STUDY AND REVISION GUIDE

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Cambridge IGCSE™

Physics

Third Edition

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Boost

HODDER EDUCATION

Contents

REVISED TESTED EXAM READY

Answers to exam-style questions are available at:
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1 Motion, forces and energy

Key terms

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Term	Definition
Acceleration of free fall, *g*	For an object near to the surface of the Earth this is approximately constant and is approximately 9.8 m/s^2
Accuracy	An accurate measurement is one that is close to its true value
Air resistance	Frictional force opposing the motion of a body moving in air
Centre of gravity	The point at which all the mass of an object's weight can be considered to be concentrated
Density	The mass per unit volume
Energy	Energy may be stored as kinetic, gravitational potential, chemical, elastic (strain), nuclear, electrostatic or internal (thermal)
Equilibrium	When there is no resultant force and no resultant moment on an object
Extension	Change in length of a body being stretched
Friction	Force which opposes one surface moving, or trying to move, over another surface
Gravitational field strength	The force per unit mass
Mass	A measure of the quantity of matter in an object at rest relative to an observer
Moment of a force	Moment = force × perpendicular distance from the pivot
Non-renewable	Cannot be replaced when used up
Power	The work done per unit time and the energy transferred per unit time
Pressure	The force per unit area
Principle of conservation of energy	Energy cannot be created or destroyed; it is always conserved
Principle of moments	States when a body is in equilibrium; the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about the same point
Random error	Error introduced by the person taking the measurement
Renewable	Can be replaced; cannot be used up
Speed	The distance travelled per unit time
Systematic error	Error introduced by the measuring device
Velocity	Speed in a given direction
Weight	A gravitational force on an object that has mass
Work	A measure of the amount of energy transferred. Work done = force × distance moved in the direction of the force. SI unit is the joule (J)
Acceleration	Change of velocity per unit time
Deceleration	A negative acceleration; velocity decreases as time increases
Efficiency	(useful energy output/total energy input) × 100% (useful power output/total power input) × 100%
Impulse	Force × time for which force acts
Limit of proportionality	The point at which the load–extension graph becomes non-linear
Momentum	Mass × velocity
Principle of conservation of momentum	When two or more bodies interact, the total momentum of the bodies remains constant provided no external forces act

Term	Definition
Resultant force	The rate of change in momentum per unit time
Resultant vector	A single vector that has the same effect as the two vectors combined
Scalar	A quantity with magnitude only
Spring constant	Force per unit extension
Terminal velocity	Constant velocity reached when the air resistance upwards equals the downward weight of the falling body
Vector	A quantity which has both magnitude and direction

1.1 Physical quantities and measurement techniques

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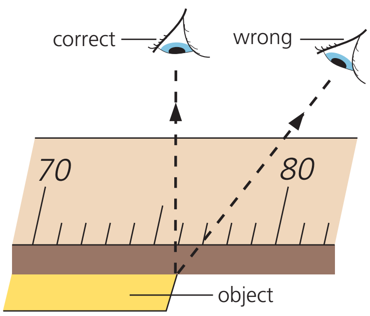
Key objectives

By the end of this section, you should be able to:
- describe how to measure length, volume and time using appropriate measuring instruments
- determine an average value for a small distance or short time by measuring multiples
- understand the difference between scalar and vector quantities and give examples of each
- determine the resultant of two vectors of force or velocity at right angles to each other either by calculation or graphically

Each time you measure a quantity you are trying to find its true value. How close you get to the true value is described as the **accuracy** of the measurement.

Length



▲ **Figure 1.1 The correct way to measure with a ruler**

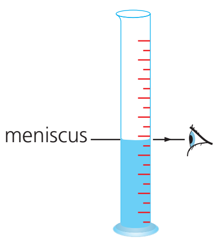
Length is the distance from one end of an object to the other. It is measured using a ruler. To measure length accurately your eye must be perpendicular to the mark on the ruler you are trying to read. This avoids parallax (see Figure 1.1).

Most rulers have millimetre markings. They give values to the nearest mm. For example, if you have to measure a small distance of 4 mm you only know the value to 4 ± 1 mm. To improve this measurement, you measure multiple distances and find an average distance.

Volume

Volume is the amount of space occupied. Figure 1.2 shows how to measure volume using a measuring cylinder. You measure the volume of a liquid by looking at the level of the bottom of the meniscus (see Figure 1.2). (For mercury, you should look at the level of the top of the meniscus.)

Measuring cylinders often measure in millilitres. Remember 1 ml = 1 cm^3.



▲ **Figure 1.2 The correct way to measure a volume of liquid**

Skills

Converting cm³ to m³

The SI unit of length is the metre. It is easy to convert lengths from cm into metres.

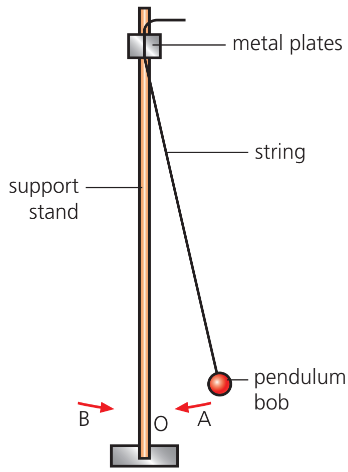
$$1\text{ cm} = \frac{1}{100}\text{ m} = 0.01\text{ m} = 1 \times 10^{-2}\text{ m}$$

The SI unit of volume is m^3. When you convert the units of volume, you have to divide by 100 for each dimension.

$$1\text{ cm}^3 = \frac{1}{100 \times 100 \times 100}\text{ m}^3 = 0.000\,001\text{ m}^3$$
$$= 1 \times 10^{-6}\text{ m}^3$$

Time

You need to be able to use analogue and digital stopwatches or clocks to measure time intervals. To improve the accuracy of the measurement of a short, repeated time interval, you can measure multiple times. For example, measuring the period of the pendulum in Figure 1.3. The period is the time taken for the pendulum to move from A to B and then back to A. You would measure the time for 10 such swings and then divide the time by 10.



