Lesson One

Speed, Distance and Time

Aims

By the end of this lesson you should be able to:

- know and use the formulae:

  average speed = distance moved ÷ time taken

  acceleration = change in velocity ÷ time taken

- plot and explain distance-time and velocity-time graphs
- determine:
  - acceleration from the gradient of a velocity-time graph
  - distance travelled from velocity-time graph
- use the relationship $v^2 = u^2 + 2as$
- understand experiments to investigate the motion of everyday objects such as toy cars or tennis balls

Context

This lesson covers sections 1.3-1.10 of the Edexcel IGCSE Physics specification.

Edexcel IGCSE Physics, Chapter 1, pages 1-10.

Oxford Open Learning

Introduction

Many of the laws which govern how objects move were first worked out by the English scientist Isaac Newton (1642-1727), who measured their motion using numbers. In this lesson we study the connection between how far objects move (distance or length), how fast they move (speed) and how long they take (time). We also look at the mysterious ideas of acceleration and velocity, and learn how to draw graphs to illustrate these things. Then in the next lesson we study the role of forces in producing movement.

Speed

The **speed** of an object means how fast it is moving, and in Physics it is measured in "metres per second", abbreviated as **m/s**. "Speed" is a quantity, and "m/s" is its unit (see the introductory lesson, 'Using Numbers in Physics').

You can work out the *average* speed of an object by measuring the time it takes to travel a measured distance, using the formula:

$$\textbf{average speed} = \frac{\textbf{distance moved}}{\textbf{time taken}}$$

So, if a tennis ball travels 25 metres in 2 seconds, its speed is

$$\frac{25}{2} = 12.5 \text{ m/s}$$

You can also rearrange the equation (see 'Using Numbers in Physics') to find out the distance moved if you know its speed and the time taken, or the time taken if you know its speed and the distance moved.

Activity 1

A toy car was travelling at a speed of 3m/s.

(a) How far would it travel in 3s?

(b) How long would it take to travel 12m?

Now two complications:

1. It is unlikely that the tennis ball travels at a constant (fixed) speed throughout its journey. So our formula actually calculates the **average speed** of the ball overall, not the **instantaneous speed** of the ball at any one time.

2. The tennis ball may curve as it moves, rather than going in a straight line. To allow for this Physics uses another term **velocity**. The velocity of an object is its speed *in a certain direction*. So if the tennis ball glances off a wall as it travels, its *speed* may stay the same, but its *velocity* will have changed, because it is now moving in a different direction.

There will be more about this in Lesson Two. For now it is OK to use "speed" and "velocity" as meaning roughly the same thing.

Using Symbols

We have already met the use of abbreviations, or symbols, for *units*: "m" stands for "metre", "s" stands for "second", and so on. You will notice from the textbook that we can also use symbols for *quantities*, especially when they in formulae. The symbols for the quantities used in this lesson are:

- "*d*" for distance or length

- "t" for time
- "a" for acceleration, and
- "v" for velocity or speed

So the formula connecting speed, distance moved and time taken can also be written:

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

Obviously there is a danger of confusing the symbols for quantities and units. For example "m" can stand for the quantity "mass" or the unit "metre", so you need to be alert!

If we want to put the formula "distance moved = speed × time taken" into symbols, we can do it in three ways:

$$d = v \times t$$
$$d = v.t$$
$$d = vt$$

In each case, the right hand side means "speed times time taken", and physicists usually write it in the third way: as $d = vt$.

Acceleration

In everyday life, **acceleration** means "getting faster". In Physics it means something similar, but it is tied down more exactly as *the rate of change of velocity*. It is calculated using this formula:

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

Now, the change in velocity equals the final velocity (given the symbol v) minus the initial or starting velocity (given the symbol u). So we can also write the formula in symbols like this:

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

It has the units **m/s²** said "metres per second squared", which means the number of metres per second the velocity changes each second.

For example, if a toy car, rolling down a hill, speeds up from rest to reach a speed of 3m/s after 2s, then:

$$a = \frac{(3-0)}{2} = 1.5\text{m/s}^2$$

Its acceleration is 1.5 metres per second squared.

Two complications:

1. If an object is slowing down, u is bigger than v, so the acceleration becomes a negative (minus) number. We can call this either "negative acceleration" or **deceleration**.

2. Acceleration is defined as the change in *velocity* over time, not the change in *speed* over time. So if an object is whirling in a circle at constant *speed*, it will be *accelerating* all the time. This will become important in Lesson Two, but we can ignore it for now.

