- The **faster** an object moves through a fluid the **greater the frictional force** that acts on it.
- An object falling through a fluid will initially accelerate due to the force of gravity. Eventually the resultant force will be **zero** and the object will move at its **terminal velocity** (steady speed).
- Understand why the use of a parachute reduces the parachutist's terminal velocity.
- Draw and interpret **velocity-time graphs** for objects that reach terminal velocity, including a consideration of the **forces acting on the object**.
- Calculate the **weight** of an object using the force exerted on it by a gravitational force :

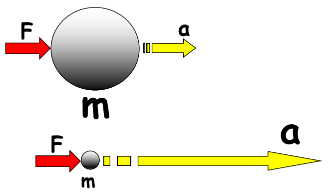
$$W = m \times g$$

W = the **weight in newton** (N).
m = the **mass in kilogram** (kg).
g = the **gravitational field strength in newton per kilogram** (N/kg).

FALLING BODIES

The **mass (m)** of an object is the amount of matter it contains.

- **Mass** is measured in **kilogram (kg)**
- The **mass** of an object is **the same** anywhere in the universe.
- The **mass** of an object is a measure of its **opposition to acceleration**.



Since **F = ma**,

for a given **force (F)**, the **smaller** the **mass (m)**, the **greater** is the **acceleration (a)**.

The **weight (W)** of an object is the force of gravity acting on it.

- **Weight** is measured in **newton (N)**
- **Weight** is calculated using the equation :

Weight = mass × gravitational field strength

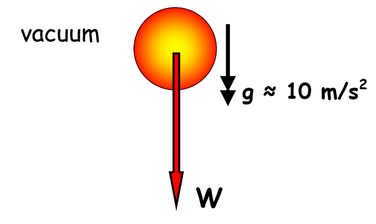
$$W = m \times g$$

(N) (kg) (N/kg)

- The **weight** of an object depends on the value of **g** and so, unlike mass which is the same everywhere, it varies from place to place.
- On **Earth**, **g ≈ 10 N/kg**, whereas on the **Moon**, **g ≈ 1.67 N/kg**.
- The value of **g is different on different planets**.

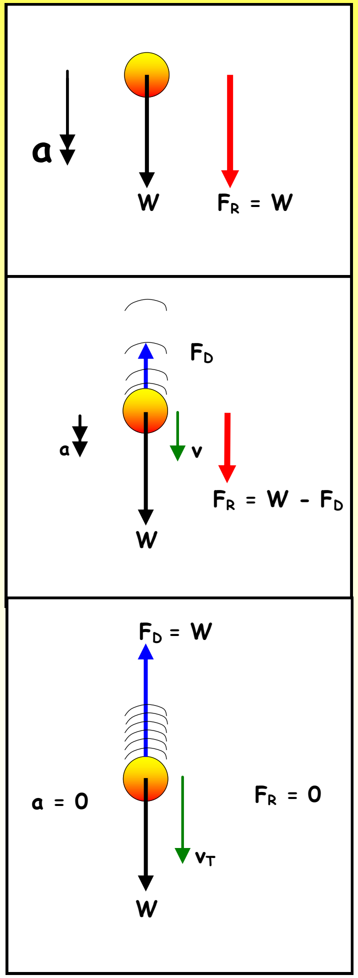
- Objects fall under the action of the **force of gravity** (i.e. their **weight**).

If an object falls **freely (i.e. in a vacuum)**, the only force acting on it is its **weight (W)** and it then falls with the **constant acceleration due to gravity, g ≈ 10 m/s²**.



- If an object falls in a **FLUID** (e.g. air, water..) there are two forces acting :
  - The **weight (W)** acting **downwards**. This stays the same as the object falls.
  - The **drag force (F_D)** acting **upwards**. This increases as the object's speed increases.

Consider a ball bearing dropped through water or oil.



- **At the instant of release** the ball accelerates under the action of its **weight (W)**.

