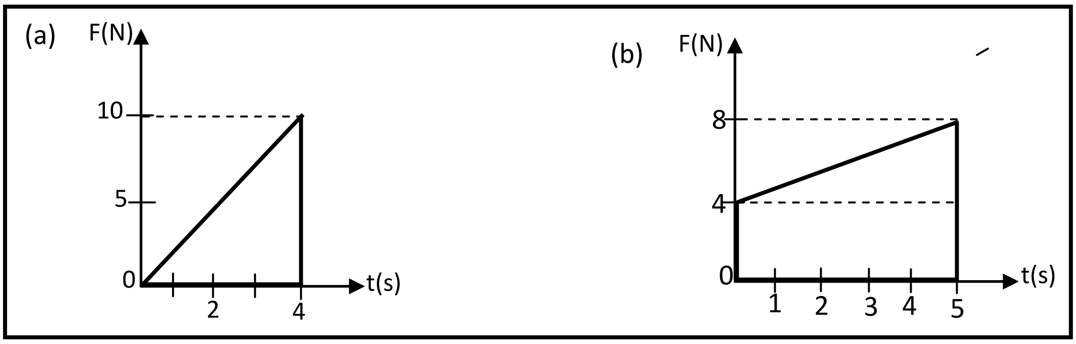
The impulsive force that acts on his legs is 6000N! This force is great enough to break his legs.

The above examples show us that the effective way to reduce impulsive force is to increase the time of collision. This means that the greater the time of contact in collision, the less the impulsive force will be. Also, the less time of collision will result in greater impulsive force which is more dangerous. This is why some vehicles have air-bags installed in them.

Impulse can also be determined from the area under a force time graph. The area under the graph is the change in momentum.

The area under the graph is the change in momentum

Example 5
Find the areas under the graphs (a) and (b) below.



Solutions

a) Impulse = area under graph

$$= \frac{1}{2}(10 \text{ x } 4)$$
$$= 20\text{Ns}$$

b) Impulse = area under graph

$$= \frac{1}{2}(4 \text{ x } 5) + 4 \text{ x } 5$$
$$= 30\text{Ns}$$

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

Learning Activity 10

20 minutes

Answer the following questions on the spaces provided.

1. A tennis player hits an incoming 0.06kg tennis ball with a velocity of 60m/s. The ball bounces off in the opposite direction at 90m/s. Find the time of impact between the racket and the ball if the impulsive force acting on the ball is 125N.

2. Tiger Woods hits a golf ball of mass 0.045kg at a velocity of 30m/s. If the time of impact is 0.005s, what is the average impulsive force applied on the ball by the club?

3. A 0.045kg golf ball strikes a wall at a speed of 30m/s and rebounds at a speed of 20m/s. What is the impulse of the ball?

   If the force on the ball is 500N, find the time of contact of the ball with the wall.

Thank you for completing learning activity 10. Now check your work. Answers are at the end of the module.

Elastic and Inelastic Collisions

In the previous topic on impulse, we saw that during a collision between two masses, momentum is conserved. We will now look at kinetic energy during collisions using:

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

There are two types of collisions: Elastic and Inelastic.