Log on to Twig and look at the film titled: **Speed, Velocity, Acceleration**

www.ool.co.uk/1491qt

Discover how speed, velocity and acceleration are interlinked but very different measurements of motion.

Activity 2

1. A toy car is accelerating at 2m/s^2. It starts at a velocity of 5m/s. What will its velocity be after 3s?

2. A tennis ball slows down from 18m/s to 12m/s in 2s. What is its acceleration?

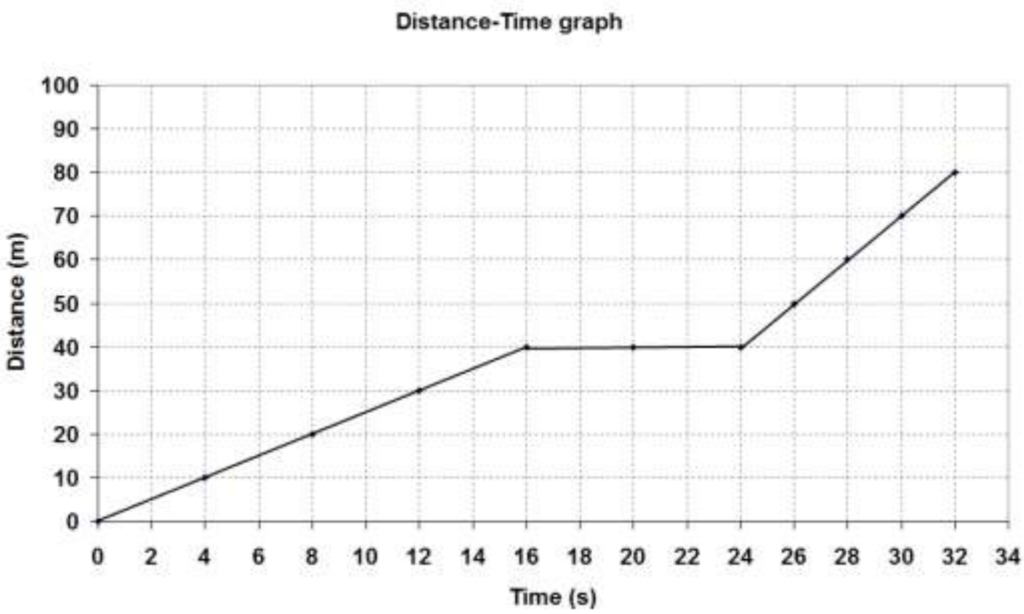
Distance-time graphs

In Physics, we often draw a **graph** to show visually how two related quantities are changing.

For example, suppose we measure the distance travelled by a cyclist every 4 seconds, and obtain the results in this **table**:

Time / s	Distance / m
0	0
4	10
8	20
12	30
16	40
20	40
24	40
28	60
32	80

We can draw a **distance-time graph** of these results as below:



Drawing Graphs in Physics

When drawing any graph:

- Both the quantities and their units are written along the **axes** of the graph as shown: Distance (m) and Time (s) in this case.

- The quantity whose measurements we have chosen, called the **independent variable**, goes along the bottom or ***x*-axis**. In this case Time, because we chose to measure the distance travelled by the bicycle every 4 seconds.

- The quantity whose measurements we discover, rather than choosing in advance, called the **dependent variable**, goes up the side or ***y*-axis**. In this case distance.

- Numbers are written at regular intervals along the axes. Each space must correspond to the same number all the way along. For example, one space corresponds to 2 seconds all along the *x*-axis, and one space to 10 metres right up the *y*-axis.

- Each pair of numbers from the table is plotted as a single **point** on the graph. For example 12 seconds and 30 metres are plotted as a point.

- When doing a graph by hand, each point should be plotted as a small *cross*, in *sharp* pencil (not as a small blob as shown above). The point must be accurate – which means less than half a small square of graph paper away from where it should be.

- A **line** is drawn to show the pattern formed by the points. This may be one or more straight lines (as here) or a curve. The line should be drawn with a *pencil*. If it is one or more straight lines it should be drawn with a *ruler*.

- In a later lesson we will discuss how to draw the line if some of the points are inaccurate. For this lesson we shall *join up* all of the points with one or more straight lines.

- The graph is given a **title**, which is made up using the quantities plotted on the two axes. For example "A graph of distance against time for a bicycle" would be a good title in this case.

