Year 11

# Physics

## 1.1 Motion Under Constant Acceleration

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## Subtopic 1.1: Motion Under Constant Acceleration

In this subtopic students become familiar with examples of motion under constant acceleration and with the use of notation, units, prefixes, and representations in physics. Students develop an awareness of the differences between vertical and horizontal motion under constant acceleration, with an emphasis on motion under the acceleration due to gravity.

| Science Understanding | Possible contexts |
|---|---|
| Linear motion with constant velocity is described in terms of relationships between measurable scalar and vector quantities, including displacement, distance, speed, and velocity.<br>• Solve problems using $v = \frac{s}{t}$.<br>• Interpret solutions to problems in a variety of contexts.<br>• Explain and solve problems involving the instantaneous velocity of an object.<br>Acceleration is a change in motion.<br>Uniformly accelerated motion is described in terms of relationships between measurable scalar and vector quantities, including displacement, speed, velocity, and acceleration.<br>• Solve problems using equations for constant acceleration and $a = \frac{\Delta v}{\Delta t}$.<br>• Interpret solutions to problems in a variety of contexts.<br>• Make reasonable and appropriate estimations of physical quantities in a variety of contexts. | This connects to the concept of acceleration used in Stage 1 Subtopic 1.2: Forces and Stage 2 subtopics 1.1: Projectile motion, 1.2: Forces and momentum, 1.3: Uniform circular motion and gravitation, and 2.2: Motion of charged particles in electric fields.<br>Compare current definitions of units with other systems of measurement such as imperial measure and consider the benefits and limitations of each.<br>Discuss the nature and difference between scalar and vector quantities, and how each explains different aspects of motion.<br>Discuss velocity vectors for an object moving in a curved path, to understand instantaneous velocity.<br>Investigate the physical interpretation of negative velocities and accelerations in context.<br>Use SI units and common prefixes, such as 'kilo' (k), 'milli' (m) and 'micro' (μ), in practical activities to develop an awareness of reasonable estimates of physical quantities.<br>Extend understanding and use of the equations $v = \frac{s}{t}$ and $a = \frac{\Delta v}{\Delta t}$.<br>This could include the vector equations $\vec{v} = \frac{\Delta \vec{s}}{\Delta t}$ and $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$. |
| | Explore and clarify the relationship between velocity and acceleration using the computer interactive 'The Maze Game', https://phet.colorado.edu/. |
| | Investigate the development and use of the SI units. Analyze the significance of the development of internationally agreed definitions of absolute measures of time, mass, and distance, and the challenges facing scientists since the introduction of SI units. |

| Science Understanding | Possible contexts |
|---|---|
| Graphical representations can be used qualitatively and quantitatively to describe and predict aspects of linear motion.<br>• Use graphical methods to represent linear motion, including the construction of graphs showing:<br>◆ position vs time<br>◆ velocity vs time<br>◆ acceleration vs time.<br>• Use graphical representations to determine quantities such as position, displacement, distance, velocity, and acceleration.<br>• Use graphical techniques to calculate the instantaneous velocity and instantaneous acceleration of an object. | Demonstrate how the gradient of a displacement vs time graph can be shown to be equivalent to the velocity of the object.<br>Relate the gradient of a velocity vs time graph to the acceleration of the object.<br>Use the area under the graph to determine the distance and displacement of an object.<br>Construct different graphical representations using sections from popular movies or television shows. Those with chase scenes may be particularly effective. Graphical representations can be constructed using data from professional athletes.<br>Construct position vs time graphs and velocity vs time graphs using trolleys on an inclined plane. Consider the accelerations of different masses.<br>Use motion sensors or other multi-image technology to collect data.<br>Refer to computer interactive 'The Moving Man', https://phet.colorado.edu/.<br>Connect and investigate different graphical representations by calculating gradients and areas. For example:<br>• use a position vs time graph to construct a velocity vs time graph<br>• use a velocity vs time graph to construct an acceleration vs time graph |
| | Work out how to determine the instantaneous velocity and instantaneous acceleration from non-linear graphs, using mathematical techniques. |
| Equations of motion quantitatively describe and predict aspects of linear motion.<br>• Solve and interpret problems using the equations of motion:<br>$v = v_0 + at$<br>$s = v_0 t + \frac{1}{2}at^2$<br>$v^2 = v_0^2 + 2as.$<br>Vertical motion is analyzed by assuming that the acceleration due to gravity is constant near Earth's surface. | Show how equations can be derived using different methods:<br>• $v = v_0 + at$, using the definition of acceleration<br>• $s = v_0 t + \frac{1}{2}at^2$, using a velocity vs time graph<br>• $v^2 = v_0^2 + 2as$, algebraically.<br>Calculate and analyze the acceleration due to gravity on the Moon using NASA footage showing a hammer and feather being dropped simultaneously. Use and discuss appropriate estimations.<br>Use stop-motion animation to illustrate an understanding of motion. Footage of objects in motion may be analyzed using tracking software. |

