Chapter 3
Forces and motion

IN THIS CHAPTER YOU WILL:

- discover the differences between mass and weight
- describe the ways in which a resultant force may change the motion of a body
- find the resultant of two or more forces acting along the same line
- find out about the effect of friction (or air resistance or drag) on a moving object

> learn about circular motion

> learn how force, mass and acceleration are related

> define what a force is, understand the concepts of momentum and impulse and apply the principle of the conservation of momentum

> understand the difference between scalars and vectors and learn how to determine the resultant of two vectors acting at right angles to each other.

GETTING STARTED

Look at the following questions. Your teacher will give you some time to think about them on your own. You may also take some time to discuss them with the person sitting next to you. Be prepared to share your answers with the class.

1 While sitting on your seat, describe any forces acting on you.

2 Imagine a ball thrown in the air. Sketch the ball. Draw an arrow or arrows to show any forces acting on the ball and, if possible, label the arrows.

3 Describe daily life without friction. What do you think would change the most?

4 Look at Figure 3.1 and decide which path the Earth would follow if gravity stopped acting.

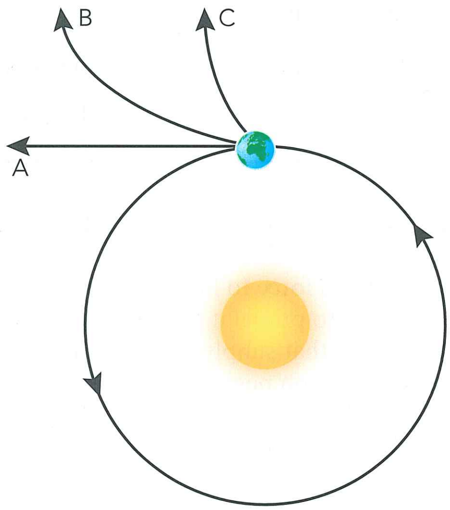


Figure 3.1: The Earth orbiting the Sun. Which of the paths would Earth follow if the Sun suddenly stopped existing?

HYPERLOOP ONE: SUPERSONIC TRAVEL INSIDE VACUUM TUBES

Transport systems would be much more efficient if less energy was wasted working against friction or air resistance. Hyperloop One promises to get rid of both. Elon Musk proposed it on 12 August 2013 as a faster alternative to air travel. It combines two existing technologies – maglev (magnetic levitation) and vactrain (vacuum tube train). Maglev trains use magnetic repulsion (like poles repel) to make the train float, which eliminates friction. A linear motor then accelerates the train: magnetic attraction (unlike poles attract) pulls the train from the front while magnetic repulsion pushes it from behind. The trains will travel through tubes with most of the air removed using pumps. This will allow them to travel at Mach 7 (that is, seven times the speed of sound at sea level). This is about 2000 m/s, much faster than supersonic aircraft. In 2016, Hyperloop One launched its Hyperloop One Global Challenge and selected five countries for the development of the hyperloop networks: US, UK, Canada, Mexico, and India.

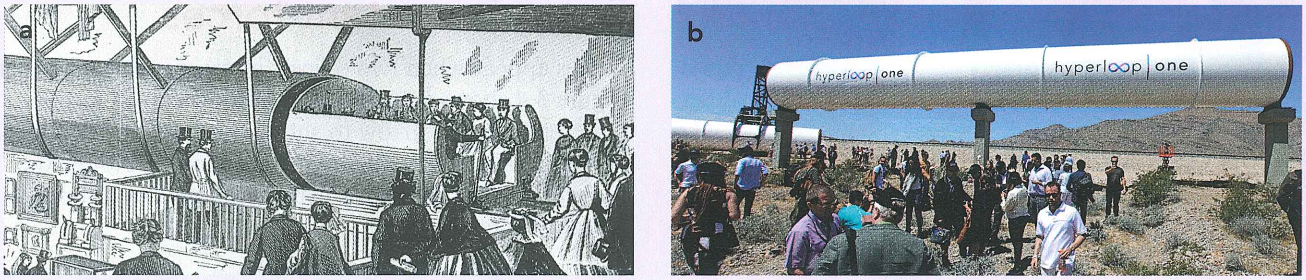


Figure 3.2a: The idea of passengers travelling through a tube is not new. Passengers taking a ride in the first pneumatic passenger railway in the US, erected at the Exhibition of the American Institute at the Amory, New York City, in 1867.
b: A Hyperloop tube on display during the first test of the propulsion system at the Hyperloop One Test and Safety site on 11 May 2016 in Las Vegas, Nevada.

CONTINUED

Discussion questions

1 Describe the ways in which friction will be reduced in Hyperloop One.

2 Describe any potential dangers of travelling in Hyperloop One.

3.1 We have lift-off

It takes an enormous force to lift a giant space shuttle off its launch pad, and to propel it into space (Figure 3.3). The booster rockets that supply the initial thrust provide a force of several million newtons. As the spacecraft accelerates upwards, the crew experience the sensation of being pressed firmly back into their seats. That is how they know that their craft is accelerating.

Figure 3.3: A space shuttle accelerating away from its launch pad. The force needed is provided by several rockets. Once each rocket has used all its fuel, it will be jettisoned (dropped), to reduce the mass that is being carried up into space.

Unbalanced forces change motion

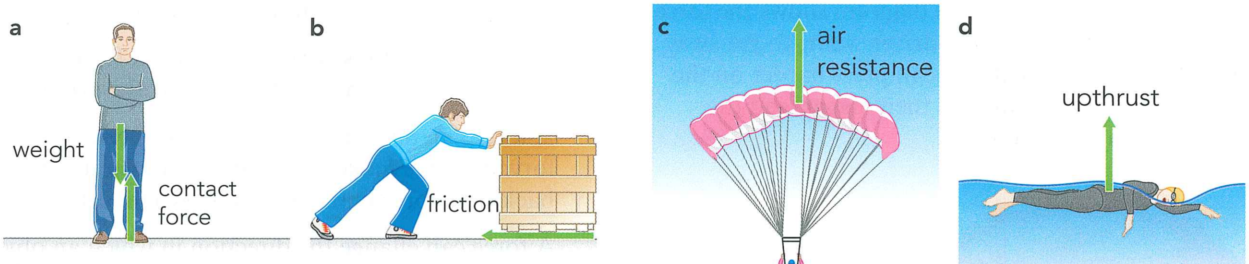
One moment, the shuttle is sitting on the ground, stationary. The next moment, it is accelerating upwards, pushed by the force provided by the rockets.

In this chapter, we will look at how **forces** – pushes and pulls – affect objects as they move. You will be familiar with the idea that the unit used for measuring forces is the **newton** (N). To give an idea of the sizes of various forces, here are some examples:

- You lift an apple. The force needed to lift an apple is roughly one newton (1 N).
- You jump up in the air. Your leg muscles provide the force needed to do this, about 1000 N.
- You reach the motorway in your high-performance car, and press the accelerator pedal. The car accelerates forwards. The engine provides a force of about 5000 N.
- You are crossing the Atlantic in a Boeing 747 jumbo jet. The four engines together provide a thrust of about 500 000 N. In total, that is about half the thrust provided by each of the space shuttle's booster rockets.

Some important forces

Forces appear when two objects interact with each other. Figure 3.4 shows some important forces. Each force is represented by an arrow to show its direction. Usually, the longer the arrow, the bigger the force is. Notice the convention that the arrow usually points away from the object of interest.



The **weight** of an object is the pull of gravity on it. Weight always acts vertically downwards. When two objects touch, there is a **contact force**. It is the contact force that stops you falling through the floor.

Friction opposes motion. Think about the direction in which an object is moving (or trying to move). Friction acts in the opposite direction.

Air resistance or **drag** is the force of friction when an object moves through air or water.

Upthrust is the upward push of a liquid or gas on an object. The upthrust of water makes you float in the swimming pool.

Figure 3.4: Some common forces.

The car shown in Figure 3.5 is moving rapidly. The engine is providing a force to accelerate it forwards, but there is another force acting, which tends to slow down the car. This is **air resistance**, a form of **friction** caused when an object moves through the air. (Friction is also called **drag**, especially for motion through liquids.) The air drags on the object, producing a force that acts in the opposite direction to the object's motion.