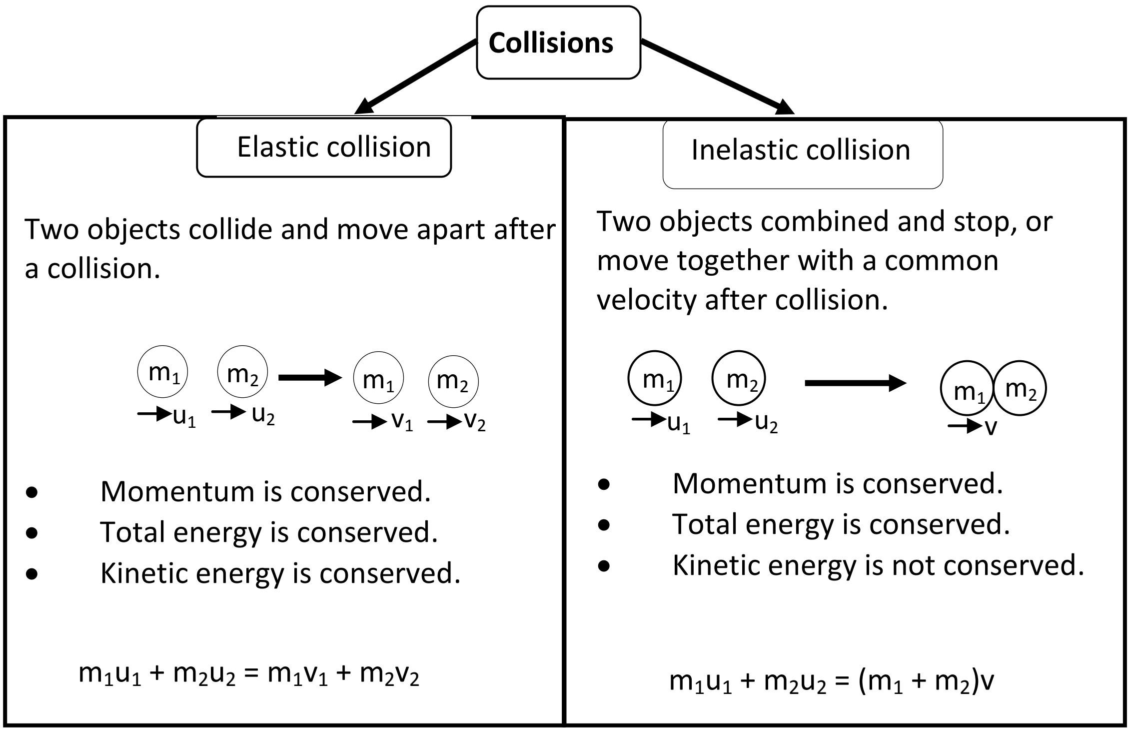


Figure 30 Definitions of Elastic and Inelastic collision.

Elastic collisions	**Inelastic collisions**
In an elastic collision, kinetic energy is conserved. It means that the total kinetic energy before the collision equals the total kinetic energy after the collision. **Example** A 3kg mass with a velocity of 4m/s collides with a stationary 1kg mass. After impact, the 3kg mass continues moving in the same direction at 2m/s. The 1kg mass moves at 6m/s in the same direction as the 3kg mass. Is this an example of elastic collision? **Solution** Total KE before the collision: $= \frac{1}{2}m_1u_1^{\ 2} = \frac{1}{2} \text{ x } 3$ Total KE after collision: $= \frac{1}{2}m_1v_1^{\ 2} + \frac{1}{2}m_2v_2^{\ 2}$ $= \frac{1}{2} \text{ x } 3 \text{ x } 2^2 + \frac{1}{2} \text{ x } 1 \text{ x } 6^2$ $= 24\text{J}$ So the total KE before the collision equals the total KE after the collision, and therefore the collision is elastic. *Note*: Momentum is conserved in this case.	In an inelastic collision, kinetic energy is not conserved. It means that the total kinetic energy after the collision is less than the total kinetic energy before the collision. There is a loss of kinetic energy. The lost energy is transformed into other forms of energy such as heat and sound. **Example** An 8kg mass travelling at 5m/s strikes a 2kg mass at rest. After impact, the two masses stick together and move off at 4m/s. Is the collision elastic? **Solution** Total KE before collision: $= \frac{1}{2}m_1u_1^{\ 2} + 0$ Total KE after collision: $= \frac{1}{2}(m_1 + m_2)v^2$ $= \frac{1}{2}(8 + 2)4^2$ $= 80\text{J}$ The collision is inelastic because there is a loss of KE but momentum is conserved.

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

Learning Activity 11

20 minutes

Answer the following questions on the spaces provided.

1. A body of mass 6kg travelling at 3m/s strikes a 2kg mass at rest. After impact, the 6kg mass travels at 2m/s.

   Find the velocity of the 2kg mass after impact. Is the collision elastic or inelastic?

2. A body of mass 5kg moving at 16m/s collides with another 3kg mass at rest. The two continue in motion together.

   Find their common speed. Is the collision elastic?

Thank you for completing learning activity 11. Now check your work. Answers are at the end of the module.

11.3.4 Applications of Newton's Laws

As stated in the introduction of topic two (2), the laws and concepts of Newton can help us understand the things happening around us. We can apply Newtons' Laws to improve the environment and our standard of living.

The knowledge obtained in Newtons' Laws of Motion has a close connection with the practical developments in engineering and technology. For example, the applications of these fundamental laws have enable engineers and scientists to put satellites into orbit, design pulley systems and inclined planes to lift very heavy objects. The elevators used to transport people up and down high rise buildings are some of those many applications of Newtons' Laws.

These laws and the principles of Newton help to improve the quality of life and explain the operation of many modern home and industrial appliances.

Applications of Newton's Laws

Let us look at some everyday experiences that involves the Newton's Laws of Motion. As we go through the situations and experiences, we must always remember Newton's Three Laws of Motion. Most of the experiences that we will be discussing, directly involves Newton's Laws.

Let us start by considering a situation where we are standing on the ground. You will feel an upward contact force or normal reaction force of the ground supporting you. At most times, you push down on the floor or on the ground with a force equal to your weight. The ground, on the other hand, pushes back with an equal and opposite force.