Reading a distance-time graph

Notice the following about the line on the distance-time graph:

- when the line is horizontal, it means the bike is stopped (its speed is zero);
- the greater the gradient (steepness) of the line, the greater the speed of the bike.

Using a distance-time graph

We can use the graph to find out the average speed of the bike between any two times. For example, between 2 seconds and 22 seconds (a time of 22-2 = 20s) its distance has changed by 40 – 5 metres = 35m:

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

$$= \frac{35}{20}$$

$$= 1.75\text{m/s}$$

So the bike's *average* speed, *between these two times*, is 1.75 metres per second.

Activity 3

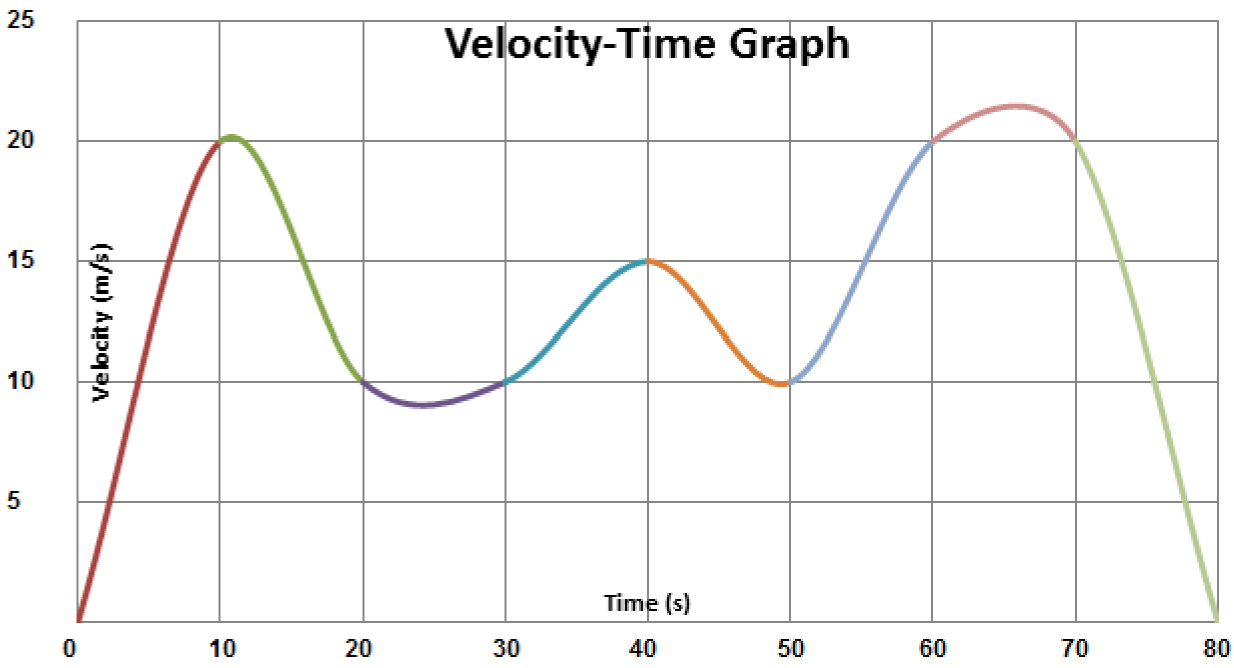
1. Using the graph above, calculate the average speed between 0 and 32 seconds.
2. Compare the motion of the bike between 24 -32 seconds with its motion between 0 -16 seconds.

Velocity-time graphs

Suppose a motor cyclist, travelling along a straight road, measures his instantaneous speed every 10 seconds by reading his speedometer. Because the road is straight, his speed and velocity are the same. He gets these results:

Time / s	Velocity / m/s
0	0
10	20
20	10
30	10
40	15
50	10
60	20
70	20
80	0

We can draw a **velocity-time graph** of these results as below. The points have not been marked as crosses, but they occur at 0, 10, 20 ... 80 seconds.



Reading a velocity-time graph

Note carefully that the gradient (steepness) of the line on a velocity-time graph means something quite different to the gradient of the line on a distance-time graph. On a velocity-time graph:

- when the line is horizontal it means that the bike is moving at *constant velocity* (speed), it does *not* mean it is stopped;
- the greater the gradient of the line the greater the *accleration*, *not* the greater the velocity.

In addition, a *straight* upwards line means that the acceleration of the bike is *constant*, while a straight downwards line means that its deceleration is constant.