▲ **Figure 1.3 A pendulum**

Errors in measurements

In any measurement there may be a measurement error. This is why results are not always the same. The error might be **random** (a **random error**) and cause an **anomaly** when you repeat the result. For example, an error introduced by your reaction time as you start and stop a stopwatch. The error may be a **systematic error**. For example, a newton meter might have a reading even when there is no force applied. This type of error is a zero error. In this case the same error is introduced to all the readings.

Scalars and vectors

Quantities can be divided into **scalar** or **vector**:

Scalars:

- only have magnitude (size)
- are added by normal addition

Examples of scalars you should know are distance, time, mass, speed, energy and temperature.

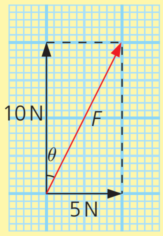
Vectors:

- have direction and magnitude (size)
- are represented by an arrow – the length of the arrow shows the magnitude of the vector and the direction shows the direction it acts
- are added by taking into account their direction

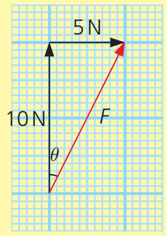
Examples of vectors you should know are force, weight, velocity, acceleration, momentum, electric field strength and gravitational field strength. Always state the direction of a vector, for example, the velocity is 10 m/s northwards.

Finding the resultant of two vectors

When you add vectors, you find the **resultant vector**. This is a single vector that has the same effect as the vectors you have combined. For example, if a force of 200 N pulls a boat to the east and a force of 800 N pulls it to the west, the resultant force is 600 N to the west. You may be asked to find the resultant of two vectors perpendicular to each other. Figure 1.4 shows a 10 N and a 5 N force acting at right angles to each other and their resultant vector *F*. The forces have been drawn using the parallelogram method and the triangle method.



Draw the vectors so they start at the same point. Draw in the sides of the parallelogram. The resultant is the diagonal.



Draw the vectors nose-to-tail. The resultant vector is the line drawn from the start to the finish.

▲ **Figure 1.4 Finding the resultant of two forces acting at right angles to each other**

As you can see from Figure 1.4, the resultant is the same whether you use the parallelogram method or the triangle method. Use whichever one you find easiest. There are two ways to find the value of the resultant vector:

1 By calculation: As it is a right-angled triangle, you can use Pythagoras' theorem to determine the magnitude of the vector.

$$F = \sqrt{10^2 + 5^2} = 11 \text{ N to 2 s.f.}$$

You can use trigonometry to find the angle θ.

$$\tan\theta = \frac{5}{10}, \theta = 27° \text{ to 2 s.f.}$$

Therefore, the resultant is an 11 N force acting at an angle of 27° to the 10 N force.

2 Graphically: By drawing the vectors to scale, you can then use a ruler to measure the length of the resultant vector. Do not forget to convert back using your scale and always write your scale down, e.g. 1 cm : 10 N. You can measure the angle using a protractor. Check this gives the same answer for the resultant force as by calculation using Figure 1.4.

Sample questions

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1 A student wishes to time how long it takes a ball to fall 1.5 m. Describe how to obtain reliable results for the measurements of time and height. [4]

Student's answer

Start the stopwatch as soon as the ball is released and stop when the ball hits the floor. Repeat three times. If there is an anomalous result, leave it out when you calculate the average time. Measure the height using a ruler and make a mark so that the ball is dropped from the same height each time. [3]

Teacher's comments

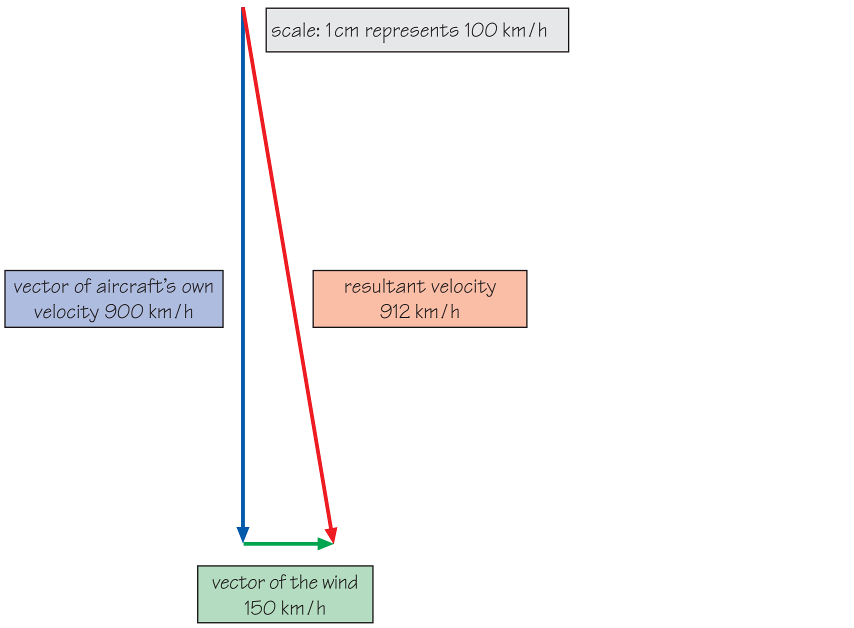
The question is answered well in terms of measuring the time. The student realises that they have to repeat because of the random errors when timing. They need to be more detailed in describing the distance measurement. The height is 1.5 m so a tape measure would be needed. It is not accurate to use two smaller rulers. Though they do include the idea of a mark so that the height is the same each time.

Correct answer

Use a tape measure to make a mark at the correct height of 1.5 m. Release the ball from this height each time. Start the stopwatch when the ball is released and stop it when the ball hits the floor. Repeat the experiment and discard any anomalous results before calculating the average time. [4]

2 An aircraft flies at 900 km/h heading due south. There is a crosswind of 150 km/h from the west. Graphically, find the aircraft's resultant velocity. [4]

Student's answer



▲ **Figure 1.5 (Diagram is not drawn to scale)** [3]

Teacher's comments

On the whole, the question is extremely well answered and the graphical work is accurate; stating the scale shows excellent work. The student assumed the top of the page was north. However, the student has omitted the direction part of the resultant velocity, stating only the magnitude.