However, imagine the ground is now taken away from where your feet stands, what do you think will most likely happen to you? You are going to fall through the air. It means that, you will have no experience of normal contact force acting on you. This will make you feel weightless. This is what we call **apparent weight**.

$$F_N = F_w + F_A$$

Apparent weight = True weight + Applied force

Thus, when you are in an elevator or a lift going up to the tenth-floor in a twenty-storey building, you can experience an apparent weight that is different from your true weight.

When the elevator gains speed on its way up the building, you will feel heavier than usual. The two forces acting on you are your weight and the normal reaction force provided by the floor. You can gain speed and accelerate if the normal reaction force is greater than your weight.

If the elevator is accelerating downwards, the net resultant force acting on you would be in the downward direction. The normal reaction force must be less than your weight and you will feel lighter than usual.

$$F_W = F_N - F_A$$

True weight = apparent weight – applied force.

This happens when the elevator speeds up while going down. On the other hand, if the elevator slows down while going up, you will also experience weightlessness just before and at the instant it comes to a stop.

On both occasions of being lighter while going up or going down, you would feel like the floor of the elevator was going to go away from your feet.

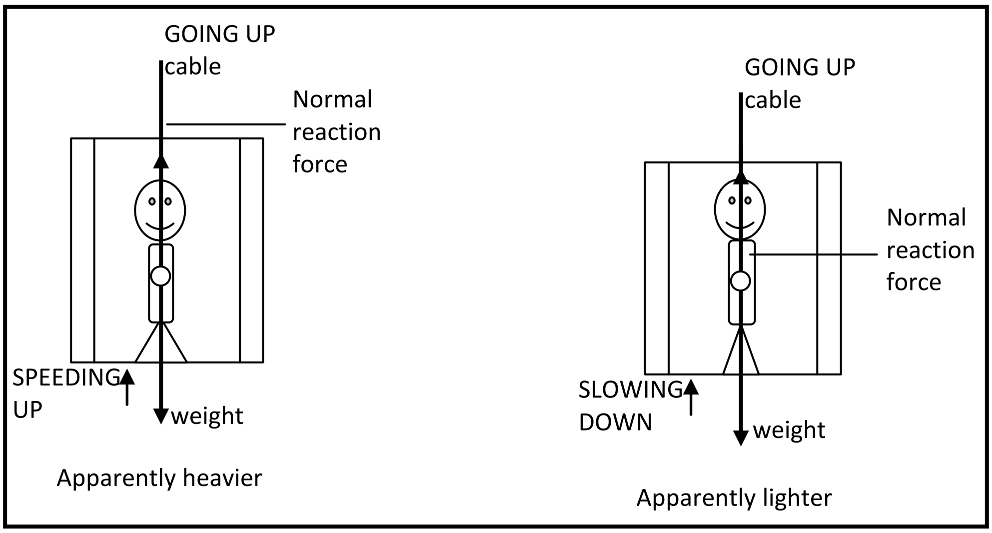


Figure 31 You sense your weight only because the floor pushes up on you.

Example 1

If you were standing on a weighing scale in an elevator and it accelerated upwards, the reading on the scale (your apparent weight, F_N) would increase. If the elevator accelerates upward at $1 m/s^2$, then your apparent weight would be your true weight ($F_w = mg$) plus the upward force exerted by the scale ($F = ma$).

Solution

The scale pushes upward with a normal force F_N that equals the reading on the scale. It is the apparent weight. Your true weight remains constant anywhere on the surface of the earth.

Example 2

What is the apparent weight of a 50 kg person accelerating upwards in a lift at $1.5 m/s^2$?

Solution

$F_N = mg + ma = (50 \times 10) + (50 \times 1.5) = 500N + 75N = 575N.$

Newton's Laws applied to inclined planes

From our previous studies on the resolution of forces, we will now apply those ideas together with Newton's Second Law of Motion on inclined planes.

Let us now consider an object placed on a frictionless inclined plane. Obviously, the object will accelerate down. The accelerating force is provided by the component of the object's weight in the direction down the plane.

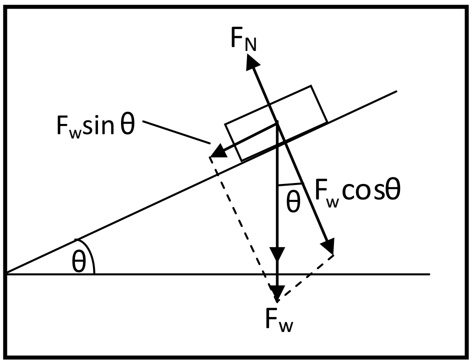


Figure 32 The components of weight (F_w) are: **Fw cos θ** and **Fw sin θ.**

In the figure above, the weight of the object (F_w = mg) has been resolved into two components at right angles – one perpendicular to the plane ($F_N = F_w \cos\theta$) and the other parallel to the plane ($F_p = F_w \sin\theta$).

