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Third edition

Mike Crundell
Geoff Goodwin

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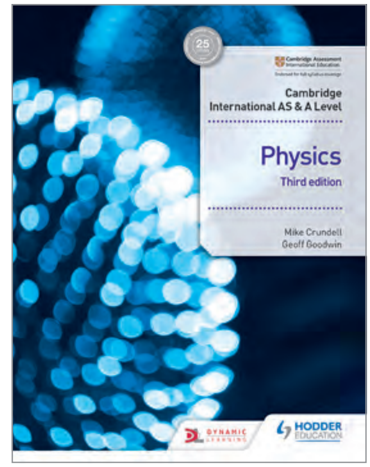

Cambridge International AS & A Level Physics Third Edition *Student Book*	ISBN 9781510482807	£42	March 2020
Cambridge International AS & A Level Physics *Student eTextbook*	ISBN 9781510483118	1-year access: £29.50 2-year access: £42	April 2020
Cambridge International AS & A Level Physics *Whiteboard eTextbook*	ISBN 9781510483125	£130 (subscription expires Aug 2023)	March 2020
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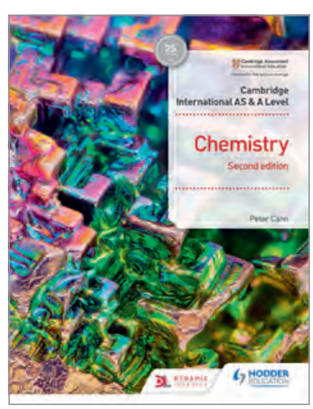

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2 Kinematics

Learning outcomes

By the end of this topic you will be able to:

2.1.1 define and use distance, displacement, speed, velocity and acceleration

2.1.2 use graphical methods to represent distance, displacement, speed, velocity and acceleration

2.1.3 determine displacement from the area under a velocity–time graph

2.1.4 determine velocity using the gradient of a displacement–time graph

2.1.5 determine acceleration using the gradient of a velocity–time graph

2.1.6 derive, from the definitions of velocity and acceleration, equations which represent uniformly accelerated motion in a straight line

2.1.7 solve problems using equations which represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance

2.1.8 describe an experiment to determine the acceleration of free fall using a falling object

2.1.9 describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.

Starting points

- Kinematics is a description of how objects move.
- The motion of objects can be described in terms of quantities such as position, speed, velocity and acceleration.

2.1 Equations of motion

Distance, displacement, speed, velocity and acceleration

Distance and displacement

The ***distance*** moved by a particle is the length along the actual path travelled from the starting point to the finishing point. Distance is a scalar quantity.

The ***displacement*** of a particle is its change of position. The displacement is the length travelled in a straight line in a specified direction from the starting point to the finishing point. Displacement is a vector quantity.

Consider a cyclist travelling 500 m due east along a straight road, and then turning around and coming back 300 m. The total distance travelled is 800 m, but the displacement is only 200 m due east, since the cyclist has ended up 200 m from the starting point.

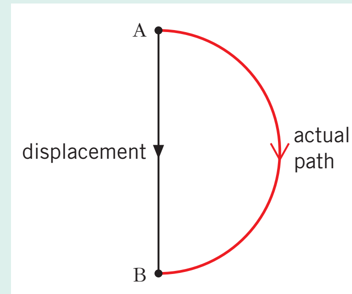
WORKED EXAMPLE 2A

1 A particle moves from point A to point B along the path of a circle of radius 5.0 m as shown in Figure 2.1.

What is

a the distance moved by the particle?

b the displacement of the particle?



▲ Figure 2.1

Answers

1 a the actual path of the particle along the circumference of the circle = $\pi \times 5$ = **16 m**.

b the displacement of the particle is the straight line from A to B along the diameter of the circle = **10 m in the direction downwards**.

Average speed

When talking about motion, we discuss the way in which the position of a particle varies with time. Think about a particle moving its position. In a certain time, the particle will cover a certain distance. The ***average speed*** of the particle is defined as the distance moved along the actual path divided by the time taken. Written as a word equation, this is

$$\text{average speed} = \frac{\text{distance moved along actual path}}{\text{time taken}}$$

The unit of speed is the metre per second ($m\,s^{-1}$).

