

MODULE

1

Newton's Laws of Dynamics

UNIT 1

Newton's First Law of Motion

UNIT 2

Newton's Second Law of Motion

UNIT 3

Newton's Third Law of Motion

In this module you will develop the following COMPETENCES:

- explaining phenomena of everyday life in light of the principles of dynamics
- forming questions and adopting strategies for solving problems of dynamics, and evaluating their solutions
- mastering the linguistic tools for handling communication and learning in English
- reading, understanding and interpreting various types of written texts relating to Newton's laws
- producing various types of text suitable for interpreting and reporting what you have learnt about Newton's laws



Newton's First Law of Motion

LEAD-IN

1 Working in groups of three or four, state whether the following sentences are *true* or *false*, and correct the false ones.

- 1 If a book is simply lying still on a table, no forces are acting upon it. T F
- 2 An object can move when no forces are acting on it. T F
- 3 When the bus comes to a sudden stop, you experience a force which pulls you forward. T F

KINEMATICS AND DYNAMICS

Kinematics is the study of the characteristics of motion: it teaches you to describe almost every kind of motion in terms of position, displacement, velocity, and acceleration over time. In this module, motion will be considered from a new perspective: dynamics.

Dynamics tells you what causes a body to rest, or why it moves at a constant velocity or a constant acceleration. The most important question in this module is "why?" The three fundamental laws of dynamics are Newton's three laws of motion.

2 Match the terms (1-8) to their corresponding definitions (a-h).

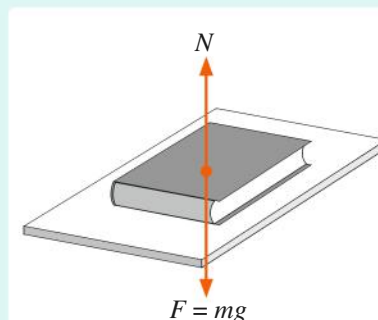
- | | |
|---|--|
| ☐ 1 Force | a A physical entity with both an appropriate unit and a direction. |
| ☐ 2 Dynamics | b A coordinate system used to measure the properties of a physical entity. |
| ☐ 3 Frame of reference | c The property of matter that keeps an object in the same position, or keeps it moving at a constant velocity and direction. |
| ☐ 4 Kinematics | d The rate of change of velocity over time. |
| ☐ 5 Acceleration | e A physical entity with an appropriate unit. |
| ☐ 6 Vector | f The branch of physics that studies what causes the motion of a system, especially those causes which originate outside the system (external forces). |
| ☐ 7 Inertia | g The cause of every change in the velocity of an object. |
| ☐ 8 Scalar | h The study of motion in terms of position, velocity and acceleration. |

3 Have a look at these pictures representing forces, then read and answer the question.

Do the two statements contradict each other?



← Forces are the cause of every change in the velocity (acceleration) of an object.



← Forces are associated with static systems.

READING AND LISTENING

Newton's First Law of Motion

2

Newton's first law of motion states that:

every object remains in its state of rest, or moves at uniform velocity in a straight line, as long as no net external force acts upon it.

Note that the term 'net' is very important to understanding this law. The **net force** is the **vector sum** of all forces acting upon the object. It is also called the **resultant force**.

Newton's first law of motion can be considered from two different points of view.

- If you know that a body is at rest or is moving at a constant velocity, then you assume that the resultant force is equal to zero.
- If you know, or deduce from the known data, that the sum of all the forces applied to the object is equal to zero, then you also know that the object will remain still if it is still, or will continue moving at a constant velocity if it is moving.

If a book is lying stationary on a table, you can assume that the sum of the gravitational force and the reaction force exerted by the table is zero, and that this reaction force must be opposed to the gravitational force. Similarly, if you observe a person skiing down a hill at a constant speed, Newton's first law tells you that the resultant force in the direction of motion is zero.



ISAAC NEWTON
(1643-1727)

Newton is one of the most brilliant minds in the history of science.

He observed and formulated the laws of dynamics, the law of universal gravitation, and the ingenious mathematical method of calculation. His contributions to these fields of knowledge remain fundamental today.

COMPREHENSION QUESTIONS 1

Answer the following questions.

- 1 According to Newton, what does an object do if the sum of the forces acting upon it is zero?
- 2 Your bag is lying on your bed, and isn't moving. What is the magnitude of the net force acting on it?
- 3 Why is the term 'net' important to understanding Newton's first law?

Net Force

3

Newton's first law of motion concerns net force, which can be evaluated as follows:

$$\Sigma \vec{F}_e = 0 \quad (1.1)$$

The subscript *e* indicates **external forces**. Internal forces such as bond forces or interactions between atoms don't have any influence on the motion of objects. **Only external forces cause objects to move or to stand still.** In the equation above, the symbol Σ (sigma) is used for *the sum of terms like*, and in this case it means *the sum of all external forces acting upon the object in every direction*. The arrows above the terms in the equation show that the resultant force acting on a body is a vector sum. The study of vectors taught you that the addition of two or more vectors can be done graphically or analytically. Graphical methods aren't accurate enough, so it's important to use the analytical method (i.e. adding components of the same direction).

COMPREHENSION QUESTIONS 2

Answer the following questions.

- 1 What influence do bond forces have on the movement of an object?
- 2 What do the arrows in equation 1.1 indicate?
- 3 In equation 1.1, is the object accelerating, moving in a straight line at a constant speed, or at rest?
- 4 Can you write equation 1.1 as a sentence?



4

Inertial Reference Frames



Imagine that you are going to school by car, and some books are lying on the passenger seat. If the car suddenly stops, your books and every other object on the seats will immediately slide forward onto the car floor.

Can you figure out which force causes them to slide? When applying Newton's first law of motion (also called the **law of inertia**), if you observe an object accelerating, you look for the force that causes its acceleration. There seems to be no force acting on the book: nothing is pulling or pushing it forward. It appears to be a mystery, but it depends entirely on the reference frame you are observing it from.

The answer is that you and the book are both in the car's reference frame, which decelerates quickly until it stops. While the car is moving, the objects in the car move together at the same speed. When it suddenly stops the objects slide forward, continuing their state of motion at the same speed while the velocity of the car decreases.



5

An Observer's Frame of Reference

LISTENING ACTIVITY

With your partner, consider the gaps in the text to the right. Try to guess the missing words in each space, or what kind of words (nouns, verbs, connectors, etc.) might be used to fill them. When you have finished, listen to the text and copy what you hear. Were they correct?

COMPREHENSION QUESTIONS 3

Answer the following questions.

- 1 Why do the books fall onto the car floor when you brake suddenly?
- 2 How do the driver of the car and the observer on the pavement see things from their different perspectives?
- 3 What conclusion can you draw about Newton's first law from this example?

Actually, an ¹ standing outside the car sees the car and the objects inside moving ² before it starts to accelerate. When the car's velocity suddenly ³ due to the braking action, the observer outside sees the books and other objects freely moving at constant velocity, but sees the passengers, who are firmly tied to ⁴ , slow down.

So, you can see that when the observer's frame of reference

⁵ , the same phenomenon ⁶

different. An observer standing on the pavement won't perceive any change in the velocity of the sliding ⁷ This is in agreement with Newton's first law, since there is no net external force applied to them.

