Biomechanics

CHAPTER 11:

Linear motion in physical activity

LEARNING OBJECTIVES

By the end of this chapter you should have knowledge and understanding of:

- Newton's three laws of motion
- why there can never be motion without force but there can be force without motion
- what is meant by the terms mass, inertia and momentum, and their relevance to sporting performance
- the quantities used to describe linear motion and their relevance to sporting techniques
- how to distinguish between distance and displacement and between speed and velocity
- how to use equations to make simple calculations for speed, velocity and acceleration
- how to plot and interpret information from distance/time and velocity/time graphs.

INTRODUCTION TO THE SECTION

Biomechanics is often thought of as the science underlying technique; knowledge in this area helps athletes and coaches to develop efficient techniques and correct errors in performance. Most of today's top performers will use biomechanical analysis to improve their technique and take it one step closer to perfection. High quality techniques will place less stress and strain on the body's musculo-skeletal system and thereby reduce the possibility of incurring injury or tissue damage, such as the conditions you learned about last year in your anatomy and physiology course.

There are five chapters in this section on Biomechanics. In the first four chapters, the mechanics of motion will be revisited and the field of biomechanics will be looked at in detail. Some of the concepts involved were introduced to you in Chapter 2 of *OCR AS PE*, so it may be beneficial to review this chapter before reading further. In the final chapter, we will work together to ensure that the knowledge you have built up in working through this section is sufficient to allow you to critically evaluate efficient performance in a range of physical activities.

Before you begin, it is worth pointing out that you do not need to be a mathematical genius to do well in this section of the specification. For the purposes of A-level Physical Education, the study of biomechanics involves very few scientific formulas and no difficult calculations, although definitions remain important. It is hoped that by delving into this section, you will develop an appreciation for biomechanics and use its principles to enhance your own and others' performances – as well as score well in your exam!

INTRODUCTION TO THE CHAPTER

This chapter looks at the mechanical concepts associated with understanding **linear motion**. By this we mean that a body's centre of mass is travelling in a straight or curved line. The first of these concepts is Newton's laws of motion. These three well-known laws explain all the characteristics of motion and are fundamental to fully understanding human movement in sport. The chapter also looks at the important concepts of mass, inertia and momentum and their relevance to sporting techniques. We then go on to explain how the linear motion of a performer can be described in terms of linear measurements, and the quantities of distance, displacement, speed, velocity and acceleration are considered. Analysis of linear motion in this way is useful because many movements in sport happen so quickly that techniques are difficult to analyse by visual observation alone. This is particularly notable in the 100m sprint event. You will learn how to present the data collected in graphical form and how to interpret the shape of such graphs.

KEY TERM

Linear motion

When a body moves in a straight or curved line, with all its parts moving the same distance in the same direction and at the same speed. For example, a performer in the skeleton bobsleigh will travel with linear motion in a straight line when sliding down the straight parts of the track and with linear motion in a curved line when sliding around the bends.

Fig 11.1 Sporting example of linear motion in a straight and curved line

Newton's laws of motion

Newton's laws of motion play an important role in explaining the close relationship between motion and **force**.

KEY TERM

Force

A push or a pull that alters, or tends to alter, the state of motion of a body.

EXAM TIP

For the AS exam, the examiner was happy for you to be able to give different sporting examples for each of Newton's laws. This year, however, the examiner may ask you to state each of the three laws and apply them to one particular sport. It is therefore a good idea to practise this in class.

NEWTON'S FIRST LAW OF MOTION – THE LAW OF INERTIA

> 'A body continues in a state of rest or of uniform velocity unless acted upon by an external force.'
>
> Newton's first law of motion

Newton's first law is often appropriately referred to as the law of **inertia**. In Latin, *inertia* means laziness.

KEY TERM

Inertia

The resistance of a body to change its state of rest or motion. (See also pages 275–276 for more about inertia.)

> 'Everything in the universe is lazy; so lazy that force is necessary to get it on the move, when it then travels in a straight line with constant

speed; so lazy that, once in motion, further force must be applied to slow it down, stop it, speed it up or change its direction.'

A famous biomechanical scientist's explanation of inertia.

As with all of Newton's laws, Newton's first law can be applied to any sporting activity. It explains two fundamental concepts linked with motion and force:

1 It tells us that a stationary body will remain at rest until an external force is applied. For example, for a centre pass in netball, the ball will remain in the centre's hands until she applies a force to the ball to pass it to a team mate.
2 It tells us that a moving body will continue to move with constant **velocity** until made to change its speed and/or direction by an external force. For example, the netball will continue travelling at constant velocity in the direction thrown until caught by another player, when the ball's velocity will decrease. If this player then imparts an external force on the ball, it will travel in a different direction.

KEY TERM

Velocity

The rate of motion in a particular direction (see also page 279).

