Forces Make

Things Change

L1 Resultant forces

The forces acting on any object can be shown using a **free-body diagram**. A force diagram uses labelled arrows to show all the forces acting on the object.

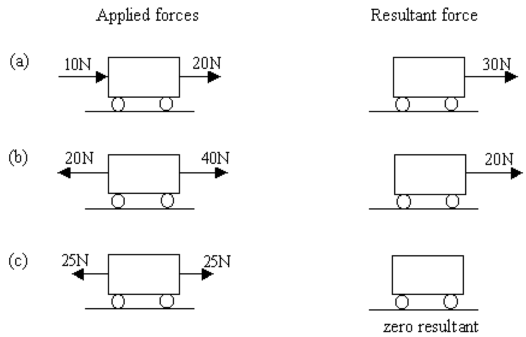
- The **direction** of each arrow shows the **direction** of each force.
- The **length** of each arrow is proportional to the **size** of the force.

The motion of the object will depend on the **resultant force**. This is calculated by adding all the forces together, taking their direction into account. When more than one force acts on an object, the forces combine to form a **resultant force.**

To draw resultant force, you need to add one force onto the end of the other and draw a line from the start to the finish.

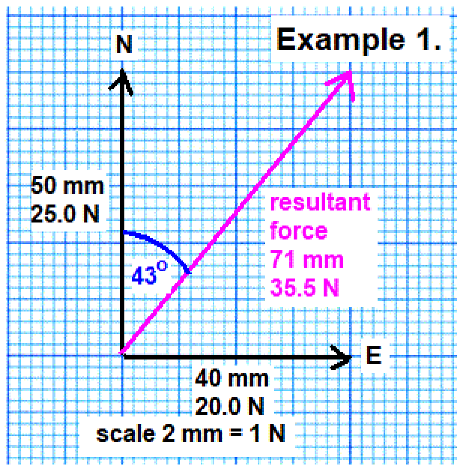
Calculating Resultant Force:

Sometimes, two forces act on an object in a straight line. In such cases, you can easily calculate the resultant force by simply adding or subtracting the forces depending on their directions. For example, if one force pushes to the right with a strength of 20 Newtons, and another force pushes to the left with a strength of 40 Newtons, the resultant force would be 40N - 20N = 20N to the right.



How to calculate Resultant forces when component forces are at angles:

1. Decide on a scale.
2. Draw the forces to scale.
3. Box it off.
4. Draw a diagonal line through the box.
5. Measure the diagonal.
6. Multiply by the scale factor.

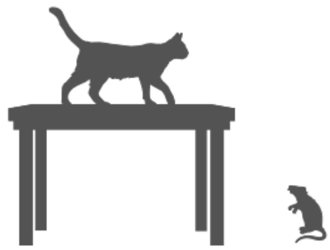


Balanced Forces: When the forces acting on an object balance out, meaning they cancel each other out, the resultant force is zero. This leads to a situation called equilibrium, where the object stays still or moves at a constant speed. Imagine a tug of war where the teams are equally matched, and no one is pulling harder than the other – the rope doesn't move because the forces are balanced.

Independent practice

1. What is a resultant force, and how does it relate to multiple forces acting on an object?
2. Describe how you would calculate the resultant force when two forces act in a straight line.
3. Describe how you would calculate the resultant forces when the components are acting at angles?
4. Can you provide an example of forces acting on an object and explain how they balance each other out?
5. How do free body diagrams help us understand the forces acting on an object?
6. Explain the concept of balanced forces and provide an example of when they occur in everyday life.

1. What does the length of an arrow in a force diagram show?
2. What does the direction of an arrow in a force diagram show?
3. A cat has a weight of 35N and is standing still on a table.
   a) What direction does the weight of the cat act in?
   b) What is the name of the other force acting on the cat?
   c) What direction does the force named in b) act in?
   d) Give the size of the force named in b).
   e) Draw two arrows on the diagram to represent the two forces acting on the cat. Label your arrows with the name and size of the force they show.