Using a velocity-time graph

A velocity-time graph can be used to calculate two other things about the motion of the object: its acceleration, and the distance travelled:

1. The average acceleration between any two times is calculated by reading the velocities at the two times from the line, and then using the equation

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

   For example, between 25 and 55 seconds:

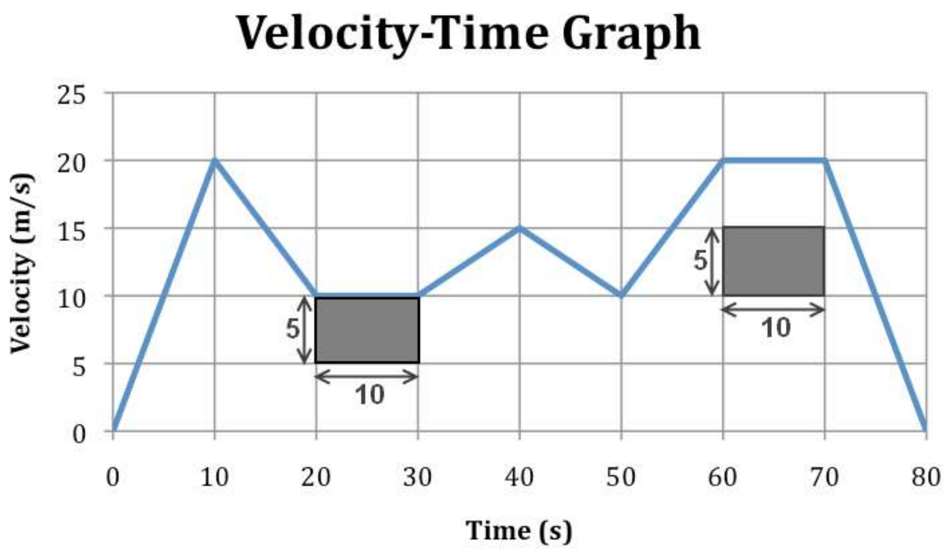
   $$a = \frac{(15-10)}{30}$$

   $= 0.17\text{m/s}^2$

2. The distance travelled between two times is given by the *area under* the line between those two times. This needs more detailed explanation.

The area under a graph

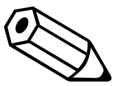
Look at the graph below:



Each rectangle on the graph represents 5m/s for 10s. This is a distance of 5 × 10 = 50m, because distance = speed × time.

To find the distance travelled in the first 50s, count the rectangles under the line between 0s and 50s. Add parts of rectangles together to make whole rectangles.

There are 12 such rectangles, so the distance travelled during the first 50s is 12 × 50 = 600m. The bike travels 600 metres during the first 50 seconds of its journey.

Activity 4	Using the graph above, calculate: (a) the acceleration between 30 seconds and 40 seconds (b) the total distance travelled between 0 and 80 seconds
	

Speed, acceleration and distance (June 2019 onwards)

If an object is accelerating, the distance it moves, its average acceleration, and its starting and finishing speeds are connected by this equation:

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

(final speed)^2 = (initial speed)^2 + (2 × acceleration × distance moved)

Get it right!

"Distance" is represented by the symbol "*s*" in this equation, *not* by the symbol "*d*".

This equation is often used to calculate:

- the initial or final speed when travelling a known distance
- the distance moved while accelerating
- the acceleration

by rearranging the equation appropriately.

For example, say you were asked to calculate the initial speed given the other three quantities. First state the equation:

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

Then rearrange it to get u (the initial speed) on its own on one side. When doing this, a "+" on one side of the equals sign becomes a "–" on the other. So:

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

Then take the square root of both sides:

$$\sqrt{(v^2 - 2as)} = \sqrt{u^2} = u$$

Then fill in the figures for v, a and s, and calculate the value of u.