| Science Understanding | Possible contexts |
|---|---|
| The constant acceleration due to gravity near the surface of the Earth is approximately $g = 9.80\,\mathrm{m\,s^{-2}}$. <br>• Solve problems for objects undergoing vertical motion because of the acceleration due to gravity in the absence of air resistance. <br>• Explain the concept of free-falling objects and the conditions under which free-falling motion may be approximated. <br>• Describe qualitatively the effects that air resistance has on vertical motion. <br>Use equations of motion and graphical representations to determine the acceleration due to gravity. | Further develop scientific inquiry skills by investigating different aspects of projectile motion in sport. <br>Experimentally determine the acceleration due to gravity by recording an object falling against an appropriate scale using a ticker-timer, motion sensor, or other multi-image applications. Use data to construct a velocity vs time graph. <br>Design investigations to determine if mass has any effect on vertical acceleration. <br>Investigate sideshow rides to measure and calculate physical quantities. Investigate what quantities make a ride enjoyable and how these are maximized. Consider factors such as g-force, acceleration, average speeds. Mobile devices could have suitable sensors and applications to record measurements. |
| | Explore the principles behind different methods used to determine the speed of an object and evaluate the benefits and limitations of each method. Examples include radars and laser guns, point-to-point cameras. <br>Decide the best location for point-to-point cameras to identify speeding vehicles. |
| | Investigate the methods used to determine the gait and speed of dinosaurs based on their tracks (such as that devised by Robert Alexander), which contribute to better understanding of early life on Earth. Conduct experiments and analyze data based on this work. |

# 1 Position

One important term to understand when analysing straight line motion is position.

Position describes the location of an object at a certain time with respect to the origin.

Position is a vector quantity and therefore requires a direction.

# 2 Distance & Displacement

Distance describes the total length of the pathway taken between the starting point and the finishing point of a journey. Distance travelled, ‘d’, describes the length of the path covered during an object’s entire journey.

- Distance travelled is a scalar quantity and is measured in metres (m).

Displacement, ‘s’, indicates the location of the destination relative to the journey’s starting location, irrespective of the path actually taken between the two points.

- Displacement is a vector quantity and is measured in metres (m).

Displacement is usually represented by the symbol ‘s’ in equations of motion, but other symbols such as ‘x’ or ‘r’ may also be encountered.

# 3 Speed & Velocity

## 3.1 Average speed & velocity

The average speed of an object over a journey is determined by dividing the total distance the object travelled by the time taken to complete the journey:

$$Speed = \frac{Distance}{Time}$$

- Like distance, average speed is a scalar quantity.

The average velocity ($v_{av}$), of an object over a journey is calculated by dividing an object’s total displacement by its journey time:

$$v_{av} = \frac{s}{t}$$

- Average velocity is vector quantity acts in the same direction as the displacement vector.

## 3.2 Instantaneous speed & velocity

The speed at any particular instant in time is called the instantaneous speed. The velocity at any particular instant in time is called the instantaneous velocity.

If an object moves with a constant velocity during a time interval, it’s instantaneous velocity throughout the interval is the same as its average velocity.

- Instantaneous velocity is the first derivative of position vector wrt to time

Example 1

If a champion swimmer completes 30 laps of a 50 m swimming pool, a distance of 1500 m, in a time of 15 minutes, what is:

(a) their average speed in m s $^{-1}$

(b) their average velocity in m s $^{-1}$?

We knowthat distance travelled is ‘d’ = 1500 m but the displacement is ‘s’ = 0 m

$$Speed_{ave} = \frac{distance}{time} = \frac{1500}{15*60} = 1.7\ ms^{-1}$$

$$v_{ave} = \frac{s}{t} = \frac{0}{15*60} = 0\ ms^{-1}$$

Example 2

Sam is an athlete performing a training routine by running back and forth along a straight stretch of running track. He jogs 100 m north in a time of 20 s, then turns and walks 50 m south in a further 25 s before stopping.

a) What is Sam’s average velocity in m s $^{-1}$?

b) What is Sam’s average speed in m s $^{-1}$?

d = distance travelled = 100 + 50 = 150 m

s = sum of displacements = 100 m north + 50 m south = 100 + (–50) = +50 m or 50 m north

time taken = 20 + 25 = 45 s

$$Speed_{ave} = \frac{distance}{time} = \frac{150}{45} = 3.3\ ms^{-1} \quad or \quad 3.3*3.6 = 11.88\ kmh^{-1}$$

$$v_{ave} = \frac{s}{t} = \frac{50}{45} = 1.1\ ms^{-1} \quad or \quad 1.1*3.6 = 3.6\ kmh^{-1}$$

## 3.3 Relative velocity

The velocity of an object measured by a moving observer is referred to as the relative velocity. The relative velocity is the difference between the velocity of the object relative to the ground and the velocity of the observer relative to the ground.

