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PHYSICS

Module 1

KINEMATICS

STUDENT BOOKLET

Theory covered:

1. Definition of Terms
   - 1.1. Types of Motion
   - 1.2. Vector and Scalar Quantities
   - 1.3. Distance and Displacement
   - 1.4. Speed and Velocity
   - 1.5. Acceleration
   - 1.6. Speeding up and slowing down
   - 1.7. Uniform Motion and Non-uniform motion

YEAR 11

Name:

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1. Definition of Terms

1.1. Types of Motion

There are many types of motions:

1. **Circular motion:** this is when a particle moves in a circle.
2. **Projectile motion:** this is motion in two dimension, the particle moves up and down
3. **Rectilinear motion:** this when a particle moves in a straight line.

In this section we are only looking at **rectilinear motions.**

1.2. Vector and Scalar Quantities

Vector Quantities: Quantities that have magnitude and direction
e.g. displacement, velocity and acceleration

Scalar Quantities: Quantities that have magnitude only, no direction
e.g. distance, speed, energy and time.

Note: Vector quantities are denoted by a letter with an arrow on top i.e. $\vec{x}$ The magnitude (length of the vector) represented as $|\vec{x}|$.

Example 1

Which of the following list contains only one vector quantity?

(A) Time, velocity, momentum, force
(B) Acceleration, force, velocity, kinetic energy
(C) Momentum, force, velocity, impulse
(D) Time, distance, kinetic energy, speed

Example 2

Which of the following list contains three vector quantities?

(A) Momentum, energy, impulse
(B) Force, speed, displacement
(C) Velocity, acceleration, time
(D) Acceleration, force, momentum

1.3. Distance and Displacement

There are three quantities used in describing how an object moves:

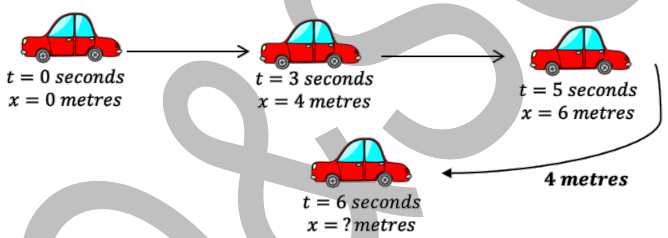
1. Position, distance, displacement
2. Velocity
3. Acceleration

We will explore the first three terms:

- **Position** is where an object is
- **Distance** is how far, in total, an object has travelled in a journey
- **Displacement** is how far an object is from its initial position
    - To find the displacement, you get your final position minus initial position

An example to highlight the differences between these three terms:

Here we have a car. Its starts at $x = 0$ and moves to the right, after 3 seconds it is 4 metres to the right of zero and the at $t = 5$ seconds it is 6 metres to the right of zero, stops and turns around and goes to the left. At $t = 6$seconds it has travelled 4 metres from where it had stopped.



What is its position, distance and displacement at $t = 6$ seconds?

Position: When we talk about position we are asking where it is on our axis. Here it goes to the right 6m and then goes back left $4m$, so we are at $x = 2m$.

So $x = 2m$ is where we are at; it is our position. Therefore, our position is 2m to the right of zero.

Distance: The distance is how much we have travelled in total. It does not consider direction. We travel to the right 6m and left 4m

So total is $10m$. It does not matter if it is going right or left, the total distance travelled is 10m.

Displacement: This is how far we are from our original position. It has a magnitude and a direction. To get the magnitude, get final position minus our initial position. The final position is 2m and our initial position is $0m$

The magnitude is $2 - 0 = 2$.

Now let's look at the direction. The final position is to the right of the initial position so our displacement is 2m to the right.

To find the distance, add all the intervals covered by the object. To find displacement get the final position minus the initial position.