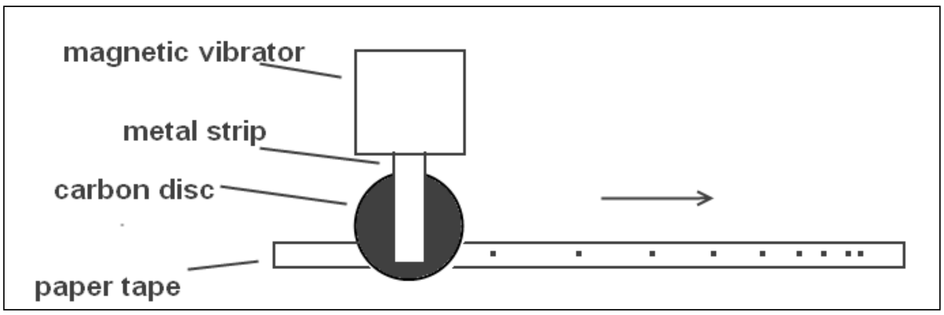
Activity 5

1. An object speeds up from 3m/s to 7m/s while travelling a distance of 20m. Calculate its average acceleration.

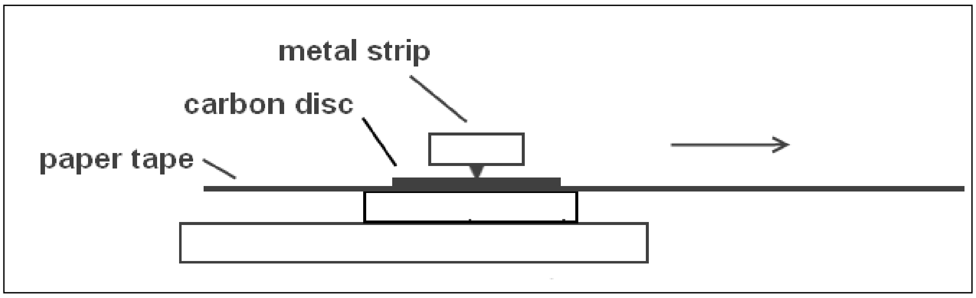
2. A tennis ball slows down from 20m/s to 2m/s with an acceleration of -3m/s. Calculate the distance travelled during this reduction in speed.

Investigating motion using a Ticker Tape Timer (all candidates)

Investigating the motion of objects such as toy cars in the laboratory can be done using a **ticker tape timer**. A long strip of paper (the tape) is attached to the back of the car and pulled through the ticker timer. This vibrates rapidly, making a black dot on the tape every 0.02s (1/50th of a second).



Top view



Side view

If the car accelerates the dots get further apart, and if it decelerates they get closer together. If the car moves at constant speed, the small dots on the tape will be equally spaced. The speed of the car can be calculated using the formula:

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

where "d" is the distance between two of the dots, and "t" is 0.02s.

In addition:

- the total time taken in seconds can be found by counting the spaces between the dots and multiplying by 0.02;
- the total distance travelled can be found by measuring the distance between the first and last dots.

This gives you all the information you need for calculating the distance, speed, time and acceleration for the car, and for plotting distance-time and velocity-time graphs for it.

Activity 6

Investigate your speed and acceleration with the help of a friend.

Measure out a known distance in metres (or use a running track if you can, which is 400m round the inside lane). Get your friend to time you (a) walking and (b) running the distance, and work out your average speed for both walking and running.

Then get your friend to time how long it takes you to get up to your running speed from rest, and calculate your acceleration.

Log on to Twig and look at the fact-pack titled: **Speed, Velocity, Acceleration**

www.ool.co.uk/1497jp

In the race to change velocity the fastest, can man-made objects outstrip nature's fastest accelerators?

Summary

The summary lists some of the key skills you have learned.

Speed and velocity
Acceleration
Distance-time graphs
Velocity-time graphs
Using a ticker tape timer

Keywords

speed	**velocity**
distance	**time**
acceleration	**deceleration**
m/s	**m/s^2**
graph	**table**
axes	**point**
independent variable	**dependent variable**
ticker tape timer	

These are the terms from this lesson that you may need to define or employ correctly.

What you need to know

- the meanings of the terms printed in **bold** in the lesson
- the equations for calculating speed from distance and time and for calculating acceleration from change in velocity and time
- the equation $v^2 = u^2 + 2as$
- the difference between speed and velocity
- the meaning of the gradient of the line in distance-time and velocity-time graphs
- how a ticker tape timer can be used to measure speed, distance and time
- the abbreviations for the quantities and units used in the lesson

What you might be asked to do

- perform calculations using the formulae given in the lesson, rearranging them if necessary
- draw a distance-time or velocity-time graph given a table of data
- calculate velocity from a distance-time graph
- calculate acceleration or distance travelled from a velocity-time graph
- describe how to investigate the motion of objects like toy cars

Self-Assessment Test: Lesson One

* When setting out calculations in Physics, always write down these four things in order:

1. the formula you will use;
2. the formula with the numbers filled in, before doing any calculation;
3. the calculated answer;
4. the correct unit.