Example 1

Suppose two cars A and B are moving with uniform velocities with respect to ground along parallel tracks and in the same direction. Let the velocities of A and B be 35 km h $^{-1}$ due east and 40 km h $^{-1}$ due east respectively. What is the relative velocity of car B with respect to A?

The relative velocity of B with respect to A,

$V_{BA} = V_B - V_A = 40 – 35 = 5$ km h $^{-1}$ due east.

The relative velocity of A with respect to B,

$V_{AB} = V_A – V_B = 35 – 40 = -5$ km $h^{-1}$ due west.

Example 2

Consider two trains A and B moving along parallel tracks with the same velocity in the same direction. Let the velocity of each train be 50 km $h^{-1}$ due east. Calculate the relative velocities of the trains.

The relative velocity of B with respect to A,

$V_{BA} = V_B - V_A = 50 + (-50) = 0$ km $h^{-1}$.

Similarly, relative velocity of A with respect to B i.e., $V_{AB}$ is also zero. Thus each train will appear to be at rest with respect to the other.

Example 3

How long will a boy sitting near the window of a train travelling at 36 km $h^{-1}$ see a train passing by in the opposite direction with a speed of 18 km $h^{-1}$. The length of the slow-moving train is 90 m.

The relative velocity of the slow-moving train with respect to the boy is (36+18) 54 km $h^{-1}$, which is equal to (54/3.6) = 15 $ms^{-1}$.

Since the boy will watch the full length of the other train, to find the time taken to watch the full train: then, 15 = 90/t, which yields t = 90/15 = 6 s.

Example 4

A swimmer's speed in the direction of flow of a river is 12 km $h^{-1}$. Against the direction of flow of the river the swimmer's speed is 6 km $h^{-1}$. Calculate the swimmer's speed in still water and the velocity of the river flow.

Let Vs and Vr , represent the velocities of the swimmer and river respectively with respect to ground.

$Vs + Vr = 12$ km $h^{-1}$ and

$Vs – Vr = 6$ km $h^{-1}$

Adding the both equations $2Vs = 18$ km $h^{-1}$ and $Vs = 9$ km $h^{-1}$

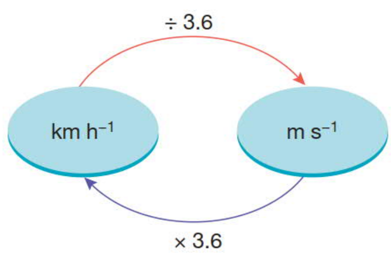
From the above equation, $Vr = 9 – 6 = 3$ km $h^{-1}$

## 3.4 Converting units of speed and velocity

While the SI units for both speed and velocity are $ms^{-1}$, it is common to encounter values for them given in km $h^{-1}$.

To convert km $h^{-1}$ to m $s^{-1}$, divide by 3.6

To convert m $s^{-1}$ to km $h^{-1}$, multiply by 3.6



Year 11

# Physics

## 1.2 Forces

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## Subtopic 1.2: Forces

Students apply Newton's Laws of Motion to a variety of contexts. Students investigate how these laws have influenced design and safety in different contexts such as cars, boats, submarines, playground equipment, and air and space transport. Through experiments and activities, students build a sound understanding of forces in the physical world, including those relating to various kinds of resistance and friction.