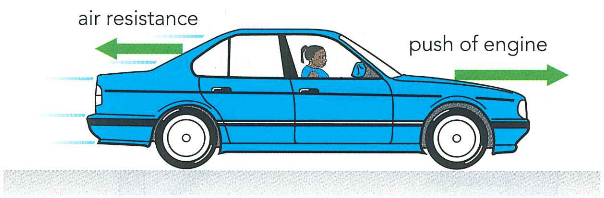


Figure 3.5: A car moves through the air. Air resistance acts in the opposite direction to its motion.

A driver who needs to stop quickly will apply the brakes to take advantage of **solid friction**, when two surfaces make contact (the brake pads and brake discs, in this case). The kinetic energy of the car transfers into thermal energy, raising the temperature of the brakes. You can demonstrate this for yourself by rubbing your hands together. Energy transformations like these are discussed in more detail in Chapter 6. Solid friction exists even when the surfaces are not moving against each other, unless one or both surfaces are like ice and offer almost no resistance to motion (then they are said to have a very low coefficient of friction). Compare standing on concrete with standing on ice. There is much more solid friction on concrete and you do not have to think about keeping your balance. The solid friction between the sole of your shoes and concrete impedes motion (so reduces the possibility of slipping) and, because there is no motion of one surface against another, there is no increase in thermal energy. If you are running quickly on concrete and fall over you may notice that the graze on your knee feels hot. This is because your kinetic energy transfers into thermal energy due to the solid friction between your skin and concrete. A 'shooting star' is a meteor (lump of rock that burns up in our atmosphere). It shows that air resistance and drag lead to the transfer of kinetic energy to thermal energy.

KEY WORDS

force: the action of one body on a second body; unbalanced forces cause changes in speed, shape or direction

newton (N): the force required to give a mass of 1 kg an acceleration of 1 m/s^2

air resistance: friction acting on an object moving through air

friction: the force that acts when two surfaces rub over one another

drag: friction that acts on an object as it moves through a fluid (a liquid or a gas)

solid friction: the resistance to motion caused when two surfaces are in contact

Unbalanced forces produce acceleration

The car driver in Figure 3.6a is waiting for the traffic lights to change. When they go green, he moves forwards. The force provided by the engine causes the car to accelerate. In a few seconds, the car is moving quickly along the road. The arrow in the diagram shows the force pushing the car forwards. If the driver wants to get away from the lights more quickly, he can press harder on the accelerator. The forward force is then bigger, and the car's acceleration will be greater.

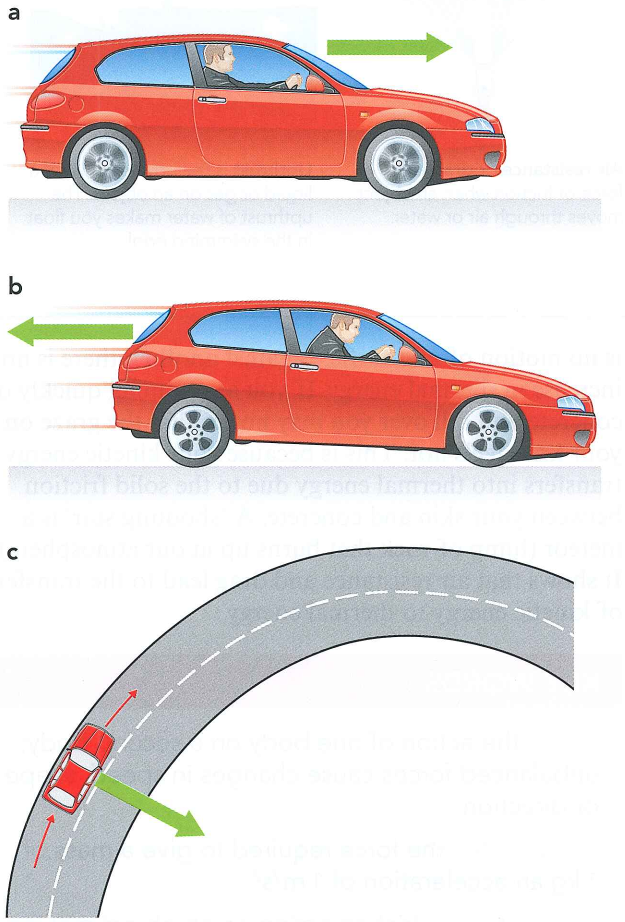


Figure 3.6: A force can be represented by an arrow. **a:** The forward force provided by the engine causes the car to accelerate forwards. **b:** The backward force provided by the brakes causes the car to decelerate. **c:** A sideways force causes the car to change direction.

The driver reaches another junction, where he must stop. He applies the brakes. This provides another force to slow down the car (see Figure 3.6b). The car is moving forwards, but the force needed to make it decelerate is directed backwards. If the driver wants to stop in a hurry, a bigger force is needed. He must press hard on the brake pedal, and the car's deceleration will be greater.

Finally, the driver wants to turn a corner. He turns the steering wheel. This produces a sideways force on the car (Figure 3.6c), so that the car changes direction.

To summarise, we have seen several things about forces:

- They can be represented by arrows. A force has a direction, shown by the direction of the arrow.
- A force can make an object change speed. A forward force makes it speed up (accelerate), while a backward force makes it slow down (decelerate).
- A force can change the direction in which an object is moving.

This can be summarised by saying that a body will remain at rest or will move at a constant speed in a straight line unless acted upon by a resultant force. There are alternative ways of saying the same thing. For example, a resultant force will change the speed or direction of a body. However, the problem with this statement is that some people forget to include starting and stopping as changes in speed. Another alternative is to say that a resultant force will change the velocity of a body, but as velocity is a vector, a resultant force can change the direction as well as the speed of a body. A resultant force can change both speed and direction at the same time.

Question

1 Figure 3.7 shows three objects that are moving. A force acts on each object. For each, say how its movement will change.

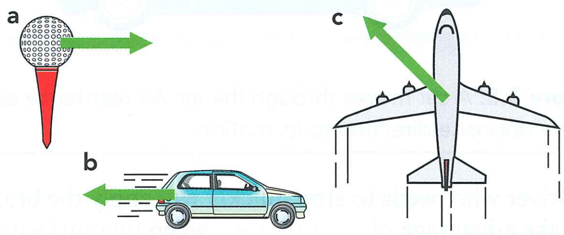


Figure 3.7: Three moving objects.

Two or more forces along the same straight line

The two forces acting on the car in Figure 3.8a are:

- push of engine = 600 N to the right
- drag of air resistance = 400 N to the left.

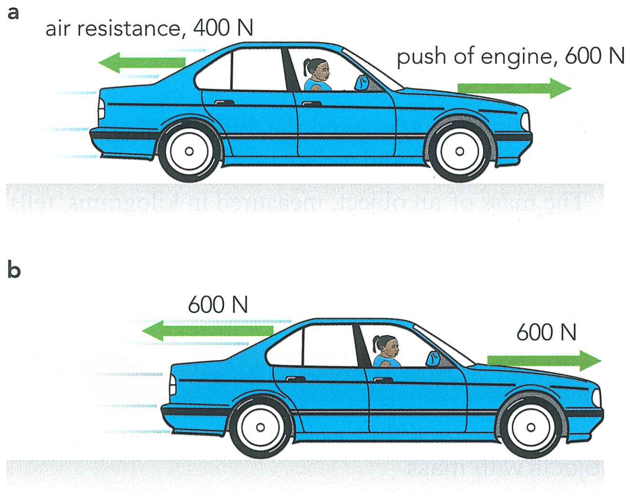


Figure 3.8: A car moves through the air. Air resistance acts in the opposite direction to its motion.

We can work out the combined effect of these two forces by subtracting one from the other to give the **resultant force** acting on the car. The resultant force is the single force that has the same effect as two or more forces. So, in Figure 3.8a:

resultant force = 600 N − 400 N

= 200 N to the right

This resultant force will make the car accelerate to the right, but not as much as if there was no air resistance.

In Figure 3.8b, the car is moving even faster, and air resistance is greater. Now the two forces cancel each other out. So, in Figure 3.8b:

resultant force = 600 N − 600 N = 0 N

We say that the forces on the car are balanced. There is no resultant force and so the car no longer accelerates. It continues at a constant speed in a straight line.