  Since the ball is not moving, $F_D = 0$

  Resultant force, $F_R = W - F_D = W$

- As the ball's **velocity increases**, the **drag force (F_D) increases** and so the downward resultant force **decreases**.

  Resultant force, $F_R = W - F_D$

  So the **acceleration (a) decreases**.

- The **faster** the ball falls, the **greater** the **drag force (F_D)** becomes and eventually :

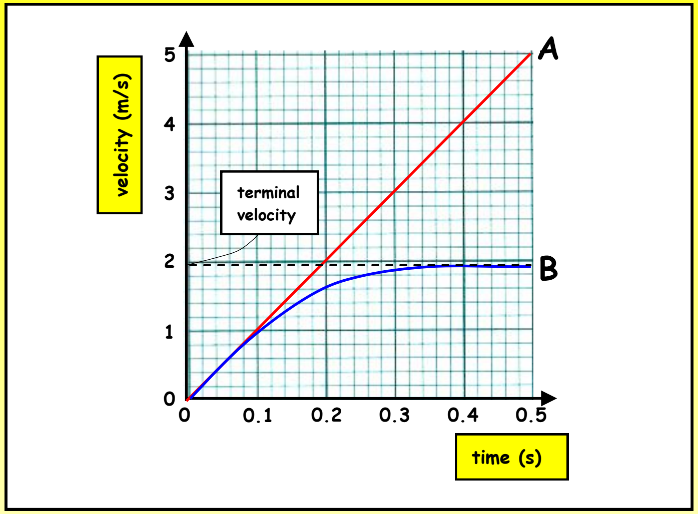
  $F_D = W$

  And $F_R = W - F_D = 0$

  So, **acceleration, $a = 0$**

  The ball then continues to fall at **constant velocity**.................This is called the **terminal velocity (v_T)**.

VELOCITY-TIME GRAPH FOR A FALLING OBJECT



- **Graph A** is the velocity-time graph for an object **falling freely (i.e. in a vacuum)**.

  The only force acting on the object is that **due to gravity** (i.e. its weight) and since this force is **constant**, the object falls with a **constant acceleration** (the acceleration due to gravity = **$g \approx 10$ m/s^2**). This is shown by the fact that the velocity-time graph is a straight line whose **gradient = 10 m/s^2**.

- **Graph B** is the velocity-time graph for an object **falling through a fluid (e.g. oil)**.

  At the **instant of release**, the only force acting on the object is that **due to gravity** so the **initial acceleration** (and hence the gradient of the graph is the same as that for an object falling in a vacuum).

  As the object's **velocity increases**, an **increasing upward drag force** acts on it. This causes the **resultant force to decrease** and so the object's **acceleration decreases** (shown by the fact that the gradient of the velocity-time graph decreases).

  Eventually, when the **terminal velocity** is reached, the **drag force becomes = the weight** and the **resultant force is then zero**. This means that the object's **acceleration = zero** and so the object's **velocity is constant** (shown by the fact that the gradient of the velocity-time = 0).

SKYDIVING

Let's consider the forces acting, and hence the motion, of a skydiver from the moment he jump out of the aeroplane until he lands.

(1) At the instant he exits the aeroplane, his **weight, W** causes him to accelerate downwards.