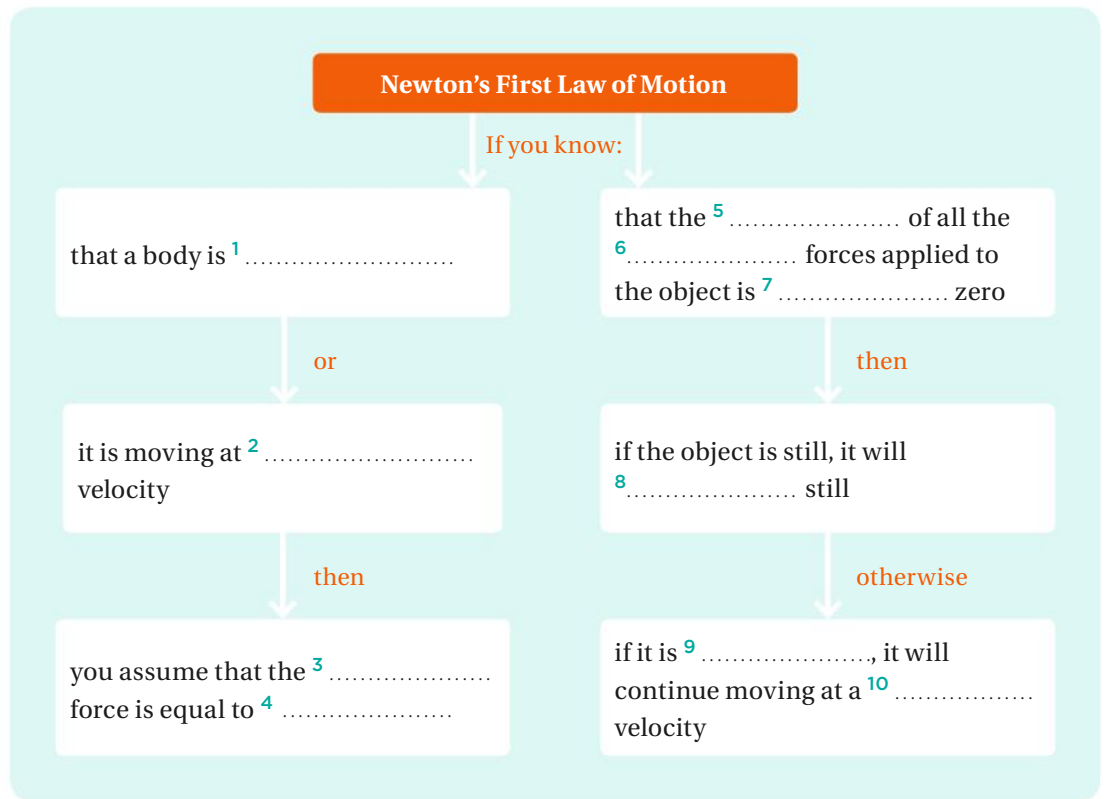
This and many other examples demonstrate that Newton's first law doesn't apply in an ⁸ reference frame (also called a noninertial reference frame): it holds only in reference frames that are static or are moving at a constant velocity.

Earth is generally ⁹ to be an inertial frame, as the effect of its rotation can be ¹⁰ for most purposes.



PRACTICE**4** Fill in the gaps in the diagram with the appropriate words.

still
external
constant
remain
resultant
equal to
moving
constant
zero
sum

**5** Use the correct form of the verbs to complete the following sentences.
Finding the verb elsewhere in this unit will help you!

to call
to move
to act upon
not to cause
to accelerate
to remain
to cause
to be associated with
to hold
to appear

- 1 The 'net' force (also called the resultant force) is the vector sum of all forces the object.
- 2 Forces the acceleration of all objects, but static conditions as well.
- 3 Internal forces objects or at rest.
- 4 Newton's laws of dynamics only in reference frames that are static or moving at a constant velocity.
- 5 A phenomenon will differently to an observer depending on whether his reference frame is moving at a constant velocity, is stationary, or is
- 6 Newton's first law of motion the law of inertia.

6 Are the following sentences *true* or *false*?

- | | |
|---|---|
| 1 If an object is moving at a constant velocity, only one force is being applied to it. | ☐ T ☐ F |
| 2 If an object starts moving, you can always state that a force has been applied to it. | ☐ T ☐ F |
| 3 Newton's first law of motion is a universal law and is therefore always valid. | ☐ T ☐ F |

Applied Physics

- 7 You have decided to suspend a valuable antique chandelier (mass=100 kg) from the ceiling with a chain of negligible mass, which has a maximum strength (tension) of 900 N (beyond which the chain will break). Is it safe to suspend the lamp from this chain? Would you happily lie down and relax underneath it?

Known

lamp mass $m = 100 \text{ kg}$

chain maximum strength $T_{\max} = 900 \text{ N}$

acceleration caused by Earth's gravity $g = 9.81 \text{ m/s}^2$

Find

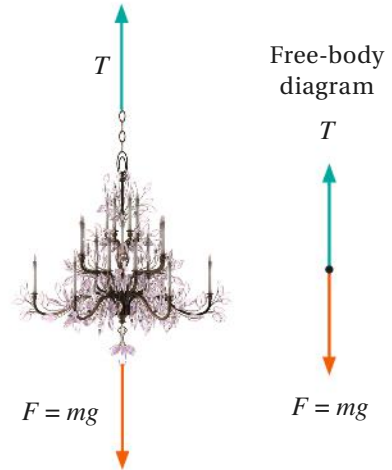
Is it safe?

Analysis

Look at the free-body diagram to the right, which shows the chandelier (represented as a point) and arrows indicating every force acting upon it. Because the suspended chandelier is motionless, Newton's first law of motion is valid. This means that the sum of the opposing forces is zero. So, you can determine the value of the tension needed to suspend the chandelier:

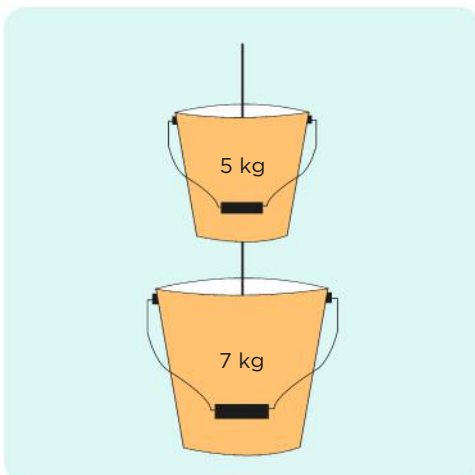
$$\Sigma F_{e,y} = T - mg = 0 \rightarrow T = mg = 100 \cdot 9.81 = 981 \text{ N}$$

This is the value of the force that the chain must exert on the chandelier in order to sustain it. Note that this value exceeds the maximum strength the chain can apply. Are you still going to use this chain? Would you feel comfortable relaxing underneath the chandelier in your chair?



↑ Always draw a free-body diagram: it is a schematic representation of all of the forces (arrows) acting upon an object, which is shown as a point. Be sure to include every force acting on the object in question, but don't show forces acting upon other objects.

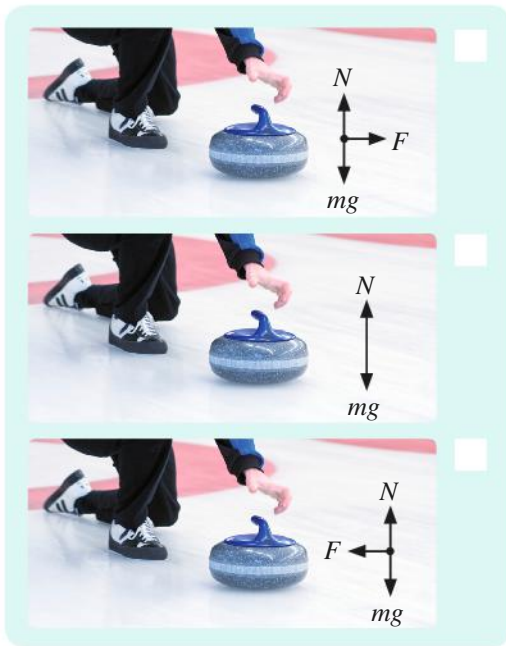
- 8 A 7.0 kg paint bucket is hanging by a massless cord from another 5.0 kg paint bucket, which is also hanging by a similar massless cord as shown in the figure. Draw an appropriate free-body diagram and write what happens if the maximum tension of the cord is 70 N. Are the buckets at rest? If not, indicate the tension of each cord and say which one will break first.



- 9 A United Airlines Boeing 777 is flying at a constant speed of 900 km/h, and is carrying around 300 passengers. The aircraft has a twinjet propulsion system which exerts a thrust force of approximately 500 kN. Can the effect of air friction be considered negligible? If not, can you evaluate the intensity of the frictional force, or do you need more data?



- 10 A curling stone is sliding at constant velocity across a flat ice surface that is assumed to be frictionless. Which of the following is the correct free-body diagram?



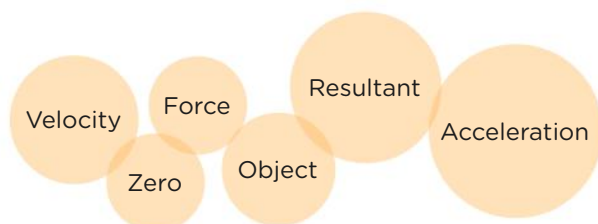
CURLING: A SPORT ON ICE

Of Scottish origin, curling is a game similar to bowls or golf, but is played on ice instead of grass. It requires skill, dexterity, power, and determination,

and as with all team sports, it takes cooperation to win. Each team consists of four players: the lead, the second, the third, and the skip. Round balls of granite (called 'stones') are launched from a platform (hack). The objective is to position the stones in a goal consisting of four concentric circles called the 'house', which is located 38 metres from the hack. After the launch, the most delicate moment is sweeping: when one player throws, two of his teammates travel with the stone and sweep the ice in front of it to decrease the friction along its path. Curling was first included in the Winter Olympic Games in 1924, but only became an official sport in 2006.