One of the most fundamental of physical constants is the speed of light in a vacuum. It is important because it is used in the definition of the metre, and because, according to the theory of relativity, it defines an upper limit to attainable speeds. The range of speeds that you are likely to come across is enormous; some are summarised in Table 2.1.

	Speed/$m\,s^{-1}$
light	3.0×10^8
electron around nucleus	2.2×10^6
Earth around Sun	3.0×10^4
jet airliner	2.5×10^2
typical car speed (80 km per hour)	22
sprinter	10
walking speed	1.5
snail	1×10^{-3}

▲ **Table 2.1 Examples of speeds**

It is important to recognise that speed has a meaning only if it is quoted relative to a fixed reference. In most cases, speeds are quoted relative to the surface of the Earth, which – although it is moving relative to the Solar System – is often taken to be fixed. Thus, when we say that a bird can fly at a certain average speed, we are relating its speed to the Earth. However, a passenger on a ferry may see that a seagull, flying parallel to the boat, appears to be practically stationary. If this is the case, the seagull's speed relative to the boat is zero. However, if the speed of the boat through the water is 8 $m\,s^{-1}$, then the speed of the seagull relative to Earth is also 8 $m\,s^{-1}$. When talking about relative speeds we must also be careful about directions. It is easy if the speeds are in the same direction, as in the example of the ferry and the seagull. If the speeds are not in the same direction the addition of the motions should follow those introduced for vectors as considered in Topic 1.

WORKED EXAMPLE 2B

1 The radius of the Earth is 6.4×10^6 m; one revolution about its axis takes 24 hours (8.6×10^4 s). Calculate the average speed of a point on the Equator relative to the centre of the Earth.

2 How far does a cyclist travel in 11 minutes if his average speed is 22 $km\,h^{-1}$?

3 A train is travelling at a speed of 25 $m\,s^{-1}$ along a straight track. A boy walks along the corridor in a carriage towards the rear of the train, at a speed of 1 $m\,s^{-1}$ relative to the train. What is his speed relative to Earth?

Answers

1 In 24 hours, the point on the equator completes one revolution and travels a distance of $2\pi \times$ the Earth's radius, that is $2\pi \times 6.4 \times 10^6 = 4.0 \times 10^7$ m.

The average speed is (distance moved)/(time taken), or $(4.0 \times 10^7)/(8.6 \times 10^4) = \mathbf{4.7 \times 10^2\ m\,s^{-1}}$.

2 First convert the average speed in $km\,h^{-1}$ to a value in $m\,s^{-1}$.

22 km (2.2×10^4 m) in 1 hour (3.6×10^3 s) is an average speed of 6.1 $m\,s^{-1}$. 11 minutes is 660 s. Since average speed is (distance moved)/(time taken), the distance moved is given by (average speed) × (time taken), or $6.1 \times 660 =$ **4000 m**.

Note the importance of working in consistent units: this is why the average speed and the time were converted to $m\,s^{-1}$ and s respectively.

3 In one second, the train travels 25 m forwards along the track. In the same time the boy moves 1 m towards the rear of the train, so he has moved 24 m along the track. His speed relative to Earth is thus 25 – 1 = **24 $m\,s^{-1}$**.

Now it's your turn 2.1

1 The speed of an electron in orbit about the nucleus of a hydrogen atom is 2.2×10^6 $m\,s^{-1}$. It takes 1.5×10^{-16} s for the electron to complete one orbit. Calculate the radius of the orbit.

2 The average speed of an airliner on a domestic flight is 220 $m\,s^{-1}$. Calculate the time taken to fly between two airports on a flight path 700 km long.

3 Two cars are travelling in the same direction on a long, straight road. The one in front has an average speed of 25 $m\,s^{-1}$ relative to Earth; the other's is 31 $m\,s^{-1}$, also relative to Earth. What is the speed of the second car relative to the first when it is overtaking?

Speed and velocity

In ordinary language, there is no difference between the terms *speed* and *velocity*. However, in physics there is an important distinction between the two. ***Velocity*** is used to represent a vector quantity: the magnitude of how fast a particle is moving *and* the direction in which it is moving. ***Speed*** does not have an associated direction. It is a scalar quantity (see Topic 1).

So far, we have talked about the total distance travelled by a body along its actual path. Like speed, distance is a scalar quantity, because we do not have to specify the direction in which the distance is travelled. However, in defining velocity we use the quantity displacement.