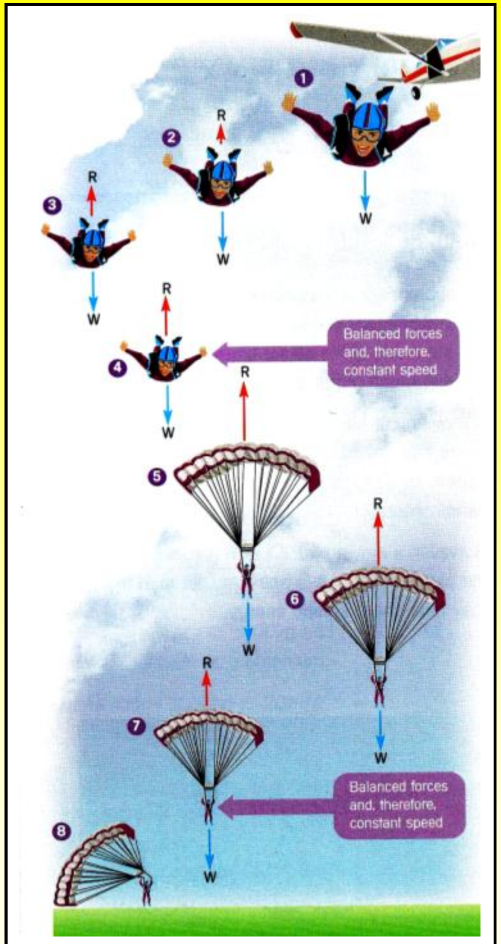
(2) As he falls, he experiences the opposing force of **air resistance, R** which **increases with velocity (3)**.

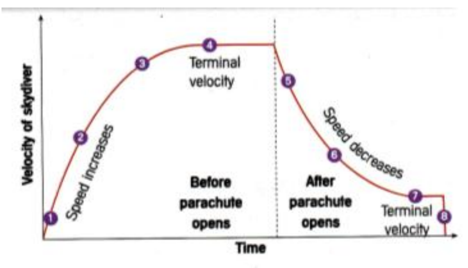
(4) **R** increases until it is **equal to W**, so that the **resultant force** acting on the skydiver is **zero**. **Zero** resultant force means **zero acceleration**, so his velocity is now **constant** (this is the **terminal velocity ≈ 120 mph**).

(5) When the parachute is opened **R** is greatly increased and it is **greater than W**. Thus there is a **resultant upward force** which **decelerates** the skydiver.

(6) & (7) As the **velocity decreases**, **R decreases** until it is once again **equal to W**. The forces acting are balanced once again and the skydiver now falls at a **new slower terminal velocity (≈ 5 mph)**.

The diagram opposite shows the v/t graph for the whole motion. Study it carefully and make sure you fully understand how it describes The skydiver's motion **before** and **after** he opens his parachute.





PRACTICE QUESTIONS

1 Complete the sentences below using the following words :

equal to **greater than** **less than**

When an object is released in a fluid :

(a) The **drag force** on it is ………………………………… its **weight** before it reaches its terminal velocity.

(b) The **acceleration** is ………………………………… zero after it reaches its terminal velocity.

(c) The **resultant force** on it is initially ………………………………… its **weight**.

2 A fully kitted astronaut has a total mass of **165 kg**. Calculate his **weight** :

(a) On Earth, where the gravitational field strength is **10 N/kg**.

(b) On the Moon, where the gravitational field strength is **1.67 N/kg**.

4 Two forces, **X** and **Y**, act on the skydiver in the diagram.

(a) Write down the equation which links **weight, mass** and **gravitational field strength**.

(b) Name the forces **X** and **Y**.

(c) As the skydiver falls, **force X increases**. What happens to **force Y**?

(d) **Describe the motion** of the skydiver when :

(i) **Force X is smaller than force Y.**

(ii) **Force X is equal to force Y.**

4 A skydiver of mass **95 kg** is supported by a parachute having a mass of **15 kg**. He is descending at **constant velocity**.

(a) Explain, **in terms of the forces acting**, why the skydiver is moving at **constant velocity**. What is this constant velocity called?

(b) Calculate :

(i) The **total weight** of the skydiver and parachute **(g = 10 N/kg)**.

(ii) The **size** and **direction** of the **force of air resistance** acting on the parachute when the skydiver is falling at **constant velocity**.

5 Use the words supplied to fill in the blanks in the paragraph below about a skydiver.

decelerates/decrease/less/balances/increase/constant/greater/accelerates

When a skydiver jumps out of a plane, his weight is .... than his air resistance, so he .... downwards. This causes his air resistance to .... until it .... his weight. At this point, his velocity is .... When his parachute opens, his air resistance is .... than his weight, so he .... This causes his air resistance to .... until it .... his weight. Then his velocity is .... once again.