PRODUCTION

- 11 Working in groups, discuss the following questions and then write down your answer. When you have finished, compare your answers with the other groups.
- 1 Your team's goalkeeper is holding the ball in his hands. Identify all of the forces acting upon the ball. What changes when he kicks the ball out of his hands, and while the ball is airborne?
 - 2 A passenger in the rear seat of a taxi claims that he was injured by a box of crystal glasses that was leaning against the front seat of the car when the taxi braked suddenly. If you were judging this case in court, what verdict would you make? Why?
 - 3 At the airport, you are pulling your luggage with a constant strength of 10 N. If you move at a constant speed of 1 m/s, can you tell whether or not there is a friction force? If so, can you calculate its size?
 - 4 Look around the room, find examples of Newton's first law of motion at work, and draw their free-body diagrams.
 - 5 Consider the words in the circles to the right. Include all six of them in a logical sentence, and read it out to your class.
- 12 Working independently, look up the Leaning Tower of Pisa on the web or in your school library. Research its history and its structural problems, and discuss the results of your research with your group. When you have finished, write a short report.
- 13 Working in groups, explain how a space shuttle moves through space thanks to Newton's first law of motion. Use the web to find out when a spacecraft consumes most of its fuel: during take-off, or while travelling to a distant planet. Write your answer as a short report.
- 14 Together with other members of your group, design and implement a simple experimental demonstration of Newton's law of inertia. When you have finished, compare your demonstration with those of the other groups.



Newton's Second Law of Motion

LEAD-IN

1 Working in groups of three or four, state whether the following sentences are *true* or *false*, and correct the false ones.

- 1 While you are travelling in the back seat of a car, the driver turns suddenly and you slide away from the direction in which the car is turning. You move as a result of a force that acts upon your body.
- 2 A parked car is hit from behind in a traffic accident. If the car is large, the passengers will suffer less whiplash damage.
- 3 Before opening their parachutes, skydivers often spend time in freefall, accelerating more and more until they reach their maximum speed and a constant velocity.

T F

T F

T F

2 Match the terms (1-6) to their corresponding definitions (a-f).

- | | |
|--|--|
| ☐ 1 Free-body diagram | a The sequence of positions followed by an object in motion. |
| ☐ 2 Resultant force | b The projection of a vector in a direction. Vectors are usually projected in the positive x and y directions of a Cartesian reference frame. A single vector is equivalent to the vector sum of its x and y components. |
| ☐ 3 Vector equation | c The rate of change of velocity over time. |
| ☐ 4 Trajectory | d A sketch representing all forces acting upon the object, which is represented as a point. It doesn't show forces that the object exerts on its surroundings. |
| ☐ 5 Acceleration | e An equation involving vectors. |
| ☐ 6 Vector components | f The vector sum of all forces acting upon an object. The external effect it has upon the object is the same as the effects of all the forces acting upon the object combined. |



SKYDIVING

The history of **skydiving** begins with Leonardo da Vinci, who had the idea that an inverted cone would slow the fall of a body immersed in a fluid. This principle is also relevant to his studies of flight. Later on, Andre-Jacques Garnerin made the first successful parachute jump from a hot-air balloon in 1797. In World War I parachuting technology was used exclusively for emergency purposes, but went on to assist in deploying soldiers to battlefields in World War II. Skydiving later became a recreational activity and a competitive international sport in 1952. A typical jump is from an altitude of 1,000 to 4,000 metres.

READING AND LISTENING

Newton's Second Law of Motion

Introduction

6

Newton's first law of motion deals with bodies that are motionless or moving at a constant velocity. You know that both conditions are met if net force is equal to zero, but what happens if it isn't?

Imagine that you are sailing downwind, and can feel the wind on your back. You know that the wind is powering the boat, and that the stronger the wind blows, the more quickly the boat sails. Similarly, if you are taking a penalty for your soccer team, you know that the ball will accelerate more rapidly if you kick it harder.

These are examples of forces which act in the direction of motion and increase velocity in the direction of motion. Conversely, if a net force acts contrary to the direction in which an object is moving, its velocity will decrease. When a force acts against the direction of an object's motion, it *decelerates*. If you slide an object along a table, the force of friction, which always acts in the direction opposite to motion, slows it to a stop.

COMPREHENSION QUESTIONS 1

An object is moving at a constant speed in a straight line. What happens to the object if...

- 1 you increase the magnitude of the force **acting in** the direction of motion?
- 2 you increase the magnitude of the force **acting against** the direction of motion?

Expressing Newton's Second Law

7

Newton's second law of motion states that:

when a nonzero resultant force (F) acts upon an object, the object undergoes an acceleration (a) equal to the ratio between the resultant force and the mass (m) of the body.

This law can be expressed with the following equation:

$$\vec{a} = \frac{\Sigma \vec{F}_e}{m} \quad (2.1) \quad \text{which is equivalent to: } \Sigma \vec{F}_e = m \cdot \vec{a} \quad (2.2)$$

where $\Sigma \vec{F}_e$ indicates the sum of all external forces applied to an object, expressed in N (newtons), a is the object's acceleration measured in m/s^2 , and m is the mass of the body in kg.

So, a nonzero net force acting upon an object doesn't cause motion: it causes a variation in velocity which is measured as acceleration. The arrows above 'force' and 'acceleration' indicate that both are vectors, and equation 2.1 shows you that acceleration is a vector with the same direction as the resultant net force. It also shows you that its intensity is equal to the ratio between the net force and the mass of the object. Note that equation 2.2 is a vector equation, and is therefore equivalent to the following three component equations:

$$\Sigma F_{e,x} = m \cdot a_x \qquad \Sigma F_{e,y} = m \cdot a_y \qquad \Sigma F_{e,z} = m \cdot a_z$$

Note that if you apply a force F to an object at rest on a frictionless surface, it undergoes an acceleration a (see eq.2.1), whereas if you apply the same force F to another object which has twice the mass,



COMPREHENSION QUESTIONS 2

Answer the following questions.

- 1 You see an object that isn't accelerating. Is it possible that only one force is acting upon it?
- 2 What does a nonzero net force acting on an object do to it?
- 3 What's the difference between the final three equations on page 15?

its acceleration is $a/2$. If the mass of the object is half that of the first object, the acceleration is $2a$. Thus, Newton's second law of motion can be read as: *"The acceleration of an object moving in an inertial reference frame is proportional to the net force acting on it and inversely proportional to its mass."*

Mass is therefore a measure of the inertia of an object (i.e. the tendency of an object to remain motionless if it is at rest or to oppose changes in its velocity). So, the greater the mass of an object, the greater the force necessary to make it accelerate. In other words, it will be harder to move it from rest and harder to stop if it is moving.

WATCH OUT!



You will probably have read the following sentence somewhere: *"the weight of an object is 2 kg"*. It's important to remember, however, that *mass* and *weight* are two different quantities. The weight of an object is equal to the magnitude of the gravitational force exerted upon it, and it varies with location. The mass of an object is a scalar quantity and an inherent property, and it therefore doesn't depend on external conditions. A typical set of bathroom scales uses kilograms, even though the kilogram is a unit of mass, not a unit of force.

The Motion of a Projectile

8

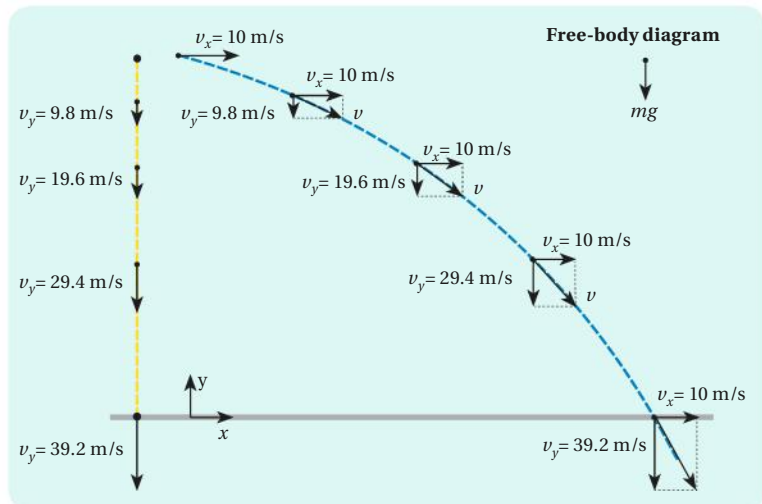
There are plenty of examples of Newton's second law of motion. You can find them by simply looking around you!