This can be summarised as:

Parallel component:	$\mathbf{F_p = F_w \sin\theta = mg \sin\theta}$
Perpendicular Component:	$\mathbf{F_N = F_w \cos\theta = mg\cos\theta}$
Normal force:	$\mathbf{F_p = - F_w \cos\theta}$

You can see from Figure 33 above that the normal force is equal and opposite to the force that is perpendicular to the plane. Hence, there is no acceleration in that direction.

Using Newton's Second Law, the resultant force F equals **ma** (F= ma). Hence, F_w= ma = mg sin θ so a = g sin θ.

Note: The mass terms cancels out, so we can say that the acceleration does not depend on the mass of the object but acceleration due to gravity.

Example 3
A 15kg box is allowed to slide freely down a smooth 30^0 inclined plane.

Using g = 10m/s, find the:

a) Resultant force down the incline plane

b) Acceleration of the object

Solution
a) $F_p = ma = mg \sin \theta = 15 \times 10 \times \sin 30^0 = 75N$

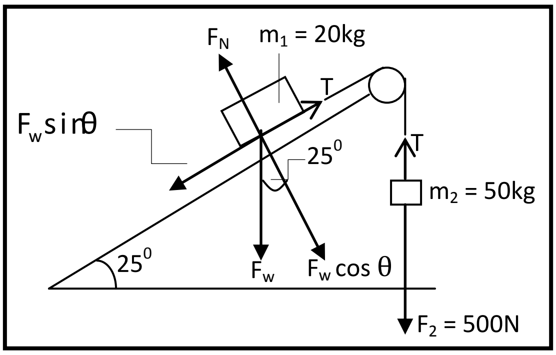
b) $a = g \sin \theta = 10 \times \sin 30^0 = 5m/s^2$.

Example 4
A 20kg object is attached by a thin rope to a 50kg mass that hangs over a frictionless pulley at the top of a 25^0 incline. (Use $g = 10m/s^2$)

Calculate the:

a) Acceleration

b) Tension in the string



Solution
a) Let m_1 be the 20kg mass on the incline, $m_2$is the 50kg hanging mass.

F(down the incline)= $F_p = m_1 g \sin\theta$

$= 20 \times 10 \times \sin 25^0 = 85N.$

F(up the incline) = $F_A = m_2 g$

$= 50 \times 10 = 500N.$

$F_R = F_A - F_p = 500N - 85N$

$= 415N$ up the incline.

$F_R = ma$: i.e. $a = m/s^2$ up the incline.

$$a = \frac{F_R}{m_{total}}$$

$$= \frac{415}{20 + 50}$$

$$= 5.9 m/s^2 \text{ up the incline}$$

b) $T = F_w \sin\theta + ma$

$= mg \sin \theta + ma$

$= 20 \times 10 \times \sin 25^0 + 20 \times 5.9$

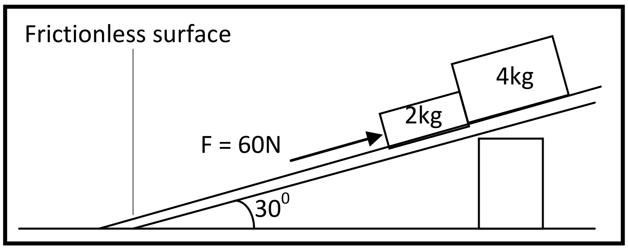
$= 203N$

Example 5

Consider the system of coupled masses sitting on a frictionless surface as shown in the diagram. A force of 60N is applied to the slope. Determine:

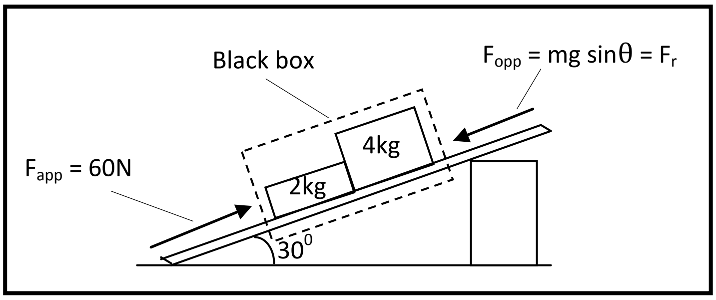
a) The acceleration of the system,

b) The force that 2kg mass exerts on the 4kg mass.