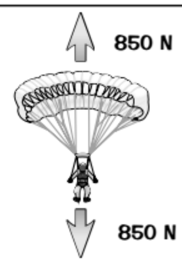
4. In each of the examples to the right, work out the overall force and say whether the object is accelerating, decelerating or moving at a constant speed.

Overall force = ...

The boat is ....

Overall force = ...

The car is ....



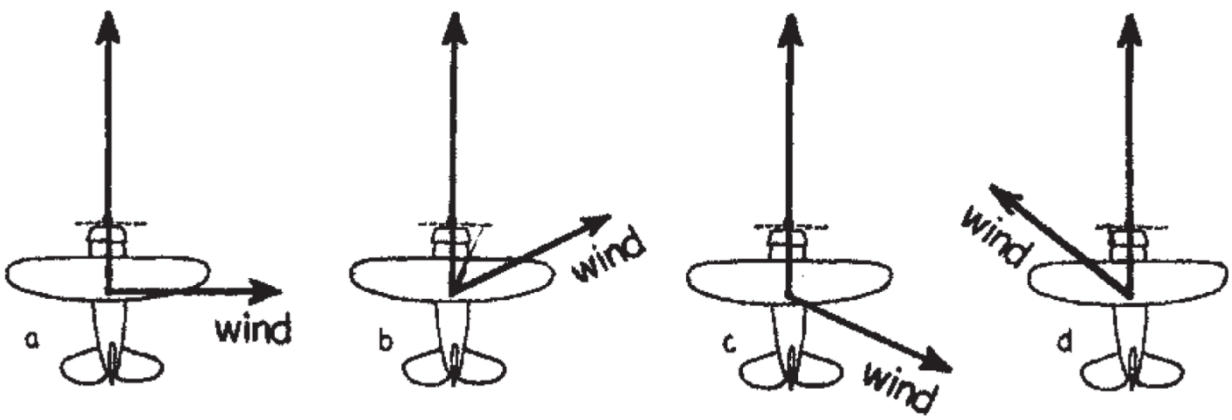
Overall force = ...

The skydiver is ....

....

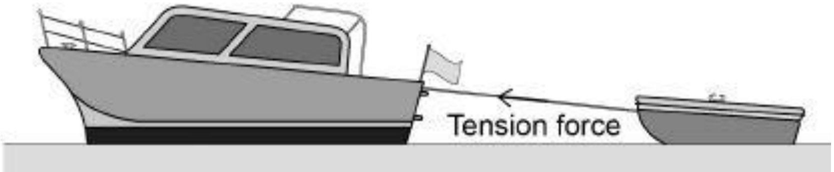
Medium

5. Below we see a top view of an airplane being blown off course by wind in various directions. Draw the resultant speed and direction of travel for each case. In which case does the airplane travel fastest & slowest?



(e) **Figure 3** shows the boat towing a small dinghy.

Figure 3



The tension force in the tow rope causes a horizontal force forwards and a vertical force upwards on the dinghy.

horizontal force forwards = 150 N
vertical force upwards = 50 N

Draw a vector diagram to determine the magnitude of the tension force in the tow rope and the direction of the force this causes on the dinghy.

Magnitude of the tension force in the tow rope = ______________________ N

Direction of the force on the dinghy caused by the tension force in the tow rope = ________________________

L2 Newtons laws

Imagine you're in a car at rest, or in uniform motion, cruising down the road at a steady pace. Newton's First Law, also known as the law of inertia, dictates that an object at rest tends to stay at rest, and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an external force. This concept of inertia is fundamental - it's the measure of an object's resistance to changes in its motion.

Consider a scenario where you're driving at a constant velocity. This means that the forces acting on the vehicle, such as the driving force from the engine and the resistive forces like friction and air resistance, are perfectly balanced. As per Newton's First Law, there's no resultant force acting on the car, thus it maintains its velocity without any change. Essentially, the equilibrium of forces maintains the status quo of motion.