- If no resultant force acts on an object, it will not accelerate; it will remain at rest or it will continue to move at a constant speed in a straight line.
- If an object is at rest or is moving at a constant speed in a straight line, we can say that there is no resultant force acting on it.

KEY WORDS

resultant force: the single force that has the same effect on a body as two or more forces

Question

2 The forces acting on three objects are shown in Figure 3.9.

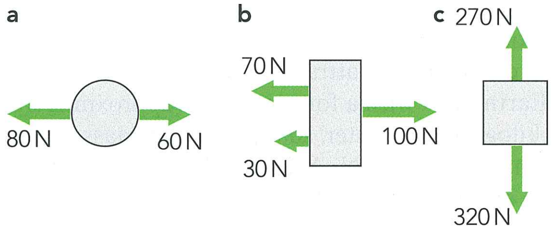


Figure 3.9: Forces acting on three objects.

For each of a, b and c:

i state whether the forces are balanced or unbalanced

ii if the forces are unbalanced, calculate the resultant force on the object and give its direction

iii state how the object's motion will change.

3.2 Mass, weight and gravity

If you drop an object, it falls to the ground. It is difficult to see how a falling object moves. However, a multi-flash photograph can show the pattern of movement when an object falls.

Figure 3.10 shows a ball falling. There are seven images of the ball, taken at equal intervals of time. The ball falls further in each successive time interval. This shows that its speed is increasing – it is accelerating.

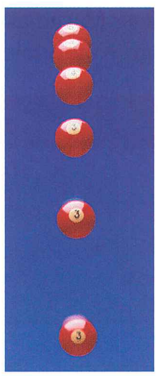


Figure 3.10: The increasing speed of a falling ball is captured in this multi-flash image.

When an object accelerates, there must be a force that is causing it to do so. In this case, the force of **gravity** is pulling the ball downwards. The name given to the gravitational force acting on an object that has mass is its weight. Because weight is a force, it is measured in newtons (N).

Every object on or near the Earth's surface has weight. This is caused by the attraction of the Earth's gravity. The Earth pulls with a force of 10 N (approximately) on each kilogram of matter, so an object of mass 1 kg has a weight of about 10 N. Actually, the Earth pulls with a force of 9.8 N on each kilogram so an object of mass 1 kg has a weight of 9.8 N.

Because the Earth pulls with the same force on every kilogram of matter, every object falls with the same acceleration close to the Earth's surface. If you drop a 5 kg ball and a 1 kg ball at the same time, they will reach the ground at the same time.

The acceleration caused by the pull of the Earth's gravity is called the **acceleration of free fall** or the **acceleration due to gravity**. This quantity is given the symbol g and its value is approximately constant close to the surface of the Earth. It is approximately 9.8 m/s^2.

Calculating weight and gravitational field strength

We have seen that an object of mass 1 kg has a weight of 9.8 N; an object of mass 2 kg has a weight of 19.6 N; and so on. To calculate an object's weight W from its mass m, we multiply by 9.8, the value of the acceleration of free fall g. We can write this as an equation in words and in symbols:

weight = mass × acceleration of free fall

$$W = mg$$

The **gravitational field strength** at a point is the gravitational force exerted per unit mass placed at that point. From the equation, $W = mg$, the gravitational field strength, g, is:

KEY EQUATION

$$\text{gravitational field strength} = \frac{\text{weight}}{\text{mass}}$$

$$g = \frac{W}{m}$$

On the Earth's surface, the gravitational field strength is 9.8 N/kg. It has the same value as the acceleration of free fall or acceleration due to gravity that we met earlier and is often rounded up to 10 N/kg.

Distinguishing mass and weight

It is important to understand the difference between the two quantities, mass and weight.

- The mass of an object, measured in kilograms, tells you how much matter an object is composed of.
- The weight of an object, measured in newtons, is the gravitational force that acts on the object.

KEY WORDS

gravity: the force that exists between any two objects with mass

acceleration of free fall: the acceleration of an object falling freely under gravity

acceleration due to gravity: the acceleration of an object falling freely under gravity

gravitational field strength: the gravitational force exerted per unit mass placed at that point

If you take an object to the Moon, it will weigh less than it does on Earth, because the Moon's gravity is weaker than the Earth's. However, its mass will be unchanged, because the object is made of just as much matter as when it was on Earth.

When we weigh an object using a balance, we are comparing its weight with that of standard weights on the other side of the balance (Figure 3.11). We are making use of the fact that, if two objects weigh the same, their masses will be the same. We always talk about weighing an object. However, if the balance we use has a scale in kilograms or grams, we will find its mass, not its weight.

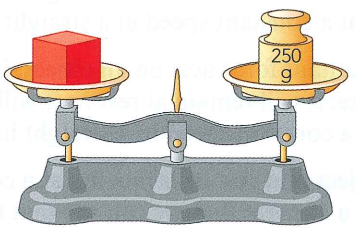


Figure 3.11: When the balance is balanced, we know that the weights on opposite sides are equal, and so the masses must also be equal.

Questions

3 List the differences between mass and weight.

4 A bag of sugar has a mass of 1 kg so its weight on Earth is 10 N. What can you say about the bag's mass and its weight if you take it:

a to the Moon, where gravity is weaker than on Earth?

b to Jupiter, where gravity is stronger?

5 a Look at Table 3.1. Calculate the missing values i–v. Show your method.

Planet or asteroid	Object on planet or asteroid	Mass of object / kg	Acceleration due to gravity / m/s^2	Weight of object / N
Earth	astronaut	70	9.8	i
Moon	astronaut	ii	1.60	112.0
Jupiter	tin of beans	0.44	23.0	iii
Geographus (asteroid 1620)	bus	iv	0.00153	7.650
Toro (asteroid 1685)	astronaut	70	v	0.538

Table 3.1

b What do you notice about the mass of the astronaut?

c Explain why a tin of beans weighs more on Jupiter than a bus weighs on the asteroid Geographus.

3.3 Falling and turning

Objects fall to the ground because they have weight. Their weight is caused by the gravitational field of the Earth, pulling downwards on their mass. The Moon's gravitational field is much weaker, which is why objects weigh less when they are on the Moon.

In this section, we will look at two situations in which we have to take careful account of the directions of the forces acting on an object.

Falling through the air

The Earth's gravity is equally strong at all points close to the Earth's surface. If you climb to the top of a tall building, your weight will stay the same. We say that there is a uniform gravitational field close to the Earth's surface. This means that all objects fall with the same acceleration as the ball shown in Figure 3.10, provided there is no other force acting to reduce their acceleration. For many objects, the force of air resistance can affect their acceleration.

Parachutists make use of air resistance. A free-fall parachutist (Figure 3.12a) jumps out of an aircraft and accelerates downwards. Figure 3.12b shows the forces on a parachutist at different points in his fall. Notice that his weight does not change (so the length of the downward-pointing arrow does not change). At first, air resistance has little effect. However, air resistance increases with the speed of motion. As the parachutist falls faster, eventually air resistance balances his weight. Then the parachutist stops accelerating: he falls at a steady rate known as the **terminal velocity**. The resultant force on the free-fall parachutist is the result of two forces acting along the same line and acting in opposite directions.

KEY WORDS

terminal velocity: the greatest speed reached by an object when moving through a fluid

Opening the parachute greatly increases its area and hence the air resistance. Now there is a much bigger force upwards. The forces on the parachutist are again unbalanced, and he slows down. The idea is to reach a new, slower, terminal velocity of about 10 m/s, at which speed he can safely land. At this point, weight = drag, and so the forces on the parachutist are balanced.

Figure 3.12c shows how the parachutist's speed changes during a fall.

When the graph is horizontal, speed is constant and forces are balanced. When the graph is sloping, speed is changing. The parachutist is accelerating or decelerating, and forces are unbalanced.