Example 3

Justin walks out from his house following the directions below:

Total time (min)	*Distance travelled (m)*	*Direction*
5	*20*	*East*
9	*40*	*North*
17	*60*	*West*
20	*40*	*South*
24	*40*	*East*

a) *Find the total distance Justin travelled.*
b) *Using a diagram, find his displacement at each of the five points in time*

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Example 4

A person walked along the following path. He travelled 4 metres west then turned south and travelled a further 4 metres then turned and travelled east for 7 metres. What was the magnitude of the person's displacement from the starting point?

(A) 25 *metres*
(B) 3 *metres*
(C) 15 *metres*
(D) 5 *metres*

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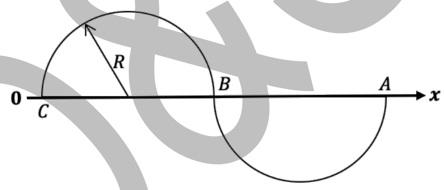
Example 5

As shown in the figure below, a particle travels from A to C along the semi-circles whose radii are R. Given that the positive direction is rightwards, what is the placement and direction travelled of the particle, respectively, during the whole process?



(A) $4R, 2\pi R$
(B) $4R, -2\pi R$
(C) $-4R, 2\pi R$
(D) $-4R, -2\pi R$

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Practice 1

A car is driven East for a distance of 50 km, then North for 30 km, and then East for 40 km.

(a) Find the total distance travelled by the car.

(b) Using a diagram, find the magnitude and direction of the displacement of the car.

Practice 2

An object heads north and travels for 4 meters from point O to point A. It then heads east and travels for 3 meters to arrive at point B. Finally it heads south and travels for 1 meter to arrive at point C.

(a) What is the total distance traveled during this whole process? (1 mark)

(b) What's the magnitude and direction of the displacement after the whole movement process (from point O to point C)? (2 marks)

1.4. Speed and Velocity

Speed is the rate of change of the distance

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

Velocity is the rate of change of the displacement.

$$\boldsymbol{\vec{v} = \frac{displacement}{time} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}}$$

Let's look at an example.

An object travels from $x = 0$ to $x = 20$ metres (north) and then back south 5 metres. It takes 5 seconds to do this. Find the velocity and speed of the object.

$$speed = \frac{distance}{time} = \frac{25}{5} = 5\ m/s$$

$$\vec{v} = \frac{displacement}{time} = \frac{15}{5} = +3\ m/s = 3\ m/s\ (North)$$

Note:

- To find speed we use distance
- To find velocity we use displacement. When finding velocity, the answer must have direction.

What we have found is called the **average velocity**.

As the object travels, there will be times it is travelling greater than 3m/s and less than 3m/s. 3m/s is just the average.

Instantaneous velocity is the velocity of the object at a given time or position.

In the example above, the instantaneous velocity could be the velocity exactly at $x = 3$ or after 2 seconds. From the information, we cannot find the instantaneous velocity. In this module, we will not be dealing with instantaneous velocity.

Example 7

An object moves in the positive direction for 6 meter and then turns and moves 22 *metres in the negative direction. It takes* 4 *seconds to do this. What is the average speed and velocity?*

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Example 8

In terms of instantaneous velocity, average velocity, and average speed of an object, which one of the following statements is correct?

(A) The average velocity of the object is equal to the ratio between the displacement and the time of the object travelling in a period
(B) For an object with variable velocity, the magnitude of the average speed is the same as that of the average velocity of the object
(C) The instantaneous velocity of the object corresponds to the speed of the object at any position or any time
(D) For an object with variable velocity, the average velocity corresponds to the ratio between the distance travelled to the time of the object in a period

1.5. Acceleration

Acceleration is the rate of change of the velocity. It is a measurement of how quickly velocity is changing.

To find acceleration we use the formula

$$a = \frac{\Delta v}{\Delta t} = \frac{v - u}{t_1 - t_0}$$

Where:
$a =$ acceleration
$v =$ final velocity
$u =$ initial velocity
$t_0 =$ initial time
$t_1 =$ final time
$\Delta v =$ change in velocity
$\Delta t =$ change in time.