The ***average velocity*** is defined as the displacement divided by the time taken

$$\text{average velocity} = \frac{\text{displacement}}{\text{time taken}}$$

Because distance and displacement are different quantities, the average speed of motion will sometimes be different from the magnitude of the average velocity. If the time taken for the cyclist's trip in Worked example 2B is 120 s, the average speed is 800/120 = 6.7 m s^{-1}, whereas the magnitude of the average velocity is 200/120 = 1.7 m s^{-1}. This may seem confusing, but the difficulty arises only when the motion involves a change of direction and we take an average value. If we are interested in describing the motion of a particle at a particular moment in time, the speed at that moment is the same as the magnitude of the velocity at that moment.

▲ Figure 2.2

We now need to define average velocity more precisely, in terms of a mathematical equation, instead of our previous word equation. Suppose that at time t_1 a particle is at a point x_1 on the x-axis (Figure 2.2). At a later time t_2, the particle has moved to x_2. The displacement (the change in position) is $(x_2 - x_1)$, and the time taken is $(t_2 - t_1)$.

The average velocity $\overline{v}$ is then

$$\overline{v} = \frac{x_2 - x_1}{t_2 - t_1}$$

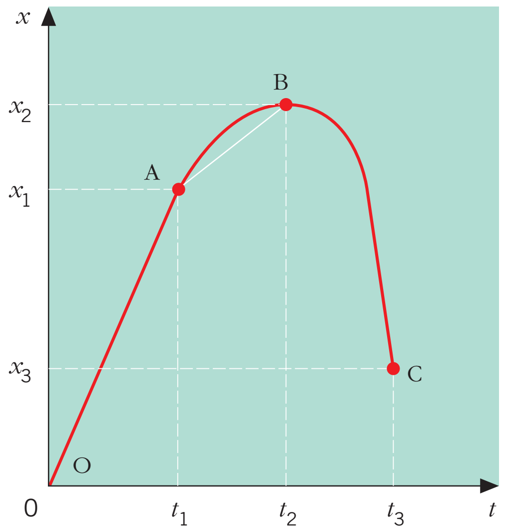
The bar over v is the symbol meaning 'average'. As a shorthand, we can write $(x_2 - x_1)$ as Δx, where Δ (the Greek capital letter delta) means 'the change in'. Similarly, $t_2 - t_1$ is written as Δt. This gives us

$$\overline{v} = \frac{\Delta x}{\Delta t}$$

If x_2 were less than x_1, $(x_2 - x_1)$ and Δx would be negative. This would mean that the particle had moved to the left, instead of to the right as in Figure 2.2. The sign of the displacement gives the direction of particle motion. If Δx is negative, then the average velocity v is also negative. The sign of the velocity, as well as the sign of the displacement, indicates the direction of the particle's motion. This is because both displacement and velocity are vector quantities.