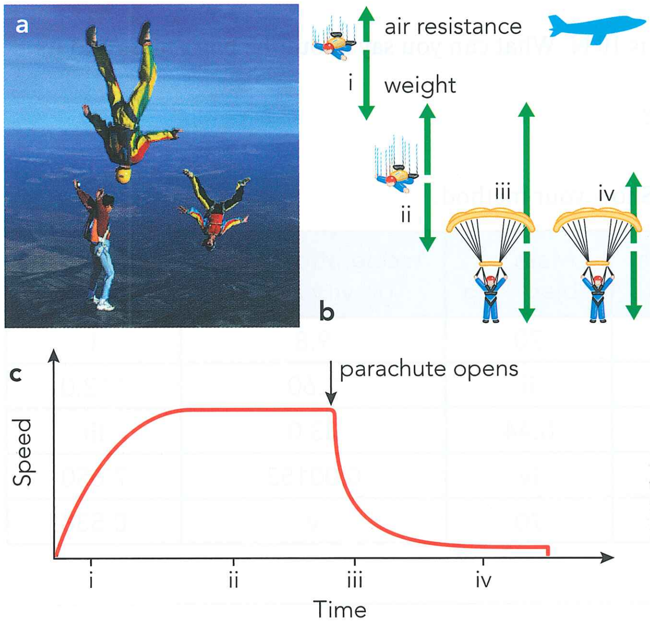


Figure 3.12a: Free-fall parachutists, before they open their parachutes. They can reach a terminal velocity of more than 50 m/s. **b:** The forces on a falling parachutist. Notice that his weight is constant. When air resistance equals weight, the forces are balanced and the parachutist reaches a steady speed. The parachutist is always falling (velocity downwards), although his acceleration is upwards when he opens his parachute. **c:** A speed–time graph for a falling parachutist.

Question

6 Look at the speed–time graph in Figure 3.12c. Find a point at which the graph is sloping upwards.

 a Is the parachutist accelerating or decelerating?

 b Which of the two forces acting on the parachutist is greater when the graph is sloping upwards?

 c Explain the shape of the graph after the parachute is opened.

Going round in circles

When a car turns a corner, it changes direction. Any object moving along a circular path is changing direction as it goes. A force is needed to do this. Figure 3.13 shows three objects following curved paths, together with the forces that act to keep them on track.

In Figure 3.13a, the boy is spinning an apple around on the end of a piece of string. The tension in the string pulls on the apple, keeping it moving in a circle.

In Figure 3.13b, an aircraft 'banks' (tilts) to change direction. The lift force on its wings provides the necessary force.

In Figure 3.13c, the Moon is held in its orbit around the Earth by the pull of the Earth's gravity.

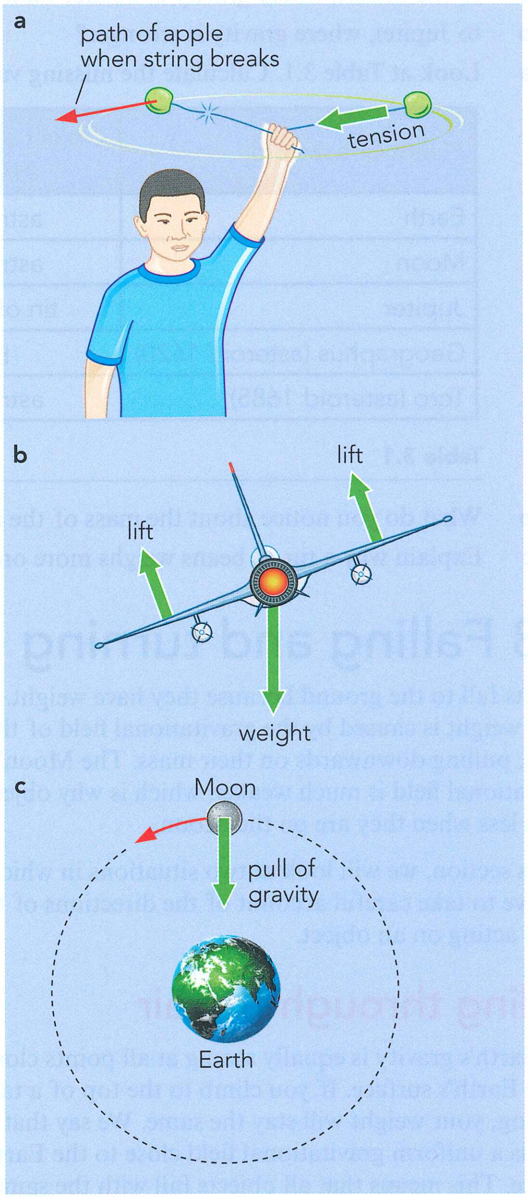


Figure 3.13: Examples of motion along a curved path. In each case, there is a sideways force holding the object in its circular path.

For an object following a circular path, the object is acted on by a force perpendicular (at right angles) to its motion. The force that keeps an object moving in a circle always acts towards the centre of the circle. If the force disappears, the object will move off at a tangent to the circle; it will not fly outwards, away from the centre.

By moving in a circle, an object will be changing direction continuously (all the time). Therefore, even if the object is moving at a constant speed, its velocity is changing. Remember that velocity is a vector and so has direction as well as magnitude (size). If the velocity of an object is changing, it must be accelerating. This means that an unbalanced force is acting on the object and this force acts towards the centre of the circle. The resultant force that acts towards the centre of a circle is the result of a force acting perpendicular to the motion of the object.

The size of the resultant force needed to make an object travel in a circle depends on the object's mass, its speed and the radius of the circle in which it is moving. A bigger force is needed if:

- the object's mass is bigger (and speed and radius stay the same)
- the object's speed is bigger (and mass and radius stay the same)
- the radius of the circle is smaller (and mass and speed stay the same).

An object moving in a circle is changing direction. It requires less force to change the direction of an object that has less mass. An insect is easier to deflect than a rhinoceros, even if the rhino is moving slowly. When you are travelling in a car, you will feel a bigger force when you travel faster round a bend in the road or when the bend is sharper.

The 'wall of death' is a stunt where motorcycles or cars appear to defy gravity as they are driven around the circular wall inside a giant cylinder (Figure 3.14a). The vehicles do not slide down the wall because their weight is balanced by friction. As they move faster, the force of friction increases because the force pushing the vehicle towards the centre of the cylinder increases. If they were to stop, the vehicles would slide down the wall.

A spin dryer works by spinning about its axis of symmetry. The walls push the clothes towards the centre of the drum. Water droplets pass out through the holes where they do not experience this force.

Some of you will have ridden a carousel or merry-go-round (Figure 3.14b). Passengers sit on a circular platform that is made to spin. It feels like you are being pushed outwards, away from the centre, but this is an illusion. If you were lucky your merry-go-round had seats with a railing along the circumference where you could sit facing the centre; it would feel like the railing

Figure 3.14a: The 'wall of death' in Rajkot, India.
b: A mother and her sons playing on a merry-go-round.

was pushing you towards the centre. Imagine the railings disappeared and there was nothing to hold onto. Where would you go? You would move at a tangent to the circular motion (along path A in Figure 3.1).

If you roll a ball along a flat surface it will move in a straight line until friction brings it to a stop. If someone pushes it at right angles to its motion, it will change direction. You may have seen a footballer gently tap a ball to divert it into the goal.

You might want to try the following challenge with a smaller ball. Gather some classmates around a square table. One of you rolls a marble or other small ball close to and parallel to an edge of the table. As the ball passes each person, they push it once with a flat edge like a ruler or book but only towards the centre of the table. See if you can get the ball to travel in a circle before it is slowed down by friction. As the ball slows down, you will notice that you need to apply a smaller force to keep it moving in a circle. If someone misses their turn, notice which way the ball moves. It should move in a straight line at a tangent to the circle, so long as the table is perfectly horizontal and there is no spin on the ball. If the Sun suddenly stopped existing the Earth would travel in a straight line in the direction that it was moving the instant the Sun disappeared.

Questions

7 Draw a diagram (seen from above) to show the forces acting on a car as it turns a corner.

8 What provides the force keeping the planets in orbit round the Earth?

9 Throwing the hammer is an Olympic sport (Figure 3.15), where the thrower spins around inside a circle while swinging a 'hammer'. Throwers spin as fast as they can before releasing the hammer. Looking down from above, sketch the path of the hammer moving in a circle followed by its path after it is released.

Figure 3.15: Zheng Wang of China competes in the Women's hammer throw in the 2019 World Championships.

Describe how the force needed by the athlete would change if:

a the speed of the hammer increased

b the length of the hammer was reduced

c the mass of the hammer increased.

3.4 Force, mass and acceleration

A car driver uses the accelerator pedal to control the car's acceleration. This alters the force provided by the engine. The bigger the force acting on the car, the bigger the acceleration it gives to the car. Doubling the force produces twice the acceleration; three times the force produces three times the acceleration, and so on.