Correct answer

Figure 1.5 should have an arrow pointing up the page labelled north. The answers shown in Figure 1.5 are correct except that the resultant velocity label should be resultant velocity 912 km/h at 9° east of due south. [4]

3 Speed and velocity are related quantities. Explain why speed is a scalar quantity and velocity is a vector. [2]

4 Name two more scalar quantities and two more vectors. [4]

Student's answers

3 Speed is much faster than velocity. [0]
4 Vectors: force, magnetic field strength [2]
Scalars: energy, colour [1]

Teacher's comments

3 The student has shown no understanding of the difference between a scalar and a vector.
4 Two good answers are given as examples of vectors; IGCSE students are not expected to know that magnetic field strength is a vector but it is a correct response.
Colour is not measurable so is not a scalar quantity.

Correct answers

3 Speed has magnitude only, but velocity has magnitude and direction. [2]
4 Correct answers could include:
Vectors: force, acceleration
Scalars: energy, mass [4]

Revision activity

Create four vector addition questions where the force or velocity vectors are at right angles to each other. For each question, calculate the answer by both calculation and graphically. Swap your questions with another student and check each other's workings.

Exam-style questions

Answers available at: www.hoddereducation.co.uk/cambridgeextras

1 A stack of 160 sheets is 7 mm high. Calculate the average thickness of a single sheet of paper. [1]

2 A student uses a stopwatch to time the swing of a pendulum. They forget to zero the timer, which reads 0.5 s when it starts. They start the stopwatch at the end of the first swing of the pendulum and stop the stopwatch at the end of the tenth swing. The final reading on the timer is 5.9 s.
   a State the type of error the student introduced when they forgot to zero the timer. [1]
   b Calculate the number of swings timed. [1]
   c Calculate the time taken for these swings. [1]
   d Calculate the time for each swing. [1]

3 Sort the following quantities into vector quantities and scalar quantities:
velocity mass weight kinetic energy time acceleration [6]

4 A swimmer swims directly across a river at 1.0 m/s heading due east. The river current is 4.0 m/s from the south.
Calculate the resultant velocity of the swimmer. [2]

1.2 Motion

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Key objectives

By the end of this section, you should be able to:

- define speed and velocity, and recall and use the equations to calculate speed and average speed
- define acceleration and use the equation to calculate acceleration and know that a negative acceleration is a deceleration

- sketch, plot and understand the motion shown on distance–time and speed–time graphs
- determine from data or the shape of a distance–time graph or speed–time graph when an object is at rest, moving with constant speed, accelerating or decelerating
- calculate speed from the gradient of a distance–time graph and distance travelled from the area under a speed–time graph
- know the approximate value of the acceleration of freefall, g, for an object close to the Earth's surface
- determine from data or the shape of a speed–time graph when an object is moving with constant acceleration and changing acceleration
- calculate acceleration from the gradient of a speed–time graph
- describe the motion of an object falling in a uniform gravitational field with and without air or liquid resistance

Speed

Speed is defined as the distance travelled per unit time. **Velocity** is speed in a given direction. If someone sees a runner moving at 5 m/s in a northerly direction, then the runner's speed is 5 m/s and their velocity is 5 m/s north. The speed, v, can be calculated from the distance travelled, s, in a very short time, t, using the equation:

$$v = \frac{s}{t}$$

In most cases, speed is calculated using a much longer time. This is then the average speed of the object. The average speed is calculated using the equation:

$$\text{average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

Acceleration

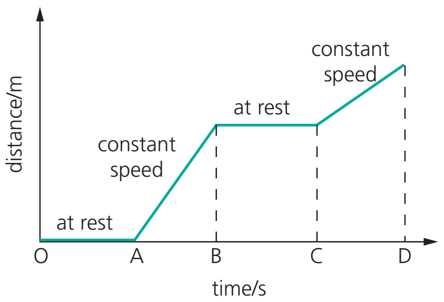
Acceleration is the change in velocity per unit time. The acceleration, a, for a change in velocity, Δv, when the time taken for the change is Δt is given by:

$$a = \frac{\Delta v}{\Delta t}$$

A negative acceleration is called a **deceleration**.

Distance–time graphs

Distance–time graphs show how an object's distance changes with time. Figure 1.6 shows the motion of an object plotted on a distance–time graph.



▲ **Figure 1.6 Distance–time graph**

The gradient of the graph for the section AB is greater than the gradient for section CD. This shows the object was moving at a faster constant speed at AB. The gradient of the distance–time graph is equal to the speed.

Skills

Calculating the gradient of a graph

To calculate the gradient of a graph, you need to read values for the change in y in a set change in x. See Figure 1.7.

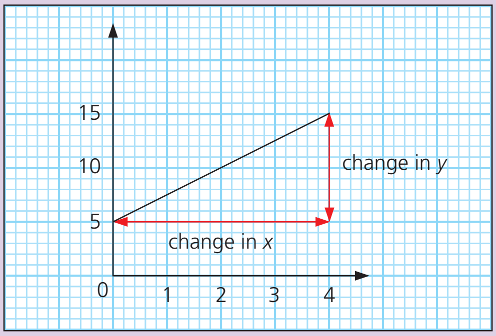


Figure 1.7 Calculating the gradient

The gradient is then given by:

$$\text{gradient} = \frac{\text{change in } y}{\text{change in } x}$$

In Figure 1.7, the gradient = $\frac{(15 - 5)}{(4 - 0)}$ = 2.5.

If the speed increases, the object is accelerating. If the speed decreases, the object is decelerating. When the speed changes, the distance–time graph will curve. An upward curve shows the object is accelerating as the gradient is increasing. The solid green line in Figure 1.8 shows the object accelerating. A downward curve (the dashed green line in Figure 1.8) shows the object is decelerating.