Solution

a) We will first construct a "black box" around the whole system and determine the unbalanced force acting on it.



$F_{un} = F_{app} + F_{opp}$

We will choose up the slope as positive direction, down as the negative direction and g = 9.8m/s^2. i.e. $F_{un} = F_{app} – mg \sin\theta$

$= 60 – (4 + 2 \times 9.8\sin 30^0)$

$= 60 – (6 \times 9.8\sin 30^0)$

$= 60 – 29.4$

$= 30.6N$ up the slope.

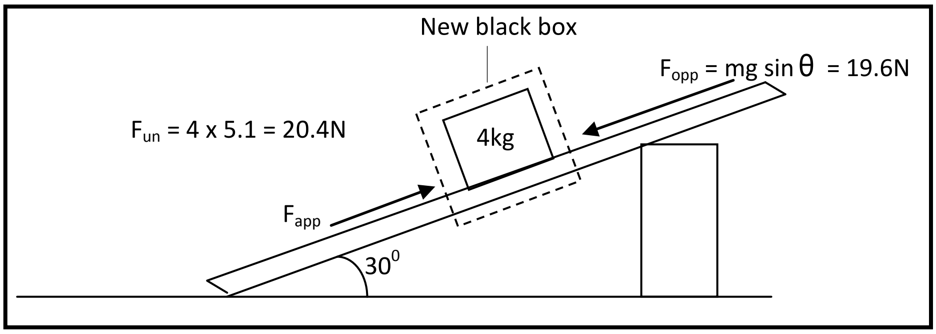
Hence, the acceleration of the whole system given by the Newton's Second Law is:

$$a = \frac{F_{un}}{m}$$

$$= \frac{30.6}{6}$$

$$= 5.1 m/s^2 \text{ up the slope}$$

b) To determine the force that the 2kg mass exerts on the 4kg mass, we will construct a second "black box" around the 4kg mass only.



The 4kg mass is part of the whole system and will therefore accelerate up the slope at $5.1m/s^2$. So the unbalanced force acting on this mass must be:

$F_{un} = ma = 4 \times 5.1 = 20.4N$

The force opposing the 4kg mass being pushed up the slope is simply the parallel component of its weight. So

$F_{un} = mg \sin\theta = 4 \times 9.8 \times \sin30^0 = 19.6N$. If we use the same equation as before,

$F_{un} = F_{app} + F_{opp}$

$20.4N = F_{app} - 19.6N$

i.e. $F_{app} = 20.4N + 19.6N = 40N$ the force that 2kg mass is exerting on the 4kg mass.

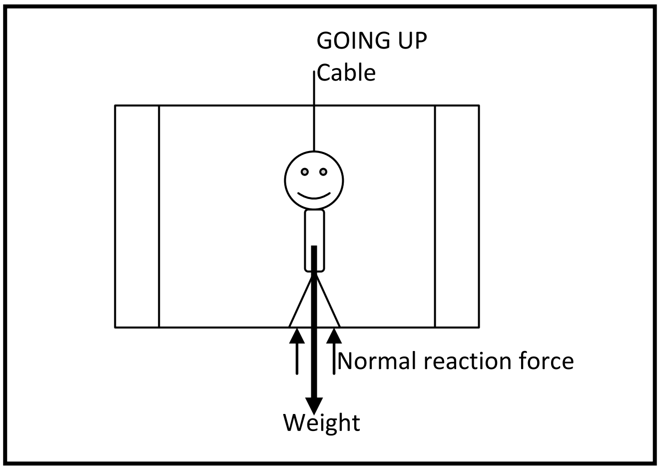
Now check what you have just learnt by trying out the learning activity on the next page!

Learning Activity 12

20 minutes

Answer the following questions on the spaces provided.

1. When you are standing in an elevator, there are only two significant forces acting on you, your weight and the normal reaction force. The only object that pushes you upward is the floor of the elevator. (Note that the tension in the cable is not pulling on you; it is pulling on the elevator.)