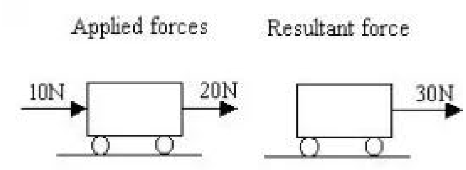
<table>
<tr><th>Science Understanding</th><th>Possible contexts</th></tr>
<tr><td>A force, $\vec{F}$, is any action which causes motion to change, $\vec{a}$.<br>Uniform motion is a state of motion in which the body travels with a constant speed (in a straight line).<br>Rest is a state of uniform motion in which the speed of the body is zero.<br>To change the state of motion of an object, a net force must be applied.</td><td>This connects to the concepts of force used in Stage 1 subtopics 4.1: Energy and 4.2: Momentum, and Stage 2 subtopics 1.2: Forces and momentum, 1.3: Circular motion and gravitation, 2.1: Electric fields, 2.2: Motion of charged particles in electric fields, and 2.4: Motion of charged particles in magnetic fields.<br>Review understanding of forces.</td></tr>
<tr><td rowspan="2">Newton's Three Laws of Motion describe the relationship between the force or forces acting on an object, modelled as a point mass, and the motion of the object due to the application of the force or forces.<br>Newton's First Law: An object will remain at rest, or continue in its motion, unless acted upon by an unbalanced force:<br>• Explain Newton's First Law using the concept of inertia.<br>• Use Newton's First Law to explain the motion of objects in a variety of contexts.<br>• Describe and explain the motion of an object falling in a uniform gravitational field with air resistance.<br><br>Newton's Second Law: If an unbalanced force acts upon an object, the object will accelerate in the direction of the net force.<br>This can be given mathematically as: $\vec{a} = \frac{\vec{F}}{m}$.<br>• Solve problems involving $\vec{F} = m\vec{a}$.<br>• Explain the difference between mass and weight.</td><td>Refer to computer interactive 'Forces in 1 Dimension', https://phet.colorado.edu/.<br>Discuss the concepts of weight and weightlessness in different contexts (e.g. on the surface of the Earth, on the surface of the Moon, inside a moving lift, in the International Space Station).<br>Discuss the motion of spacecraft in an essentially frictionless environment.<br>Study satellites in circular orbits with acceleration but constant speed.<br>Discuss motion in different circumstances (e.g. on an inclined plane, in thick liquids, or for rigid objects).</td></tr>
<tr><td>Use computer Interactive 'Forces and Motion: Basics' and 'Forces and Motion', https://phet.colorado.edu/.<br>Investigate Newton's First Law by moving objects of different mass over surfaces of very low friction (e.g. air tracks, ice, or layers of ball bearings).<br>Investigate the relationships between terminal speeds and forces in a variety of contexts. Design and carry out individual or group investigations involving dropping objects in different fluids to observe and quantify non-uniform acceleration.</td></tr>
</table>

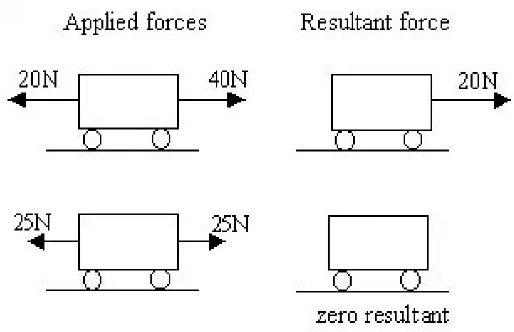
| Science Understanding | Possible contexts |
|---|---|
| Newton's Third Law: When two objects interact, they exert forces on each other equal in magnitude and opposite in direction.<br>The forces are identified in pairs, and the accelerations of each object will differ if the objects differ in mass.<br>• Use Newton's Third Law to solve problems.<br>• Identify pairs of forces in a variety of contexts, including the normal reaction force.<br>• Describe and explain motion where Newton's Third Law occurs.<br>• Use Newton's Laws to explain the motion of spacecraft.<br><br>Undertake experiments to investigate the relationship between acceleration and either force or mass. | Use computer interactive 'Masses and Springs', https://phet.colorado.edu/.<br>Investigate spring constants using Hooke's Law. Design experiments to investigate the effect of multiple springs. Students could test elastic bands, cooked spaghetti or noodles, or confectionery to compare differences in results.<br>Use an air track, light gate, and slotted masses to investigate relationship between forces and acceleration.<br>Investigate different types of air or water rockets. The design may be manipulated and the effect on the rockets' motion determined.<br>Determine the coefficient of kinetic friction by measuring the acceleration of a moving object as it comes to rest. Design, build, and evaluate structures individually or in groups. |
| | Investigate and assess the wide range of evidence from many sources that have contributed to the current understanding of motion.<br>Investigate the influence that an understanding of the balance of forces has on the design of ancient and modern buildings, bridges, and other forms of engineering.<br><br>Investigate and discuss the application of Newton's Laws of Motion in the development of various safety features involving people or objects in motion. Evaluate their social and economic impacts. |

# 1 Forces

In simpler terms, we can say that a force is a 'push' or a 'pull'. As force is a vector quantity, it has both magnitude and direction associated with it. The SI unit of force is the Newton (N).

If more than one force acts on a body at the same time, the body behaves as if only one force - the vector sum of all the forces - is acting. The vector sum of the forces is called the resultant or net force, $F_{net}$.