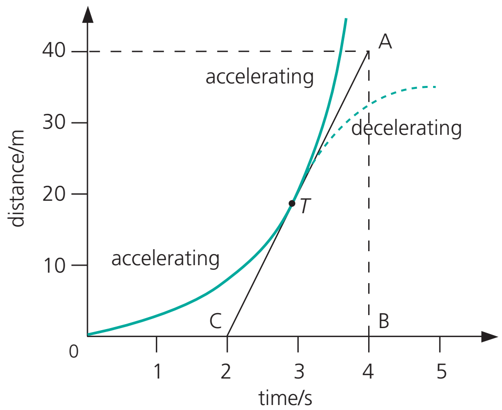


Figure 1.8 Non-constant speed

The speed at any point on a distance–time graph where the object is changing speed is given by the gradient of the tangent drawn at that point. In Figure 1.8, the speed at time T is equal to the gradient of the tangent (line AC) drawn at that point.

$$\text{gradient} = \frac{40 - 0}{4 - 2} = \frac{40}{2} = 20 \text{ m/s}$$

$$\text{speed at time } T = 20 \text{ m/s}$$

Determining the motion of an object from data

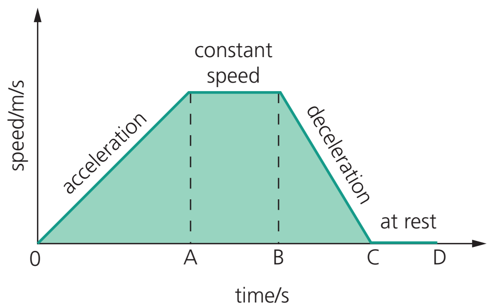
It is easy to interpret the motion from the shape of distance–time graphs, but you can also tell when you look at data in tables. When the object travels at a constant speed, the distance increases the same amount in equal times. When the object is stationary, the distance remains the same. When the distance increases in different amounts in equal times, the speed is changing. Table 1.1 shows how the distance of an object changes with time.

▼ **Table 1.1 Distance–time data**

Time/s	0	2	4	6	8	10	12	14
Distance/m	0	5	10	15	15	16	18	24
	Constant speed: Every 2 seconds distance increases by 5 m			Stationary: The distance remains the same		Changing speed: The distance travelled every 2 seconds is increasing		

Speed–time graphs

Speed–time graphs show the speed of an object over time. The area under the speed–time graph is the distance travelled (green shaded area in Figure 1.9).



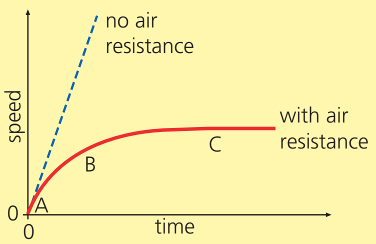
▲ **Figure 1.9 Speed–time graph showing acceleration, constant speed and deceleration**

In Figure 1.9, the object is accelerating between 0 and A, at constant speed between A and B and between B and C it is slowing down or decelerating.

The steeper the gradient of a speed–time graph, the greater the acceleration. In Figure 1.9 the deceleration is greater than the acceleration. The same change in speed happened in a much shorter time interval and the gradient is steeper.

Near the surface of the Earth the **acceleration of free fall** (g) is approximately constant and is equal to 9.8 m/s².

You can calculate the acceleration using the gradient of a speed–time graph. Figure 1.10 shows the speed–time graph for an object falling both without air resistance and with air resistance.



▲ **Figure 1.10 A body in free fall in the atmosphere**

Without air resistance the gradient of the graph is constant and equal to $9.8\,m/s^2$. However, with air resistance the acceleration decreases. You can see this because the gradient of the graph is decreasing. At point A in Figure 1.10, the speed is slow so there is negligible air resistance and the body has free fall acceleration. At point B, the speed is higher and there is some air resistance, so acceleration is less than free fall. At point C, the body has high speed and high air resistance, which is equal to its weight. Therefore, there is no acceleration – this constant speed is called the **terminal velocity**.

Sample question

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5 A runner completes an 800 m race in 2 min 30 s after completing the first lap of 400 m in 1 min 10 s. Find their average speed for the last 400 m. [3]

Student's answer

Total time = 2 mins 30 s = (2 × 60) + 30 = 150 s

$$\text{speed} = \frac{400}{150} = 2.67\,m/s$$

[2]

Teacher's comments

The student used the correct equation and the correct distance, but used the time for the whole race instead of the time for the last 400 m. The answer is quoted to 3 s.f.

Correct answer

Time = 2 min 30 s – 1 min 10 s = 1 min 20 s = 80 s [1]

$$\text{speed} = \frac{400}{80} = 5.0\,m/s$$

[2]

Sample question

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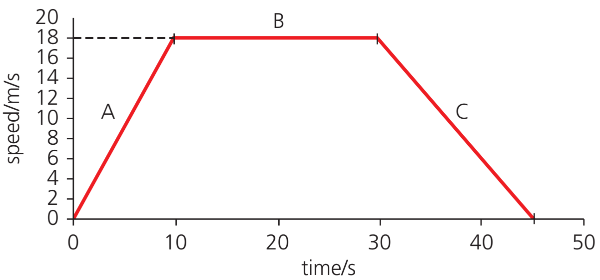
6 A car is moving in traffic and its motion is shown in Figure 1.11.



