



In this activity you will see how Newton's Laws of Motion are used to connect the motion of an object with the forces acting on it. You will practise applying Newton's three laws in some real contexts.

### Information sheet

In 1687, Isaac Newton published the *Principia*. In this book he brought together his understanding of mathematics and the science we now call physics.

Newton recognised that, when forces act, they change the motion of objects. Before this, dating as far back as Aristotle (384–322 BC), it was thought that forces caused motion.

If Aristotle and Newton were to slide stones across the ice, Aristotle would suggest they need a force to keep them going. Newton would argue that, if a force acts on the stones, they will accelerate. The stones actually decelerate, slowing down so that they eventually stop.

### Thinking about Newton's Laws

Read the statements about each of Newton's First, Second and Third Laws.

Think about how it applies in each of the situations described in each section.

Write down your thoughts about the questions asked.

Draw diagrams to help explain your thinking.

#### Newton's First Law

**A particle will remain at rest or continue to move uniformly in a straight line unless acted upon by a non-zero resultant force.**

##### In Newton's words:

*'Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon.'*

Modelling the apple as a particle, the forces acting on it are the tension in its stalk and its weight.

There is no resultant force, so the apple remains at rest.

Apple attached to tree

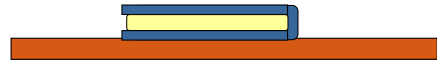


## Notes on Newton's First Law

**Uniform motion** is motion with constant velocity. As velocity includes speed *and* direction, uniform motion is motion with constant speed and always in the same direction.

A body with no resultant force acting on it is in **equilibrium**. It is in **static equilibrium** if it is not moving; it is in **dynamic equilibrium** if it is moving with constant velocity.

**A** The diagram shows a book lying on a table.



### Think about ...

- What forces are acting on the book?
- What does Newton's First Law tell you about them?

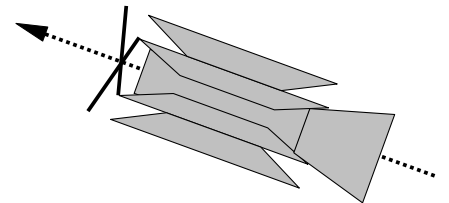
**B** This picture shows a ball thrown through the air. Neglect air resistance.



### Think about ...

- What forces are acting on the ball?
- What is the resultant force acting on the ball?
- Consider horizontal and vertical forces separately. Apply Newton's First Law in each direction.
- What does Newton's First Law suggest will happen to the ball?
- What effect does ignoring air resistance have on the answer?

**C** A space probe is shown here travelling freely, without using its rockets, in deep space.



### Think about ...

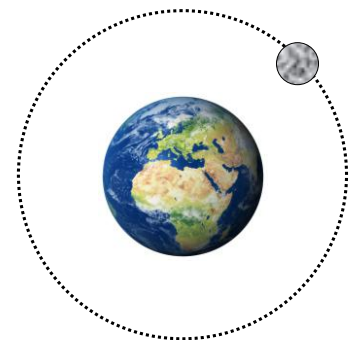
- What does Newton's First law predict will happen to the space probe?

**D** The Moon travels in a nearly circular orbit about the Earth.

### Think about ...

- What does Newton's First law tell you about the motion of the Moon?

It was by thinking about such motion that Newton arrived at his three Laws. He was able to explain the motion of the Moon rotating about the Earth, and the motion of an apple falling to the ground, using the same underlying principles.



## Newton's Second Law

If a non-zero resultant force acts on a particle, then the particle will not be in equilibrium. A resultant force,  $F$  newtons, acting on a particle of mass  $m$  kilograms, will give rise to acceleration,  $a \text{ m s}^{-2}$ , of the particle.

The acceleration is in the direction of the resultant force and the magnitude of the acceleration is given by the relationship:

$$F = ma$$

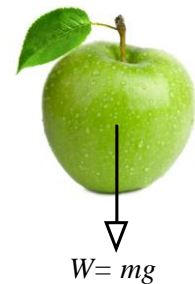
**One newton** is defined as the force required to give a mass of 1 kg an acceleration of  $1 \text{ m s}^{-2}$ .

Modelling the apple as a particle, the resultant force acting on it is its weight,  $mg$  newtons. It accelerates vertically downwards;  $a = g = 9.8 \text{ m s}^{-2}$  when air resistance can be considered negligible.