3 Discuss the following question with your partner.

A tennis ball at rest is dropped onto the ground. At the exact same moment, another ball is thrown horizontally from the same height as the first ball. Ignoring the effect of air friction, which ball hits the ground first?

- ☐ A The ball at rest hits the ground first.
- ☐ B Both balls hit the ground at the same time.
- ☐ C The ball thrown horizontally hits the ground first.

In order to understand which answer is right, see the following diagram:



↑ There are two balls in the diagram. The yellow dashed line indicates the path of the vertically dropped ball, and the blue line is the trajectory of the horizontally thrown ball. Velocity vector components are shown for the second case.

Galileo was the first person to study and describe projectile motion accurately, and his hypothesis was that all motion could be described by analysing its horizontal and vertical components separately. The resultant motion is, moment by moment, the vector sum of the two velocity components.

The diagram shows the ball that drops travelling at an increasing vertical velocity. The ball thrown horizontally, however, proceeds at such a speed that the x -component is *constant* but the y -component increases, resulting in a parabolic trajectory. In order to understand

what happens in each case, note that the only force that acts on the balls is gravity, directed downward.

The ball that drops vertically has no initial velocity in any direction. According to Newton's second law, the action of the gravitational force upon it causes the vertical velocity to increase, thus producing a constant acceleration in the vertical direction only:

$$\vec{a} = \frac{\Sigma \vec{F}_e}{m} = \frac{mg}{m} = g = 9.81 \frac{\text{m}}{\text{s}^2}$$

In the case of the second ball, you have to distinguish between
 1 In the 2 direction there is no
 difference between the two balls. The only force acting vertically upon
 each ball 3 , which is the same in both cases.
 4 , in the horizontal direction the thrown ball
 5 10 m/s.
 As 6 forces acting in the horizontal direction,
 motion along the x direction follows 7 : when there
 is no net force acting in a direction the object remains still if it is still,
 but if it has an initial velocity and a direction, 8
 9 , the motion of the ball thrown horizontally has
 10 : the horizontal component v_x , which remains
 11 and is 12 , and the vertical
 component v_y , which 13 equal to g . The vector sum
 of the uniform 14 and the accelerating
 15 is the projectile's trajectory, which is tangential
 to the velocity vector at any instant.

Because the vertical motion of the two balls is identical, the result of
 this example (as predicted by Galileo) is: *an object thrown horizontally
 will reach the ground at the same time as an object dropped vertically.*

LISTENING ACTIVITY

With your partner, consider the gaps in the text to the left. Try to guess the missing words in each space, or what kind of words (nouns, verbs, connectors, etc.) might be used to fill them. When you have finished, listen to the text and copy what you hear. Were they correct?

COMPREHENSION QUESTIONS 3

Answer the following questions.

- Does the vertically dropped ball move at a constant speed? Why, or why not?
- Why doesn't the horizontally thrown ball accelerate in the x -direction?
- If you test Galileo's idea by standing on the pavement and dropping one ball and throwing another downwards at the same moment, do you think you will observe them reaching the pavement simultaneously? Explain your answer.

PRACTICE**4** Fill in the gaps with the appropriate words or expressions.

which	resultant
mass	acceleration
constant	vector
variable	direction
whether	equal to

The 1 of an object is always 2
 the ratio between the 3 force and the object's
 4 Its acceleration is a 5 ,
 the direction of 6 is always equal to the
 7 of the resultant vector. Finally its acceleration
 remains 8 or varies, depending on
 9 the resultant is constant or 10

5 The bold words below are in the wrong sentences, so the sentences don't make sense at all! Using "Introduction" and "Expressing Newton's Second Law" to help you, put the bold words in the right sentences.

- Newton's second law of motion **causes** with nonzero net forces.
- A nonzero net force makes an object **accelerates** an acceleration.
- The harder you throw something, the faster it **decrease**.
- A nonzero net force **acts** acceleration.
- Friction causes the velocity of an object to **undergo**.
- Friction **deals** against the direction of motion.

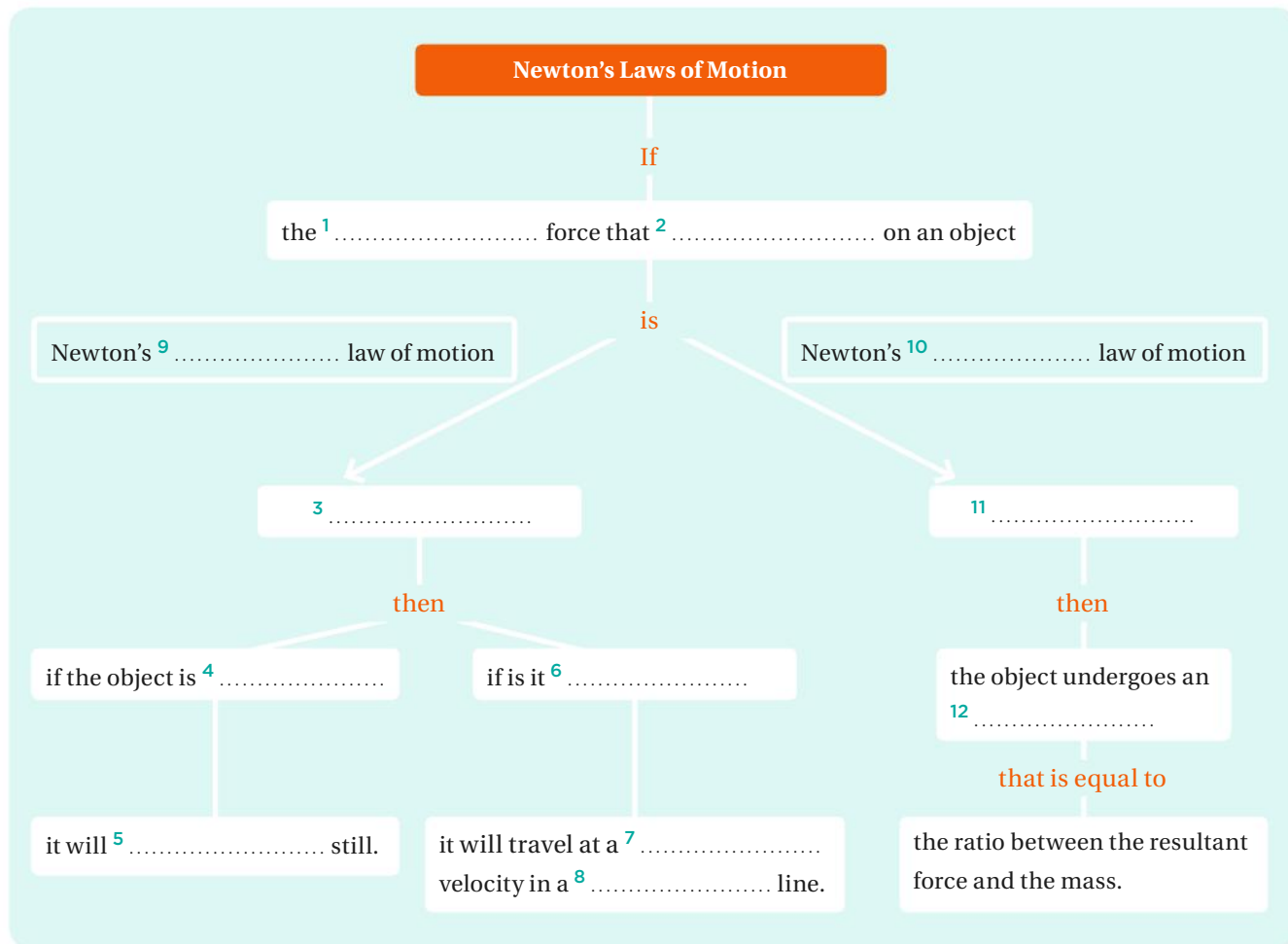
6 Fill in the gaps in the diagram with the appropriate words.

resultant
still
zero

remain
nonzero
constant

moving
straight
acceleration

first
second
acts



7 There are four statements after the following sentences. Which is correct? Explain why, and use the texts in this unit to help you.