▲ **Figure 1.11**

a Choose from the following terms to describe the motion in parts A, B and C: acceleration, deceleration, steady speed. [3]

b Calculate the total distance covered. [5]

c Calculate the acceleration in part C. [2]

Student's answers

a Part A: acceleration; part B: deceleration; part C: steady speed [1]

b distance = speed × time = 18 × 45 = 810 m [0]

c acceleration $a = \frac{\Delta v}{\Delta t} = \frac{18}{15} = 1.2 \text{ m/s}^2$ [1]

Teacher's comments

a The answers to parts B and C are the wrong way around.

b The equation used is distance = average speed × time, but this is not appropriate, as the average speed is unknown. The student should have worked out the area under the graph, which equals the distance covered.

c The calculation is correct but the student should have specified a negative acceleration. [1 mark given]

Correct answers

a Part A: acceleration; part B: steady speed; part C: deceleration [3]

b distance = area under graph [1]

Part A area = $\frac{1}{2}$ × 18 × 10 = 90 m [1]

Part B area = 18 × 20 = 360 m [1]

Part C area = $\frac{1}{2}$ × 18 × 15 = 135 m [1]

distance = total area = 90 + 360 + 135 = 585 m = 590 m to 2 s.f. [1]

c acceleration $a = \frac{\Delta v}{\Delta t} = \frac{-18}{15} = 1.2 \text{ m/s}^2$ [2]

Exam-style questions

Answers available at: www.hoddereducation.co.uk/cambridgeextras

5 Runner A runs 100 m in 20 seconds at a constant speed.

- **a** Sketch this information on a distance–time graph. [3]
- **b** Calculate their average speed. [2]
- **c** Runner B is twice as fast. Add a line to your distance–time graph and label it B. Assume they also run at a constant speed and run 100 m. [2]

6 A bus accelerates at a constant rate from standstill to 15 m/s in 12 s. It continues at a constant speed of 15 m/s for 8 s.

- **a** Sketch this information on a speed–time graph. [3]
- **b** Use the graph to calculate the total distance covered. [2]
- **c** Calculate the average speed of the bus. [2]
- **d** Calculate the acceleration in the first 12 seconds. [2]

Revision activity

Create a revision poster on motion. Start in the middle of sheet with the four types of motion you have to recognise: a) at rest, b) moving with a constant speed, c) accelerating, d) decelerating. Draw distance–time and speed–time graphs to represent each type of motion. Include all the key words used to describe motion and how motion can be calculated. Link these to your graphs. Swap posters and see how another student has summarised the same information.

1.3 Mass and weight

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Key objectives

By the end of this section, you should be able to:
- define mass and weight and know that weights (and masses) can be compared using a balance
- define gravitational field strength, g, and use the equation relating g, weight and mass
- describe how the weight of an object depends on the gravitational field it is in

Mass is the amount of matter in an object. The unit of mass is the kilogram, kg.

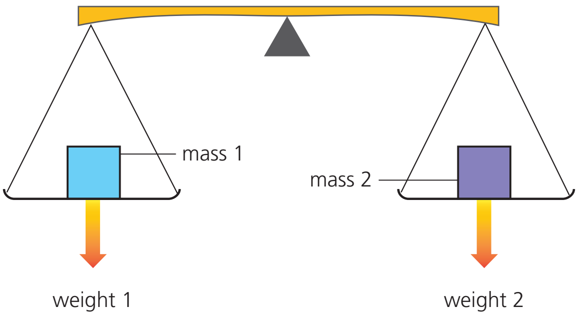
Weight is the gravitational force acting on an object that has mass. As it is a force, the unit of weight is the newton, N.

Weight, W, and mass, m, are related. The weight depends on the strength of the gravitational field the mass is in. **Gravitational field strength** is defined as the force acting per unit mass and is given by the equation:

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

Gravitational field strength has the same symbol g as the acceleration of free fall as they are equivalent. The units are different. Near the surface of the Earth, gravitational field strength is 9.8 N/kg and acceleration of free fall is 9.8 m/s^2.

A balance such as the one shown in Figure 1.12 compares an unknown weight with a known weight.



▲ **Figure 1.12 Balanced weights**

As mass determines weight, a balance also compares masses. In Figure 1.12, mass 1 = mass 2 because weight 1 = weight 2.

The mass of an object at rest is always the same as it depends on the matter in the object. However, the weight depends on the gravitational field the mass is in. A 1 kg mass has a weight of 9.8 N on Earth. Jupiter has a gravitational field strength of 25 N/kg. The same 1 kg mass would have a weight of 25 N on Jupiter.

Exam-style questions

Answers available at: www.hoddereducation.co.uk/cambridgeextras

7 A rover used to explore planets weighs 8820 N on Earth. On Mars the rover weighs 3330 N.
  a Calculate the mass of the rover. [2]
  b Calculate the gravitational field strength on Mars. [1]

Revision activity

Create flashcards for the definitions of the key terms in this section and the equation $g = \frac{W}{m}$.

1.4 Density

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Key objectives

By the end of this section, you should be able to:

- define density, and recall and use the equation relating density, mass and volume
- describe how to determine the density of a liquid, a regularly shaped solid and an irregularly shaped solid, including appropriate calculations
- use density data to determine whether an object will float or sink in a liquid
- use density data to determine whether one liquid will float on another liquid

Density is the mass per unit volume of a substance.

For a mass m with volume V the density ρ is given by the equation:

$$\rho = \frac{m}{V}$$

The units of density are kg/m^3.

Skills

Measuring the density of different substances

To find the density of a substance you must make accurate measurements of the mass and volume:

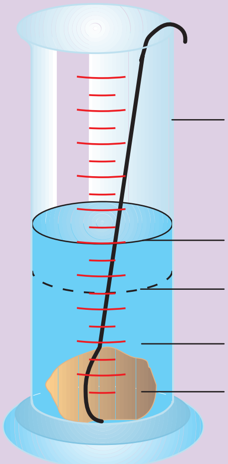
For a regularly shaped solid, measure the dimensions and work out the volume, then find the mass on a balance.

volume of a rectangular block = length × breadth × height

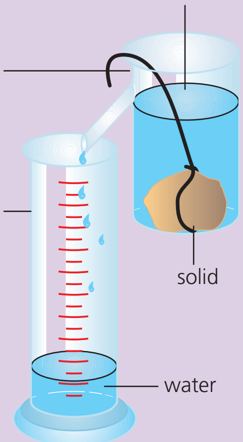
volume of a cylinder = $\pi r^2 h$

For an irregularly shaped solid, use a displacement method where the solid is placed in water (Figure 1.13). In method 1, the volume of the solid is the increase in the reading on the measuring cylinder (see Figure 1.13a). In method 2, where a displacement can is used, the volume of the solid is the volume of liquid displaced (see Figure 1.13b).

