# Speed velocity and acceleration

In this chapter we will look at the concepts of speed, acceleration, and velocity. As we all know gravity is a large factor in the acceleration of an object. For the purposes of this chapter we will differentiate between linear and vertical acceleration as being objects that move linearly or horizontally i. e. linear acceleration, versus objects that fall, fly, or are thrown etc. i. e. vertical acceleration. Vertical acceleration is much more governed by the force of gravity and is covered in greater detail in chapter 12 ‘ Newton’s Laws’. A short section at the end of the chapter addressing vertical acceleration is however included to put the area into context.

You may have heard the old adage “ Speed kills.” And you know whether you are driving your car or playing sport it’s a dangerous variable. Fast athletes are very difficult to handle, as are fast cars. However, having speed is of vital importance in sports. In this chapter we’ll look at speed, velocity and acceleration and the factors that influence them. Speed, acceleration and velocity are all different. If you have ever watched a 100 meter race, you will notice that some athletes start faster than others, so their acceleration is different. Athletes finish the race at different times so their speed is different and athletes reach top speed at different stages so their velocity is different. The key terms to be covered in this chapter are speed, acceleration, velocity, distance, displacement, vertical and horizontal acceleration and velocity.

The variables of speed, acceleration, displacement, etc. are about linear kinematics. Kinematics is a general term related to describing motion. Kinematics is also a branch of mechanics (specifically dynamics) that evaluates moving objects. In order to accurately describe kinematics there are certain terms that we must fully understand. They include the terms mentioned above (speed, acceleration, and displacement) and distance, velocity and position. Accurate understanding of these terms will allow us to accurately describe the movement of any object. There is often a lot of confusion about the terms acceleration, speed, and velocity. We often use the term speed in everyday language to imply all three terms and the word fast is an even more general term. Consider the following: A person can be moving fast and not be accelerating. A person can accelerate fast and not have a high velocity or high speed. A nice sporting example was the great Boston Celtics player Larry Bird. Larry Bird was very quick to accelerate over three or four steps, was not very fast at his top speed. So while Larry was very quick and dangerous over 3-4 steps, he would not make a good sprinter because his top end speed was not high. So if an object is accelerating, it is changing its velocity. Acceleration has to do with the change in how fast an object is moving. Therefore, if an object is not changing its velocity, it is not accelerating.

We know that distance and displacement have different meanings. The same is true for speed and velocity. Speed can be considered as the rate at which an object covers a certain distance. Objects that move slowly cover distances in long periods of time, i. e., low speed. An object moving quickly covers distance in shorter amounts of time, i. e., high speed. If an object is not moving at all it has zero speed, zero velocity and zero acceleration.

Let us consider some of these simple terms in more detail.

Position: Position is simply the location of an object in space. You could consider it using coordinates on a map for example, or on a field, or gymnasium.

Displacement: Displacement is simply the straight line distance an object has travelled.

Distance: Distance is how far an object has travelled in any direction. It is also viewed as the total amount of displacement (regardless of ending position).

## Look at this simple example.

Let’s say a basketball court from baseline to baseline is 25m. If a player runs baseline to baseline and back what is his displacement and distance?

Distance. This is the easy one since he ran up and down the court so that is 25m + 25m = 50m.

Displacement. Since the player ran down the court and back again he ended up in the same place he started. So even though he covered a distance of 50m his displacement is actually zero, since he is back where he started.

Let’s say the player now runs up and down the court twice. His distance covered would be 25m + 25m + 25m +25m = 100m. Since he ended up back where he started his displacement is still zero.

Finally, let’s say the player runs from one baseline to the other and stops. In this case both his displacement and distance are the same at 25m.

For the most part we use distance rather than displacement to describe movements as it is difficult to correctly measure displacement as we make a lot of turns when we travel. You say displacement is really like the old saying “ as the crow flies” which means straight line. For example, the distance you travel in a car from New York City to Boston might be 250 miles (but your displacement is only 175 miles). When you drive in a car you get on the highway and follow the roads around the coast, over bridges, around hills, around towns etc. However, when you fly the plane flies right over everything in a straight line and you end up only travelling 175 miles (your displacement).

