UNIT

1 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.

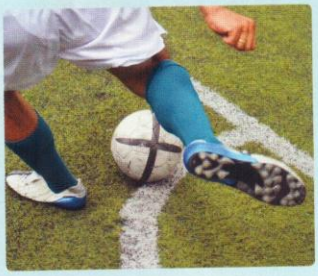
2 Match the terms (1-8) to their corresponding definitions (a-h).

- ☐ 1 Force
- ☐ 2 Dynamics
- ☐ 3 Frame of reference
- ☐ 4 Kinematics
- ☐ 5 Acceleration
- ☐ 6 Vector
- ☐ 7 Inertia
- ☐ 8 Scalar

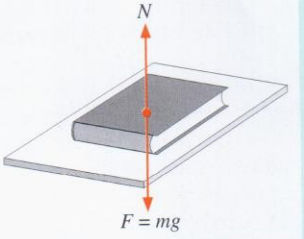
a A physical entity with both an appropriate unit and a direction.
b A coordinate system used to measure the properties of a physical entity.
c The property of matter that keeps an object in the same position, or keeps it moving at a constant velocity and direction.
d The rate of change of velocity over time.
e A physical entity with an appropriate unit.
f The branch of physics that studies what causes the motion of a system, especially those causes which originate outside the system (external forces).
g The cause of every change in the velocity of an object.
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?

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.

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?

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.

COMPREHENSION QUESTIONS 3

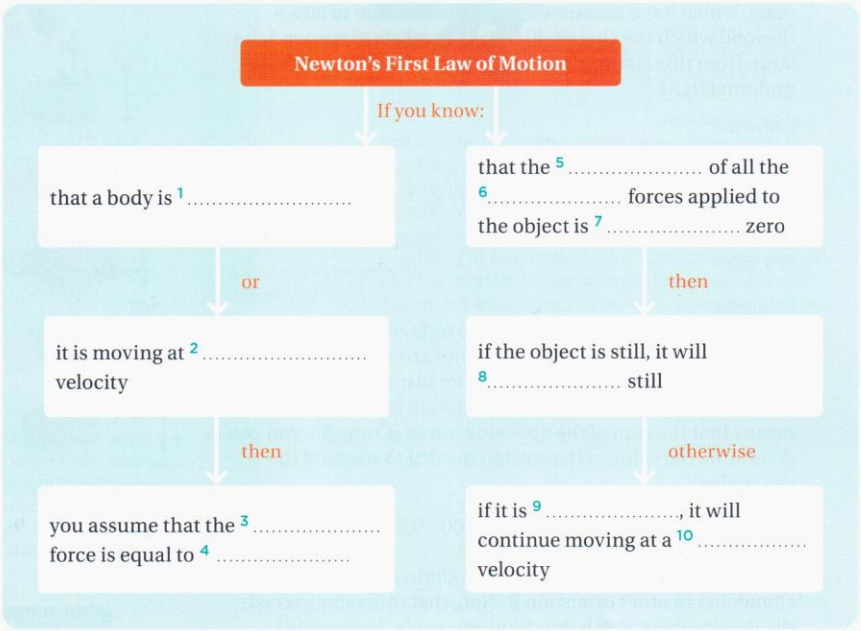
Answer the following questions.

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?

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?**

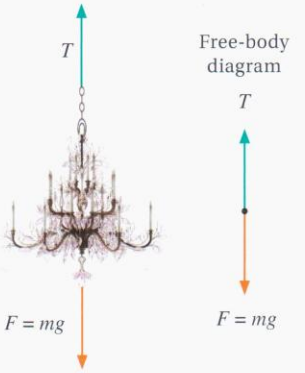
Known
lamp mass $m = 100$ kg
chain maximum strength $T_{max} = 900$ N
acceleration caused by Earth's gravity $g = 9.81$ m/s^2

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:

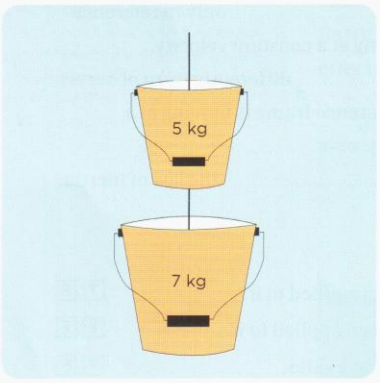
$$\Sigma F_{e,y} = T - mg = 0 \rightarrow T = mg = 100 \cdot 9.81 = 981 \text{ N}$$

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?



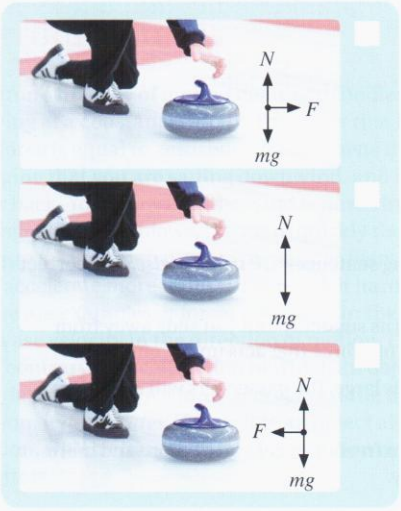
↑ Always draw a free-body diagram: it is a schematic representation of all of the forces (arrows) acting upon an object, which is shown as a point. Be sure to include every force acting on the object in question, but don't show forces acting upon other objects.

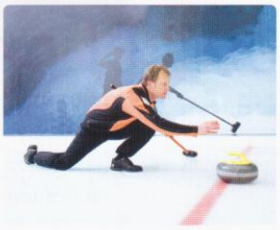
8 **A 7.0 kg paint bucket is hanging by a massless cord from another 5.0 kg paint bucket, which is also hanging by a similar massless cord as shown in the figure. Draw an appropriate free-body diagram and write what happens if the maximum tension of the cord is 70 N. Are the buckets at rest? If not,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