Describing motion by graphs

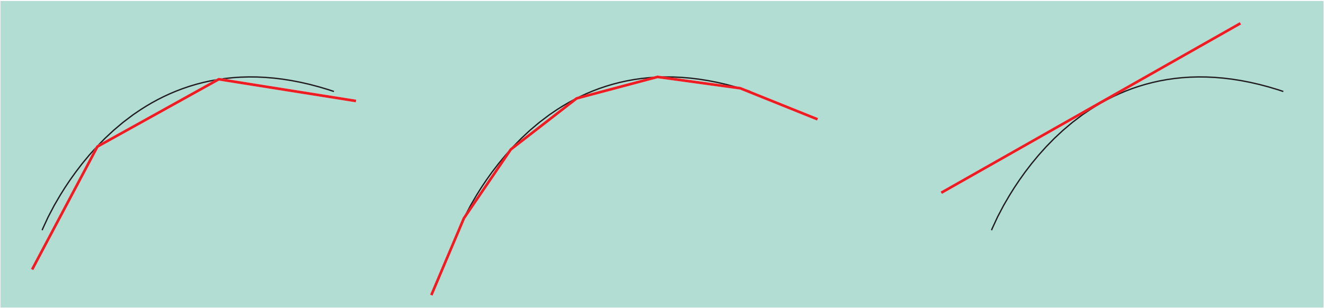
Position–time graphs



▲ Figure 2.3

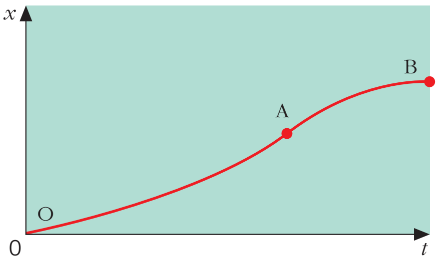
Figure 2.3 is a graph of position x against time t for a particle moving in a straight line. This curve gives a complete description of the motion of the particle. We can see from the graph that the particle starts at the origin O (at which $x = 0$) at time $t = 0$. From O to A the graph is a straight line: the particle is covering equal distances in equal periods of time. This represents a period of *uniform velocity*. The average velocity during this time is $(x_1 - 0)/(t_1 - 0)$. Clearly, this is the gradient of the straight-line part of the graph between O and A. Between A and B the particle is slowing down, because the distances travelled in equal periods of time are getting smaller. The average velocity during this period is $(x_2 - x_1)/(t_2 - t_1)$. On the graph, this is represented by the gradient of the straight line joining A and B. At B, for a moment, the particle is at rest, and after B it has reversed its direction and is heading back towards the origin. Between B and C the average velocity is $(x_3 - x_2)/(t_3 - t_2)$. Because x_3 is less than x_2, this is a negative quantity, indicating the reversal of direction.

Calculating the average velocity of the particle over the relatively long intervals t_1, $(t_2 - t_1)$ and $(t_3 - t_2)$ will not, however, give us the complete description of the motion. To describe the motion exactly, we need to know the particle's velocity at every instant. We introduce the idea of ***instantaneous velocity***. To define instantaneous velocity we make the intervals of time over which we measure the average velocity shorter and shorter. This has the effect of approximating the curved displacement–time graph by a series of short straight-line segments. The approximation becomes better the shorter the time interval, as illustrated in Figure 2.4. Eventually, in the case of extremely small time intervals (mathematically we would say 'infinitesimally small'), the straight-line segment has the same direction as the tangent to the curve. This limiting case gives the instantaneous velocity as the gradient of the tangent to the displacement–time curve.

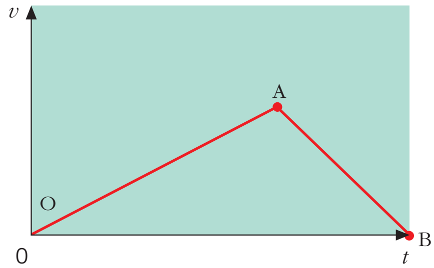


▲ Figure 2.4

Displacement–time and velocity–time graphs



▲ Figure 2.5



▲ Figure 2.6

Figure 2.5 is a sketch graph showing how the displacement of a car, travelling along a straight test track, varies with time. We interpret this graph in a descriptive way by noting that between O and A the distances travelled in equal intervals of time are progressively increasing: that is, the velocity is increasing as the car is accelerating. Between A and B, the distances for equal time intervals are decreasing; the car is slowing down. Finally, there is no change in position, even though time passes, so the car must be at rest. We can use Figure 2.5 to deduce the details of the way in which the car's instantaneous velocity v varies with time. To do this, we draw tangents to the curve in Figure 2.5 at regular intervals of time, and measure the slope of each tangent to obtain values of v. The plot of v against t gives the graph in Figure 2.6. This confirms our descriptive interpretation: the velocity increases from zero to a maximum value, and then decreases to zero again. We will look at this example in more detail later in the topic, where we shall see that the area under the velocity–time graph in Figure 2.6 gives the displacement x.

Acceleration

We have used the word *accelerating* in describing the increase in velocity of the car in the previous section. Acceleration is a measure of the rate at which the velocity of the particle is changing. ***Average acceleration*** is defined by the word equation

$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

The unit of acceleration is the unit of velocity (the metre per second) divided by the unit of time (the second), giving the metre per (second)^2 which is represented as m s^{-2}. In symbols, this equation is

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

where v_1 and v_2 are the velocities at time t_1 and t_2 respectively. To obtain the ***instantaneous acceleration***, we take extremely small time intervals, just as we did when defining instantaneous velocity. Because it involves a change in velocity (a vector quantity), acceleration is also a vector quantity: we need to specify both its magnitude and its direction.