Force can:

- make a stationary body move
- change the speed of a body
- change the direction of motion of a body (It is possible to change the direction of motion of a body without changing its speed.)
- change the size or shape of the body

Forces can be categorised as either contact forces or non-contact forces.

Contact Forces; These are those types of forces when two objects interact with each other; they have a physical contact with each other. Types of contact forces are: Frictional force; Tension force; Normal Force; Air Resistance Force, Applied Force, Spring Force.

Non-contact Forces; These types of forces happen when two interactive objects are not in physical contact with each other; yet they are able to push or pull. They are also called as 'Action at a distance forces', and the types are: Gravitational force, Electrical force and Magnetic forces, Electrostatic forces, Nuclear forces.

| | |
|---|---|
| net force | – the sum of all forces acting on an object |
| balanced forces | – combined forces that result in a zero net force on an object |
| equilibrium | – the state in which the net force on an object is zero |
| normal force | – the perpendicular force that a surface exerts on an object. |
| free-body diagram | – a diagram showing all the forces acting on an object |

## 2 Newton's First law

Newton's first law states that "Every object continues to be in the state of rest or of uniform motion (constant velocity) unless there is an external force acting on it".

To truly understand Newton's first law, one could be able to state it in different ways yet still recognise it as being consistent with Newton's first law.

All of these following statements are consistent with Newton's first law:

- An object will maintain a constant velocity unless an unbalanced, external force acts on it.
- A body will either remain at rest or continue with constant speed in a straight line (i.e. constant velocity) unless it is acted on by a net force.
- If a net force is applied, then the object's velocity will change.
- If a net force is applied, an acceleration will result.
- Constant velocity means no net force is applied.

From Newton's first law we can say that force is a physical quantity due to which, a stationary body comes into motion or a moving body changes its velocity. Thus Newton's first law of motion gives us the definition of force, but it does not give information about the value (magnitude) of force.

Newton's First Law of Motion is often referred to as the 'law of Inertia'. The inertia of an object is its tendency to resist changes to its motion. Inertia is not a force; it is a property of all objects.

### 2.1 Inertia

Inertia is the natural tendency of an object to remain in its current state of motion. This includes changes to the object's speed, direction, or state of rest.

The amount of an object's inertia is directly related to its mass. As the mass of the object increases, the inertia also increases.

It is important to note that the effect of inertia is independent of gravity.

Since inertia depends on mass, and weight force due to gravity also depends on mass, so, it is a common misunderstanding to think that the effects of inertia only apply in the presence of gravity. However, even in space it would be just as difficult to change the state of motion.

Depending on the circumstances, there can be three types of inertia.

Inertia of Rest

The inability of an object to change its state of rest on it's own is called inertia of rest.

- Person sitting in a car falls backwards, when the car suddenly starts. It is because the lower portion in contact with the car comes in motion where as the upper part tries to remain at rest due to inertia of rest.

Inertia of Motion

The inability of an object to change it's state of uniform speed (constant speed) on it's own is called inertia of motion.

- When a moving car suddenly stops the person sitting in the car falls forward because the lower portion of the body in contact with the car comes to rest whereas the upper part tends to remain in motion due to inertia of motion.

Inertia of Direction

The inability of an object to change it's direction of motion on it's own is called inertia of direction.

- When a car moves round a curve the person sitting inside is thrown outwards in order to maintain his direction of motion due to inertia of motion
- A stone moves tangential to  circle due to inertia of direction

Question 1

A student observes a box sliding across a surface and slowing down to a stop. From this observation what can the student conclude about the forces acting on the box?

The box has changed its velocity so by using Newton's first law to conclude that an unbalanced force must have acted on the box to slow it down.

Question 2

A car changes its direction as it turns a bend in the road while maintaining its speed of 16 m $s^{-1}$. From this, what can you conclude?

Even though the car has maintained its speed, the direction has changed, which means the velocity has changed. Using Newton's first law, it can be concluded that an unbalanced force has acted on the car to change its direction.

Question 4

If a person is standing up in a moving bus that stops suddenly, the person will tend to fall forwards. Has a force acted to push the person forwards? Use Newton's first law to explain what is happening.

No horizontal force acts on the person. In accordance with Newton's first law of motion, the bus slows, but the standing passenger will continue to move with constant velocity unless acted on by an unbalanced force; usually the passenger will lose his or her footing and fall forwards.

Question 5

What horizontal force has to be applied to a wheelie bin if it is to be wheeled to the street on a horizontal path against a frictional force of 20 N at a constant 1.5 m $s^{-1}$?

Constant speed, so $F_{net} = 0$, then frictional force = applied force = 20 N.