Fig 11.2 Netball players showing an example of Newton's first law of motion

NEWTON'S SECOND LAW OF MOTION – THE LAW OF ACCELERATION

'When a force acts on an object, the rate of change of momentum experienced by the object is proportional to the size of the force and takes place in the direction in which the force acts.'

Newton's second law of motion

Newton's second law is very closely related to Newton's first law. From the first law it is understood that the velocity of a body remains constant until a force acts upon it. Newton's second law explains that any change in velocity will be directly proportional to the amount of force used and will take place in the direction in which the force acts. Again, there are endless examples, but we will stick with netball. A goal shooter who has received the ball in a strong position close to the goal will only need to impart a relatively small amount of force in the direction of the ring. However, a goal shooter who has been forced to the edge of the shooting circle before taking a shot will need to impart a larger amount of force in the direction of the ring as the ball will need a greater change in **momentum** to travel to the goal.

A final concept that comes from Newton's second law is the equation:

Force = mass x acceleration or F = ma

KEY TERMS

Momentum

The quantity of motion possessed by a moving body. Momentum = mass x velocity and is measured in kg m s^{-1}. See also page 276.

Acceleration

The rate of change of velocity.

Fig 11.3 A netball shooter uses Newton's second law of motion to judge the size of force needed to give the correct change in momentum to the ball

REMEMBER

Momentum = mass x velocity. In most sporting examples, to show a force causing a change in momentum, the mass of the body in question does not change. So, a change in momentum is down entirely to a change in velocity.

EXAM TIP

F = ma is the equation you will need to use if you are asked to calculate the size of a force. Remember that the units for force are Newtons (N) and these must be given as well as your answer.

NEWTON'S THIRD LAW OF MOTION – THE LAW OF REACTION

> 'For every force that is exerted by one body on another, there is an equal and opposite force exerted by the second body on the first.'
>
> Newton's third law of motion

Newton's third law simply states that for every action there is an equal and opposite reaction. It is usual to call one of the forces involved the **action force** and the other the **reaction force**. There are no strict rules that govern which force is which, but for the purpose of sports mechanics, it is presumed that the athlete exerts the action force.

To return to the netball game, Newton's third law can be clearly explained by a player giving a bounce pass to a team mate. The player exerts an action force on the ball in the downward direction. At the same time, the ball exerts a reaction force in the upward direction on the player, felt by a slight increase in pressure on the fingers. The ball then travels down towards the floor and, on contact, the ball exerts a downward action force on the ground that in turn exerts an upward reaction force on the ball and the ball bounces up into the hands of the receiving player.

Newton's third law states that not only does every force have an opposite, but also that this second force is equal in size to the first. Does it not therefore follow that these two forces will cancel each other out and there will be no external force and therefore no movement (Newton's first law)? It is agreed that this is a difficult concept to understand, but it can be explained by the difference in mass of the two bodies concerned: the larger the mass, the smaller the effect of the force and the less the acceleration.

Let's consider the netball bouncing on the court as mentioned above. At the moment of impact, the netball exerts an action force on the court and the court surface exerts a reaction force on the netball. The fact that the ground supports the netball court means it has a colossal mass compared to the mass of the netball. It follows that the reaction force on the ball is great, but the action force on the court is negligible compared to their respective masses.

KEY TERMS

Action force

A force exerted by a performer on another body. For example, the backward and downward action force exerted by a sprinter on the blocks at the start of a race.

Reaction force

An equal and opposite force to the action force exerted by a second body on the first. For example, the forward and upward reaction force exerted by the blocks on the sprinter at the start of a race.

A FINAL THOUGHT ON NEWTON'S LAWS

At this stage, it is important to point out that Newton's first law of motion explains that motion in sport can only be produced when an external force is applied, i.e. there can be no motion without force. However, although this is more difficult to appreciate, it is important to remember that it is possible to have force without motion and this occurs when all opposite forces are balanced. Take, for example, a gymnast performing a handstand on the parallel bars. From our knowledge of Newton's third law, we know that the gymnast exerts a downward action force on the parallel bar that in turn exerts an upward reaction force on the gymnast. These forces are both opposite and equal, meaning there can be no movement and the gymnast remains balanced and still.

TASK 1

1 Copy Table 1 into your file and complete the missing information.

Newton's first law of motion is sometimes called:	
It states that:	
Newton's second law of motion is sometimes called:	
It states that:	
Newton's third law of motion is sometimes called:	
It states that:	

Table 1 Newton's laws

2 Learn each of Newton's laws word for word so that you are able to recite them when asked.

3 Select Newton's first, second or third law and design a poster to display as many sporting applications of this law as you can find. Use pictures or photographs of sporting activities or techniques to help with your explanations. Check that other members of your group are doing different laws so that you have plenty of sporting examples for all three laws.

Fig 11.4 A gymnast balancing on the parallel bars demonstrates that there can be force without motion.