1 A man is skiing down a hill at a constant speed.

- a The effect of friction caused by the ice cannot be ignored.
- b No forces are being applied to him.
- c It is possible that only a single force is acting on the skier.
- d The frictional force is lower than the gravitational force.

2 You hit an object, which experiences a net force and accelerates.

- a The acceleration has the same direction as the object's velocity.
- b The object moves in the direction of the net force.
- c The object moves in the opposite direction to the net force.
- d The object's acceleration has the same direction as the net force.

3 A car travelling westward suddenly begins to slow down.

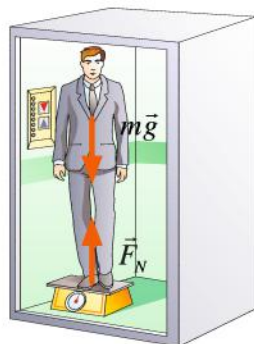
- a The braking force is directed westward but its intensity is decreasing.
- b The net braking force is directed eastward.
- c The braking force is directed westward and its intensity is increasing.
- d The net resultant force is directed westward.

Applied Physics

8 Weight loss

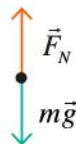
One day, your physics teacher asked you this question: “Would you like to lose weight? Don’t go on a diet! Just weigh yourself while going down in the lift!”

Is he totally deranged, or does physics have amazing effects? As Newton’s laws of motion are the foundation of dynamics, investigate this case using the most appropriate of Newton’s laws. Consider the following sketch diagrams. The one on the left shows a man in a stationary lift, while the one on the right shows a man going down in a lift at an acceleration of $\vec{a}$. He is reading his weight on a scale.

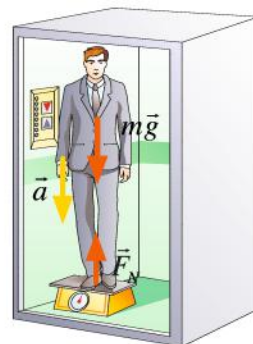


A. Man in a stationary lift.

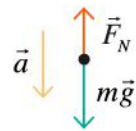
Free-body diagram



$\leftrightarrow m\vec{g}$ is the person’s weight, $\vec{F}_N$ is the normal force the scale exerts on the person and the weight measured by the scale, and $\vec{a}$ is the acceleration of the lift and the person.

B. Man in a lift moving downward at an acceleration of $\vec{a}$.

Free-body diagram



Known

Case A

Stationary lift $\rightarrow v_{\text{lift}} = \text{constant}, \vec{a} = 0$

Case B

$\vec{a}$ = the downward acceleration of the lift

Find

The man’s weight = $\vec{F}_N$

Analysis

The above diagrams show every force that acts upon the man, with the appropriate free-body diagram to the left. The force $\vec{F}_N$ is the force that the scale exerts on the man, and is equal and opposite to the force that he exerts on the scale. This force is what the scale measures.

In case A) no motion is occurring, so you have to use Newton’s first law of motion:

$$\Sigma \vec{F}_e = 0 \quad \text{which implies} \quad \vec{F}_N - m\vec{g} = 0 \quad \text{and therefore} \quad \vec{F}_N = m\vec{g}$$

In these equations, consider the x -axis to be positive to the right and the y -axis to be positive upward, as is conventional. Therefore, the weight measured by the scale is equal to mg .

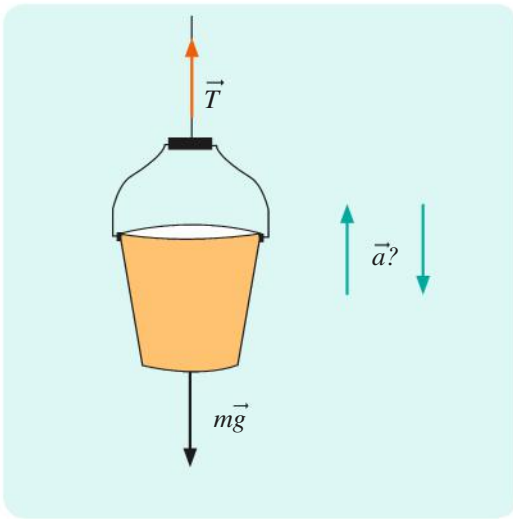
In case B) the system is accelerating, so you have to refer to Newton’s second law of motion:

$$\Sigma \vec{F}_e = -m \cdot \vec{a} \quad \text{which implies} \quad \vec{F}_N - m\vec{g} = -m \cdot \vec{a}$$

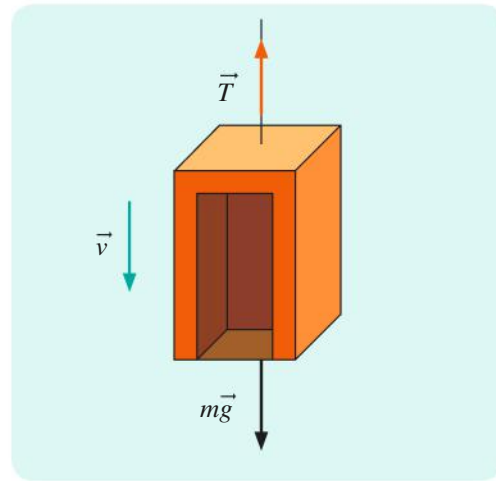
$$\text{Solve for } \vec{F}_N: \quad \vec{F}_N = m\vec{g} - m \cdot \vec{a}$$

So, the measurement taken in the moving lift is lower than that taken in the stationary lift. Take the mass of the man to be 65 kg, and the lift to be moving at an acceleration of 1 m/s². Calculate the man’s weight at rest, and his weight in motion. His weight at rest is equal to 637 N, which is the gravitational force corresponding to a mass of 65 kg, while his weight in motion is 572 N, which corresponds to a body mass of 58.3 kg. The man has lost weight without going on a diet!

- 9 A 16 kg bucket is moved vertically by a rope which has an average tension of 163 N. What is the average acceleration of the bucket? Will it move upwards or downwards?



- 10 An elevator hanging from a single cable is moving downwards and slowing down. Suppose friction and air resistance to be negligible. Is the tension of the cable greater than, less than, or equal to the gravitational force on the elevator?



PRODUCTION

- 11 Working in groups, discuss the following questions and then write down your answer. When you have finished, compare your answers with the other groups.

- One of your classmates is explaining Newton's laws of motion to you, and he asserts that if you throw a ball upward, gravitational force is exerted on the ball at every point in its path except for the highest point. Is this statement correct? Why, or why not?
- Your friend asks you to push his sled along the ice. You push it with a constant force for 10 seconds, and having started at rest the sled achieves a final velocity of 5 m/s. Then you decide to repeat the experiment with another friend of yours, who helps you push the sled. If both friends working together now apply a force twice the size of the previous one, how long will it take for the sled to reach the same speed of 5 m/s?
- The engines of the two cars in the following diagram are leaking oil. Examine the diagram and answer the following questions for each car:
 - What is the direction of net force?
 - Can the situation be described using Newton's first law of motion or Newton's second law of motion?

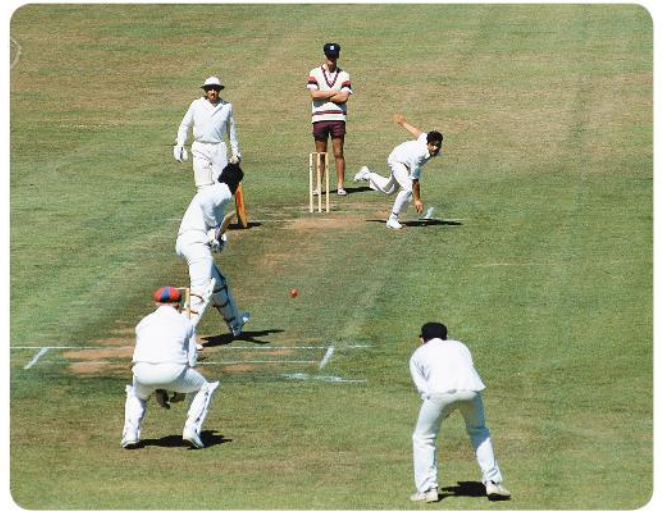


- In an advertisement, you read that a car is equipped with an airbag that will protect you using Newton's second law. Is this advert correct? Why, or why not?