Now, when we want to alter the motion, like accelerating or decelerating, we turn to Newton's Second Law. This law states that the acceleration of an object is directly proportional to the resultant force acting on it and inversely proportional to its mass. Mathematically, this relationship is represented as $F = ma$, where F is the resultant force, m is the mass of the object, and a is the acceleration produced.

In this context, the term "inertial mass" emerges as a critical concept. Inertial mass is essentially a measure of how difficult it is to change the velocity of an object. The greater the inertial mass, the more resistance the object offers to changes in its motion.

Moreover, inertial mass can be defined as the ratio of force to acceleration. This means that for a given force applied to an object, the amount of acceleration it undergoes depends on its inertial mass. Objects with larger inertial masses will experience smaller accelerations for the same force, while objects with smaller inertial masses will experience larger accelerations.

Practically speaking, when we accelerate a car, the inertial mass of the car determines how quickly it responds to the force applied by the engine. A heavier car will have greater inertial mass, requiring more force to achieve the same acceleration as a lighter car.

Therefore, Newton's Second Law, with its incorporation of inertial mass, elucidates the intricate relationship between force, mass, and acceleration, providing a foundational understanding of how objects respond to external influences.

In practical terms, when you press down on the gas pedal to accelerate, you're increasing the force applied to the car, leading to a corresponding increase in acceleration. Conversely, when you brake, you're applying a force in the opposite direction, resulting in deceleration.

Newton's Third Law, often stated as "for every action, there is an equal and opposite reaction," illuminates the symmetry of forces in nature. When two objects interact, they exert equal and opposite forces on each other. This principle underpins many phenomena, from the propulsion of rockets to the recoil of firearms.

So, whether we're discussing the inertia of an object, the relationship between force and acceleration, or the interaction of forces, Newton's laws provide the framework for understanding the mechanics of motion in our universe. And through experimentation, where we manipulate variables like force and mass, we can witness these laws manifest in tangible ways, enriching our comprehension of the physical world.

Independent practice

1. According to Newton's First Law, what happens to an object that is stationary when no external force acts upon it?
2. How does Newton's Second Law define the relationship between force, mass, and acceleration?
3. Explain the concept of inertia and its significance in Newton's First Law.
4. What role does inertial mass play in determining the response of an object to an applied force, as described in Newton's Second Law?
5. Give an example from everyday life that illustrates Newton's Third Law of motion.
6. Extended writing: Explain the motion of a car colliding with a lorry using newtons laws.

L3 Newtons second law

Newton's 2nd law:

The acceleration of an object is **directly proportional to the force** applied. The acceleration of an object is also **inversely proportional to the mass** of an object. This can be summarised by the equation below:

Force = mass × acceleration

$$\boldsymbol{F = m \times a}$$

where **F** is the force (in N)

m is the mass (in kg)

a is the acceleration (in m/s^2).

Independent practice

Give the **units and symbol** for each term in the table below

Term	Symbol	Unit
Acceleration		
Force		
Mass		

2. Work out **force** in each of the following:
    a. mass = 4kg, acceleration = 2 m/s^2
    b. mass = 150kg, acceleration = 3 m/s^2
    c. mass = 20kg, acceleration = 2.7 m/s^2
    d. mass = 500kg, acceleration = 5 m/s^2
3. How much **force** is needed to accelerate a 66 kg skier at 2 m/s^2?
4. What is the **force** on a 1,000 kg elevator that is falling freely at 9.8 m/s^2?
5. A 50 kg skater pushed by a friend accelerates 5 m/s^2. How much **force** did the friend apply?

Medium

7. Complete the equations for mass and acceleration below by rearranging the equation

Force = mass x acceleration	**mass =**	**acceleration =**

8. Work out the **mass** in each of the following:
    a. acceleration = 5 m/s^2, force = 12N
    b. acceleration = 25 m/s^2, force = 200N
    c. acceleration = 15 m/s^2, force = 3N
    d. acceleration = 0.5 m/s^2, force = 3N
9. Work out the **acceleration** in each of the following:
    a. force = 20N, mass = 5kg
    b. force = 7N, mass = 14kg
    c. force = 2,000N, mass = 1250kg
    d. force = 0.75N, mass = 0.45kg
10. What is the acceleration of a 50 kg object pushed with a force of 500 newtons?
11. A force of 250 N is applied to an object that accelerates at a rate of 5 m/s^2. What is the mass of the object?