Now it's your turn 2.2

1. A sprinter, starting from the blocks, reaches his full speed of $9.0\,m\,s^{-1}$ in 1.5 s. What is his average acceleration?
2. A car is travelling at a speed of $25\,m\,s^{-1}$. At this speed, it is capable of accelerating at $1.8\,m\,s^{-2}$. How long would it take to accelerate from $25\,m\,s^{-1}$ to the speed limit of $31\,m\,s^{-1}$?
3. At an average speed of $24\,km\,h^{-1}$, how many kilometres will a cyclist travel in 75 minutes?
4. An aircraft travels 1600 km in 2.5 hours. What is its average speed, in $m\,s^{-1}$?
5. Does a car speedometer register speed or velocity? Explain.
6. An aircraft travels 1400 km at a speed of $700\,km\,h^{-1}$, and then runs into a headwind that reduces its speed over the ground to $500\,km\,h^{-1}$ for the next 800 km. What is the total time for the flight? What is the average speed of the aircraft?
7. A sports car can stop in 6.1 s from a speed of $110\,km\,h^{-1}$. What is its acceleration?
8. Can the velocity of a particle change if its speed is constant? Can the speed of a particle change if its velocity is constant? If the answer to either question is 'yes', give examples.

Uniformly accelerated motion

Having defined displacement, velocity and acceleration, we shall use the definitions to derive a series of equations, called the *kinematic equations*, which can be used to give a complete description of the motion of a particle in a straight line. The mathematics will be simplified if we deal with situations in which the acceleration does not vary with time; that is, the acceleration is uniform (or constant). This approximation applies for many practical cases. However, there are two important types of motion for which the kinematic equations do not apply: circular motion and the oscillatory motion called simple harmonic motion. We shall deal with these separately in Topic 12 and Topic 17.

Think about a particle moving along a straight line with constant acceleration a. Suppose that its initial velocity, at time $t = 0$, is u. After a further time t its velocity has increased to v. From the definition of acceleration as (change in velocity)/(time taken), we have $a = (v - u)/t$ or, rearranging,

$$v = u + at$$

From the definition of average velocity $\bar{v}$ (distance travelled)/(time taken), over the time t the distance travelled s will be given by the average velocity multiplied by the time taken, or

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

The average velocity $\bar{v}$ is written in terms of the initial velocity u and final velocity v as

$$\bar{v} = \frac{(u + v)}{2}$$

and, using the previous equation for v,

$$\bar{v} = \frac{(u + u + at)}{2} = u + \frac{at}{2}$$

Substituting this we have

$$s = ut + \frac{1}{2}at^2$$

The right-hand side of this equation is the sum of two terms. The ut term is the distance the particle would have travelled in time t if it had been travelling with a constant speed u, and the $\frac{1}{2}at^2$ term is the additional distance travelled as a result of the acceleration.

The equation relating the final velocity v, the initial velocity u, the acceleration a and the distance travelled s is

$$v^2 = u^2 + 2as$$

If you wish to see how this is obtained from previous equations, see the Maths Note below.

MATHS NOTE

From $v = u + at$,

$$t = \frac{(v-u)}{a}$$

Substitute this in $s = ut + \frac{1}{2}at^2$

$$s = \frac{u(v-u)}{a} + \frac{1}{2}\frac{a(v-u)^2}{a^2}$$

Multiplying both sides by $2a$ and expanding the terms,

$$2as = 2uv - 2u^2 + v^2 - 2uv + u^2$$

or $v^2 = u^2 + 2as$.

The five equations relating the various quantities which define the motion of the particle in a straight line in uniformly accelerated motion are

$$v = u + at \qquad v^2 = u^2 + 2as$$

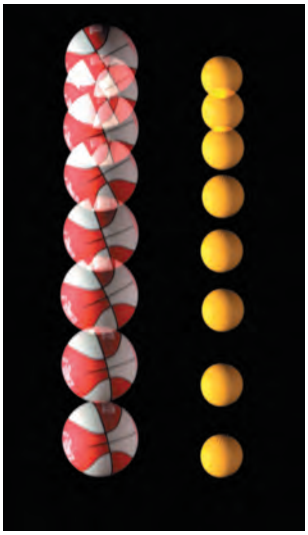
$$s = ut + \frac{1}{2}at^2 \qquad s = \frac{(u+v)t}{2}$$

$$s = vt - \frac{1}{2}at^2$$

In these equations u is the initial velocity, v is the final velocity, a is the acceleration, s is the distance travelled and t is the time taken. The average velocity, $\bar{v}$, is given by $(u + v)/2$.