### In Newton's words:

*'The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.'*

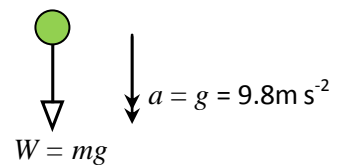
Apple falling from a tree



## Notes on Newton's Second Law

Newton's Second Law brings together the ideas of a **gravitational force** and **acceleration due to gravity**. The weight of an object is the force of attraction due to the Earth. It is the weight of an object that causes it to accelerate.

If you apply Newton's Second Law to a mass of  $m$  kilograms near the Earth's surface, you find that it has a weight,  $W = mg$ .



**E** The picture shows a ball thrown through the air. Neglect air resistance.

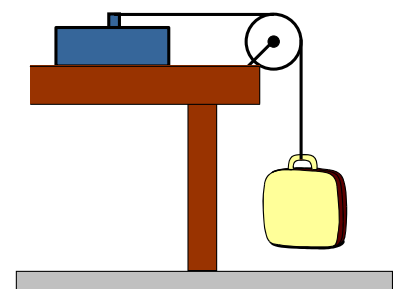
### Think about ...

- What is the resultant force acting on the ball?
- Apply Newton's Second Law in both the horizontal and vertical directions to explain the motion of the ball.

**F** One end of a light inextensible string is attached to an empty tool box which is lying on a smooth table. The string passes over a smooth pulley and is tied at the other end to a heavy bag as shown. When this system is released from rest the bag falls vertically to the ground.

### Think about ...

- Use Newton's Second Law to explain the motion of the tool box.
- Use Newton's Second Law to explain the motion of the bag.



## Newton's Third Law

Every force arises as the action of one body on another. The objects are subject to forces that are equal in magnitude and act in opposite directions.

The force on the apple due to the table is equal and opposite to the force on the table due to the apple.

Apple on a table



### In Newton's words:

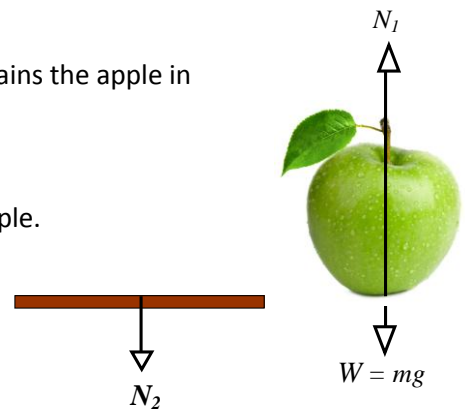
*'To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal and directed to contrary parts.'*

## G Forces on the apple

$N_1$  is the normal contact force acting on the apple. This force maintains the apple in equilibrium.

### Force on the table due to the apple

$N_2$  is the force that acts on the table because of  $N_1$  acting on the apple.

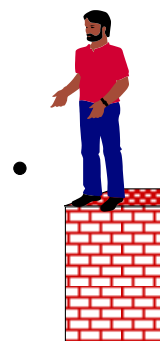


### Think about ...

- What is the magnitude of the normal contact force on the apple?
- What is the magnitude of the force that acts on the table because of the apple?
- What happens to the magnitudes of the forces if the mass of the apple is increased?
- How does Newton's Third Law apply in this situation?

## H Think about a falling ball (neglecting air resistance).

- What is the resultant force acting on the ball? What causes this?
- How does Newton's Third Law apply in this case?



## Try these

Use Newton's Laws to answer the following questions.

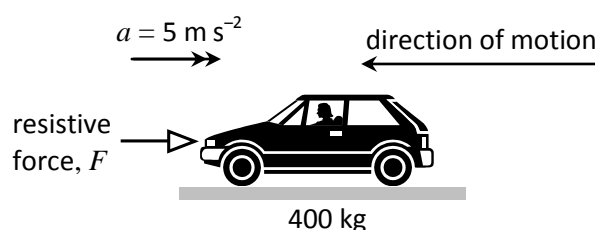
Model all objects as particles.

Take the acceleration due to gravity to be  $g = 9.8 \text{ m s}^{-2}$ .

**1** A resultant force of 6 newtons acts on a particle of mass 3 kilograms. What is the acceleration?

**2** What force applied to a mass of 2.5 kg will cause an acceleration of  $8 \text{ m s}^{-2}$ ?

**3** A car of mass 400 kg travels along a horizontal road with constant deceleration  $5 \text{ m s}^{-2}$ . Find the resultant horizontal resistive force,  $F$ , acting on the car.



**4** A tennis player serves a ball of mass 55 grams. Consider the ball at any point on its path before it bounces. Assume that air resistance is negligible.