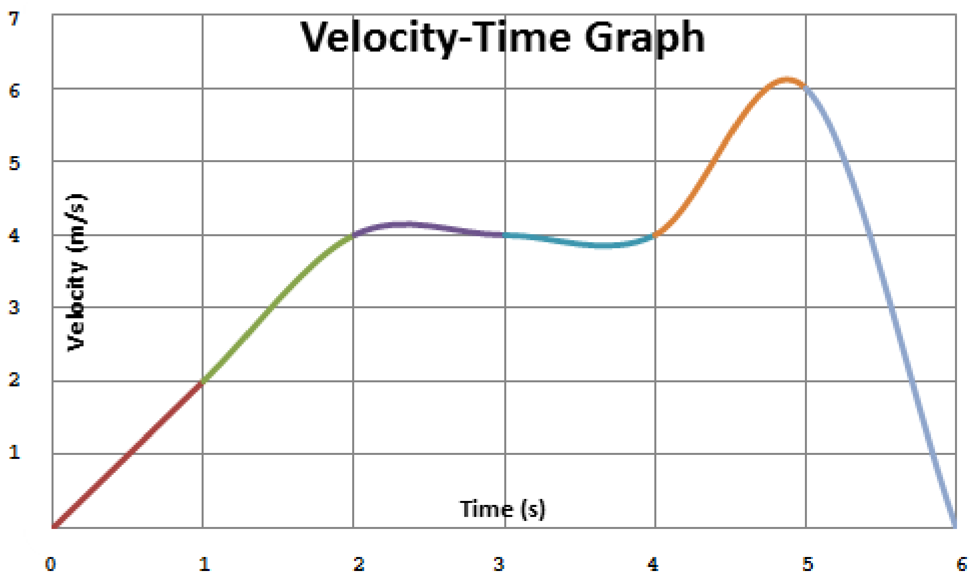
This way you will always score full marks (if you get it right!)

Many people forget the units – don't be one of them!

1. (a) An object is moving at 24m/s. Calculate how long it will take to cover a distance of 6m.

   (b) It then decelerates at $3m/s^2$. What will its velocity be after 3s?

2. Here is a velocity-time graph for a moving car.



   (a) How far does the car travel between 2 and 4 seconds?

   (b) Calculate the acceleration between 5 and 6 seconds.

   (c) Describe the motion of the car between 2 and 4 seconds.

3. (June 2019 onwards)

   An object is moving at an initial speed of 2m/s. It accelerates at $3m/s^2$ over a distance of 10m. What is its final speed?

Suggested Answers to Activities

Activity 1

(a) Distance = speed × time = 3m/s × 3s = 9m (9 metres)

(b) Time = distance / speed = 12m / 3m/s = 4s (4 seconds)

Activity 2

1. $a = (v - u) / t$. Multiplying both sides by "t" gives:

$at = v - u$

Now adding "u" to both sides gives:

$at + u = v$

So

$v = (2 \times 3) + 5 = 11\text{m/s}$

Its new velocity will be 11m/s.

2. $a = (v - u) / t$

$= (12 - 18) / 2$

$= -3\text{m/s}^2$

Its acceleration is *minus* 3m/s^2 because it is slowing down.

Activity 3

1. $v = d / t$

$= 80\text{m} / 32\text{s}$

$= 2.5\text{m/s}$

2. It is travelling faster (its speed is greater) between 24-32 seconds, as the gradient of the line is steeper.

Activity 4

(a) $a = (v - u) / t$

$= (15 - 10) / 10$

$= 0.5 m/s^2$

(b) There are 21 full squares under the line, so the total distance covered is $21 \times 50 = 1050m$.

Activity 5

1. $a = \frac{v^2 - u^2}{2s} = \frac{49-9}{2 \times 20} = \mathbf{1\ m/s}$

2. $s = \frac{v^2 - u^2}{2a} = \frac{2^2 - 20^2}{2 \times -3} = \mathbf{66m}$

Answers to Self-Assessment Test: Lesson One

1. (a) $v = d / t$, so

$t = d / v$

$= 6 / 24$

$= 0.25s$

(b) $a = (v - u) / t$, so

$at + u = v$

so $v = (-3 \times 3) + 24$

$= 15m/s$

2. (a) speed = distance / time, so

distance = speed × time

$= 4 \times 2$

$= 8\text{m}$

(b) $a = (v - u) / t$

$= (0 - 6) / 1$

$= -6\text{m/s}^2$

(Note the minus sign)

(c) It is moving at constant velocity.

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

$= 2^2 + (2)(3)(10)$

$= 64$

So $v = \sqrt{64} = 8\text{m/s}$