- 12 One of your other teachers asks you what you have been studying. You all answer: "We've been learning about Newton's second law of motion." He asks you what Newton's second law of motion is, so you explain it to him. He smiles, and his response is simple: "I don't believe you. Prove it."

- First, get into groups of three people. Together, write a simple summary of Newton's second law in your own words.
- Galileo, in his experiments on motion and acceleration, used simple scientific equipment (the inclined plane) and simple situations (the Leaning Tower of Pisa) to test his ideas. Think of objects in and around the school that you could use to demonstrate, measure, and apply Newton's second law. Together, make a list of objects you could use, and agree on an experiment to show your teacher.
- Thirdly, discuss the details of the experiment: how will you perform it, and why? Together, write down a procedure for your experiment.
- Finally, choose one student from your group to roleplay the sceptical teacher. He or she should observe the experiment of a different group, and point out any problems or contradictions.

- 13** You and your partner both want to buy a new scooter, but you don't have enough money. So, you decide to make money by writing a bestselling diet book: *The Newton's Second Law Weight Loss Plan*. Together, discuss your proposal and how you will present it to the (not very clever) people who buy your book. Then, write the introduction to the book, outlining the basic idea. Remember: the more convincing you are, the more money you will earn!
- 14** A fielder in a cricket match moves his arms back when he tries to catch a cricket ball. With your partner, search the Internet to find out why he does this, and write your answer as a short report. Is it related to anything you have just studied?



Dynamics: General Strategy for Solving Problems

All examples presented in this section can be approached using a four-part strategy. You will become a better problem-solver if you adhere to this strategy when you do your homework problems.

	Equilibrium Problems Objects at rest or moving at a constant velocity.	Dynamics Problems Accelerating objects.
Model	Make a simplified assumption, if necessary.	Make a simplified assumption, if necessary.
Visualise	• Translate the words into symbols. • Draw a sketch to visualise the situation. • Identify the forces involved. • Draw a free-body diagram.	• Translate the words into symbols. • Draw a sketch to visualise the situation. • Draw a motion diagram or a few sketches representing different moments on the object's path. • Identify the forces involved. • Draw a free-body diagram.
Solve	Use Newton's first law of motion $\vec{F}_{net} = \Sigma \vec{F}_e = 0$ Take the vectors from the free-body diagram.	Use Newton's second law of motion $\vec{F}_{net} = \Sigma \vec{F}_e = m \cdot \vec{a}$ Take the vectors from the free-body diagram and use kinematics to find the velocity and positions.
Assess	Is the result reasonable?	Is the result reasonable?

Newton's Third Law of Motion

LEAD-IN

1 Working in groups of three or four, state whether the following sentences are *true* or *false*, and correct the false ones.

- 1 The gravitational force acting on an object with a mass of 10 kg is twice that which acts on an object with a mass of 5 kg. As a result, the heavier mass will fall faster than the lighter one.
- 2 In a basketball game, you dribble the ball: in other words, you drop the ball to the floor and it bounces back up. No force is required to make it bounce back.
- 3 A truck hits a car at the intersection of two streets. The force exerted by the truck on the car is equal to that exerted by the car on the truck.

T F

T F

T F

2 Match the terms (1-6) to their corresponding definitions (a-f).

- ☐ 1 Plastic polymer
- ☐ 2 Anticlockwise
- ☐ 3 Action force
- ☐ 4 Backwards
- ☐ 5 Reaction force
- ☐ 6 Upwards

- a Moving in or facing a higher position.
- b Moving in or facing the opposite direction to normal.
- c The force exerted by an object in response to the force exerted upon it.
- d A substance made of giant molecules formed by the union of simple molecules (monomers).
- e In the opposite direction to the movement of a clock's hands.
- f The initial force exerted upon an object.



THROWING THE JAVELIN

The sport of javelin-throwing came from the spears thrown by pre-historic humans. Later on, the Greeks hunted with javelins, fought with javelins, and threw javelins in athletic competitions. The Greek athlete took a few quick steps, moved his right leg forward, and then threw the javelin as hard as he could. It flew forwards and upwards, and eventually landed point-first in the ground. The throw did not count if the javelin didn't hit a specific target, so the most powerful throw was not always the best one. It became an Olympic sport in 1908, and also became a women's event in 1932. It was originally dominated by Scandinavians, who won the first six gold medals. In 1996 a world record of 98.48 meters was set by the Czech javelin thrower Jan Zelezný.

READING AND LISTENING

Newton's Third Law of Motion

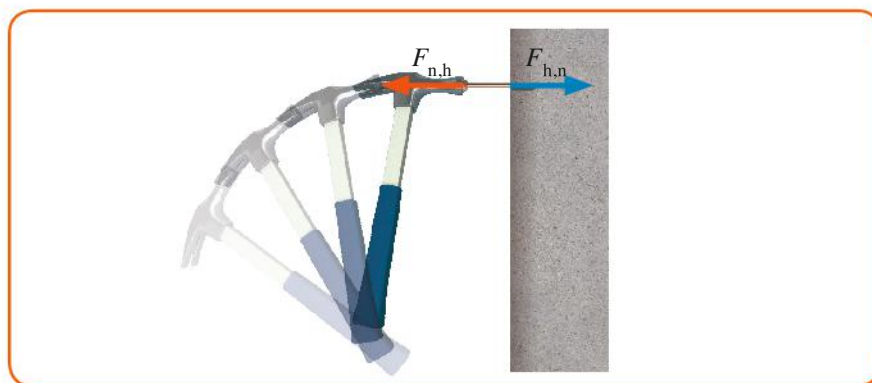
Introduction



If you bang your leg on a wall or the edge of a table, you feel pain. This is because a force has acted upon your leg, and the harder you hit it, the greater that force is. Similarly, if you kick a football while bare-footed, you feel a force acting against your foot. Where does that force come from? How can a table or a ball exert a force on you?

Newton hypothesised that **nature never generates a single force; forces always occur in pairs**. This is a simple statement but not an easy one, and it shows Newton's deep insight. Even though you continually encounter examples of Newton's third law of motion in your everyday life, you rarely notice them.

When, for example, you are hammering a nail into a wall, you are always aware of the force that you are exerting upon the nail. Note that the hammer suddenly stops when it hits the nail; what causes this rapid deceleration? Newton's second law of motion states that a body always undergoes acceleration when a nonzero net force acts upon it.



← Hammer and nail: the hammer exerts a force on the nail, pushing it into the wall, and the nail exerts a force upon the hammer that makes it stop.

Newton argued that exerting a force was not a one-sided process. So, every time the hammer exerts a force on the nail, the nail applies a force to the hammer in return. This force causes the hammer to slow down rapidly and stop. In the figure above, $F_{n,h}$ is the force that the hammer exerts on the nail, while $F_{h,n}$ is the reaction force that the nail exerts on the hammer.

COMPREHENSION QUESTIONS 1

Answer the following questions.

- 1 Is it possible for a stationary object to exert a force upon you?
- 2 Why does the hammer in the diagram to the left stop?
- 3 Can you give any other examples of pairs of forces?

Expressing Newton's Third Law



Newton's third law of motion states that:

if an object (A) exerts a force on another object (B), then object B will react, exerting upon object A an equal force in the opposite direction.

It is very important to note that even though the first force (**the action force**) and the second force (**the reaction force**) are equal in magnitude and opposite in direction, **they act on different objects**. You probably know the popular paraphrase of Newton's third law: "**for every action**

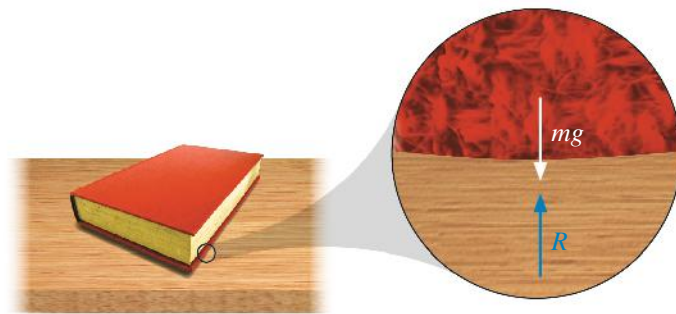
there is an equal and opposite reaction". This statement, though not wrong, very often causes misunderstanding as it doesn't explicitly state that those forces act on two different objects.