Hard

To go from g to kg → ÷ 1000

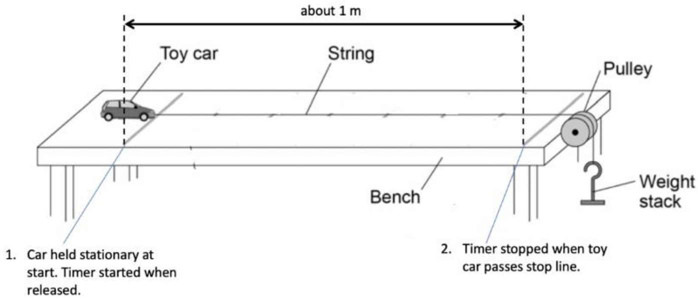
12. A force of 20 N acts upon a 500 g block. Calculate the acceleration of the object.
13. A 200 g block is pulled across a table by a horizontal force of 40 N with a frictional force of 8 N opposing the motion.
    a) Calculate the resultant force.
    b) Calculate the acceleration of the object.
14. An object of mass 300 g is falling in air and experiences a force due to air resistance of 1.5 newtons. Determine the net force acting on the object and calculate the acceleration of the object.
15. If a 60 kg person on a 15 kg sled is pushed with a force of 300 N, what will be person's acceleration?

L4 Newtons second law RPA

To embark on our investigation, we assemble our apparatus. This includes a trolley, a bench pulley, hanging masses of varying weights, a stopwatch, a meter ruler, and a set of electronic scales. These tools will enable us to measure critical parameters such as length, mass, and time accurately.

Using the meter ruler, we measure the length over which the trolley will travel. This distance serves as our reference point for observing the motion of the trolley. Next, we utilize the electronic scales to measure the mass of the trolley, ensuring that it remains constant throughout the experiment.

The bench pulley system allows us to apply forces to the trolley by suspending masses of different weights. By adjusting the masses hanging from the pulley, we can vary the force acting on the trolley. Additionally, the stopwatch enables us to record the time taken by the trolley to travel certain distances, aiding in the determination of speed and acceleration.



Experiment Procedure:

With our apparatus in place, we commence the experiment. Firstly, we set the trolley on a flat surface and ensure it is stationary. Then, we attach the bench pulley to the edge of the surface and suspend a mass from it. This mass will exert a force on the trolley once it is released.

Before releasing the trolley, we measure the distance over which it will travel using the meter ruler. Once all measurements are recorded, we release the trolley, allowing it to accelerate due to the force exerted by the hanging mass. Simultaneously, we start the stopwatch to record the time taken for the trolley to travel the specified distance.

Upon completion of the first trial, we repeat the experiment multiple times, each time varying the mass hanging from the pulley. By doing so, we can observe how altering the force applied to the trolley affects its acceleration.

Similarly, we conduct another set of experiments where we keep the force constant but alter the mass of the trolley. This time, we adjust the masses placed on the trolley itself while keeping the force exerted by the hanging mass consistent. Again, we record the time taken for the trolley to travel a set distance for each trial.

Observations and Analysis:

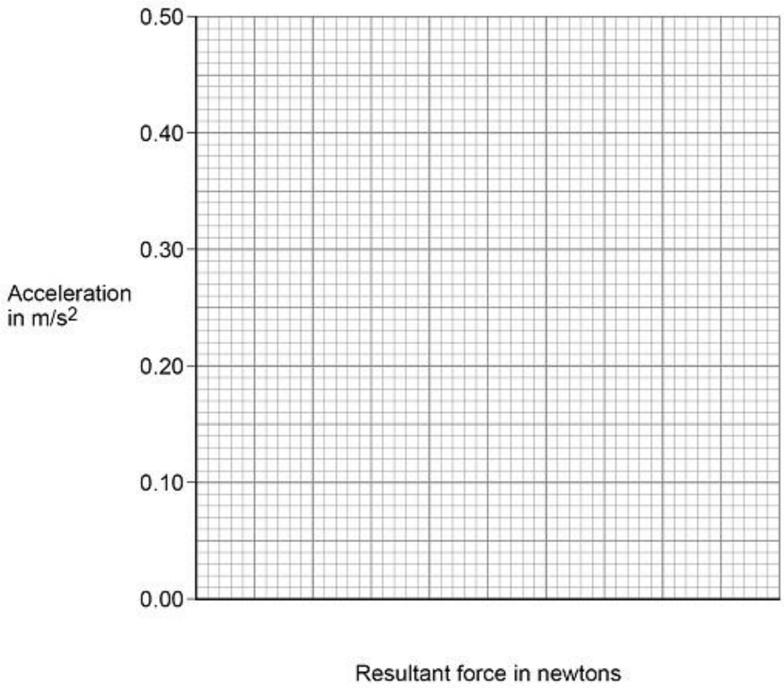
As we conduct our experiments, several patterns emerge. We notice that increasing the force applied to the trolley leads to a corresponding increase in acceleration. This aligns with Newton's second law of motion, which states that the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

Conversely, when we keep the force constant and vary the mass of the trolley, we observe that acceleration decreases as mass increases. This reaffirms Newton's second law, emphasizing the inverse relationship between mass and acceleration under constant force conditions.

Independent practice

1. How does altering the force applied to the trolley affect its acceleration, according to the observations made during the experiment?
2. What principle of physics is reaffirmed when the mass of the trolley is increased while keeping the force constant? Explain.
3. Describe the apparatus used in the experiment and its role in conducting the investigation.
4. Why is it important to record accurate measurements of length, mass, and time during the experiment?
5. How does Newton's second law of motion explain the relationship between force, mass, and acceleration as observed in the experiment?
6. The light gate and data logger were used to determine the acceleration of the trolley.
   The student increased the resultant force on the trolley and recorded the acceleration of the trolley.
   The table below shows the results.

Resultant force in newtons	Acceleration in m/s^2
0.05	0.08
0.10	0.18
0.15	0.25
0.20	0.32
0.25	0.41



The graph below is an incomplete graph of the results. Complete the graph.

- Choose a suitable scale for the x-axis.
- Plot the results.
- Draw a line of best fit.

L5 calculating momentum.

Any mass that is moving carries **momentum**. The equation for this is below:

Momentum = mass × velocity

p = m × v

Where p is momentum in kg m/s

m is mass in kg

v is velocity in m/s

Note that because the equation for momentum contains velocity, momentum must be a **vector**.

If two objects collide or interact, the forces acting on each one will be the same size but in opposite directions. The same is true for the change in momentum of each object.

This means that the momentum lost by one of the objects will be gained by the other object. Therefore, whenever two objects collide or interact, **momentum is conserved**.

Example question: Dr. Edmunds drops his iPad. Just before it hits the ground it has a velocity of 5 m/s. If the iPad has a mass of 500g, what is its momentum?

Step 1: Write the equation. Rearrange if necessary.

p = m × v

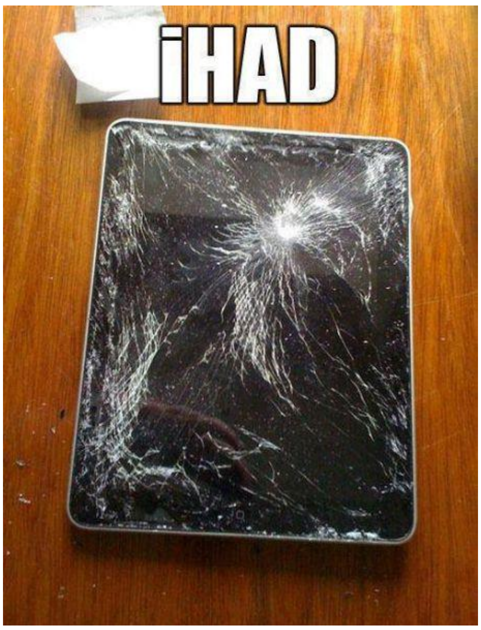
Step 2: Write down the variables

m = 500 g = 0.5 kg

v = 5 m/s

Step 3: Calculate the answer

p = m × v = 0.5 × 5 = 2.5 kg m/s



Independent practice

Basic

Q1. The momentum of this snowball increases because two factors increase as it rolls down the hill. What do you think the two factors are?