APPLY IT!

Choose your two favourite sports and describe as many sporting applications of Newton's three laws as you can for each of the sports you have chosen.

STRETCH AND CHALLENGE

There can be no motion without force but there can be force without motion. Prepare a PowerPoint presentation to explain this statement using Newton's laws of motion, giving plenty of different sporting examples in your answers.

Mass, inertia and momentum

MASS

Mass simply means substance. If a body occupies space, it has mass; the more substance from which it is made, the larger the mass. A large performer in sport, such as a sumo wrestler, may be referred to as 'massive'! Likewise, we can be confident in saying that, in general, a rugby front row forward has a greater mass than a winger.

KEY TERMS

Mass

The amount of matter or substance in a body. An athlete's mass is made from bone, fat, tissue and fluid. Mass is measured in kilograms (kg).

INERTIA

Inertia is the reluctance of a body to change its state of motion. All bodies simply want to continue doing whatever they are doing. They want to remain at rest when still and want to continue moving in the same direction at the same velocity if moving. From Newton's first law of motion, we know that a force is required to change this state of motion. Inertia is directly related to mass, so the bigger the mass, the larger the inertia of a body and the bigger the force must be to change its state of motion. Think about the different weights of bowling balls at a ten-pin bowling alley. It is considerably easier to send a lighter ball towards the skittles than it is a bigger and heavier ball. Similarly, if equal force is applied to a javelin and a shot put, the acceleration of the javelin will be greater. Likewise, once in motion, it requires a larger force to stop a body with greater mass than it does to stop a body of smaller mass. A 100m sprinter will expend greater amounts of energy exploding out of the blocks and building velocity at the start of the race than they will expend in the middle and end segments of the race.

REMEMBER

Inertia is directly related to mass: the greater the mass the greater the inertia and the greater the force needed to get it moving, stop it moving or change its direction.

Consider a rugby prop forward and a rugby winger who are both running at the same speed towards the try line. Although the prop forward would have required a greater force to get him moving in the first instance, once moving he will be very difficult to stop due to his large inertia. It will take a strong and brave tackle to stop him from scoring! The same is true for changing direction. An athlete with a large inertia has to generate a greater force to change direction and it will often take them more time to change direction than a lighter opponent. This is one of the reasons why performers tend to be small and lightweight in sports requiring quick changes of direction such as badminton and squash.

A final thought on inertia is that it is the reason behind having different weight categories in contact sports. For example, in judo it would be very difficult for a lighter competitor with less mass and less inertia to throw a heavier competitor with greater mass and greater inertia.

APPLY IT!

In certain sports a large inertia can be an advantage and in other sports a disadvantage. Discuss this statement with reference to the body build of current sports performers at the top of their game. Are there any exceptions to your findings?

REMEMBER

Inertia resists motion and then persists motion.

MOMENTUM

Momentum is the quantity of motion possessed by a body and is quite simply 'mass on the move'. The amount of momentum possessed by a body depends on its mass and its velocity. If the mass or the velocity of the body increases, the momentum increases and vice versa.

Momentum = mass x velocity
(Mo = mv)

From the above equation for momentum, it follows that a stationary body with zero velocity has no momentum and only bodies that move have momentum. In sports movements there is little opportunity to increase or decrease mass and changes in momentum are entirely due to changes in velocity. For example, a 100m sprinter will have a greater momentum at 70m than at 10m because their velocity is greater (mass has remained unchanged).

Momentum plays a more important role in sports involving collisions or impacts. The result of the impact depends on the momentum of each of the colliding bodies just before impact. The greater the momentum of the body, the more pronounced the effect it has on the other body in its path. A good example here is in rugby: players with a relatively large mass who have the ability to run at a high velocity can generate considerable momentum when at full speed. This makes it very difficult to stop them or slow their forward momentum and they are often able to run through tackles. However, a player with a smaller mass, despite being able to run quickly, can sometimes come off second best when they meet a defender with considerable inertia!

Fig 11.5 Mass, inertia and momentum all come into play in sports involving collisions, such as rugby

TASK 2

1. If you have learned to drive recently, you will know a little about the stopping distances. Use your knowledge of momentum to explain why stopping distances increase with the speed of the car. What would be the impact on stopping distances for a lorry compared to a car?
2. Use your knowledge of inertia to discuss the relevance of the weight of the forward pack at the scrum in a game of rugby.
3. Calculate the momentum of a downhill skier who has a mass of 69kg and is travelling with a velocity of 39m/s.
4. What is the momentum of an athlete whose mass is 65kg and who is running at 8.7m/s?
5. Explain the relevance of momentum to Newton's first and second laws of motion.

EXAM TIP

For any calculation, remember three things:

- always give the equation you are using first
- show all your working
- give the units of measurement.