There is another factor that affects the car's acceleration. Suppose the driver fills the boot with a lot of heavy boxes and then collects several children from college. He will notice the difference when he moves away from the traffic lights. The car will not accelerate so readily, because its mass has increased. Similarly, when he applies the brakes, it will not decelerate as readily as before. The mass of the car affects how easily it can accelerate or decelerate. Drivers learn to take account of this.

The greater the mass of an object, the smaller the acceleration it is given by a particular force.

So, big (more massive) objects are harder to accelerate than small (less massive) ones. If we double the mass of the object, its acceleration for a given force will be halved. We need to double the force to give it the same acceleration.

This tells us what we mean by mass. It is the property of an object that resists changes in its motion.

Force calculations

These relationships between force, mass and acceleration can be combined into a single, very useful, equation:

KEY EQUATION

force = mass × acceleration

$F = ma$

The force vector and the acceleration vector are in the same direction. This seems obvious when we are talking about increasing the engine force to make a car accelerate along a straight road, but recall from the previous section that the Earth must be accelerating towards the Sun because of the pull of the Sun's gravity.

The quantities involved in this equation, and their units, are summarised in Table 3.2. The unit of force is the newton. Worked Examples 3.1 and 3.2 show how to use the equation.

Quantity	Symbol	SI Unit
force	F	netwon, N
mass	m	kilogram, kg
acceleration	a	metres per second squared m/s^2

Table 3.2: The three quantities related by the equation force = mass × acceleration.

WORKED EXAMPLE 3.1

When you strike a tennis ball that another player has hit towards you, you provide a large force to reverse its direction of travel and send it back towards your opponent. You give the ball a large acceleration. What force is needed to give a ball of mass 0.10 kg an acceleration of 500 m/s^2?

Step 1: Write down what you know and what you want to find out:

mass = 0.10 kg

acceleration = 500 m/s^2

force = ?

Step 2: Substitute in the equation to find the force:

$$\text{force} = \text{mass} \times \text{acceleration}$$
$$= 0.10\,\text{kg} \times 500\,\text{m/s}^2$$
$$= 50\,\text{N}$$

Answer

You need to give the ball a force of 50 N.

Note that mass must be in kg (the base SI unit), not g, if the force is to work out in N.

WORKED EXAMPLE 3.2

An Airbus A380 aircraft (Figure 3.16) has four jet engines, each capable of providing 320 000 N of thrust. The mass of the aircraft is 560 000 kg when loaded. What is the greatest acceleration that the aircraft can achieve?

Figure 3.16: An Airbus A380.

Step 1: Write down what you know and what you want to find out:

force = 4 × 320 000 N = 1 280 000 N
(the greatest force provided by all four engines working together)

mass = 560 000 kg

acceleration = ?

Step 2: Substitute in the equation to find the acceleration:

$$\text{acceleration} = \frac{\text{force}}{\text{mass}}$$
$$= \frac{1280\,000\,\text{N}}{560\,000\,\text{kg}}$$
$$= 2.29\,\text{N/kg}$$

Answer

2.29 N/kg is the greatest acceleration the aircraft can achieve.

Questions

10 Look at Table 3.3. Calculate the missing values **a–d**. Show your working.

Force	Mass	Acceleration / m/s^2
a	50 kg	10
112 N	70 kg	b
110 kN	c	5
d	15 g	10

Table 3.3

11 **a** Calculate the weight of a brick that has a mass of 2.4 kg.

b The same brick falls with an acceleration of 9.8 m/s^2. Calculate the force on the brick.

c What can you say about your answers to parts **a** and **b**?

12 An accelerometer is a device that can detect and calculate acceleration. Calculate the acceleration of a 0.15 kg mass that experiences a force of 10 N.

ACTIVITY 3.1

Can mosquitoes fly in the rain?

Work in pairs. Using your physics knowledge and the information and data below, try to answer the question: can mosquitoes fly in the rain?

Once you have arrived at an answer, discuss it with another pair and be prepared to share your reasoning with the class.

If you are not sure where to start, work through the following questions:

1. What is the acceleration of the mosquito when hit by a raindrop in mid-air?
2. Calculate how many times bigger this is than the acceleration of free fall.
3. Do you think a human could survive this acceleration?
4. State the equation that relates force, mass and acceleration.
5. Calculate the force that the mosquito experiences.
6. Will a mosquito survive a mid-air collision with a raindrop?
7. Will a mosquito survive if it is sitting on a hard surface when struck with a raindrop? Calculate the force a raindrop would exert on a mosquito if the insect was sitting on a hard surface (such as a tree branch) and the raindrop came to a stop in 2×10^{-3} s.

In heavy rain, a mosquito might collide with a raindrop twice a minute.

If a raindrop hits a mosquito in mid-air, the mosquito falls with the raindrop for a few centimetres and the mosquito's speed increases from zero to 2.1 m/s in 1.5×10^{-3} s.

If a raindrop hits a mosquito when it is on a solid surface, such as a tree branch, the raindrop stops moving in 2×10^{-3} s.

speed of raindrops = 10 m/s
mass of raindrops = up to 100 mg
mass of mosquito = 2 mg
force that mosquito exoskeleton can survive = 0.03 N

REFLECTION

Did you need to use the questions to help you during the activity? Using these questions gives you some insight into how scientists might go about answering a question: they break a question or problem down into smaller steps or questions.

Were the questions helpful? If not, can you think of questions that would be more helpful? Could you suggest other questions to your teacher or classmates?

3.5 Momentum

A force will change an object's motion. It will make the object accelerate; it may make it change direction. The effect of a force F depends on two things:

- how big the force is
- the time interval Δt it acts for.

The bigger the force and the longer it acts for, the more the object's motion will change. The impulse equation sums this up:

$F\Delta t = mv - mu$

The quantity on the left, $F\Delta t$, is called the **impulse** of the force. On the right we have mv (mass × final velocity) and mu (mass × initial velocity).

The quantity mass × velocity is known as the **momentum** (p) of the object ($p = mv$), so the right-hand side of the equation $mv - mu$ is the change in the object's momentum, which can be written as:

$\Delta p = mv - mu = \Delta(mv)$

We can write the impulse equation like this:

impulse of force = change of momentum

Impulse and momentum are both defined by equations:

impulse = force × time for which it acts = $F\Delta t$

change in momentum = $\Delta p = \Delta(mv)$ so

impulse = $F\Delta t = \Delta(mv)$

KEY WORDS

impulse: the change in an object's momentum, Δp, or the force acting on an object multiplied by the time for which the force acts ($F \times \Delta t$)

momentum: the quantity mass × velocity, $p = mv$

KEY EQUATIONS

momentum = mass × velocity

$$p = mv$$

impulse = force × time for which the force acts

impulse = $F\Delta t = \Delta(mv)$

WORKED EXAMPLE 3.3

A car of mass 600 kg is moving at 15 m/s.

a Calculate its momentum.

The driver accelerates gently so that a force of 30 N acts on the car for 10 seconds.

b Calculate the impulse of the force.

c Calculate the momentum of the car after the accelerating force has acted on it.

Answer

a momentum = mass × velocity

= 600 kg × 15 m/s = 9000 kg m/s

b impulse = force × time = 30 N × 10 s = 300 N s

c The impulse of the force tells us how much the car's momentum changes. The car is speeding up, so its momentum increases by 300 N s.

final momentum = initial momentum + impulse of force

= 9000 + 300

= 9300 kg m/s

Note that the unit of momentum is kg m/s; this is the same as N s, the unit of impulse.

Questions

13 Calculate the momentum of a bullet of mass 10.5 g moving at 553 m/s.

14 A force of 500 N acts on a rocket for 600 s, causing the rocket's velocity to increase.

a Calculate the impulse of the force.

b By how much does the rocket's momentum increase?

Remember that $F = ma$. We know that $a = \frac{\Delta v}{\Delta t} = \frac{v-u}{\Delta t}$ so we can substitute for a to give:

$$F = m\left(\frac{v-u}{\Delta t}\right)$$

Expanding out the brackets gives:

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

Knowing that $\Delta p = mv - mu$, we can write the equation as:

$$F = \frac{\Delta p}{\Delta t}$$

KEY EQUATION

$$\text{resultant force} = \frac{\text{change in momentum}}{\text{unit time}}$$

$$F = \frac{\Delta p}{\Delta t}$$

So, the resultant force is the change in momentum per unit time.