PRACTICAL WORK

1. INVESTIGATING THE RELATION BETWEEN FORCE AND ACCELERATION

- The apparatus is set up as shown on **page 10 of 2.1.2 (Forces and Motion)**. The **force (F)** which is used to accelerate the trolley is provided by a string which passes over a pulley at the end of the track and to which slotted masses are attached.
- The **acceleration (a)** of the trolley is determined when the accelerating force is provided by a single **100 g** mass **(F ≈ 0.1 x 10 = 1 N)**.
- Corresponding **F** and **a** values are then obtained by accelerating the trolley by adding a **further 100 g** mass to the mass hanger and obtaining the acceleration (a) each time.
- The results are recorded in the table shown below :

MASS / g	0.1	0.2	0.3	0.4	0.5	0.6
FORCE (F) / N	1	2	3	4	5	6
ACCELERATION (a) / m/s^2						

- Use your results to plot a graph of **force (F)/N** along the y-axis against **acceleration (a)/m/s^2** along the x-axis.
- What kind of graph have you obtained?
- What does the graph tell you about the relationship between **force (F)** and **acceleration (a)**?
- Your graph does not pass through the origin. Why do you think this is?

2. REACTION TIME

- For this experiment the pupils work in pairs.
- One holds out his hand, with thumb and index finger about 1 cm apart.
- His partner holds the rule directly above and between their friend's thumb and finger, so that the '0' on the rule is level with the top edge of the thumb and finger.
- The ruler is then dropped **without warning** and it has to be caught between thumb and finger as quickly as possible.
- The measurement point which is level with the **bottom of the thumb** is then noted.
- The experiment is repeated **5 times** and an average value is calculated.
- The **reaction time (t)** is then calculated from :

$$t = \sqrt{(2h/g)}$$

h = height dropped by the rule before it is caught.
g = 10 m/s^2.

- The experiment can be repeated :
  - **Using the other hand**. Does it make a difference?
  - **After the pupils have changed places**. Who has the fastest reaction time?
  - **When the catcher is being distracted**. How great an effect does this have on the reaction time?

> This might be a good point at which a Traffic Police Officer could come in and give the class a talk on the importance of **speed limits, speed cameras** etc. It would link up very smoothly with the material covered on vehicle stopping distance.

EXTRA HOMEWORK QUESTIONS (1)

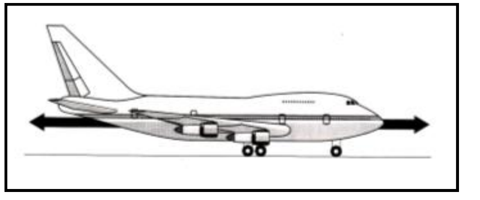
1 The diagram below shows a car travelling along a level road.

(a) The car is travelling at **constant speed**. The diagram shows the two horizontal forces, **S** and **T**, which act on the car.
Force **S** is **2000 N**.
What is the size of **force T**?

(b) **(i)** Force **S** increases to **3000 N**. Calculate the size of the **initial resultant force** acting on the car.

(ii) The total mass of the car and driver **1400 kg**. Calculate the **initial acceleration** of the car when force **S** is increased to **3000 N**.

2 **(a)** The diagram shows an aircraft and the horizontal forces acting on it as it moves along a runway.
The resultant force on the aircraft is **zero**.



(i) What is meant by the term **resultant force?**

(ii) Describe the movement of the aircraft when the **resultant force is zero**.