## Speed

Speed is a very general term. Speed is a scalar quantity and is described as Distance divided by time (D/T, where D= distance and T= time). Scalar implies that speed has magnitude but not necessarily any direction, for example temperature or volume. People often use speed and velocity interchangeably but they are different. Speed relates to the distance an object has traveled, while velocity refers to the displacement that has taken place. So, the speed of an object tells us how far an object has traveled in a given amount of time but doesn’t tell us anything about the direction in which it traveled. It all sounds a little heavy on the definitions but these are important. Therefore:

## Average speed = Distance traveled (m)

## Time (s)

Now there are also different types of speed. We refer to them as average speed versus instantaneous speed. When an object is moving it often changes its speed (or direction) during its motion. When there is a change in speed we can alter our definitions. Instantaneous speed is the speed at any given instant, while average speed is the average of all the instantaneous speeds. For example, let's say a runner runs 400m in 60 seconds and crosses the line at 18 kmh or 5 m/s. This means his average speed over the 400m was 6. 66 m/s even though he crossed the line at 5 m/s which is his instantaneous speed at the finish line. In other words, he was slowing down as he was getting to the end. If you have ever ran a 400m race then you will now how tired you are at the end and are definitely slowing down. How did we do these calculations?

Average speed = Distance/time – 400m/60 seconds – 6. 66 m/s

The instantaneous speed recording of 5 m/s would have been measured with a radar or timing device. You could also look at various split times for different portions of the race. Many coaches do in fact do this, so a 400m coach might look at each 100m split and look at both the acceleration and deceleration patterns and average speeds during each of the four separate 100 meters.

Here is another problem for you to try. Can you calculate the average speed of a swimmer that completes the 200m butterfly in 2. 15 seconds?

Answer: 2. 15 seconds = 135 seconds. So 200m/135 seconds = 1. 48 m/s

A 400m freestyler swims the race in 4. 10 seconds. The 200m split was 2. 02 seconds. Can you calculate the following?

a. What was the swimmer's average speed for the race?

b. What was the difference in speed for the first 200m versus the second 200m?

Answer:

a. 400m/250 seconds = 1. 6 m/s

b. First 200m split = 1. 64 m/s

Second 200m split – 1. 56 m/s

## As you can see, the swimmer slowed down over the second 200m.

## Velocity

Velocity is somewhat similar to speed but velocity involves both direction and speed. So, whereas speed is a scalar quantity, velocity is a vector quantity, that is, it has both magnitude and direction. Velocity also uses displacement as opposed to distance. Remember displacement is measured as the straight line distance an object travels from starting to ending position. Velocity is direction sensitive since it is dependent upon displacement. Therefore, when you calculate velocity, you must also keep track of direction. Therefore, if you say an airplane has a velocity of 600 kmh, you would actually be a little vague. You should really say the airplane has a velocity of 600 kmh North. So, speed doesn't worry about direction, velocity does. Velocity is a positive number as we don't have negative velocity. So to summarize, a airplane traveling at 600 kmh as a speed of 600 kmh. The same airplane has a velocity of 600 kmh, North. Finally, the same airplane probably had little acceleration in the middle of its trip as it would only need positive acceleration and negative acceleration during take off and landing.

Here is an interesting and challenging little problem for you to solve. Can you fill in the following table with acceleration, speed, and velocity data? We know the following, the direction of travel is south and acceleration doubles every second. If you're feeling confident you can also try and calculate the total distance that was covered over the 6 seconds. Hint! You can use the velocity for each second to help you.

Time

Vel. m/s

Accel. m/s2

*Speed. m/s

0s

1

1

1

1s

2

2s

7

3s

8

4s

31

5s

3

6s

64

## Answers

Time

Vel. m/s

Accel. m/s2

*Speed. m/s

0s

1

1

1

1s

3

2

1. 5

2s

7

4

3. 5

3s

15

8

5. 0

4s

31

16

7. 75

5s

63

32

12. 6

6s

127

64

21. 16

*Average speed through that time period

So:

## Average velocity = Displacement

## Time

## Let try some additional calculation examples:

For example, if an athlete runs around a 400 meter track in 50 seconds we can calculate numerous factors.

What was the distance traveled?

What was the displacement?

What was the average speed?

What was the average velocity?

1. What was the distance traveled?

Answer: Easy enough = 400 meters

2. What was the displacement?

Answer: Since the athlete ended up in the same place as they started, displacement is equal to zero.

3. What was the average speed?

Answer: Speed = Distance/Time = 400 m/60 seconds = 6. 66 m/sec

4. What was the average velocity?

Answer: Velocity = Displacement/Time = 0/60 seconds.