This defines the force as the rate of change of momentum but it is really just a different way of writing the more familiar equation $F = ma$ in a way that makes it easier to explain some physics. For example, it explains why cars are fitted with seatbelts, airbags and crumple zones. It also explains why we automatically bend our knees when we jump down from a tall object.

When a car crashes at a given speed say, (10 m/s), the passengers experience the same impulse or change in momentum whether or not they are wearing seatbelts. However, the time taken to come to a stop increases for those wearing seatbelts. This makes the right-hand side of the equation $\left(F = \frac{\Delta p}{\Delta t}\right)$ smaller. This reduces the force experienced by the passengers, which reduces the risk of injury. The same reasoning can be applied to other safety measures, including the use of air bags in Worked Example 3.4.

WORKED EXAMPLE 3.4

Crash tests allow scientists to investigate the forces on passengers during collisions. In the first test, a car travelling at 15 m/s crashes into a wall (Figure 3.17). The crash test dummy, which has a mass of 70 kg, comes to a stop in 0.03 s. In the second test, the car is fitted with an airbag so the dummy takes five times longer to come to a stop. What forces are acting on the dummy in both tests?

CONTINUED

Figure 3.17: A crash test.

Step 1: Start by writing down what you know and what you want to know.

First test	Second test
$m = 70\,\text{kg}$	$m = 70\,\text{kg}$
$v = 15\,\text{m/s}$	$v = 15\,\text{m/s}$
$\Delta t = 0.03\,\text{s}$	$\Delta t = 0.15\,\text{s}$
$F = ?$	$F = ?$

Step 2: Now write down the equation.

$$F = \frac{\Delta p}{\Delta t}$$

Step 3: Substitute the values of the quantities on the right-hand side and calculate the answer.

First test	Second test
$F = \frac{70\,\text{kg} \times 15\,\text{m/s}}{0.03\,\text{s}}$ $= 3.5 \times 10^4\,\text{N}$	$F = \frac{70\,\text{kg} \times 15\,\text{m/s}}{0.15\,\text{s}}$ $= 7.0 \times 10^3\,\text{N}$

Answer

In the first test, the force on the crash test dummy was 3.5×10^4 N. In the second test, the force was 7.0×10^3 N. The airbag increased the time that it took for the dummy to come to a stop and reduced the force by a factor of five. An airbag reduces the risk of injury.

Question

15 In a car crash the driver and his passenger both experience the same impulse. However, the driver is wearing a seatbelt so it takes him longer to stop moving. Explain why his injuries are less serious than those of his passenger.

16 Superman is a fictional character who was made for life on the planet Krypton but arrived on Earth as a child. While he could have grown up to become average on Krypton, this question explores why he appears to have superpowers on Earth.

- **a** Write down an equation for force in terms of momentum and time.
- **b** Assume that Superman has a mass of 100 kg and launches himself upwards with a speed of 60 m/s. What force would he apply if he spent 0.25 s pushing off from the ground?
- **c** What is Superman's weight?
- **d** How many times bigger is the force he exerted (your answer to part **b**) compared to his weight (your answer to part **c**)?
- **e** Calculate the gravitational field strength of Krypton. (Hint: You need to know the value of the gravitational field strength for the Earth's surface and that, when most people jump, they apply a force approximately equal to their weight.)

ACTIVITY 3.2

Public awareness campaign

Work in pairs to develop your ideas and then join with another pair to complete the activity. Develop a public awareness campaign (posters, video clips) to highlight road traffic accidents (RTAs). The aim of your campaign is to reduce serious injury.

In your campaign make sure you include why the following are important in reducing serious injury in RTAs:

- keeping to speed limits
- wearing seatbelts
- installing airbags
- crumple zones on cars
- not driving after taking drugs
- not driving when tired.

Remember that the audience are not scientists, so you will need to explain, by using physics, why these precautions reduce serious injury in RTAs.

Momentum in a collision

Figure 3.18 shows a game of swing ball, in which a ball hangs from a length of string. The player hits the ball horizontally with a racket.

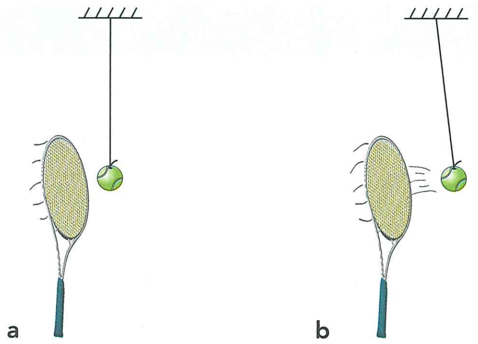


Figure 3.18: Hitting a ball with a tennis racket. **a:** Before the hit. **b:** after the hit.

How can we use the idea of momentum to describe what happens? We need to think about momentum before the racket collides with the ball, and then after the collision.

In Figure 3.18a, before the **collision**, the racket is moving to the right; it has momentum. The ball is stationary, so it has no momentum.

In Figure 3.18b, after the collision, the racket is moving to the right, but more slowly than before. It has lost momentum. The ball is moving rapidly to the right. It has gained momentum.

So you can see that, when the racket exerts a force on the ball, momentum is transferred from the racket to the ball. Whenever a force acts on an object, its momentum changes. At the same time, the momentum of the object causing the force also changes. If one object gains momentum, then the other loses an equal amount of momentum. This is known as the **principle of the conservation of momentum**.

KEY WORDS

collision: the meeting of particles or of bodies in which each exerts a force upon the other

principle of the conservation of momentum: the total momentum is constant and does not change because of an interaction between bodies (such as collisions)

We can state the principle in a different way. Whenever two objects interact, the total amount of momentum before they interact is the same as the total amount of momentum afterwards:

total momentum before = total momentum after

Worked Example 3.5 shows how we can use this to work out how fast the ball in Figure 3.18 will be moving after it has been hit by the racket.

WORKED EXAMPLE 3.5

During a game of swing ball, a player hits the ball horizontally with a racket.

- mass of tennis racket = 3.0 kg
- velocity of tennis racket before it strikes the ball = 20 m/s
- velocity of tennis racket after it strikes the ball = 18 m/s
- mass of tennis ball = 0.25 kg
- velocity of tennis ball before the racket strikes it = 0 m/s

Find:

a the momentum of the racket

 i before the collision

 ii after the collision

b the momentum of the ball after the collision

c the velocity of the ball.

Answer

a momentum = mass × velocity

 i Before the collision:

 momentum = 3.0 kg × 20 m/s = 60 kg m/s

 ii After the collision:

 momentum = 3.0 kg × 18 m/s = 54 kg m/s

 Note: After the collision, the racket is moving more slowly and so its momentum is less.

b The momentum gained by the ball is equal to the momentum lost by the racket.

 So, momentum of ball = 60 kg m/s − 54 kg m/s

 = 6.0 kg m/s

c We can calculate the velocity of the ball by rearranging the equation for momentum:

$$\text{velocity} = \frac{\text{momentum}}{\text{mass}} = \frac{6.0\ \text{kg m/s}}{0.25\ \text{kg}} = 24\ \text{m/s}$$

 The ball will move off with a velocity of 24 m/s to the right.

ACTIVITY 3.3

Finding the velocity of a tennis ball using conservation of momentum

You want to carry out an investigation to find the speed of a tennis ball, but most of the instructions are missing. You need to finish the plan.

This is the only guidance you have.

Equipment: tennis ball (or similar), cardboard box, newspaper or bubble wrap, stopwatch, measuring tape or metre rulers, mass balances.

Method: Fill a cardboard box with loosely crumpled newspaper or bubble wrap. Put the box on a smooth flat floor and throw the ball horizontally into the box (Figure 3.19). The box will slide before coming to a stop.

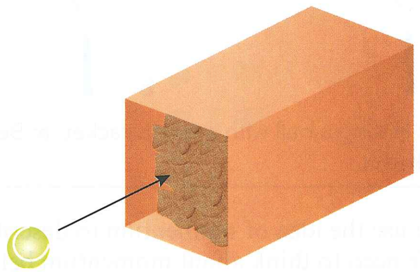


Figure 3.19

On your own, spend three minutes thinking carefully about the following activity and answer the questions. Then spend three minutes sharing ideas about the activity with the person sitting next to you. Be prepared to share your answers with the class.