STRETCH AND CHALLENGE

Mass, inertia and momentum are closely linked. Critically examine the role that each has to play in physical activities, using examples from sport to help explain your conclusions.

Describing linear motion

The following quantities are measurements that are commonly used to describe the linear motion of a body. Their values reveal how far a body moves, how fast it moves and how consistent or inconsistent is its motion.

For the purpose of the specification, you need to be familiar with the following quantities:

- mass (as discussed on page 275)
- distance
- displacement
- speed
- velocity
- acceleration.

EXAM TIP

For each of the quantities listed, you will need to know:

- a simple definition
- a relevant equation where appropriate (remember that any calculation will be very simple!)
- the unit of measurement for the quantity you have calculated.

DISTANCE VERSUS DISPLACEMENT

The measurements of **distance** and **displacement** are used to describe the extent of a body's motion or how far it has travelled.

KEY TERMS

Distance

The path taken in moving from the first position to the second. Distance is measured in metres (m).

Displacement

The shortest straight-line route between two positions in a stated direction. Displacement is measured in metres (m).

Distance is simply the length of the path taken by a body in moving from one position to another and examples from sport are easy to give:

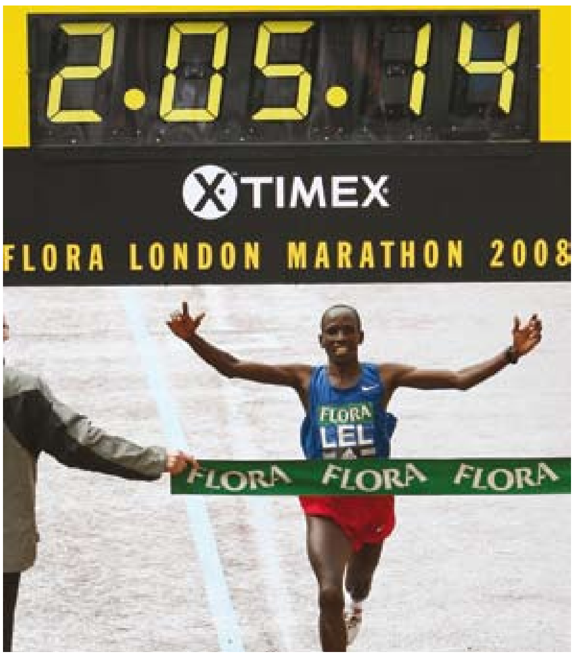


Fig 11.6 In the Flora London Marathon of 2008, Martin Lel ran a distance of 42.2 km and set a new World Record of 2 hours 5 minutes and 15 seconds. This sounds less impressive when we consider it took him over two hours to achieve a displacement of just 10km!

- the distance run by a competitor in the London Marathon is approx 42.2km
- the distance swum by a team in the 4 x 100m Freestyle relay is 400m
- the distance cycled by a female competitor in the Olympic Individual Pursuit event is 3km.

Displacement is a measurement from start to finish 'as the crow flies': the shortest route from the first position to the second.

- The displacement of a competitor in the London Marathon is approx 10km (see Fig 11.6).
- The displacement of a swimming team in the 4 x 100m Freestyle relay in a 50m pool is 0m – the fourth swimmer ends the race at the same point that the first swimmer started it.
- The displacement of a female cyclist in the Individual Pursuit event is 0m – although they cycle a distance of 3km, it is around a 200m track in the velodrome and the start line is also the finish line.

APPLY IT!

Consider field events in athletics. Field judges do not actually measure the distance thrown or jumped but the displacement.

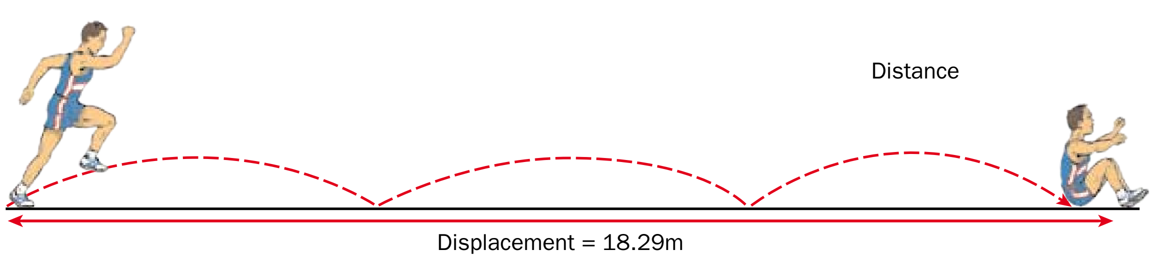


Fig 11.7 Jonathan Edwards did not set a world record distance of 18.29m in the triple event in 1995, but a world record displacement

REMEMBER

When a body moves in a straight line such as the 100m sprint, distance and displacement will have the same value.