In this case we end up with a value of zero and in this scenario average speed is a better indicator of overall performance.

In many situations we actually calculate average velocity as speed because we can't gather the correct information to calculate speed. For example, if a punt returner catches the ball on the 20 yard line and then avoids a few tackles to ultimately score a touchdown twelve seconds later, we assume the punt returner ran 80 yards. In fact, they may have run 100 yards with all the turning and weaving but we can't accurately calculate the true distance traveled and instead use displacement. For our purposes in sports, that's okay. You try the following problem.

## Review Problems

Can you accurately calculate average speed, velocity, distance and displacement for each of the following situations? Hint: You may not be able to calculate them all accurately.

## Problem:

1. A punt returner catches the ball on his own 40 yard line and scores a touchdown nine seconds later.

2. A 100 meter sprinter runs the 100 meter in 10. 0 seconds flat.

## Acceleration

## The law of acceleration is Newton’s second law and basically states “ The change of motion of an object is proportional to the force impressed and occurs in the direction in which the force is impressed”.

So far we have talked about speed and velocity and performed some calculations. However, while speed and velocity are valuable components, they tend to provide us with summary information and very little about specific detail. For example, if we consider the data for a 200 meter race run in 20 seconds we know that average speed was 10 m/sec. However, we would not know any information about who accelerated the fastest or who was leading after 100 meters. This information is also important as it helps with identifying strength and weaknesses in athletes and in developing training programs for particular athletes. The measurement of acceleration is important. Acceleration is the rate of change in velocity. Therefore, when acceleration is zero, velocity is constant. So when an object changes speed either by slowing up or down, or changes direction, it is accelerating (or decelerating). We can calculate acceleration by measuring the difference in velocity over the time it took for that change in velocity to occur. Consider this: If you were to watch a 100M race the person leading at the 50M mark doesn’t always win the race. The reason for this is that runners have different acceleration and deceleration rates, in other words their speed changes. Athletes vary dramatically in their acceleration. Some athletes are very fast over 40M but not over 100M and vice versa. So:

Acceleration (a) = Velocity2 – Velocity1 Where V2 is velocity at T2

Tim Where V1 is velocity at T1

Sometimes you will see this presented as the change in velocity (Delta sign âˆ†) or the change in time (âˆ†T)

A = âˆ†V

âˆ†T

Look at the following acceleration example.

Question: A sprinter leaves the starting block at 2. 5 m/s. One second later they are traveling at 5. 5 m/s. What is the acceleration rate?

Answer: V2 – V1 = 5. 5 m/s – 2. 5 m/s = 3 m/s squared

T 1

You will note that we end up with meters per second squared as our answer would really be presented as 3 m/s/s.

Here’s another problem to try.

Question: A punt returner catches the ball standing still and begins to return. Two seconds later his velocity was 5 m/s. What was his average acceleration over the first two seconds?

Answer: V2 – V1 = 5 m/s – 0 m/s = 3. 5 m/s squared

T 2

So far we have looked at relatively straightforward examples of speed, acceleration and velocity in that they have all been examples of horizontal movement. Now let us discuss the vertical components of projectile acceleration, speed and velocity.

## Factors Affecting Acceleration

Linear acceleration is affected by many factors and you will recall from chapter ? that the mass of an object is a very important one. Heavier objects accelerate more slowly with a given force. This has to do with both inertia and mass. Heavier objects are harder to both accelerate and decelerate. Think about how easy it is to throw a basketball versus a medicine ball. There are some other points to consider when looking at acceleration, speed, and velocity. First, we now know the units for velocity are meters per second (m/s) and meters per second squared for acceleration (m/s/s). For speed they are also m/s. Since acceleration (like velocity) is a vector quantity, it also has direction associated with it. The direction of acceleration depends on two factors:

a. Whether the object is speeding up or slowing down

b. Whether the object is moving in a negative (upwards) or positive (downward) direction

We can simplify this by saying that if an object is slowing down then its acceleration is in opposite direction of its motion. If it is speeding up then its acceleration is in the same direction as its motion.

Therefore:

Acceleration (m/s2) = mass (kg)/force (newtons)

## Vertical speed, acceleration and velocity

If you were to throw a ball up in the air and then catch it again at the same height as you released it, how would the ending velocity be? Would it be greater, less, or the same as the release speed? If you guessed the " same" you would be correct. You see, all objects, whether traveling vertically or horizontally, are subjected to the constant force of gravity (9. 81 m/s2). This means that as soon as the ball left your hands it started to negatively (de)accelerate at 9. 81 m/s2 until it had no more velocity. Then, it started to positively re-accelerate over the same distance (and time) at a rate of 9. 81 m/s2 until you caught it again.