Follow these steps to finish the plan:

1. Explain how the speed of the ball can be calculated using the principle of conservation of momentum. (Hint: this is a collision between the ball and the box.)
2. Explain how the speed of the ball can be calculated using only the equipment available. It might help to sketch a speed–time graph for the box, as this will suggest what measurements you can take.
3. Write down the steps (method) required to complete the investigation, including calculations needed and any safety precautions.

Optional

4. Compare your explanation and method with another group and improve your own.
5. If you have access to the equipment, carry out the experiment.
6. Using an alternative technique (such as video analysis) check whether you measured the correct speed and account for any difference.

PEER ASSESSMENT

Did the other group correctly and clearly:

- describe and explain what measurements to take?
- describe and explain what calculations to do?

Would you have been able to follow their method to produce reliable results?

Did the group include sensible safety precautions?

Provide constructive written and verbal feedback. As well as pointing out improvements, praise good aspects of their work.

When you get your work returned to you, make improvements based on the feedback.

3.6 More about scalars and vectors

You will recall that scalars have magnitude (size) only and no direction. We can represent forces using arrows because a force has a direction as well as a magnitude. This means that force is a vector quantity (see Chapter 2). Table 3.4 lists some scalar and vector quantities. Every vector quantity has a direction. However, it is not always necessary to state the direction if this is obvious – for example, we might say, 'The weight of the block is 10 N,' without saying that this force acts downwards.

Scalar quantities	Vector quantities
distance	velocity
time	force
speed	weight
mass	acceleration
energy	momentum
temperature	electric field strength
	gravitational field strength

Table 3.4: Some scalar and vector quantities.

Adding forces

What happens if an object is acted on by two or more forces? Figure 3.20a shows someone pushing a car. Friction opposes their pushing force. Because the forces are acting in a straight line, it is simple to calculate the resultant force, provided we take into account the directions of the forces:

resultant force = 500 N − 350 N

= 150 N to the right

Note that we must give the direction of the resultant force, as well as its magnitude. The car will accelerate towards the right.

Figure 3.20b shows a more difficult situation. A firework rocket is acted on by two forces.

- The thrust of its burning fuel pushes it towards the right.
- Its weight acts vertically downwards.

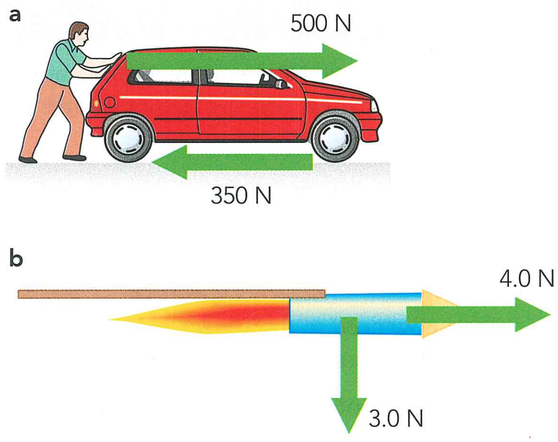


Figure 3.20a: Adding two forces in a straight line.
b: Adding two forces at right angles.

Worked Example 3.6 shows how to find the resultant force by drawing a **vector triangle** (a graphical representation of vectors) or using Pythagoras' theorem.

KEY WORDS

vector triangle: a graphical representation of vectors in two dimensions so that the resultant vector can be calculated

Rules for vector addition

You can add two or more forces using the following method. Simply keep adding arrows end-to-end.

- Draw arrows end-to-end, so that the end of one is the start of the next.
- Choose a scale that gives a large triangle.
- Join the start of the first arrow to the end of the last arrow to find the resultant.

Other vector quantities (for example, two velocities) can be added in this way. Imagine that you set out to swim across a fast-flowing river. You swim towards the opposite bank, but the river's velocity carries you downstream. Your resultant velocity will be at an angle to the bank.

Airline pilots must understand vector addition. Aircraft fly at high speed, but the air they are moving through is also moving fast. If they are to fly in a straight line towards their destination, the pilot must take account of the wind velocity (both its speed and direction).

Once you have mastered drawing a vector triangle, you could use Pythagoras' theorem to find the length of the resultant vector and trigonometry to find the angle.

WORKED EXAMPLE 3.6

Find the resultant force acting on the rocket shown in Figure 3.20b. What effect will the resultant force have on the rocket?

Method 1: Draw a scale diagram

Step 1: Look at Figure 3.20b. The two forces are 4.0 N horizontally and 3.0 N vertically.

You now need to draw a scale diagram (a vector triangle) to represent these forces.

Use a scale of 1.0 cm to represent 1.0 N.

Step 2: Draw a horizontal arrow, 4.0 cm long, to represent the 4.0 N force. Mark it with an arrow to show its direction.

Step 3: Using the end of this arrow as the start of the next arrow, draw a vertical arrow, 3.0 cm long, to represent the 3.0 N force.

Step 4: Complete the triangle by drawing an arrow from the start of the first arrow to the end of the second arrow. This arrow represents the resultant force.

Step 5: Measure this arrow, and use the scale to determine the size of the force it represents.

length of line = 5.0 cm

resultant force = 5.0 N

Step 6: Use a protractor to measure the angle of the force. (You could also calculate this angle using trigonometry.)

angle of force = 37° below horizontal

Figure 3.21 shows what your vector triangle should look like.

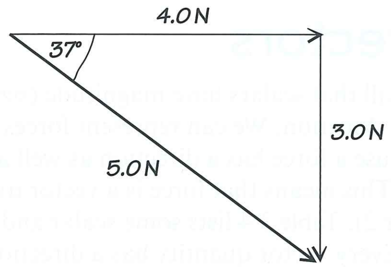


Figure 3.21: Vector triangle.

Method 2: Using Pythagoras' Theorem

Step 1: Look at Figure 3.20b. The two forces are at right angles so Pythagoras' theorem can be used. The square of the hypotenuse (the side opposite the right angle) is equal to the sum of the squares of the other two sides.

Step 2: Find the resultant force using Pythagoras' theorem.

$c^2 = b^2 + a^2$

so $c = \sqrt{a^2 + b^2}$

so $c = \sqrt{4^2 + 3^2} = \sqrt{16 + 9} = \sqrt{25} = 5\text{ N}$

Step 3: Find the angle below the horizontal using trigonometry.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{3\text{ N}}{4\text{ N}}$$

$$\theta = \tan^{-1}\left(\frac{3}{4}\right) = 37°$$

Answer

The resultant force acting on the rocket is 5.0 N acting at 37° below the horizontal. The rocket will be given an acceleration in this direction.

Notice that both methods give the same answer.

Question

17 You are rowing across the Lembeh Strait at 1.5 m/s.

a Calculate your velocity if you row against a current of 0.2 m/s?

b Use a vector triangle or calculate your resultant velocity if you travel at 4 m/s in a speedboat due south and a current pushes you towards the east at 3 m/s. Give both your speed and direction.

PROJECT

Hyperloop One was described at the beginning of the chapter. If Hyperloop One is successful, trains will travel at high speed along tubes. It will use magnetic repulsion between two unlike magnetic poles to lift trains off the floor of the tubes to eliminate solid friction. By removing air from the tubes, the trains will push against less air resistance.

While we often want to reduce friction there are other situations where friction is helpful or even essential. Later you will discover other examples in physics where something can be both helpful and hazardous (for example, ionising radiation in Chapter 23).

Imagine that there is a character called Friction who has been charged with the crime of impeding the smooth running of the natural world. Evidence is collected for and against him before his case goes to trial.

Collecting evidence for the prosecution (against Friction)

Research at least one example that you have not already met in this chapter where it is helpful to reduce solid friction or drag.

Collecting evidence for the defence (of Friction)

Research at least one example of solid friction and one example of air resistance that is necessary or helpful. For example, we need solid friction between car tyres and the road. Without this friction a car would not be able to change speed (or start or stop) or change direction in order to follow the twists and turns in the road. However, this friction produces heat and this leads to wasted energy.

The judgement

Write the transcript from the trial (what was said and who said it). This might include statements by the prosecutor, defence lawyer, expert witnesses, and the trial judge.