State whether, the normal reaction force is less than, equal to or greater than your weight when the elevator is:

a) stationary

____

____

b) moving upwards with a constant speed

____

____

c) speeding up on its way to the top floor

____

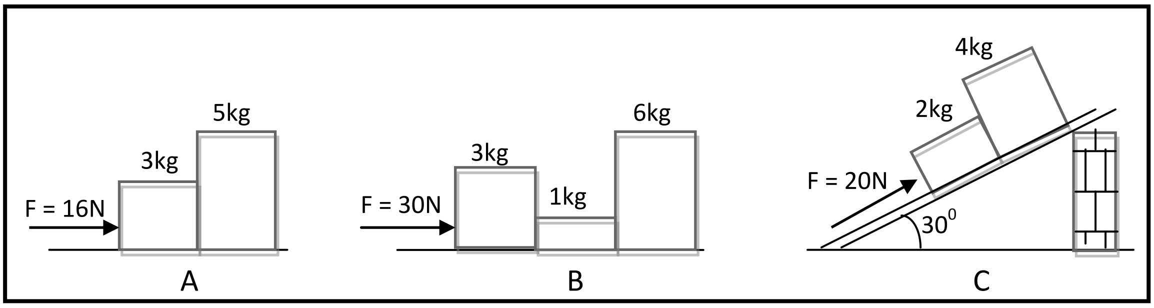
____

d) slowing down as it approaches the top floor.

____

____

2. Study the details in each of the systems shown below and then determine:



a) The total acceleration of each system

b) The forces acting between each of the masses as labelled.

Thank you for completing learning activity 12. 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 3**.
Here are the main points to help you revise. Refer to the module topics if you need more information.

- Force is a vector quantity.
- Weight is a measure of the force on an object due to the pull of gravity.
- The weight of an object is directly proportional to its mass.
- When forces are in equilibrium, the object will be at rest or move with a constant velocity.
- The vector sum of the forces acting on an object is called the net or resultant force.
- The velocity of an object changes when there is a non – zero net force acting on it. The statement is an expression of Newton's First Law of Motion.
- When a net force acts on an object, it accelerates in the direction of the net force.
- A force can be resolved into vertical and horizontal components.
- Inertia is the tendency of an object to resist a change in its motion.
- Newton's Second Law of Motion describes the relationship between the acceleration of an object, the net force acting on it and the object's mass. It can be expressed as: $F_{net} = ma$.
- Newton's Second Law can be applied to a single object or a system of multiple objects connected.
- When an object applies a force (an action) to a second object, the second object applies an equal and opposite force (a reaction) to the first object. This statement is an expression of Newton's Third Law of Motion.
- The momentum of an object is the product of its mass and its velocity.
- The principle of conservation of momentum states that the total momentum is conserved.
  a) For an inelastic collision, momentum and total energy are conserved but kinetic energy after the collision is less than the kinetic energy before the collision.
  b) In an elastic collision, momentum, total energy and kinetic energy are conserved.
  c) The impulse delivered to an object by a force is the product of the force and the time interval during which the force acts on the object.
- The impulse delivered to an object by a force is the product of the force and the time interval during which the force acts on the object.
- The impulse delivered by a net force on an object is equal to the change in momentum of the object. It can be expressed as: $Ft = mv – mu$.

Hope you have enjoyed studying this unit. We encourage you to revise well and complete assessment task 3 in your assessment booklet.

NOW YOU MUST COMPLETE ASSESSMENT TASK 3 AND RETURN IT TO THE PROVINCIAL CENTRE CO-ORDINATOR.

Answers to Learning Activities 1 - 12

Learning Activity 1

1. (a) Kinematics is the study of motion in a straight line without considering the forces associated with motion while dynamics involves the study of motion together with forces associated with motion.

   (b) Mass is a property of an object that is made up of the amount of matter present in an object. Weight is a force due to the pull of gravity.

2. The weight of the stone will change, but its mass remains the same. It is because the weight is a force and it depends on the mass of an object and the gravitational field strength of the moon.

3. a) W_{earth} (use $g = 10ms^{-2}$)

   $W_E = mg$

   $= 4.7kg \times 10ms^{-2}$

   $= 47kgms^{-2}$ or 47N

   b) $W_{moon} = mg$

   $= 4.7kg \times 1.6ms^{-2}$

   $= 7.52kgms^{-}2$ or 7.52N

4. a) A force can deform the shape of an object.

   b) A force can increase or decrease the speed of an object.

5. A contact force is a force that involves two bodies coming in contact with each other so that one body can experience a force from the other. A non – contact force is a force that acts from a distance. The body applying the force does not have to be in contact with the body experiencing the force.

Learning Activity 2

1. a) (i) The greatest force would be 80N + 60N = 140N in the same direction

(ii) The smallest will be 80N – 60N = 20N in the direction of 80N force.

b) The resultant force is:

$$F_R = \sqrt{F_1^{\ 2} + F_2^{\ 2}}$$
$$F_{net} = \sqrt{80^2 + 60^2}$$
$$= 100N$$
$$\therefore \text{Tan}\,\theta = \frac{60}{80}$$
$$\theta = \tan^{-1}(0.75)$$
$$= 36.9^0$$

c) Resolve the 60N force into components:

$F_y = 60\sin60^0 = 52N$

$F_x = 60\cos60^0 = 30N$ to the left

$F_x = 80N – 30N = 50N$ right.

$$F_{net} = \sqrt{52^2 + 50^2}$$
$= 72.13N$ in the direction of 46^0 from 80N force.