If there is no change in velocity then $\Delta v = 0$, and hence the acceleration is zero.

Acceleration has direction.

This means acceleration can be positive or negative.

If for example we let the positive be North, then if we are accelerating in the North direction, the acceleration will be positive. If we are accelerating towards the south direction, then the acceleration is negative.

Acceleration alone does not indicate whether an object speeds up or slows down.

Example 9
An object changes velocity at a constant rate, going from 2m/s to 20m/s in 36 seconds. Find the acceleration of this object.

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Example 10

A rock sinks down a medium. It starts at $12\ m/s$ *and then after* 4 *seconds, it is sinking at a rate of* 2 *metres per second. Find its acceleration.*

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Example 11

Acceleration is the rate of change of velocity per unit time. If a car is travelling at $20\ m/s$ *and accelerates at* $-2\ m/s^2$*, how fast will it be travelling after* 4 *seconds?*

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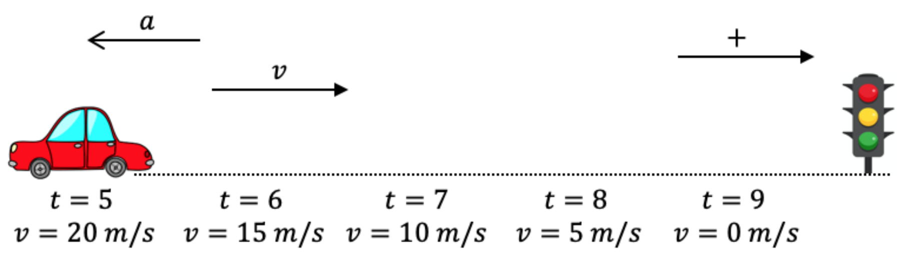
Example 12

A small ball falls from a stage which is four meters above the ground. After the ball hits the ground, it bounces back and is caught one meter above the ground. Regarding the journey of the ball, which of the following statements is correct?

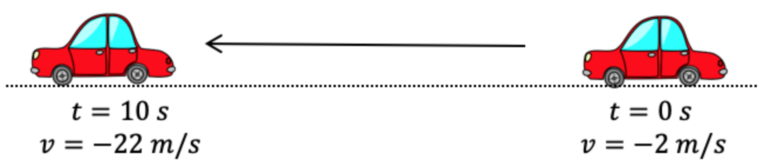
(A) The distance travelled by the ball is 5 *metres*
(B) The displacement of the ball is 5 *metres*
(C) The velocity of the ball is 5 *metres per second*
(D) The acceleration of the ball is 5 *metres per second squared*

1.6. Speeding Up or Slowing Down



Here we have a car that is going at 20 m/s and then after one second its velocity is now only 15 m/s and then after another second it is going even slower at 10 m/s. The car is clearly slowing down. By looking at how the velocity changed we can see that it is slowing down.

However, there are certain situations that may not be so easy to see if a vehicle is slowing down or speeding up. A lot of people think that if the acceleration is positive then an object is speeding up and if the acceleration is negative then then object is slowing down. This not the case. Look at the following example which shows a situation where even though an object has a negative acceleration, it is still speeding up.



A car is initially going at a velocity of -2 m/s and then after 10 seconds it travels at -22m/s. So this car is initially travelling to the left at 2m/s and then after 10 seconds it is travelling to the left 22 m/s, clearly the car has gone faster, hence speed up.

Let's find the acceleration:

$$a = \frac{final\ velocity - initial\ velocity}{time} = \frac{-22 - (-2)}{10} = -2\ m/s^2$$

So, in this example, you can see that even though the acceleration is negative, the car is still speeding up. Acceleration alone does not determine speeding up and slowing down.

Hence, what determines speeding up and slowing down?

It is the direction of the velocity and acceleration. If $va > 0$ then the object is speeding up and if $va < 0$ then the object is slowing down.