……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………………………………………………………

Q2. Momentum can be calculated using this equation:

Momentum = ……………………… x ……………………….

Q3. The units of momentum are …………………………….

Q4. Calculate the **momentum** if:

a) m = 0.3 kg, v = 7 m/s b) m = 5 kg, v = 12 m/s

Q5. Calculate the **velocity** if:

a) p = 1.5 kg m/s, m = 0.3 kg b) p = 17 kg m/s, m = 8.5 kg

Q6. Calculate the **mass** if:

a) p = 1400 kg m/s, v = 20 m/s b) p = 1,800,000 kg m/s, v =9 m/s.

Medium (re-arranging and unit conversion)

Q7. Calculate the **momentum** of a football of mass 500g travelling at a velocity of 10 m/s.

Q8. Calculate the **momentum** of a mouse of mass 400g running through the grass at 3 m/s.

Q9. An athlete running at 8 m/s has a momentum of 520 kg m/s. What is her **mass**?

Q10. Cristiano Ronaldo kicks a football at a momentum of 50 kg m/s. If the mass of the football is 500g, what **velocity** has he kicked the football at?

Q11. Dr. Edmunds is late for a lesson and runs with a momentum of 700 kg m/s. If his velocity is 10 m/s, what is his **mass**? (be nice…)

Q12. 10H1 is going on a school trip to the moon. The rocket we're using has a momentum of 700,000,000 kg m/s and is travelling at a speed of 1,400 m/s. What is the **mass** of the rocket?

Hard (hard unit conversion or using more than one equation)

Q13. A car that weighs 2 tonnes is travelling at a velocity of 20 m/s. Calculate its **momentum**.

Tonne → kg × 1000

Q14. A train is travelling at 80 mph, and has a mass of 100 Tonnes. Calculate its **momentum**.

miles → metres × 1600

Q15 Usain Bolt runs at a maximum speed of 27 mph. If he has a momentum of 960 kgm/s, what is his **mass**?

Q16 An eagle travels a distance of 150m in a time of 12 seconds. If the eagle weighs 4kg, what is the **momentum** of the eagle.

Q17. An aeroplane of mass 200 tonnes travels a distance of 900 km in a time of 90 minutes. Calculate the **momentum** of the aeroplane.

L6 conservation of momentum.

Momentum is a crucial concept in physics, especially when we examine events like collisions. Imagine two cars colliding on a road or a ball hitting a wall. In these instances, momentum plays a vital role in determining the outcome of the event.

One of the fundamental principles related to momentum is the conservation of momentum. This principle asserts that in a closed system, the total momentum before an event equals the total momentum after the event, provided no external forces act on the system. This means that momentum is not created or destroyed but rather transferred between objects involved in the event.

Let's delve into a detailed example to understand this concept better:

Step 5: Understand the implications.

In this example, the total momentum before the collision is equal to the total momentum after the collision. This demonstrates the principle of conservation of momentum.

Understanding momentum and its conservation is not only crucial in theoretical physics but also has practical applications, especially in ensuring safety in various scenarios. Engineers utilize this principle extensively when designing safety features in vehicles and other environments prone to collisions.

For instance, consider airbags in cars. Airbags deploy rapidly during a collision, extending the time over which the momentum change occurs. This helps reduce the force exerted on the occupants, thereby minimizing injuries.

Similarly, crash mats in gymnasiums and cushioned surfaces on playgrounds serve a similar purpose. They absorb and dissipate the kinetic energy of a falling person, effectively reducing the impact force experienced upon contact with the ground.