In solving problems involving kinematics, it is important to understand the situation before you try to substitute numerical values into an equation. Identify the quantity you want to know, and then make a list of the quantities you know already. This should make it obvious which equation is to be used.

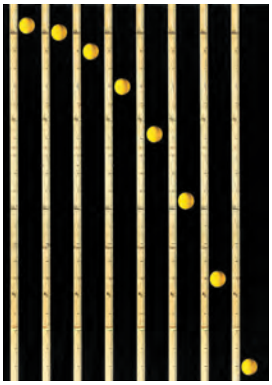
Free fall acceleration



▲ Figure 2.8 Strobe-flash photograph of objects in free fall

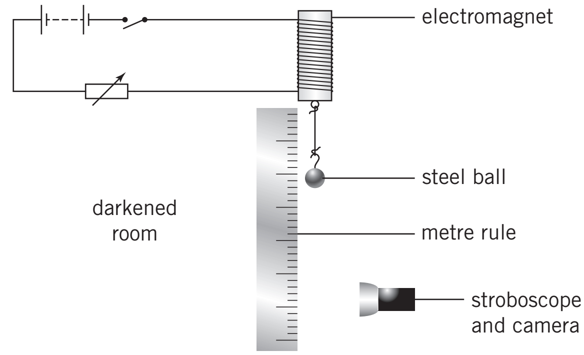
A very common example of uniformly accelerated motion is when a body falls freely near the Earth's surface. Because of the gravitational attraction of the Earth, all objects fall with the same uniform acceleration. This acceleration is called the acceleration of free fall, and is represented by the symbol g. It has a value of $9.81\,\text{m}\,\text{s}^{-2}$ and is directed downwards. For completeness, we ought to qualify this statement by saying that the fall must be in the absence of air resistance, but in most situations this can be assumed to be true.

The acceleration of free fall may be determined by an experiment in which the flight of a steel ball is recorded using strobe-flash photography. A steel sphere is released from an electromagnet and falls under gravity in a dark room



▲ **Figure 2.10** Strobe-flash photo of free fall

(Figure 2.9). A camera is used to produce a photograph of the ball's flight. The shutter of the camera is open and a stroboscope is used to flash a light at a selected frequency. The photograph shows the position of the ball at regular intervals of time against the scale on a metre rule as the ball falls vertically (Figure 2.10).



▲ **Figure 2.9** Determination of the acceleration due to free fall

If the body falls from rest, we can use the second of the equations for uniformly accelerated motion in the form

$$s = \frac{1}{2}at^2$$

to calculate the value of g. Note that, because the time of fall is likely to be only a few tenths of a second, precise timing to one-hundredth of a second is required (Table 2.3). The frequency of the stroboscope gives the time interval between flashes of light and hence images on the photo. A graph of the displacement s against t^2 should give a straight line of gradient ½a from which g can be calculated.

position/m	time/s	velocity/m s^{-1}
0.012	0.05	0.49
0.049	0.10	0.98
0.110	0.15	1.47
0.196	0.20	1.96
0.306	0.25	2.45
0.441	0.30	2.94

▲ **Table 2.3** The position, time and velocity for a free-falling object

Until the sixteenth century, the idea of the acceleration of a falling body was not fully appreciated. It was commonly thought that heavier bodies fell faster than light ones. This idea was a consequence of the effect of air resistance on light objects with a large surface area, such as feathers. However, Galileo Galilei (1564–1642) suggested that, in the absence of resistance, all bodies would fall with the same constant acceleration. He showed mathematically that, for a body falling from rest, the displacement travelled is proportional to the square of the time. Galileo tested the relation experimentally by timing the fall of objects from various levels of the Leaning Tower of Pisa (Figure 2.12). This is the relation we have derived as $s = ut + \frac{1}{2}at^2$. For a body starting from rest, $u = 0$ and $s = \frac{1}{2}at^2$. That is, the displacement is proportional to time squared.