(b) The aircraft has a take-off mass of **320 000 kg**. Each of the **4 engines** can produce a maximum force of **240 kN**.
Use the equation in the box to calculate the **maximum acceleration** of the aircraft. Show clearly how you work out your answer and **give the unit**.

resultant force = mass x acceleration

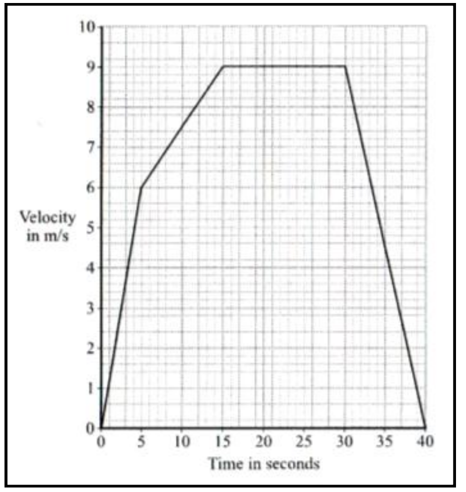
(c) As the aircraft moves along the runway to take off, its acceleration **decreases** even though the force from the engines is constant. **Explain why**.

3 A cyclist travelling along a straight, level road accelerates at **1.2 m/s²** for **5 s**.
The mass of the cyclist and the bicycle is **80 kg**.

(a) Use the equation in the box to calculate the **resultant force** needed to produce this acceleration. Show clearly how you work out your answer and **give the unit**.

resultant force = mass x acceleration

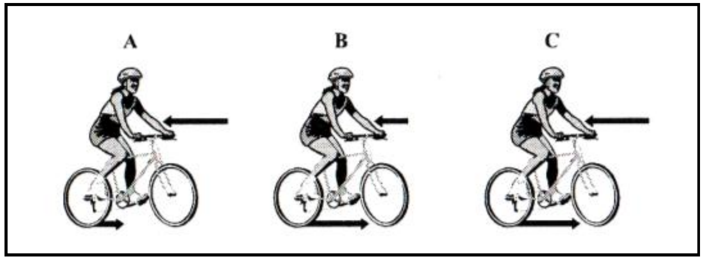
(b) The graph shows how the **velocity** of the cyclist changes with **time**.



(i) Complete the following sentence :
The velocity includes both the speed and the .... of the cyclist.

(ii) Why has the data for the cyclist been shown as a **line graph** instead of a **bar chart**?

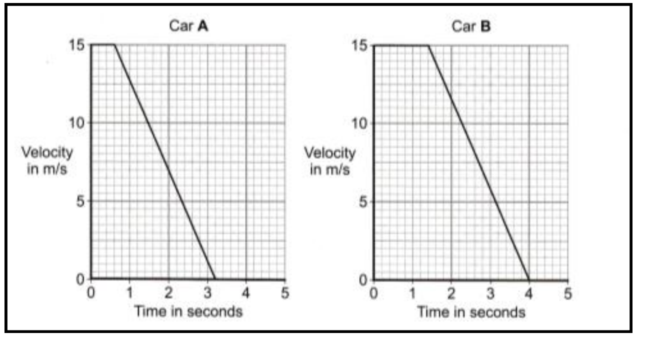
(iii) The diagrams show the horizontal forces acting on the cyclist at three different speeds.
The length of an arrow represents the size of the force.



Which one of the diagrams, **A, B** or **C**, represents the forces acting when the cyclist is travelling at a **constant 9 m/s**?

Explain the reason for your choice.

1 **(a)** The graphs show how the velocity of two cars, **A** and **B**, change from the moment the car drivers see an obstacle blocking the road.



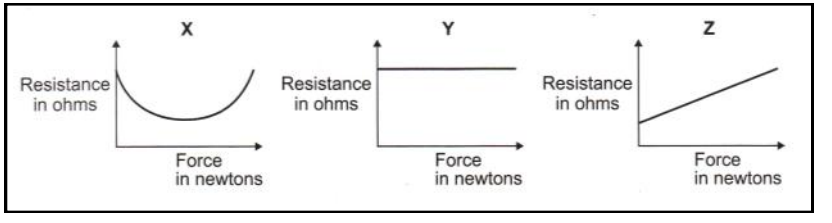
One of the car drivers has been drinking alcohol. The other driver is wide awake and alert.