Optional task: promoting an efficient mass transport system

By reducing friction, Hyperloop One promises more efficient use of energy. However, it requires the building of tubes for the trains to run inside, which requires building materials and energy for construction.

Use the Internet to find out about efficient mass transport systems (such as tram or subway systems for cities) that have a low carbon footprint. It could be an existing system or one that is proposed for the future (such as Hyperloop One). To learn about the maglev technology in Hyperloop One, you could read Chapter 16 to discover why magnets attract and repel.

Once you have found the most promising system, imagine that you are an environmental journalist with a physics background. Write an article (maximum 500 words) in support of it, which urges readers to pressure the government to adopt the transport system you are proposing. As well as writing something that grabs the attention of readers, you need to:

- justify why you support the system you have chosen, based on physics
- explain the relevant physics so that it can be understood by the public
- include relevant images.

SUMMARY

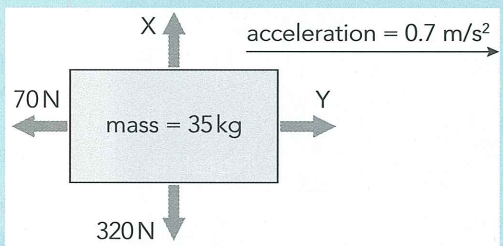
The unit of force is the newton (N).
Forces appear when two objects interact with each other.
A force can be represented by an arrow to show its direction, while length is proportional to the size of the force.
Solid friction, air resistance, and drag act in the opposite direction to the object's motion and can produce heating.
The resultant force is the single force that has the same effect as two or more forces.
A resultant force can change the speed and/or direction of an object.
The force of gravity pulls objects downwards and is normally called the weight of the object.
The acceleration caused by the pull of the Earth's gravity is called the acceleration of free fall or the acceleration due to gravity. It is given the symbol g and its value is 9.8 m/s^2 close to the surface of the Earth.
The mass of an object, measured in kilograms, tells you how much matter that object is composed of.
The weight of an object, measured in newtons, is the gravitational force that acts on that object.
Terminal velocity is the name for the maximum constant speed reached when the resultant force acting on an object becomes zero. It is often applied to parachutists when the upwards force of air resistance becomes equal and opposite to weight.
If an object moves in a circle, a force must be acting towards the centre of the path, perpendicular (at right angles) to the speed of the object.
For motion in a circular path, a bigger force is required if the body is more massive, moving faster or moving in a tighter circle.
Force = mass × acceleration, $F = ma$.
Momentum is the quantity mass × velocity, $p = mv$.
The principle of the conservation of momentum means that the total momentum after an interaction between bodies (for example, a collision) is the same as it was before the interaction.
The impulse (of a force) can be defined as the change in an object's momentum ($mv - mu$) or the force acting on an object multiplied by the time for which the force acts (Ft), so impulse = $F\Delta t$.
Force can be defined as the rate of change of momentum, $F = \dfrac{\Delta p}{\Delta t}$.
The resultant of two vectors that do not act along the same line can be found by drawing a vector triangle or by calculation.

EXAM-STYLE QUESTIONS

1 In 2014, Alan Eustace set the world record for the highest freefall parachute jump (from a height of more than 41 km). As he fell towards the Earth, he reached a terminal velocity of almost 370 m/s. The air was very thin where he started his jump and became thicker the closer he got to the ground. What happened to his terminal velocity, before he opened his parachute? **[1]**

A it increased
B it stayed the same
C it reduced but not to zero
D it reduced to zero

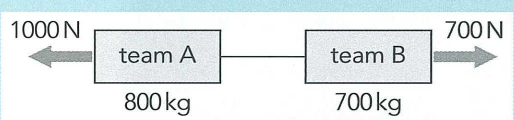
2 An object with a mass of 35 kg accelerates at 0.7 m/s^2 to the right, as shown in the diagram.



There are four forces acting on the object. What are the values of the forces labelled X and Y? **[1]**

A $X = 70$ N; $Y = 119.0$ N
B $X = 70$ N; $Y = 94.5$ N
C $X = 320$ N; $Y = 94.5$ N
D $X = 320$ N; $Y = 119.0$ N

3 This diagram shows the forces during a tug of war competition. Team A has a total mass of 800 kg and pulls with a force of 1000 N to the left. Team B has a total mass of 700 kg and pulls with a force of 700 N to the right. A strong rope joins them.

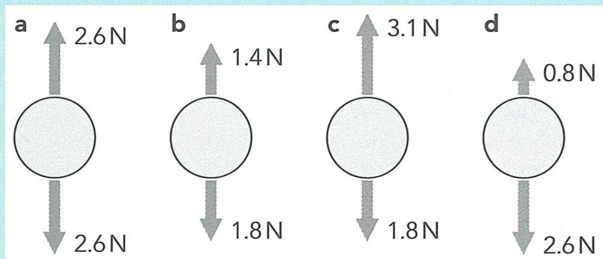


What is the acceleration of team A? **[1]**

A 0.20 m/s^2 to the left
B 1.25 m/s^2 to the right
C 1.25 m/s^2 to the left
D 0.38 m/s^2 to the left

4 These four diagrams show the forces on raindrops that are falling towards the ground.

Which raindrop is slowing down? **[1]**



CONTINUED

5 An aircraft of mass 4000 kg produces a thrust of 10 kN. The aircraft needs to travel at 35 m/s to take off.

a **State** the equation that links force, mass and acceleration. [1]

b **Calculate** the acceleration of the aircraft. [1]

c The aircraft starts from rest. Calculate the time it takes to become airborne. [2]

d **Sketch** a speed–time graph for the aircraft from the moment it starts until it takes off. Assume that its acceleration is constant. [2]

e Calculate the minimum length of the runway required for this aircraft to take off. [1]

f When it lands at the end of the flight, it travels on the ground (taxis) at a constant speed. **Explain** how this aircraft can accelerate even when it is travelling at a constant speed. [1]

[Total: 8]

6 Scientists test the safety features of a car by crashing it into a large block of concrete.

A crash test dummy sits in the driver's seat. A video camera records the crash. In one test, the car is travelling at 13 m/s and the dummy has a mass of 83 kg.

a State the equation that links momentum, mass and velocity. [1]

b Calculate the momentum of the dummy. [1]

c In another test, the momentum of the dummy changes by 1250 kg m/s in a time of 0.17 s. Calculate the average force acting on the dummy during this time. [2]

d These tests help to make our roads safer. Use ideas about momentum to explain how seat belts and the crumple zones of a car help to reduce injuries during a crash. [3]

[Total: 7]

COMMAND WORDS

state: express in clear terms

calculate: work out from given facts, figures or information

sketch: make a simple freehand drawing showing the key features, taking care over proportions

explain: set out purposes or reasons / make the relationships between things evident / provide why and / or how and support with relevant evidence

SELF-EVALUATION CHECKLIST

After studying this chapter, think about how confident you are with the different topics. This will help you to see any gaps in your knowledge and help you to learn more effectively.

I can	See Topic...	Needs more work	Almost there	Confident to move on
Recall the **two** ways that a force can change the motion of a body.	3.1			
Recall the significance of both the length and direction of arrows used to represent a force.	3.1			
Recall that friction acts between two solid surfaces; friction acts in the opposite direction to motion and can produce thermal energy.	3.1			
Recall that air resistance and drag are like friction.	3.1			
Calculate the resultant force when two or more forces act along the same line.	3.1			
Define mass and weight and recall the differences between them, including the units used.	3.2			
Recall that weight is the name given to the force of gravity on a body and that it always acts downwards.	3.2			
Recall and use the equation $W = mg$ and recall that $g = 9.8\,\mathrm{m/s^2}$.	3.2			
Define terminal velocity.	3.3			
Recall the direction of the force that acts on a body to make it move in a circle.	3.3			
Recall how the size of the force that acts on a body to make it move in a circle depends on the mass and speed of the body and the radius of the circle.	3.3			
Recall and use the equations for force and momentum.	3.4, 3.5			
Define impulse and perform calculations by recalling and using the associated equations.	3.4			
Apply the principle of the conservation of momentum.	3.5			
Define what a force is and recall and use the associated equation.	3.4			
Calculate, or draw a vector triangle to work out, the resultant force when the forces do not act along the same line.	3.6			