How can a table or a nail exert a force in return? This is a good question, and explains why you are seldom aware of applications of Newton's third law. In fact, you are probably used to associating the concept of force with actions, like those of people, animals, and objects in motion (the hammer or a car). It is hard to imagine that a motionless object, like a table or wall, can **exert** a force. The explanation is that every material, no matter how hard it is, deforms when a force is applied to it. The extent of its deformation depends on the hardness of its material, but a microscopic or macroscopic deformation always occurs. The fibres of a wooden table and the polymers of a plastic one both resist deformation induced by force, exerting an equal and opposite reaction force against the action force. The intensity of the reaction force is proportional to the strength of the bond between the atoms or molecules that make up the table's material. An object like a book and a hard object like a table react equally to the identical forces exerted upon them, but their deformations are different.

COMPREHENSION QUESTIONS 2

Answer the following questions.

- 1 What changes when the action force changes direction during an interaction between two objects?
- 2 How can a motionless object exert a force?
- 3 Does a marble table deform when a pot is resting on its surface?



The Student who Wouldn't Help his Teacher!

LISTENING ACTIVITY

With your partner, consider the gaps in the text to the right. Try to put the right words in each gap. When you have finished, listen to the text to check your answer. Were they correct?

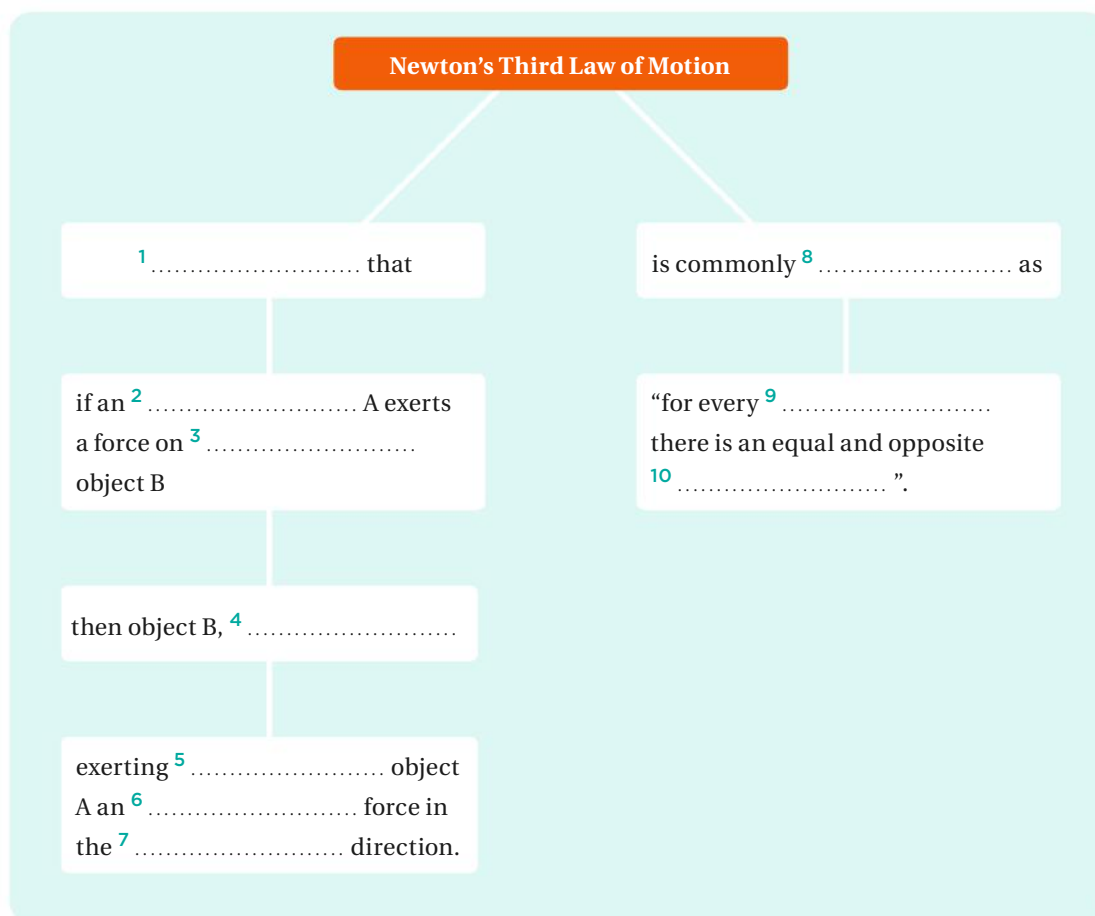
said anything simple
asked him to help push the car
two days ago
your class
equal
you realised that
fortunately
how could I ever move it
see you
completely flat

You are a physics teacher, and ¹ you explained Newton's third law to ² School was over, and you were driving home when ³ your car battery was ⁴ ⁵ , one of your students turned up, but when you ⁶ , he seemed a bit puzzled and said: "Sir, I'd love to help you, but I can't! You've just taught me that if I exert a force on your car, it will apply an equal force to me in the opposite direction. So ⁷ ? No matter how strong I am, your car will exert an ⁸ force back on me, so the net force will always be equal to zero. Sorry, Sir. ⁹ !" Is he very clever, or would it have been better to explain Newton's third law to him again the next day? Could you have ¹⁰ to explain his mistake? Just to prevent teachers having to go home by bus, discuss this case in pairs.

PRACTICE

3 Fill in the gaps in the diagram with the appropriate words.

upon
equal
opposite
states
reaction
object
another
reacts
action
paraphrased



4 There are four statements after the following sentences. Which is correct? Explain why, and use the texts in this unit to help you.

- 1 **You are in the middle of a frozen lake, and the ice is so slippery that you cannot walk. What should you do to get back to the shore?**
 - a Take off your bag and throw it away in order to be lighter.
 - b Wait for help, because you can't do anything.
 - c Throw your heavy backpack away from the shore.
 - d Throw your heavy backpack towards the shore.
- 2 **How can you move a canoe forwards?**
 - a By paddling backwards with the oar.
 - b By paddling forwards with the oar.
 - c By paddling hard.
 - d By following the flow of the water.
- 3 **A mosquito collides head-on with a car travelling at 60 km/h.**
 - a The acceleration of the mosquito is greater than the acceleration of the car.
 - b The acceleration of the mosquito is equal to the acceleration of the car.
 - c The acceleration of the car is greater than the acceleration of the mosquito.
 - d You don't have enough information to choose a, b, or c.

Applied Physics

Examples of Newton's Third Law of Motion

Since Newton's third law of motion is a universal law, there are examples everywhere. A few significant cases will be presented here.

A sprinter

Observe the athlete shown to the right: she is exerting a backward horizontal force $F_{m,g}$ on the ground with her feet. The harder the woman's feet push backwards, the quicker she goes. It may seem strange that the force acting in the opposite direction is the cause of her motion, but it's true! The athlete applies the force $F_{m,g}$ to the ground, and the ground exerts a force $F_{g,m}$ back upon her. This second force is equal in magnitude but opposite in direction.

So: $F_{m,g} = -F_{g,m}$ where the minus sign indicates the opposing directions of the two forces.

Note that these two forces are opposite, but their sum is not equal to zero! How is that possible? Is dynamics teaching you new rules of mathematics? No, don't worry: the maths you know still works, but remember that the two opposite forces are exerted on different objects, so adding them doesn't make sense. This why action and reaction force appear neither in a free-body diagram nor in a calculation of force for Newton's second law of motion, in which ΣF_e only includes forces that act on the single body in question.

Cars and Rockets

Now, you know that running, walking and climbing all occur thanks to Newton's third law of motion. What about machines like cars and rockets? If someone asked you what powers a car, you'd probably say "the engine". But can you say what applies the force that makes the car move forward? Working in groups of four, investigate this case using Newton's third law of motion.

Car tyres exert a backward horizontal force $F_{c,g}$ while turning anticlockwise. As a result of this, the ground applies a horizontal force, pushing the car forward. The reaction force the ground exerts on the car causes it to accelerate and move forward in proportion to the intensity of the backward force.



F = force m = woman g = ground

COMPREHENSION QUESTIONS 3

Answer the following questions.

- 1 Does this example also explain why a man can climb the stairs?
- 2 What would be different if the ground were frozen?
- 3 In the example, why isn't the sum of $F_{m,g}$ and $F_{g,m}$ equal to zero?



COMPREHENSION QUESTIONS 4

Answer the following questions.

- 1 How does a rocket take off?
- 2 What exerts the force that a car needs to move forwards?