2. Resolve the 8N force into components:

$F_y = 8\sin60^0 = 6.93N$, $F_x = 8\cos60^0 = 4N$ to the left.

$F_x = 12N – 4N = 8N$ right.

$$F_{net} = \sqrt{8^2 + 6.93^2}$$
$= 10.6N$ at an angle of 41^0 to 12N force.

Learning Activity 3

1. The components of 6N force:

$F_x = 6\cos30^0 = 6 \times 0.866 = 5.2N$ right.

$F_y = 6\sin30^0 = 6 \times 0.5 = 3N$ upwards.

2. (a) The components of 200N force:

$F_x = 200 \cos 33^0 = 168N$ to the right.

$F_y = 200 \sin 33^0 = 109N$ downwards.

(b) W = mg = 250 x 10 = 2500N

(c) Total force = 2500 + 109 = 2609N.

Learning Activity 4

1. Friction is a force that tries to oppose the motion of an object. It is measured in the unit called Newton (N).

2. Friction always acts in parallel in the opposite direction to the motion of an object.

3. Data:

$F_A = 10N$

$F_R = 2N$

m = 24kg

Solution:

$F_{net} = F_A - F_R$

$= 10N – 2N$

$= 8N$

$$F_{net} = ma$$
$$\therefore a = \frac{F_{net}}{m}$$
$$= \frac{8N}{24kg}$$
$$= 0.33ms^{-2} \text{ in the direction of 10N force.}$$

4. $F_x = 260 \cos 30^0$
$= 260 \times 0.0866025403$
$= 225.2N$

$$\sum F = F_x - F_R$$
$$0 = 225.2N - F_R$$
$$F_R = 225.2N$$

Since the box travels at constant speed:

$F_x = F_r$

$$\therefore = \frac{F_r}{F_n}$$
$$= \frac{225.2N}{450N}$$
$$= 0.5$$

Learning Activity 5

1. The inertia of the books above keep them in their original position and they will drop down. Again, if a book is pulled out slowly, the pile of books moves with it.

2. The passengers are in a state of motion when the bus is moving. When the bus stops suddenly, the inertia of the passengers keeps them in motion. Thus, the passengers move forward.

Learning Activity 6

1. Data:

F_{net} = 5000N – 3000N

m = 300kg

Solution

F_{net} = ma:

$$a = \frac{F_{net}}{m}$$
$$= \frac{2000N}{300kg}$$
$$= 6.7ms^{-2}$$

2. F_{net} = ma

Data:

F_{net} = 12 x 2

F_a = 50N

F_r = ?

Solution:

$F_{net} = F_a - F_r$

$24 = 50 - F_r$

$\therefore F_r$ = 50N – 24N

= 26N

3. **Data**:

$m = 70kg$

$s = 1.6m$

$t = 1.2sec$

$u = 0ms^{-1}$

$a = ?$

$F_{net} = ?$

First we need to find acceleration;

Solution:

$$s = ut + \frac{1}{2}at^2$$

$$1.6 = (0 \text{ x } 1.2) + \left(\frac{1}{2}a \text{ x } 1.2^2\right)$$

$$1.6 = 0 + \left(\frac{1}{2}a \text{ x } 1.44\right)$$

$$1.6 = \frac{1.44a}{2}$$

$$3.2 = 1.44a$$

$$\frac{3.2}{1.44} = \frac{1.44a}{1.44}$$

$$a = 2.22ms^{-2}$$

$$\therefore F_{net} = ma$$

$$= 70kg \text{ x } 2.22ms^{-2}$$

$$= 155.4N$$

4. (D) The block will move with acceleration if the forces acting on it are unbalanced. If the difference between the forces F_1 and F_2 is greater than 3 N, then there is an acceleration.

$F_{net} = F_1 – F_2$
$= 9N – 5N$
$= 4N$

Learning Activity 7

1. a) The racket slows down as the ball moves forward.

   b) The ground pushes on the legs of the grasshopper.

2. The normal reaction force equals the weight of the bag.

   F_n = mg = 2.5 x 10 = 25N3.

3. The trolley still moves because there is an unbalanced force acting on the trolley. Action and reaction happen only when forces apply on different objects.