SPEED VERSUS VELOCITY

The measurements of **speed** and velocity are used to describe the rate at which a body moves from one position to the next or how fast it is moving.

Speed is the rate of change of distance and its value is calculated by dividing the distance covered in metres by the time taken in seconds.

$$\text{Speed (m/s)} = \frac{\text{distance (m)}}{\text{time taken (s)}}$$

KEY TERM

Speed

A body's movement per unit of time with no reference to direction. Speed is measured in metres per second (m/s).

Velocity is the speed of a body in a given direction, and is the rate of change of displacement. Its value is calculated by dividing the displacement covered in metres by the time taken in seconds.

$$\text{Velocity (m/s)} = \frac{\text{displacement (m)}}{\text{time taken (s)}}$$

Velocity can change when direction changes even though the speed of the body might remain constant.

ACCELERATION

The measurement of acceleration is used to describe the rate at which a body changes its velocity. When velocity is increasing, it is known as positive acceleration and when velocity is decreasing it is known as negative acceleration or **deceleration**. Acceleration is measured in metres per second squared (m/s^2 or ms^{-2}).

v_f = final velocity (m/s)

$$\text{Acceleration (m/s}^2\text{)} = \frac{\text{change in velocity (m/s)}}{\text{time taken (s)}} = \frac{v_f - v_i}{t}$$

Where v_f = final velocity (m/s)
v_i = initial velocity (m/s)
t = time taken (s)

KEY TERM

Deceleration

The rate of decrease in velocity. A body will decelerate when velocity decreases over a certain time. This is often referred to as negative acceleration. Deceleration is measured in metres per second squared (m/s^2 or ms^{-2}).

Acceleration is a very important quantity in sport because success in many activities is directly related to an athlete's ability to rapidly increase or decrease their velocity. Consider, for example, a netball player who sprints away quickly to lose their defender and who then needs to stop abruptly on receiving the ball to avoid breaking the footwork rule.

Zero acceleration is where acceleration = 0 m/s^2 and a body is either at rest or moving with constant velocity. According to Newton's first law, the net force on the body is also 0N.

STRETCH AND CHALLENGE

In the 2008 Beijing Olympics, United States swimmer Michael Phelps became the first Olympian in history to win eight gold medals at an individual Olympic games, setting seven world records in the process. Ignoring the two relays, make a list of the times of the six other events he won.

For each event state the following:

- the distance swum
- the displacement swum
- Phelps' average speed during the race
- Phelps' average velocity during the race.

TASK 3

Table 2 gives the split times every 10m for an athlete running the 100m sprint.

Displacement (m)	0	10	20	30	40	50	60	70	80	90	100
Time (s)	0.00	1.86	2.87	3.80	4.66	5.55	6.38	7.21	8.11	8.98	9.83

Table 2 Split times for 100m sprint

1. Calculate the sprinter's velocity at 20m.
2. Calculate the sprinter's acceleration between 0m and 20m.
3. Calculate the sprinter's velocity at 40m.
4. Calculate the sprinter's velocity at 80m.
5. Calculate the sprinter's acceleration between 40m and 80m.

TASK 4

Copy Table 3 onto a sheet of A4 paper and complete the missing information. When you have completed the table, put it into your file as a revision guide for the key terms and quantities you have covered so far in this chapter.

Key term	Definition	Equation (where relevant)	Unit of measurement (where relevant)
Linear motion			
Force			
Mass			
Inertia			
Momentum			
Distance			
Displacement			
Speed			
Velocity			
Acceleration			

Table 3 Definitions, equations and units for terms connected with laws of motion

Graphs of motion

Graphs help us to make sense of motion as they are a useful means of presenting information. By using graphs, changes and patterns in motion can be recognised. Graphs are often used when data is presented very quickly to the naked eye, such as the 100m or 200m sprint events.

There are two types of graph that you need to be familiar with:

- distance/time graphs
- velocity/time graphs, or speed/time graphs.

For the purpose of sports mechanics at A2 level, velocity/time graphs and speed/time graphs can be treated as practically the same. The shape of the curve plotted on these graphs will enable you to know the pattern of motion occurring at a particular moment at time.

EXAM TIP

In a question involving graphs of motion, the examiner is more likely to refer to a velocity/time graph than a speed/time graph.

DISTANCE/TIME GRAPHS

A distance/time graph indicates the distance travelled by an object in a certain time.

KEY TERM

Gradient of graph

The slope of a graph at a particular moment in time.

$$\text{Gradient of graph} = \frac{\text{changes in y axis}}{\text{changes in x axis}}$$

EXAM TIP

For distance/time graphs:

1 Don't forget to:

- plot distance on the y-axis and time on the x-axis
- label the axes and give the units.

Both of the above will get you marks from your examiner!

2 The gradient of a distance/time graph will tell you whether the body is stationary, moving with constant speed, accelerating or decelerating (see Figs 11.7 – 11.10).