Let's relook at our example. The particle has a negative velocity. The acceleration calculated is negative and hence $va > 0$. Using our rule, since $va > 0$, then the car must be speeding up. This is correct.

The above method way to look at slowing down or speeding up is a mathematical way. However, in physics we can look at it in two other ways:

1. If the direction of the acceleration is the same as the velocity, then the particle must be speeding up. If the direction of the acceleration is opposite the velocity, then the particle is slowing down.

2. Newton said $F = ma$. Force is proportional to a. So, when we are talking about acceleration, you can replace the acceleration word with the "force" word. So now let's say if I have a car moving to the right (velocity to

the right) and accelerating to the right, then since the velocity and acceleration are in the same direction, the car must be speeding up. Now let's replace acceleration with force. The car moves to the right, and the acceleration is to the right, that means the force is to the right. Now the car is moving to the right and there is a force pushing it to the right, it must be going faster. This logic, replacing acceleration with force, may help you deal with certain questions easier.

Whenever a question asks whether an object is speeding up or slowing down

1. **Find velocity: is it negative or positive**
2. **Find acceleration: is it negative or positive**
3. **Find va. If va > 0, then speeding up, if va < 0 then slowing down.**

OR

If the direction of the velocity and acceleration are the same, then the particle is speeding up, if the direction of the velocity and acceleration are opposite, then the particle is slowing down

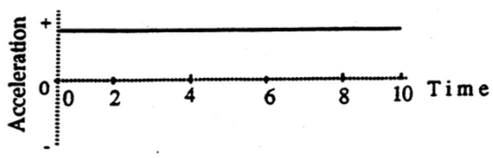
Example 13

In an investigation carried out on a car's motion, the direction east was chosen as being the positive direction. At one time during the investigation, the car has a velocity of $-25\ ms^{-1}$*. Which of the following statement is the correct statement about the car's motion?*

(A) The car was heading west and a negative acceleration would result in it slowing down.
(B) The car was heading west and a positive acceleration would result in its slowing down.
(C) The car was heading east and a negative acceleration would result in its slowing down.
(D) The car was heading east and a positive acceleration would result in its slowing down.

Example 14

Below is an acceleration time graph of an object. Describe how the object might move it if originally moves in a positive direction?



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Example 15

Which one of the following situations is not likely to happen?

(A) The acceleration of an object is zero whilst the velocity of the object is $5\ m/s$.
(B) The acceleration of an object is $5\ m/s^2$ *whilst the velocity of the object is zero.*
(C) For an object with a variable velocity, given that the direction of acceleration and velocity are the same, the velocity of the object reduces with a decreasing acceleration.
(D) For the object with a variable velocity, given that the direction of acceleration and velocity are opposite, the velocity of the object reduces with a decreasing acceleration.

1.7. Uniform Motion and Non-Uniform Motion

Uniform motion is when the object travels at a constant velocity. There is no change in velocity.

- Since there is no change in velocity then the acceleration must be zero.

For example, if an object is travelling 10 m/s all the time, then this object is moving in uniform motion.

Non-uniform motion is when the object changes velocity. Since there is a change in velocity then that means the object must have an acceleration.

Example A

A car travels 2 m/s at t= 0 seconds and then 4 m/s at $t = 3$ seconds and 6 m/s at $t = 4$ seconds. Here the car is moving quicker, the velocity is changing and hence moving in non-uniform motion.

In the above example, in the first second $a = \frac{4-2}{1-0} = 2m/s^2$, in the second second $a = \frac{6-4}{2-1} = 2m/s^2$. The acceleration is the same, it is a constant. This motion is non-uniform since it has an acceleration but since the acceleration is the same for all the time periods, it is called constant accelerated motion.

In nature, objects often change acceleration depending on time rather than have a constant acceleration. However, these motions are too difficult, so in this module we deal with constant accelerated motions only.

If a question ask to determine if a motion is uniform or non-uniform, find the acceleration. If the acceleration is zero then it is uniform.