By understanding momentum and conservation of momentum, engineers can optimize the design of these safety features to better protect individuals in various scenarios, ultimately saving lives and preventing injuries.

Independent Practice

1. How does momentum play a role in events like collisions, and why is it important to understand its implications?
2. Can you provide an example of how momentum is transferred during a collision, and explain how this affects the motion of the objects involved?
3. Explain the relationship between force, mass, and acceleration, and how these factors are interconnected in the context of Newton's second law of motion.
4. How does the equation $F = m \times a$ relate to the concept of momentum, and what does it signify in terms of the rate of change of momentum?
5. Discuss the significance of safety features like airbags, seat belts, and crash mats in terms of the concept of rate of change of momentum. How do these features help mitigate the impact of collisions?

Calculation questions

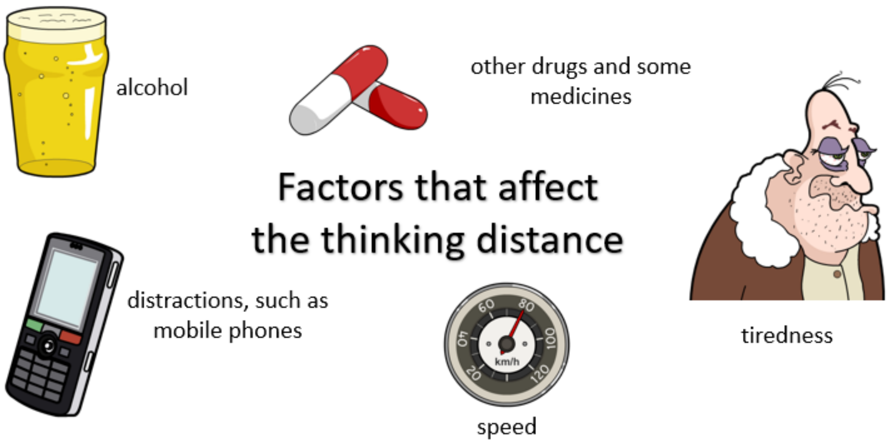
6. Two cars, each with a mass of 1000 kg, are traveling towards each other. Car A is moving at 20 m/s, and car B is moving at 15 m/s. What is their total momentum before the collision?
7. In question 1, if the cars collide and stick together after the collision, what is their combined mass?
8. Using the information from question 1, calculate the final velocity of the cars after the collision.
9. A 2000 kg car is traveling at 25 m/s. It collides head-on with a stationary car with a mass of 1500 kg. If they stick together after the collision, what is their final velocity?
10. A 500 g toy car moves with a velocity of 2 m/s. It collides with another toy car of mass 750 g, moving in the opposite direction at 3 m/s. If they stick together after the collision, what is their final velocity?
11. Two objects of masses 2 kg and 3 kg are moving towards each other with velocities of 4 m/s and 2 m/s respectively. If they collide and stick together, what is their final velocity?
12. A 1000 kg car moving at 10 m/s collides with a stationary car of mass 1500 kg. If they move off together after the collision, what is their final velocity?
13. A 50 kg person jumps onto a stationary skateboard with a mass of 2 kg. If the person's initial velocity is 3 m/s downward and the skateboard moves off with a velocity of 0.5 m/s, what is the person's final velocity?
14. Two ice skaters, one with a mass of 60 kg and the other with a mass of 40 kg, are initially at rest. They push against each other and move apart. If the 60 kg skater moves away with a velocity of 2 m/s, what is the velocity of the other skater?
15. A bullet with a mass of 0.01 kg is fired horizontally into a block of wood with a mass of 1 kg initially at rest. If the bullet embeds itself in the block and they move off together with a velocity of 0.5 m/s, what was the initial velocity of the bullet?

L7 Stopping distance

The stopping distance of a car is the minimum distance that a car can safely stop in. It is made up of the thinking distance and the braking distance.