Gradient of a distance/time graph

$$\frac{\text{distance}}{\text{time}} = \text{speed}$$

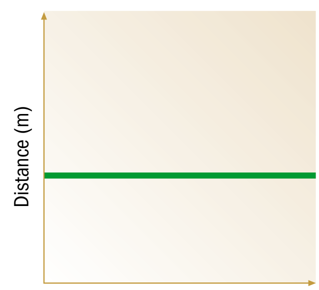


Fig 11.7 Body stationary

The body remains at the same distance over a period of time; it is not moving. For example, a hockey goalkeeper who is stationary before the penalty stroke is struck.

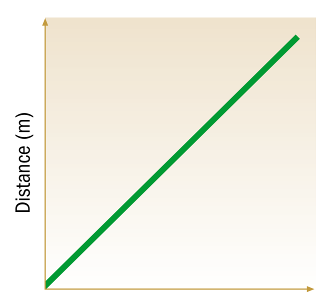


Fig 11.8 Body moving with constant velocity

The body is moving the same amount of distance at a steady rate. The gradient of the graph remains constant, therefore speed remains constant. For example, a middle-distance runner in the intermediate stages of the 1500m race.

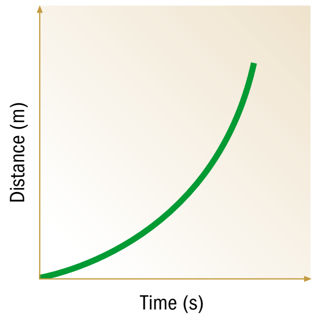


Fig 11.9 Body is accelerating

The distance travelled is increasing per unit of time. The gradient of the graph is increasing, therefore the speed is increasing and the body is accelerating. For example, a sprinter who is accelerating from the blocks over the first 20m of a 100m race.

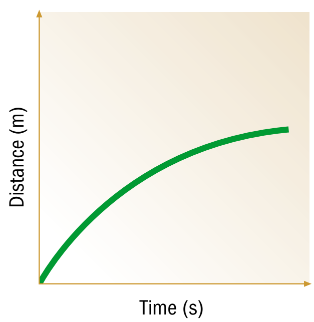


Fig 11.10 Body is decelerating

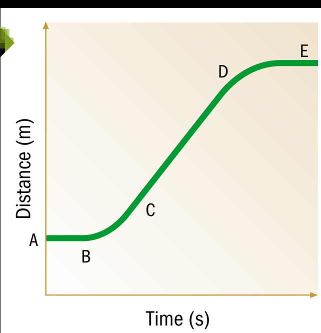
The distance travelled is decreasing per unit of time. The gradient of the graph is decreasing, therefore the speed is decreasing and the body is decelerating. For example, a downhill skier after the finish line who digs their edges into the softer snow to bring them to a standstill.

REMEMBER

For distance/time graphs:

- horizontal line = no motion (A–B)
- positive curve = acceleration (B–C)
- regular diagonal line = constant speed (C–D)
- negative curve = deceleration (D–E)
- gradient of curve = $\frac{\text{distance}}{\text{time}}$ = speed.

Fig 11.11 A distance/time graph



VELOCITY/TIME GRAPHS

A velocity/time graph indicates the velocity of an object at a certain time.

EXAM TIP

For velocity/time graphs:

1 Don't forget to:

- plot distance on the y-axis and time on the x-axis
- label the axes and give the units.

Both of the above will get you marks from your examiner!

2 The gradient of a velocity/time graph will tell you whether the body is moving with constant velocity, accelerating or decelerating (see Figs 11.12 – 11.14).

Gradient of velocity/time graph

$\frac{\text{change in velocity}}{\text{time}}$ = acceleration/deceleration

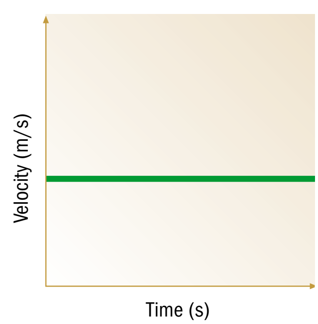
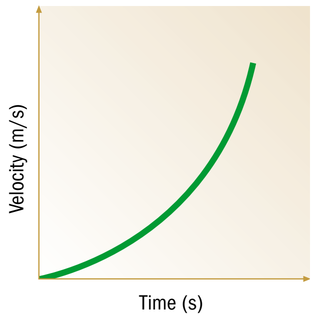


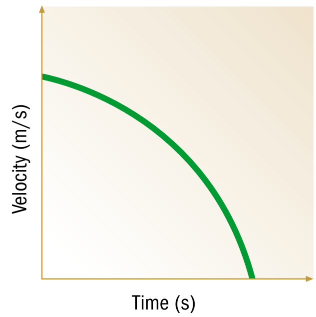
Fig 11.12 Body moving with constant velocity

The body moves with the same velocity during regular time intervals. For example, a golfer walking towards their ball after a drive.