Learning Activity 8

1. (a) P = mv = 0.1 x 16 = 1.6kgm/s

   (b) P = mv = 40 x 30 = 1200kgm/s

2. $$v = \frac{P}{m}$$
   $$= \frac{8400}{1200}$$
   $$= 7\text{m/s}$$

3. They will have the same momentum of 200kgm/s.

4. (B) 0.9kgm/s.

Learning Activity 9

1. $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

   5 x 16 + 3 x 0 = 5v + 3v

   80 = 8v

   v = 10m/s

2. $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

   5 x 6 + 2 x 3 = 5 x 2 + $2v_2$

   26 = $2v_2$

   V_2 = 13m/s.

Learning Activity 10

1. $$F = \frac{mv - mu}{t}$$
$$\therefore t = \frac{mv - mu}{F}$$
$$t = \frac{(0.06 \text{ x } 90) - 0.06\,(-60)}{125}$$
$$= 0.072 \text{ seconds}$$

2. **Data**:

m= 0.045kg

u = 0m/s

v = 30m/s

t = 0.005s

Solution:

$$F = \frac{mv - mu}{t}$$
$$t = \frac{(0.045 \text{ x } 30) - 0.045 \text{ x } 0}{0.005}$$
$$= 270\text{N}$$

3. Take the direction to the right as positive.

Impulse = change in momentum

= mv – mu

= 0.045 x 20 – 0.045(-30)

= 2.25Ns

Learning Activity 11

1. Total kinetic before collision:

$$\frac{1}{2}m_1u_1^{\ 2} + \frac{1}{2}m_2u_2^{\ 2}$$
$$= \frac{1}{2} \text{ x } 6 \text{ x } 3^2 + 0$$
$$= 27\text{J}$$

Total kinetic energy after collision:

$$\frac{1}{2}m_1 v_1{}^2 + \frac{1}{2}m_2 v_2{}^2$$
$$= \frac{1}{2} \text{ x } 6 \text{ x } 2^2 + \frac{1}{2} \text{ x } 2 \text{ x } v^2$$

Equating K_E before collision = K_E after collision:

$$v_2 = \sqrt{27 - 12}$$
$$= \sqrt{15}$$
$$= 3.87^2$$
$$\therefore \frac{1}{2} \text{ x } 6 \text{ x } 2^2 + \frac{1}{2} \text{ x } 2 \text{ x } 3.87^2$$
$$= \frac{1}{2} \text{ x } 6 \text{x } 3^2 + 0$$
$$27 = 27\text{J}$$

Hence, elastic collision

2. $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

5 x 16 + 2 x 0 = 5v + 3v

80 = 8v

v = 10m/s

Total K_E before collision:

5 x 16 + 2 x 0 = 80J

Total K_E after collision:

$$\frac{1}{2} \text{ x } 5 \text{ x } 10^2 + \frac{1}{2} \text{ x } 3 \text{ x } 10^2$$
$$= 400\text{J}$$

Note that total K_E before collision is not equal to total K_E after collision, therefore, inelastic collision.

Learning Activity 12

1. a) F_n equals your weight

   b) F_n equals your weight

c) F_n is greater than your weight

d) F_n is less than your weight

2. (i) a) $a = \frac{F_{un}}{m}$

$= \frac{16}{8}$

$= 2 m/s^2$

Note that since we have a frictionless surface, there is no opposing force. Therefore, the applied force will be equal to the unbalance force accelerating the masses.

b) F = ma = 5 x 2 = 10N

(ii) a) $a = \frac{F_{un}}{m}$

$= \frac{30}{10}$

$= 3 m/s^2$

b) (i) $F_{3\text{-}1} = 7 \times 3$

$= 21N$

(ii) $F_{1\text{-}6} = 6 \times 3$

$= 18N$

(iii) Let us take up the slope as positive.

(a) $F_{un} = F_{applied} + F_{opposing}$

$= 20 + (- mg \sin 30^0)$

$= 20 - 30$

$= -10N$

i.e. F_{un} = 10N down the slope.

$a = \frac{F_{un}}{m}$

$= \frac{10}{6}$

$= 1.67 m/s^2$

This is the acceleration of the whole system.

F_{un} = 2 x 1.67 = 3.3 N downwards. This is the force accelerating the 2kg mass downwards.

Using $F_{un} = F_{app} + F_{opp}$

$3.3 = F_{app} + (- mg \sin 30^0)$

$3.3 = F_{app} + (- 2 \times 10 \times 0.5)$

$3.3 = F_{app} – 10$

$F_{app} = 3.3 + 10 = 13.3N$

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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3	CENTRAL	C/- FODE HQ	3419228	72228110	The Coordinator	Senior Clerk	72229050
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12	MADANG	P. O. Box 2071, Madang	4222418	72228126	The Coordinator	Senior Clerk	72229063
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.