**a** What is the magnitude and direction of the ball's acceleration?

**b** What is the magnitude and direction of the resultant force acting on the ball?

**5** A train of total mass 150 tonnes decelerates at  $2 \text{ m s}^{-2}$  as it approaches a station along a straight horizontal track. (1 tonne = 1000 kg)

Find the magnitude of the resistive force,  $F$ .



**6** A woman drags a heavy load of mass 50 kg across a floor with a force of 70 N.

Modelling the floor as smooth and the load as a particle, and assuming that the rope is horizontal, calculate the acceleration of the load.

**7a** A particle of mass 5 kg is acted upon by a horizontal force of 80 N. Find the horizontal acceleration of the particle.

**b** A particle of mass 5 kg is acted upon by a force of 80 N acting vertically upwards. The only other force on the particle is its weight. Find the acceleration.

**8** A book, of mass 200 g, rests on a table within the carriage of a train. The train accelerates at  $0.5 \text{ m s}^{-2}$  out of a station.



- a** Draw the forces acting on the book.
- b** If the book does not slip, find the magnitude of the friction force acting on the book.

**9** A driver of mass 57 kg is sitting in the driving seat of a car at rest. There is no contact between the driver's back and the seat.

- a** Draw a diagram of the forces acting on the driver.
- b** The driver starts the car, and accelerates at  $1 \text{ m s}^{-2}$  along a horizontal road.
  - i** Draw a new force diagram showing the forces now acting on the driver.
  - ii** Find the value of the resultant force acting on the driver, and state where it comes from.

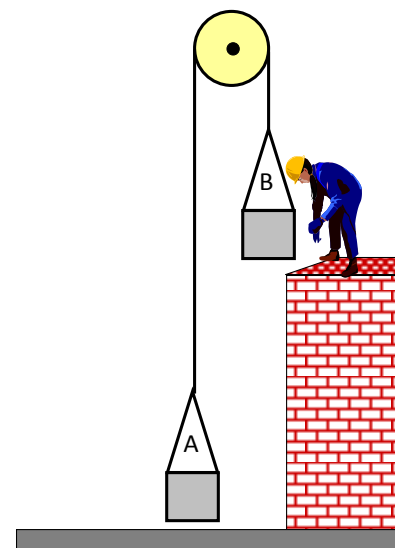
**10** Horizontal forces of 5 newtons and 3 newtons act on a particle of mass 2 kilograms. Find the acceleration produced if these forces:

- a** act in the same direction
- b** act in opposite directions.

**11** A builder raises bricks to the top of a building using a pulley system. Each platform has a mass of 20 kg. When both platforms are empty they hang in equilibrium, with the lower platform just off the ground, as shown in the diagram.

To lower platform B, the builder adds to it a load of 10 kg.

- a** Draw force diagrams showing the forces acting on:
  - i** the lower platform, A
  - ii** the upper platform, B
- b** Use Newton's Second Law to write down equations relating the forces acting on each platform to the acceleration of each.



*Hint:* Assume that the platforms are attached by a light, inextensible string passing over a smooth pulley, so that each platform will have the same acceleration, and the tension in both parts of the rope will be equal.

- c** Calculate the acceleration of each platform, and the tension in the rope.

**12** A hotel guest travels by lift from the ground floor to the fourth floor with her suitcase in her hand. The mass of the hotel guest is 70 kg and the mass of the suitcase is 20 kg.

The lift accelerates at  $0.5 \text{ m s}^{-2}$  as it sets off from the ground floor, and decelerates at  $0.4 \text{ m s}^{-2}$  as it nears the 4<sup>th</sup> floor.

- a** Draw force diagrams showing the forces acting on:
- the suitcase
  - the hotel guest as the lift sets off from the ground floor.
- b** Use Newton's Second Law at the time the lift sets off from the ground floor to find:
- the force exerted by the hotel guest on her suitcase.
  - the normal reaction between the hotel guest and the floor of the lift.
- c** Use Newton's Second Law at the time the lift nears the 4<sup>th</sup> floor to find:
- the force exerted by the hotel guest on her suitcase.
  - the normal reaction between the hotel guest and the floor of the lift.
- d** Explain briefly when, on her lift journey, the hotel guest will feel the true weight of her suitcase.

### Reflect on your work

- What are Newton's three Laws?
- If an object is moving, how can you tell if it is in equilibrium?  
Which of Newton's Laws are you using?
- How is your weight related to your acceleration due to gravity?  
Which of Newton's Laws are you using?