The body is moving with increasing velocity; the gradient of graph increases. For example, a football accelerating from the spot at a penalty kick.

Fig 11.13 Body accelerating



The body is moving with decreasing velocity; the gradient of graph decreases. For example, a cricket ball being caught by a wicket keeper.

Fig 11.14 Body decelerating

TASK 5

For each of the graphs of motion plotted in Fig 11.15 below:

1. **state the pattern of motion taking place between the points identified**
2. **give an example from sport when a curve of this shape might be plotted.**

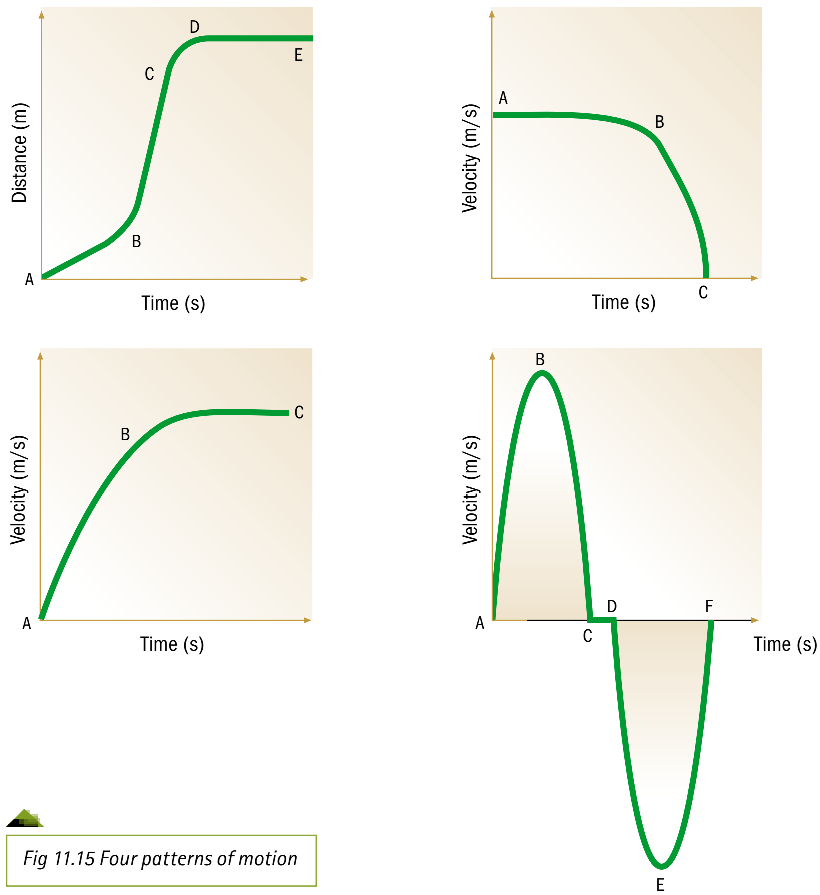


Fig 11.15 Four patterns of motion

REMEMBER

For velocity/time graphs:

- horizontal line = constant velocity (C–D)
- positive curve = acceleration (A–B)
- negative curve = deceleration (B–C)
- a curve or line below the x axis = change in direction
- gradient of curve = $\frac{\text{change in velocity}}{\text{time}}$ = acceleration.

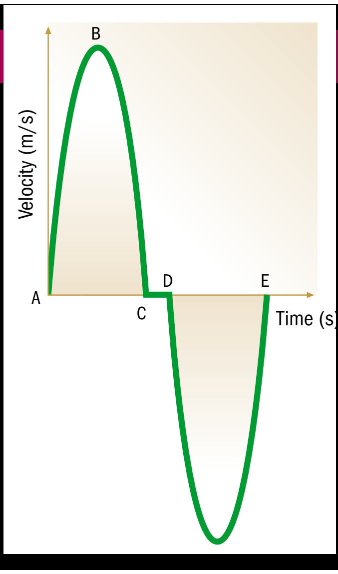


Fig 11.16 A velocity/time graph

APPLY IT!

At the 2008 Beijing Olympics, Usain Bolt became the fastest man on earth. He ran 100m in 9.69 seconds. From this, his average speed can be calculated as approximately 10.3 m/s. However, this is the speed that Bolt averaged over the 100m. At different stages of the race, he would have been running slower than this and at other stages faster.

Immediately after the starting gun fires, Bolt is gaining velocity and running considerably slower than 10.3m/s as he overcomes inertia. It follows, therefore, that he must have run faster than 10.3m/s elsewhere in the race to average this speed over the whole 100m. To know his speed at different stages of the race requires the use of specific video analysis or radar guns and marker points; the data collected can then be analysed using graphs of motion.