▲ **Figure 2.12** Leaning Tower of Pisa

▲ **Figure 2.11** Galileo in his study

WORKED EXAMPLE 2C

1 A car increases its speed from 25 m s^{-1} to 31 m s^{-1} with a uniform acceleration of 1.8 m s^{-2}. How far does it travel while accelerating?

2 The average acceleration of a sprinter from the time of leaving the blocks to reaching her maximum speed of 9.0 m s^{-1} is 6.0 m s^{-2}. For how long does she accelerate? What distance does she cover in this time?

3 A cricketer throws a ball vertically upward into the air with an initial velocity of 18.0 m s^{-1}. How high does the ball go? How long is it before it returns to the cricketer's hands?

Answers

1 In this problem we want to know the distance s. We know the initial speed u = 25 m s^{-1}, the final speed v = 31 m s^{-1}, and the acceleration a = 1.8 m s^{-2}.

We need an equation linking s with u, v and a; this is $v^2 = u^2 + 2as$.

Substituting the values, we have $31^2 = 25^2 + 2 \times 1.8s$.

Rearranging, $s = (31^2 - 25^2)/(2 \times 1.8)$ = **93 m**.

2 In the first part of this problem, we want to know the time t. We know the initial speed u = 0, the final speed v = 9.0 m s^{-1}, and the acceleration a = 6.0 m s^{-2}. We need an equation linking t with u, v and a; this is $v = u + at$.

Substituting the values, we have 9.0 = 0 + 6.0t.

Rearranging, t = 9.0/6.0 = **1.5 s**.

For the second part of the problem, we want to know the distance s. We know the initial speed u = 0, the final speed v = 9.0 m s^{-1}, and the acceleration a = 6.0 m s^{-2}; we have also just found the time t = 1.5 s. There is a choice of equations linking s with u, v, a and t. We can use

$$s = ut + \frac{1}{2}at^2.$$

Substituting the values, $s = 0 + ½ \times 6.0 \times (1.5)^2$ = **6.8 m**.

Another relevant equation is $\bar{v} = \Delta x/\Delta t$. Here the average velocity $\bar{v}$ is given by $\bar{v} = (u + v)/2$ = 4.5 m s^{-1}. $\Delta x/\Delta t$ is the same as s/t, so 4.5 = s/1.5, and s = 4.5 × 1.5 = **6.8 m** as before.

3 In the first part of the problem, we want to know the distance s. We know the initial velocity u = 18.0 m s^{-1} upwards and the acceleration $a = g$ = 9.81 m s^{-2} downwards. At the highest point the ball is momentarily at rest, so the final velocity v = 0. The equation linking s with u, v and a is $v^2 = u^2 + 2as$.

Substituting the values, $0 = (18.0)^2 + 2(-9.81)s$.

Thus $s = -(18.0)^2/2(-9.81)$ = **16.5 m**. Note that here the ball has an upward velocity but a downward acceleration, and that at the highest point the velocity is zero but the acceleration is not zero.

In the second part we want to know the time t for the ball's up-and-down flight. We know u and a, and also the overall displacement s = 0, as the ball returns to the same point at which it was thrown. The equation to use is $s = ut + ½at^2$.

Substituting the values, $0 = 18.0t + ½(-9.81)t^2$. Doing some algebra, $t(36.0 - 9.81t) = 0$. There are two solutions, t = 0 and t = 36.0/9.81 = 3.7 s. The t = 0 value corresponds to the time when the displacement was zero when the ball was on the point of leaving the cricketer's hands. The answer required here is **3.7 s**.

Now it's your turn 2.3

1 An airliner must reach a speed of 110 m s^{-1} to take off. If the available length of the runway is 2.4 km and the aircraft accelerates uniformly from rest at one end, what minimum acceleration must be available if it is to take off?

2 A speeding motorist passes a traffic police officer on a stationary motorcycle. The police officer immediately gives chase: his uniform acceleration is 4.0 m s^{-2}, and by the time he draws level with the motorist he is travelling at 30 m s^{-1}. How long does it take for the police officer to catch the car? If the car continues to travel at a steady speed during the chase, what is that speed?

3 A cricket ball is thrown vertically upwards with a speed of 15.0 m s^{-1}. What is its velocity when it first passes through a point 8.0 m above the cricketer's hands?