For a liquid, measure the volume in a measuring cylinder. To find the mass of the liquid, first find the mass of an empty beaker. Pour the liquid into the beaker and then find the total mass of the beaker and the liquid. Work out the mass of the liquid by subtraction of the mass of the beaker from the mass of the total.



▲ **Figure 1.13a Measuring the volume of an irregular solid method 1**



▲ **Figure 1.13b Measuring the volume of an irregular solid method 2**

Skills

Converting units

In your experiment, you probably measured the mass in grams and the volume in cm^3. This gives you a density in g/cm^3. To convert this to kg/m^3 you multiply by 1000.

For example, state which has the higher density: substance A at $0.8\,g/cm^3$ or substance B at $750\,kg/m^3$.

Both substances need to be in the same units of kg/m^3 so that you can compare them.

density of A = 0.8 × 1000 = $800\,kg/m^3$

Therefore, substance A has a greater density.

Floating and sinking

An object will sink in a liquid if it has density greater than the density of the liquid.

When two liquids do not mix, the liquid with the lower density will float on top of the liquid with higher density.

Sample question

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7 The mass of an empty measuring cylinder is 185 g. When the measuring cylinder contains $400\,cm^3$ of a liquid, the total mass is 465 g. Find the density of the liquid. [4]

Student's answer

$$\text{density} = \frac{465}{400} = 1.16\,g/cm^3 = 1.2\,g/cm^3 \text{ to 2 s.f.}$$ [2]

Teacher's comments

The student put the appropriate quantities into the correct equation and gave the correct units, but used the total mass instead of working out and using the mass of the liquid itself.

Correct answer

mass of liquid = 465 − 185 = 280 g

$$\text{density} = \frac{280}{400} = 0.70\,g/cm^3$$ [4]

Exam-style questions

Answers available at: www.hoddereducation.co.uk/cambridgeextras

8 **a** Copy and complete the table by filling in the missing values. [3]

▼ **Table 1.2**

Substance	Mass/g	Volume/cm^3	Density/g/cm^3
A	540	200	
B	67.5		1.5
C		250	0.5

b State which of the substances would float in a liquid with a density of $1.2\,g/cm^3$. [1]

Revision activity

Create a mind map on density. Include how to calculate density, how to measure the density of a substance and how you use density to determine whether objects float.

9 A measuring cylinder containing 20 cm^3 of liquid is placed on a top-pan balance. The top-pan balance reads 150 g. More liquid is poured into the cylinder up to the 140 cm^3 mark and the top-pan balance now reads 246 g. A solid is gently lowered into the cylinder; the liquid rises to the 200 cm^3 mark and the top-pan balance reads 411 g. Calculate:

a the density of the liquid [3]

b the density of the solid [3]

10 A student has the same mass, 85 g, of two different liquids. Liquid A has a volume of 80 cm^3 and liquid B has a volume of 92 cm^3. Determine which liquid will float on top assuming the liquids do not mix. [3]

1.5 Forces

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1.5.1 Effects of forces

Key objectives

By the end of this section, you should be able to:

- know that forces may produce changes in the size and shape of an object
- describe an experiment to collect data for a load–extension graph and plot, sketch and understand the features of a load–extension graph
- define the spring constant, and recall and use the equation and define the limit of proportionality
- determine the resultant force when two or more forces are acting along the same line
- understand that an object will remain at rest or continue at a constant speed in a straight line unless a resultant force acts on it
- understand that a resultant force may change the velocity of an object by changing its speed or direction
- recall and use the equation $F = ma$ to calculate the resultant force, F, and the acceleration, a, and know that the force and acceleration are in the same direction
- state how solid friction opposes motion between two surfaces and produces heating
- understand there is friction acting on an object as it moves through gas (air resistance) or a liquid (drag)
- describe the motion of an object in a circular path and how the force is affected as the speed, radius of the circle and mass of the object change

Forces

Forces can change the size and shape of a body. You must be able to describe an experiment to measure the **extension** of an elastic solid, such as a spring, a piece of rubber or another object, with increasing load. The extension is the change in length of the object being stretched. For some materials, the load–extension graph is a straight-line graph through the origin. This means the load is directly proportional to the extension. This means doubling the force, doubles the extension. Not all load–extension graphs are linear, which means the force required to stretch the material changes as the material is stretched.

Spring constant

The **spring constant**, k, is defined as the force per unit extension. The units are N/m. The spring constant can be calculated using the equation:

$$k = \frac{F}{x}$$

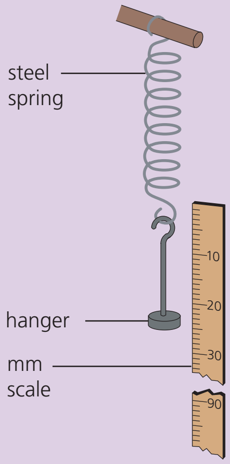
For a linear load–extension graph, the spring constant stays the same. The spring constant will be the gradient of the graph. On a load–extension graph the **limit of proportionality** is the point at which the graph is no longer linear.

Skills

Measuring extension of an object with increasing load

To investigate the load–extension graph for a spring, set up the apparatus shown in Figure 1.14.

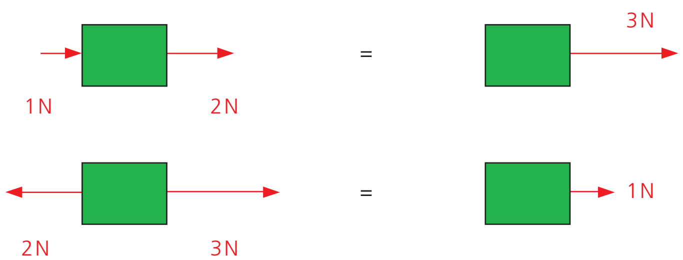
Place a 100 g mass carefully onto the hanger and record the position on the ruler of the bottom of the hanger. To help you read this accurately, attach a piece of card to the bottom of the hanger so that it lines up with the ruler. Record this measurement. Add another 100 g mass to the hanger and read the new reading on the ruler for the position of the hanger. The extension is the difference between the initial reading and this new reading. Repeat to a maximum of 500 g.