Data collected on Bolt's run shows his 10m split times to be those shown in column C of Table 4.

A	B	C	D
Time taken (s)	Displacement (m)	Time for 10m interval (s)	Average velocity for this interval (m/s) *
0.00	0	–	0.00
1.85	10	1.85	5.40
2.87	20	1.02	9.80
3.78	30	0.91	10.99
4.65	40	0.87	11.49
5.50	50	0.85	11.76
6.32	60	0.82	12.19
7.14	70	0.82	12.19
7.96	80	0.82	12.19
8.79	90	0.83	12.05
9.69	100	0.90	11.11

Table 4

Using graph paper, plot two graphs:

- a distance/time graph
- a velocity/time graph.

Use each of your graphs to describe the state of motion at various stages of Bolt's run.

Exam Café

Relax, refresh, result!

Refresh your memory

You should now have knowledge and understanding of:

- Newton's three laws of motion
- why there can never be motion without force but there can be force without motion
- what is meant by the terms mass, inertia and momentum, and their relevance to sporting performance
- the quantities used to describe linear motion and their relevance to sporting techniques
- how to distinguish between distance and displacement and between speed and velocity
- how to use equations to make simple calculations for speed, velocity and acceleration
- how to plot and interpret information from distance/time and velocity/time graphs.

REVISE AS YOU GO!

1. Explain in your own words Newton's first law, making reference to a chosen sport.
2. Explain in your own words Newton's second law, making reference to the sport chosen in question 1.
3. Explain in your own words Newton's third law, making reference to the sport chosen in question 1.
4. Define each of the following terms: mass, inertia, momentum.
5. Explain the benefits of a rugby team having a heavier pack in the scrum.
6. Why does a four-man bobsleigh take longer to stop at the end of its run than a skeleton bobsleigh?
7. State the distance and the displacement travelled in each of the following examples:
   a) a 400m sprint on a 400m track
   b) a 400m sprint on a 200m track
   c) a 100m swim in a 50m pool
   d) a 50m swim in a 25m pool
   e) a 25m swim in a 25m pool.
8. Explain the difference between speed and velocity.
9. Roughly sketch a velocity/time graph for the hockey ball in the following sporting scenario:
   Player A push passes a hockey ball to player B, who traps the ball for a short while and then sends it back to player A, where the ball stops.
10. Explain the shape of the graph you have drawn in question 9.

Ask your teachers for the answers to these Revise As You Go! questions.

Get the result!

Examination question

(a) Rugby player
Mass = 122kg

(b) Badminton player
Mass = 72kg

Define the terms mass and inertia and use your knowledge of inertia to explain why the athletes in photographs (a) and (b) above are well suited to their sports. (6 marks)

Examiner's tips

There are two parts to this question, so check the command word for each.

- The first part of the question asks for two simple definitions, so the marks available for this part are likely to be 2 marks: 1 mark for each correct definition. A top grade student would be expected to know their definitions well.
- The other 4 marks will come from the explanation part of the question, so make sure you give sufficient information.

Finally, make certain that your answer is applied to a rugby player and a badminton player.

Student answer

Mass is the weight of a body and inertia is linked to Newton's first law and is the reluctance of a body to change its state of motion. A rugby player has more inertia than a badminton player. This is important because it makes him more difficult to stop moving.

Examiner says:

Your definition of mass is not correct. Weight is a force, whereas mass is simply the size of something. However, your description of inertia is pleasing and I like the way you have applied it to Newton's first law. You have identified that the rugby player has a larger inertia than the badminton player but you have not explained why nor have you linked the inertia of both sportsmen to their respective sports. Your answer therefore lacks the explanation needed to score well in the second part of the question.

Student's improved answer

Mass is the amount of substance in a body. Inertia is the resistance of a body to change its state of motion.

Examiner says:

A straightforward, no-nonsense and accurate start to the answer that will score 2 marks.

Mass and inertia are directly linked. A person with a large mass has a large inertia. In the figure, the rugby player has a larger inertia than the badminton player. A large inertia is useful for a rugby player as it makes it more difficult to get moving, for example in a scrum or a maul. It also makes them more difficult to stop once they are moving, for example in a tackle. A small inertia is useful for a badminton player as they need to be able to move and change direction quickly. The smaller the inertia the less force needed to change their state of motion. So, it is easier for a badminton player to start to move, to stop and to change direction than it is for a rugby player. This is an important part of being able to get to different parts of the court quickly to hit the shuttle. This is as a result of Newton's first law.

Examiner says:

An immediate link made with the specifics of the question.

Examiner says:

Relevant part of the theory identified and immediately applied to the rugby player.

Examiner says:

Accurate application of knowledge of inertia to a badminton player.

Examiner says:

Reference to Newton's first law is impressive. Overall, the candidate has shown a high level of understanding and application of inertia to produce a top-grade answer.