SUMMARY

- Distance is the length along the actual path travelled and is a scalar quantity. Displacement is the distance travelled in a straight line in a specified direction and is a vector quantity.
- Speed is a scalar quantity and is described by magnitude only. Velocity is a vector quantity and requires magnitude and direction.
- Average speed is defined by: (*actual distance moved*)/(*time taken*).
- Average velocity is defined by: (*displacement*)/(*time taken*) or $\Delta x/\Delta t$
- The instantaneous velocity is the average velocity measured over an infinitesimally short time interval.
- Average acceleration is defined by: (*change in velocity*)/(*time taken*) or $\Delta v/\Delta t$.
- Acceleration is a vector. Instantaneous acceleration is the average acceleration measured over an infinitesimally short time interval.
- The gradient of a displacement–time graph gives the velocity.
- The gradient of a velocity–time graph gives the acceleration.
- The area between a velocity–time graph and the time axis gives the displacement.
- The equations for a body moving in a straight line with uniform acceleration are:
  - $v = u + at$
  - $s = ut + \frac{1}{2}at^2$
  - $s = vt - \frac{1}{2}at^2$
  - $v^2 = u^2 + 2as$
  - $s = \frac{(u + v)t}{2}$
- Objects falling freely near the surface of the Earth in the absence of air resistance experience the same acceleration, the acceleration of free fall g, which has the value $g = 9.81\,\text{m s}^{-2}$.
- The motion of projectiles is analysed in terms of two independent motions at right angles. The horizontal component of the motion is at a constant velocity, while the vertical motion is subject to a constant acceleration g.

Practice examination-style questions

1 In a driving manual, it is suggested that, when driving at $13\,\text{m s}^{-1}$ (about 45 km per hour), a driver should always keep a minimum of two car-lengths between the driver's car and the one in front.

a Suggest a scientific justification for this safety tip, making reasonable assumptions about the magnitudes of any quantities you need.

b How would you expect the length of this 'exclusion zone' to depend on speed for speeds higher than $13\,\text{m s}^{-1}$?

2 A student, standing on the platform at a railway station, notices that the first two carriages of an arriving train pass her in 2.0 s, and the next two in 2.4 s. The train is decelerating uniformly. Each carriage is 20 m long. When the train stops, the student is opposite the last carriage. How many carriages are there in the train?

3 A ball is to be kicked so that, at the highest point of its path, it just clears a horizontal cross-bar on a pair of goal-posts. The ground is level and the cross-bar is 2.5 m high. The ball is kicked from ground level with an initial velocity of $8.0\,\text{m s}^{-1}$.

a Calculate the angle of projection of the ball and the distance of the point where the ball was kicked from the goal-line.

b Also calculate the horizontal velocity of the ball as it passes over the cross-bar.

c For how long is the ball in the air before it reaches the ground on the far side of the cross-bar?

4 a The drag force F_D acting on a sphere moving through a fluid is given by the expression

$$F_D = K\rho v^2$$

where K is a constant,

ρ is the density of the fluid

and v is the speed of the sphere.

Determine the SI base units of K. **[3]**

b A ball of weight 1.5 N falls vertically from rest in air. The drag force F_D acting on the ball is given by the expression in **a**. The ball reaches a constant (terminal) speed of $33\,\text{m s}^{-1}$. Assume that the upthrust acting on the ball is negligible and that the density of the air is uniform.

For the instant when the ball is travelling at a speed of $25\,\text{m s}^{-1}$, determine

i the drag force F_D on the ball,

ii the acceleration of the ball.

c Describe the acceleration of the ball in **b** as its speed changes from zero to $33\,\text{m s}^{-1}$.

Cambridge International AS & A Level Physics (9702) Paper 21 Q1 Oct/Nov 2017

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First published in 2008
Second edition published in 2014
This edition published in 2020 by
Hodder Education,
An Hachette UK Company
Carmelite House
50 Victoria Embankment
London EC4Y 0DZ

www.hoddereducation.com

Impression number 10 9 8 7 6 5 4 3 2 1

Year 2023 2022 2021 2020

Cover photo © Korn V. - stock.adobe.com

Illustrations by Integra Software Services, Charon Tec and Aptara, Inc.

Typeset in ITC Officina Sans Std 11.5/13 by Aptara, Inc.

Printed in the U.K.

A catalogue record for this title is available from the British Library.

ISBN: 978 1 5104 82807

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