▲ **Figure 1.14 Measuring the extension of a spring with increasing force**

Forces and resultants

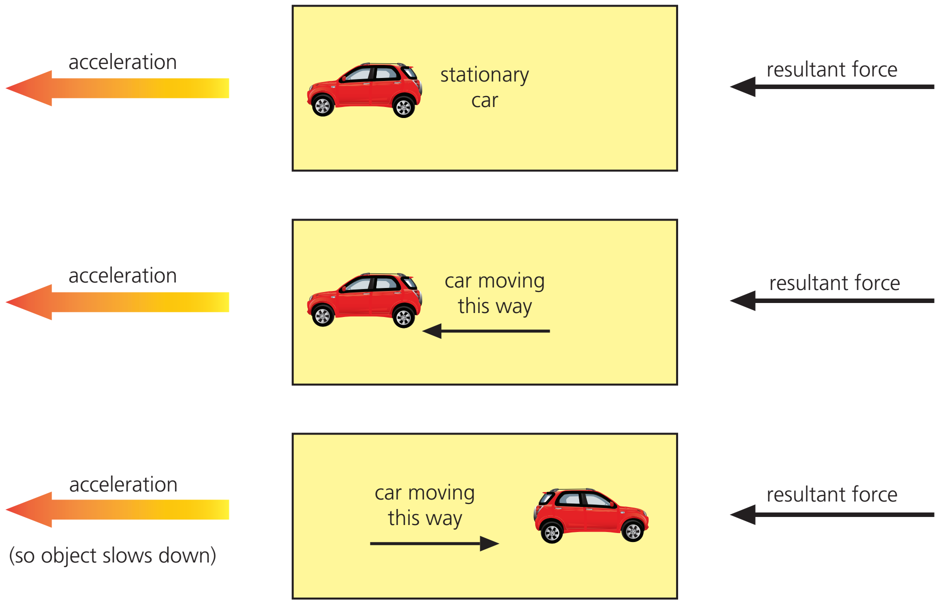
Force has both magnitude and direction. It is represented using an arrow to show the magnitude and direction the force acts. If more than one force acts on an object, you can find the resultant force. This is a single force which has exactly the same effect as all the forces added together. Figure 1.15 shows how to find the resultant of forces acting along the same line. If a question simply describes forces, it will help to sketch a force diagram showing the direction of each of the forces.



▲ **Figure 1.15 Use addition or subtraction to find the resultant of forces acting in a straight line**

If the resultant force acting on an object is zero, then the object will stay at rest or keep moving in a straight line at a constant speed.

If there is a resultant force acting on an object, then it changes velocity. This can mean a change in speed or/and a change in direction. Remember velocity is speed with direction.



▲ **Figure 1.16 A resultant force changes the motion of an object**

Friction

Solid **friction** is a force that opposes one surface that is moving or trying to move over another. Friction results in heating. When an object moves through a gas or liquid, there is a friction force opposing the motion. This friction force in liquid is called drag and in air is called **air resistance**.

Relationship between resultant force and acceleration

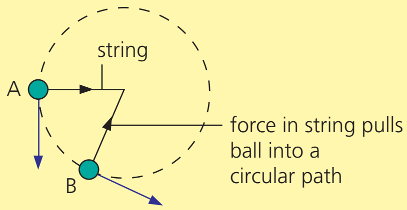
You need to know and be able to use the equation $F = ma$, where F is the resultant force and a is the acceleration. The acceleration is in the direction of the resultant force.

When the resultant force is perpendicular to motion, the object follows a circular path. Some examples of this are shown in Table 1.3.

▼ **Table 1.3 Examples of circular motion**

Object	Force	Circular motion
Planet in orbit	Gravitational force towards the Sun	Planet moves around the Sun
Car turning a corner	Friction force	Car drives around the corner
Ball on a length of string	String tension	Ball moves around in a circle on the end of the string

Although the object may be moving at a constant speed, it is still accelerating as it is continually changing direction. This means the velocity is changing. Remember velocity is a vector.



▲ **Figure 1.17 Diagram showing the direction of the force and velocity for a ball on a length of string**

The resultant force required to keep the object moving in the circle varies with the speed, radius and mass of the object:

- Increasing the speed, *increases* the force for the same mass and radius of circle.
- Increasing the radius, *decreases* the force for the same mass and speed.
- Increasing the mass, *increases* the force for the same speed and radius.

Sample question

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8 An empty lift weighs 2000 N. Four people enter the lift and their total weight is 3000 N. After the button is pressed to move the lift, the tension in the cable pulling up from the top of the lift is 4000 N.

a Work out the resultant force on the lift. [2]
b State how the lift moves. [2]
c Calculate the resultant acceleration (g = 9.8 N/kg). [3]

Student's answers

a Resultant force = 3000 + 2000 − 4000 = 1000 N [1]
b The lift will move down. [1]

c Mass of lift and people = $\frac{5000}{9.8}$ = 510.2 kg

Acceleration= $\frac{F}{m} = \frac{1000}{510.2}$ = 1.96 m/s^2 downwards [3]

Teacher's comments

a The student correctly worked out the size of the force but did not state the direction downwards.
b The words 'move down' are too vague.

c The student's answer is correct but has been quoted to 3 s.f.