This is a very neat relationship as it allows us to make many calculations based on this constant acceleration force. Projectiles are subjected to both vertical and horizontal components in their motion. The horizontal components are affected by the mass of the object and the acceleration force as previously mentioned. The vertical components are also affected by these two factors plus gravity. Consider this statement: A ball shot horizontally (at zero degrees) has the same vertical component as a ball that is simply dropped with no horizontal velocity. What this means is that if you were to throw a pass from your chest and it hit the ground 15 meters away 1. 5 seconds later, and at the same time drop a second ball straight down from the same height, they would both hit the ground at the exact same time. What this is showing us is that the force of gravity component is acting consistently regardless of whether the ball has a horizontal component or not. In other words adding a horizontal acceleration component does not affect in any way the force of gravity.

Remember also that gravitational acceleration is a vector quantity comprising both magnitude and direction and acceleration is a squared variable to the magnitude of the force of gravity. This means that for every second an object is in free fall it will accelerate by ad additional 9. 81m/s2. Thus the total distance travelled is directly proportional to the square of the time. Or we could say that if an object travels twice the time it will travel four times the distance. If an object travels for three seconds it will cover nine times the distance, for four seconds it is sixteen times the distance travelled in the first second. Look at the following.

A coin is dropped from a cliff. The table shows how fast it is travelling at different time points.

## Time

## Speed m/s

1 sec

9. 81

2sec

19. 62

3 sec

29. 43

4 sec

39. 24

5 sec

49. 05

6 sec

58. 86

7 sec

96. 23

Consider this simple math problem:

Question: A boy drops a ball from a balcony and records a time of 3 seconds for the ball to hit the ground. At what velocity did the ball hit the ground?

Answer: 29. 43 m/s

How do we get this answer? Well, remember that gravity acts as a constant 9. 81 m/s2. What this means is that for each second the ball is in flight it accelerates an additional 9. 81 m/s. So:

Insert schematic to demonstrate

after 1 second = 9. 81 m/s

after 2 seconds = 9. 81 m/s + 9. 81 m/s = 19. 62 m/s

after 3 seconds + 19. 62 m/s + 9. 81 m/s = 29. 43 m/s

This is a simple illustration of the concept. Next question, what velocity would the ball have to be released at ground height for the boy to catch it on the balcony?

Answer: A minimum of 29. 43 m/s. The answer is the same because gravity and acceleration (or deceleration) is working to the same effect when the ball is moving upwards. This is sometimes referred to a negative acceleration.

## Question.

A boy is standing on a balcony and is curious about how high the balcony is from the ground. The boy drops a ball and records the time it takes to hit the ground. It took 3. 2 seconds for the ball to hit the ground. The boy concludes that the balcony is 66. 7m high.

How did he work it out?

Well at the end of the first second the ball was travelling 9. 81m/s, at the end of the second the ball was travelling 19. 62m/s, at the end of the third second the ball was travelling 29. 43m/s. If you add these three distances together you get 58. 86 meters travelled after three seconds. If the ball travelled another full second it would travel another 39. 24m, but it only travelled in this zone for 0. 2 sec. So, 39. 24m x 0. 2sec = 7. 84m. Now we add the 58. 86m + 7. 84m = 66. 7m, and that's our answer.

There are some other factors to consider with vertical projectiles. The pattern of change in vertical velocity is symmetrical about the apex of the trajectory. So not only does the object land at the same speed it was released, it also follows the reverse flight path on the way down.

Using these constant parameters we can now extend our calculations into more complex situations. For example, let's say you are watching a volleyball game in a high school gym with a 10 meter high ceiling. An opponent spikes the ball over the net and a player " digs" the ball at ground level at which time the ball has a velocity of 15 m/s. The question is will the ball hit the ceiling? To solve for this we can use an equation that combines several variables we talked about already.