(i) How does a comparison of the two graphs suggest that the driver of car **B** is the one who has been drinking alcohol?

(ii) How do the graphs show that the two cars have the **same deceleration**?

(iii) Use the graphs to calculate how **much further car B** travels before stopping compared to **car A**. Show clearly how you work out your answer.

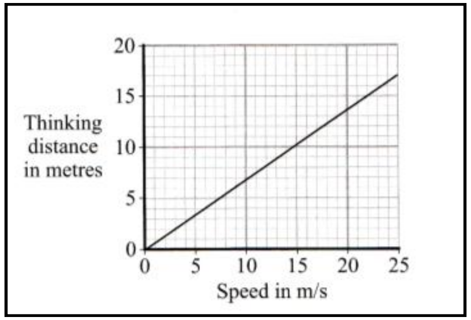
(b) In a crash test laboratory, scientists use sensors to measure the forces exerted in collisions. The graphs show how the electrical resistance of 3 experimental types of sensor, **X**, **Y** and **Z**, change with the force applied to the sensor.



Which of the sensors, **X, Y** or **Z**, would be the best one to use as a **force sensor**? **Give a reason** for your answer.

2 **(a)** A car driver takes a short time to react to an emergency before applying the brakes. The distance the car will travel in this time is called the **'thinking distance'.**

The graph shows how the **thinking distance** of a driver depends on the **speed** of a car.



(i) What is the connection between **thinking distance** and **speed**?

(ii) Many people drive while they are tired. **Draw a new line** on the graph to show how thinking distance changes with speed for a **tired driver**.

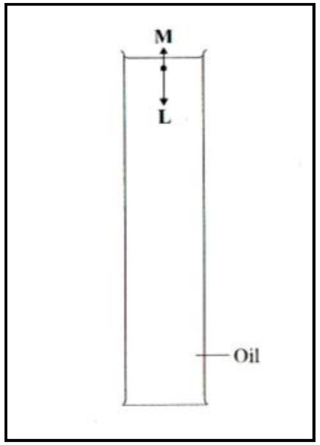
(iii) The graph was drawn using data given in the Highway Code. Do you think that the data given in the Highway Code is likely to be **reliable**? **Give a reason** for your answer.

(b) The distance a car travels once the brakes are applied is called the **'braking distance'.**

(i) What is the relationship between **thinking distance**, **braking distance** and **stopping distance?**

(ii) State **two** factors that could **increase the braking distance** of a car at a speed of 15 m/s.

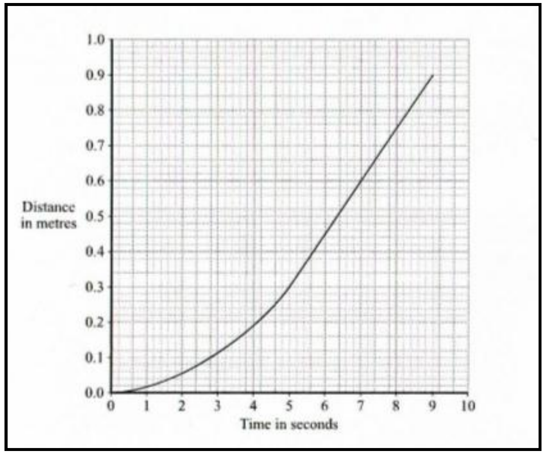
3 **(a)** The diagram shows a steel ball-bearing falling through a tube of oil.



The forces, **L** and **M**, act on the ball-bearing.

What causes force **L**?

(b) The **distance-time** graph represents the motion of the ball-bearing as it falls through the oil.



(i) Explain, in terms of the forces **L** and **M**, why the ball-bearing **accelerates at first**, but then falls at **constant speed.**

(ii) **What name is given to the constant speed** reached by the falling ball-bearing?

(iii) Calculate the **constant speed** reached by the ball-bearing. Show clearly how you use the graph to work out your answer.