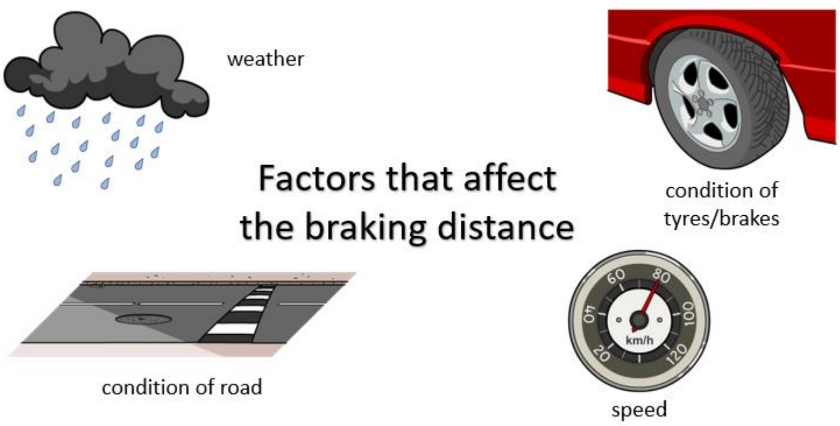
Stopping distance = thinking distance + braking distance

The thinking distance is the distance travelled by the vehicle in the time it takes for the driver to react. If the vehicle is travelling quickly, or if the drivers **reaction time** is slowed then the thinking distance will be increased.



The braking distance is the distance travelled by the vehicle during the time the braking force acts.

Speed also effects the braking distance, but so do conditions that reduce **friction**.



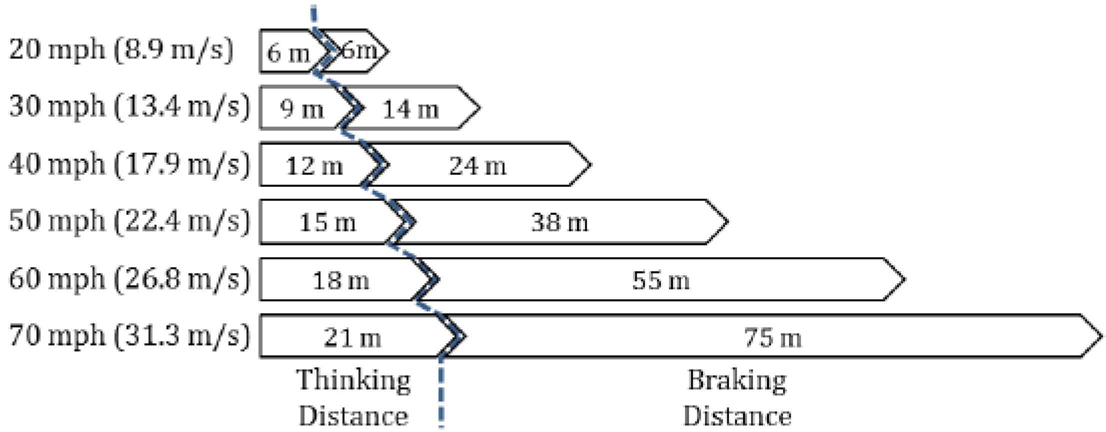
Task: Complete in your exercise book.

1. Vehicle stopping distances are made up from the thinking distance and the braking distance.

   a) Describe two factors that could affect the thinking distance.

   b) The braking distance is how far the vehicle travels from when the brakes are first pressed to when the vehicle stops. Explain the energy change that happens during this time.

2. The diagram shows typical stopping distances at different speeds.



   a) During the thinking distance, the speed of the vehicle does not change. Use the equation for speed, distance and time to work out the time taken to cover the thinking distance at 50 mph.

   b) Look at the stopping distances at 30 mph and 60 mph. Compare how the thinking distance and braking distance change with this doubling of speed.

   c) At 40 mph, the thinking distance is 12 m and the braking distance is 24m. Estimate the size of the stopping distance at 80 mph.

3. Many modern vehicles can stop in a shorter distance than those in the chart.

What difference do modern brakes and tyres make to the physics of the slowing down of the vehicle?