5 Essential Verbs

Below are six structures that are often used when speaking about forces in English: the verb "to act" can be accompanied by four prepositions, with three different meanings! Find an example in this unit of each of the structures below, and translate the verb into Italian using that context.

- 1 to act in (the direction of motion)
- 2 to act against (the direction of motion)
- 3 to act on/upon (an object)
- 4 to exert (a force) on/upon
- 5 to cause
- 6 to power

6 Expressions of equality

Look at the expressions of equality, and use the right ones to complete the sentences.

is the same
is equal to

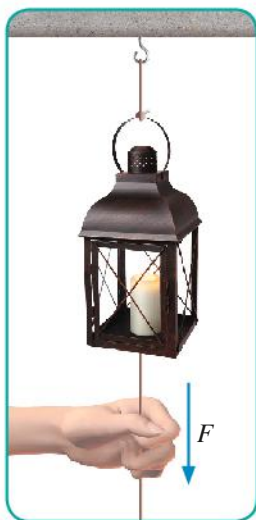
is no difference between
is constant

- 1 The intensity of the action force that of the reaction force.
- 2 There the length of the action force and reaction force vectors.
- 3 The direction of the resultant force and the direction of the acceleration of the object
- 4 The speed of an object sliding on ice This is in accordance with the first Newton's law of motion.

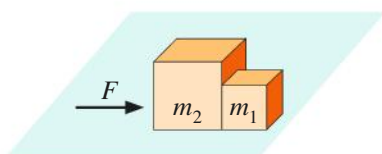
PRODUCTION

- 7** Working in groups, discuss the following questions and then write down your answer. When you have finished, compare your answers with the other groups.

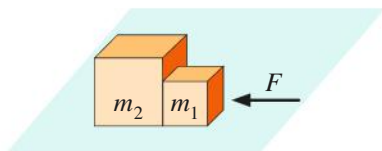
- 1** Your teacher wants to test you, so he has hung a heavy lantern from the ceiling by a thin wire, and has attached another wire to the bottom of the lantern. He asks you to pull on the lower wire in such a way that you won't break the wire connecting the lantern to the roof. Be careful! You are underneath the lantern, so if you get it wrong, the lantern will give you a pretty bad headache! Should you give it a sharp pull or a gentle pull in order to break the lower wire? Discuss it with your partner and write an explanation of your decision.



- 2** When the traffic light turns green, your car starts moving and you accelerate at 2 m/s^2 . If you and the car have a total mass of 1100 kg , do you think that the Earth will accelerate in the opposite direction in obedience to Newton's third law of motion? If so, assuming the mass of the Earth to be equal to $5.97 \cdot 10^{24} \text{ kg}$, how great is the Earth's acceleration?
- 3** You are reading a classmate's notepad. He is very good at physics, and you find two diagrams similar to the ones below in his notes:



← A force (F) is acting on the left side of two boxes in contact with each other.

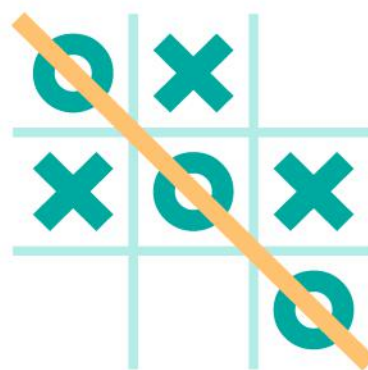


← The same force is now acting on the right side of those boxes.

Then, you read the following lines below the diagrams in his notepad "The resultant acceleration is the same in both cases, but the contact forces between the boxes change depending on whether the force acts on the left side or the right side." Is the last statement correct? Why, or why not?

- 4** At a picnic last Sunday, ten boys (five in each team) played a game of tug-of-war. Later, the minibus got stuck in a hole at the side of the road when they were going home. So, they tied the rope to the minibus's bumper, and all ten boys pulled. After a while, the rope broke. If this rope didn't break during tug of war, why did it break when they used it to pull the car out of the ditch?

- 8** Working in two groups, follow the teacher's instructions to play noughts and crosses.

Instructions

- The class divides into two teams: team A (X) and team B (O).
 - Each team makes a list of questions about Newton's first, second and third laws of motion.
 - The teacher flips a coin to decide who goes first.
 - The first player asks a question to the other team. If the answer is correct, then that team put their mark ("O" or "X") in one square of the grid on the board. Then, they ask a question to the other team.
 - The two teams continue taking turns, answering and putting "O" or "X" in the grid if they get the question right.
 - If a team answers incorrectly, the turn passes to the other team.
 - The team that gets three of their symbol in a row (diagonal, horizontal or vertical) wins.
 - When you have finished, break up into groups of six and keep playing!
- 9** Open up today's newspaper, or go to your favourite newspaper's website. Draw a Venn diagram representing the things that can be analysed using Newton's first, second, and third laws of motion.

Test your Competences

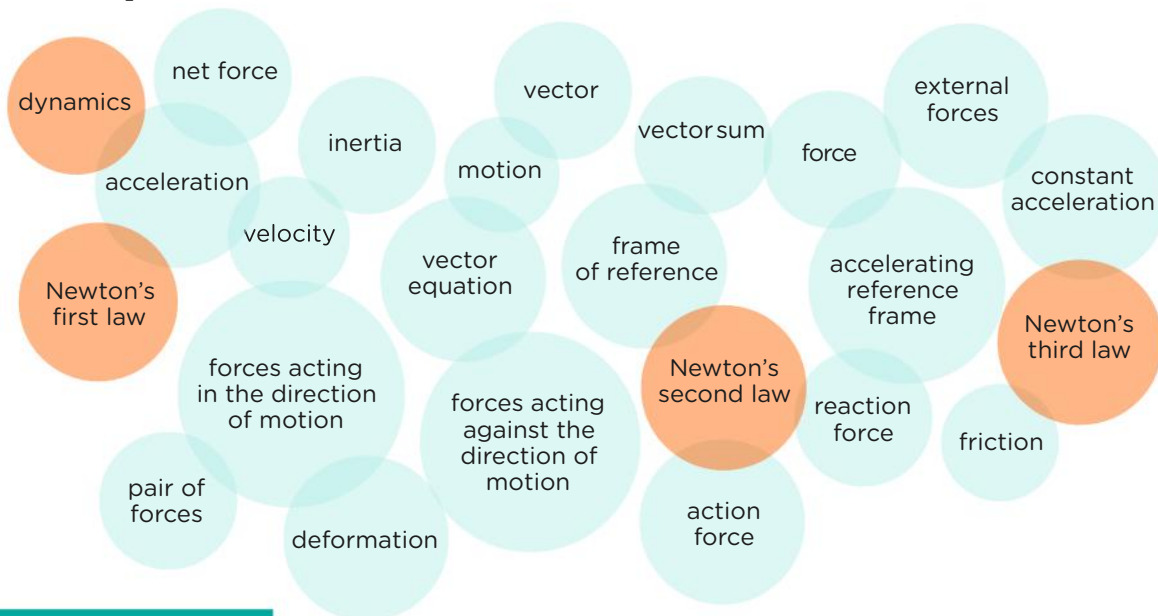
DISCUSSION

1 There are many applications of Newton's laws of motion. Read the situations described below with your partner. Thinking about how Newton's laws apply to them, discuss each case with your partner and write a short scientific explanation.

- 1 As you're riding a skateboard, you hit a stone and fly forwards off the board.
- 2 A basketball player is dribbling a basketball.
- 3 The passenger on the back seat of a motorbike moves backwards or forwards whenever the bike accelerates or decelerates.
- 4 A block of mass m is being held on an inclined sheet of ice, and is at rest. When it is released, it starts moving.
- 5 A boy is paddling a canoe with his oar.

MIND MAP

- 2** With your partner, consider the ideas in the following diagram. What are they, and what is their significance to dynamics and Newton's laws? If you're not sure, look back through your notes.
- Working with your partner, draw a mind map using the words from the circles and any others you think are necessary. It may be a good idea to start with the orange circles.
 - Draw links between the ideas on your map to show how they are logically connected, and explain them to another pair of students. Make brief notes next to the links.



RESEARCH

3 Form groups of three, and use the school library and the Internet to find out how the following topics were relevant to Newton's life.

- "Diamond"
- Gottfried Leibniz
- The Royal Mint

Include this information in a short report on Newton's life and discoveries. Remember to divide your tasks with the rest of your group in order to produce one report.