Correct answers

a Resultant force = 3000 + 2000 − 4000 = 1000 N downwards [2]
b The lift will accelerate downwards. [2]

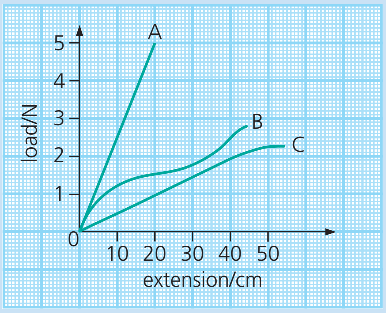
c Mass of lift and people = $\frac{5000}{9.8}$ = 510.2 kg

Acceleration = $\frac{F}{m} = \frac{1000}{510.2}$ = 2.0 m/s^2 downwards [3]

Exam-style questions

Answers available at: www.hoddereducation.co.uk/cambridgeextras

11 Figure 1.18 shows load–extension graphs for three different objects.



▲ **Figure 1.18**

Study the graphs carefully and answer the following questions:

- **a** Describe the behaviour of each object and identify which could be a spring. [6]
- **b** Calculate the spring constant for graph A. [2]
- **c** Identify the limit of proportionality on graph C. [1]

12 A car is driving along a horizontal road with a constant velocity. The driver applies the brakes and the car comes to a stop.

- **a** State the resultant force acting on the car when it is driving with a constant velocity. [1]
- **b** State the direction of the resultant force acting on the car as the brakes are applied. [1]

13 A rocket of weight 980 N is propelled upwards by a thrust of 1800 N. The air resistance is 500 N.

- **a** Calculate the resultant force on the rocket. [2]
- **b** Describe how this resultant force changes the motion of the rocket. [2]
- **c** Calculate the acceleration of the rocket (g = 9.8 N/kg). [3]

Revision activity

Create a mind map on forces. Include how forces change the shape, size and velocity of objects.

1.5.2 Turning effect of forces

Key objectives

By the end of this section, you should be able to:

- describe and give examples of the turning effect or moment of a force
- define moment and recall and use the equation for the moment of a force
- apply the principle of moments and recall the conditions for an object in equilibrium
- apply the principle of moments when there are more than two forces about a pivot
- describe an experiment to show that an object in equilibrium has no resultant moment

Moment of a force

The **moment of a force** is a measure of its turning effect. Everyday examples of moments include spanners and the handle on a door. In each case, the effort is applied at a distance from the pivot to increase the turning effect.

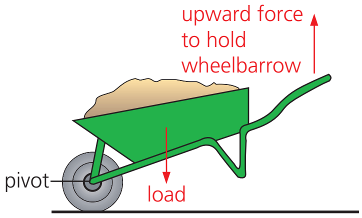
A moment is defined by the equation:

$$\text{moment} = \text{force} \times \text{perpendicular distance from pivot}$$

Principle of moments

The **principle of moments** states when a body is in equilibrium, the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about the same point.

An object is in **equilibrium** when there is no resultant force and no resultant moment on the object. Figure 1.19 shows a wheelbarrow pushed along at a constant velocity. Therefore, there is no resultant force acting on it. The clockwise moment of the load is equal to the anticlockwise moment of the upward force holding it up. Therefore, there is no resultant moment.

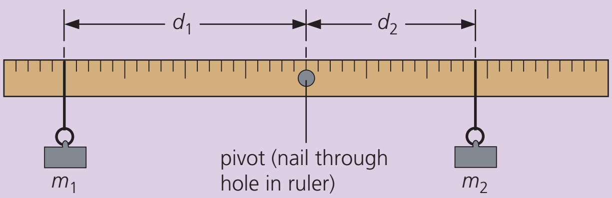


▲ **Figure 1.19 Wheelbarrow in equilibrium**

Skills

Demonstrating that there is no resultant moment when an object is in equilibrium

To demonstrate there is no resultant moment on an object in equilibrium, set up the apparatus shown in Figure 1.20.



▲ **Figure 1.20 Using a balanced ruler to measure clockwise and anticlockwise moments**

Balance a half-metre ruler in its centre. Add modelling clay to one side or the other until it is level. Hang unequal masses m_1 and m_2 either side of the pivot and alter their distances from the pivot until the ruler is balanced again. Calculate the anticlockwise moment of m_1 and the clockwise moment of m_2. You will find that when the clockwise moment is equal to the anticlockwise moment, there is no resultant moment and the beam is in equilibrium.

Sample question

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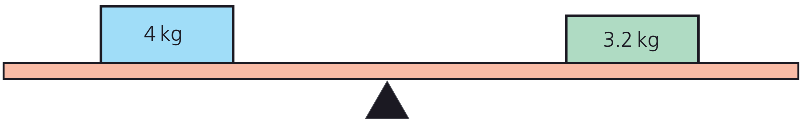
9 A student carries out an experiment to balance a regular 4 m long plank at its mid-point. A mass of 4 kg is placed 80 cm to the left of the pivot and a mass of 3.2 kg is placed 100 cm to the right of the pivot. Explain, *by calculating the moments,* whether the plank is balanced. Use g = 10 N/kg. [4]



▲ **Figure 1.21**

Student's answer

4 × 80 = 3.2 × 100, so the plank balances. [2]

Teacher's comments

The student's calculation and conclusion are entirely correct, but the instruction in italic to calculate the moments was ignored.

Correct answer

anticlockwise moment = 40 × 0.8 = 32 N m [1]

clockwise moment = 32 × 1 = 32 N m [1]

anticlockwise moment = clockwise moment, so the plank balances. [2]

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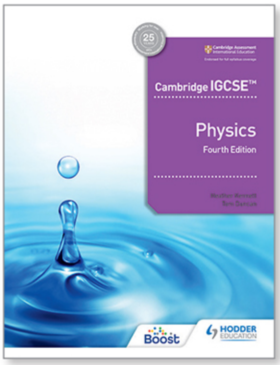

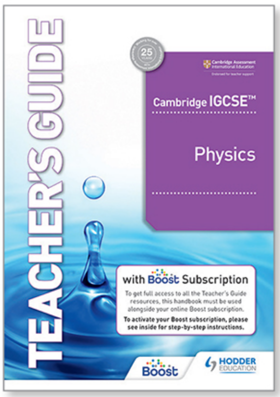

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