Where: V2 = velocity at time 2

V1 = velocity at time 1

a = acceleration

t = time

In order to answer this question we need to look at what we know and what we want to know. Well, we want to know the distance (d) the ball travels. We already know a = 9. 81 m/s2 and we know V1 = 15 m/s. We also know that at the apex the velocity is zero, so V2 can be set to zero. So now our formula looks like this:

1. 0 = V1 squared + 2ad

2. 0 = (15 m/s) squared + 2 (-9. 81 m/s squared) x d

Now if we rearrange to solve for ‘ d’ our formula looks like:

= (19. 62 m/s squared) x d = 225 m/s squared

= d = 11. 47 m

The answer is yes! The ball will hit the ceiling as it will travel 11. 47 m.

Here’s another similar problem:

A ball is deflected vertically at 18 m/s and the ceiling height is 11 meters. Will the ball hit the ceiling?

## Factors affecting projectile motion

We have discussed several factors that affect the movement (or acceleration) of an object. The factors that affect vertical acceleration are the mass of the object, the force (speed) of release and gravity. Horizontal acceleration is affected only by mass and force of release (application). Gravity is of course a factor but not in determining its horizontal component. But sometimes we want to throw objects e. g. discus, hammer, etc. and while these projectiles are influenced by force and mass, there are other factors that influence how far the projectile will travel. We generally recognize three other factors that influence how far a projectile will travel when a constant force is applied. They are:

1. Angle at which projectile is released.

2. The speed of release.

3. The height of release.

The optimum angle of release to increase horizontal displacement is 45°. Projectiles released at over or below this angle will not reach their greatest distance. Look at Table 1 to see how distance traveled varies with changing angles of release. You will see from table 1 that the optimum angle of release is 45° and after that the decrease in distance traveled is symmetrical as height compromises distance (I. e. follows the same pattern as increasing angle of release up to 45°). The greater the speed of release the greater the distance a projectile will travel. This holds true simply because there is a greater acceleration force applied in the first place. Simply put, if you want to throw a ball further you need also to throw it harder. The greater the height of release the greater the distance a projectile will travel. If you consider field sports in athletics you will notice that most successful hammer, discus and javelin throwers are taller, giving the mechanical advantage over shorter competitors in that event. If you were to throw a ball from the top of a building it would strike the ground much further away than it would if you were to throw it from standing on the ground.

Table 1: Distance a Projectile travels at a constant speed and height of release with change in angle of release. (need the reference)

# Speed of release

# Release angle

# Distance Travelled

10m/s

10

3. 49m

10m/s

20

6. 55m

10m/s

30

8. 83m

10m/s

40

10. 04m

10m/s

45

10. 19m

10m/s

50

1. 04m

If you have watched a discuss competition or a hammer throw you might notice that these athletes are quite tall (often over 1. 9m). The reason for this is that these athletes have an advantage over their shorter counterparts as their angle of release is already several centimeters higher.

## Summary

This chapter has provided a basic introduction to the concepts of speed, acceleration and velocity. We have also looked at how differentiating between these variables is important and sometimes difficult. Using some known constants, such as the accelerating force of gravity (9. 81 m/s2) allows us to calculate and even predict the speeds, velocities and flight paths of selected projectiles. We have also discussed other factors that affect projectile motion such as height and speed of release. While this information is very important, it is a basic introduction as there are many other more complex factors affecting speed, acceleration and velocity. We did not talk about shape or design or, indeed materials which also play a role in the way particular objects react to forces. The factors are extremely important but for now are beyond the scope of this text. Following this section are additional problems for you to solve and practice.

# Review Problems

Can you provide a one sentence definition for each of the follow terms?

Distance

Displacement

Acceleration

Velocity

Speed

Position

Scalar

Vector

A ball rolls with an acceleration of -. 5 m/s 2. If it stops after 7 seconds, what was its initial speed?

A wheelchair marathoner has a speed of 5m/s after rolling down a small hill in 1. 5sec. If the wheelchair underwent a constant acceleration of 3 m/s 2 during the descent, what was the marathoner’s speed at the top of the hill?

A runner completes 6. 5 laps of a 400m track in 12 mins (720 secs). He starts half way around the bend. Can you calculate the following?

a. Distance covered:

b. Displacement after 12 minutes:

c. Runner's average speed:

d. Runners average pace: min/mile =

A soccer ball is rolling across a field. At T = 0, the ball has an instantaneous velocity of 4 m/s. If acceleration occurs at a constant -0. 3 m/s2 how long will it take to stop?

A batter strikes a ground ball with an instantaneous velocity of 18m/s. If acceleration occurs at -0. 7m/s2 how long will it take to stop?