Freefall and terminal velocity

Prepared by: Adiyy Mohamed
adiyy.muhammad@gmail.com

What is freefall?

- An object is said to be falling freely if it does not experience an air resistance.
- When air resistance is absent, all objects fall with the same acceleration.
- This acceleration is called the acceleration of free fall. It is sometimes called the acceleration due to gravity.
- The acceleration of free fall (g) on the surface of the Earth is 9.8 m/s^2. This means that, for every second an object falls, its velocity will increase by 9.8 m/s.
- The symbol g also stands for the gravitational field strength, and can be used to calculate the weight of an object using its mass.

Weight = mass × gravitational field strength

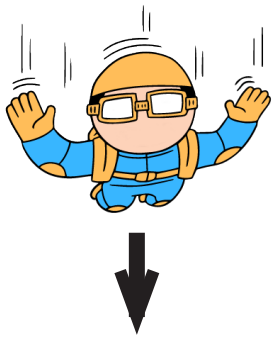
$W = mg$

The gravitational field strength on the surface of of the Earth is 9.8 N/kg. This means that a force of 9.8 N acts on every 1 kg of mass.

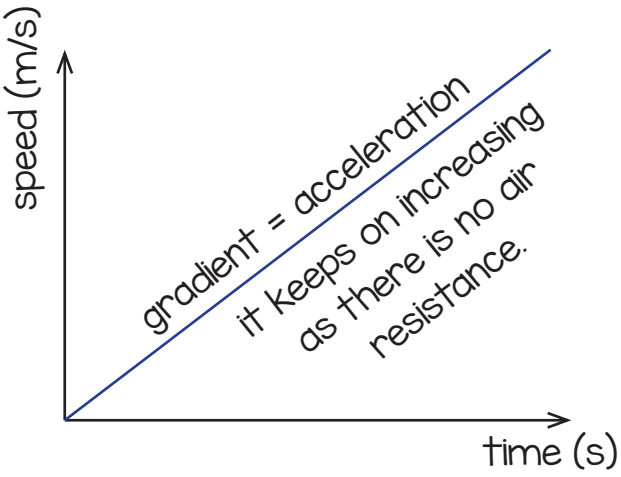
For example, an object of mass 10 kg will have a weight of 98 N.
W= mg
W = 10 ×9.8 = 98 N

Falling objects without air resistance (i.e. falling freely)

- When air resistance is absent (or it is negligible, or insignificant - terms all used in assesment papers), all objects falling in a uniform gravitational field, fall with the same acceleration, regardless of their mass.
- So long as the air resistance remains insignificant, the speed of a falling object will increase at a steady rate, getting larger the longer it falls for.



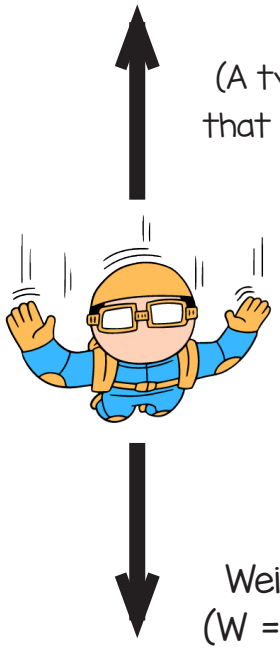
Negligible air resistance, so the only force acting is weight.



Falling objects with air resistance

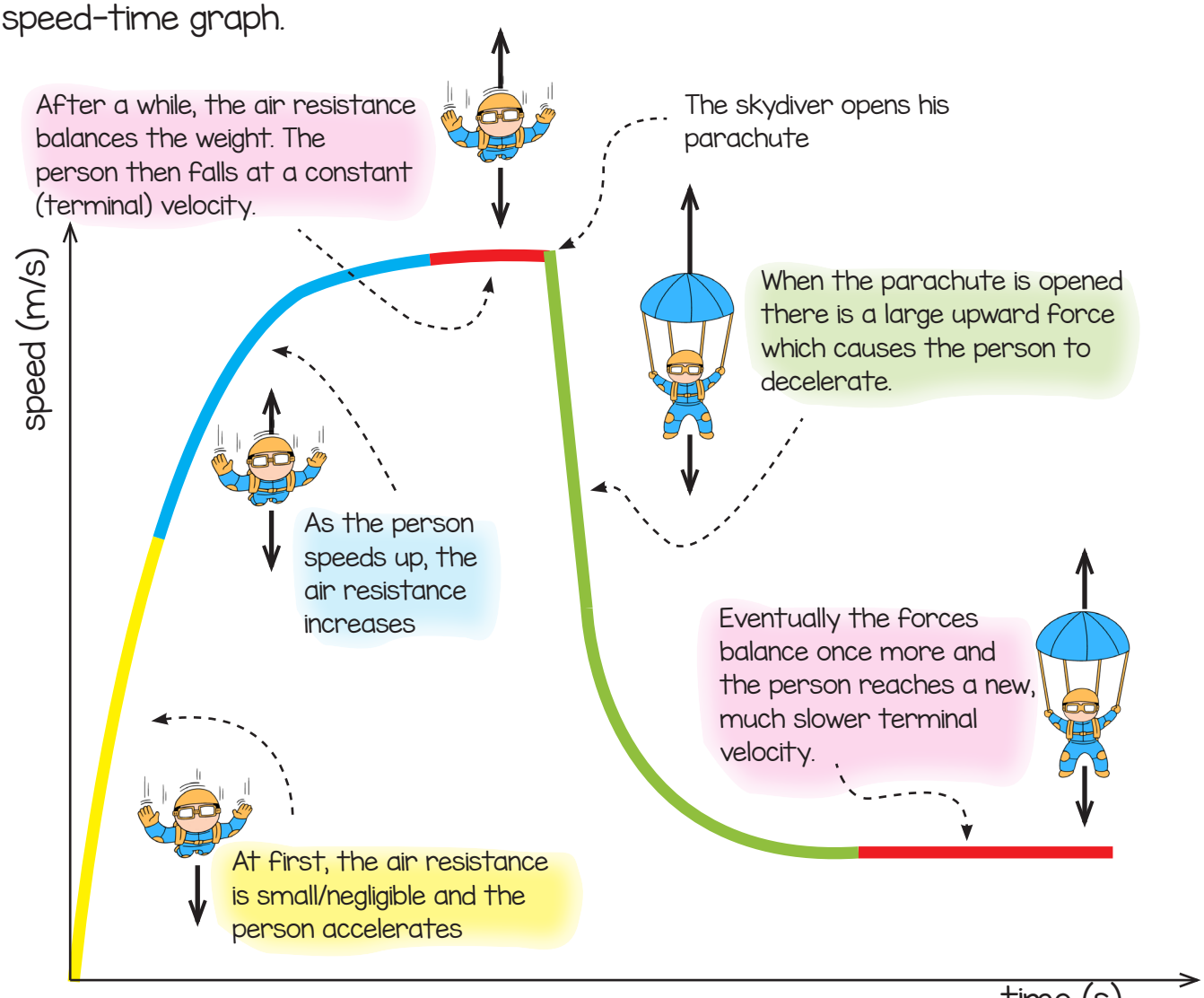
• Objects falling through fluids (i.e liquids and gases) in a uniform gravitational field experiences two forces.

1. Weight (due to gravity).
2. Friction (such as air resistance)



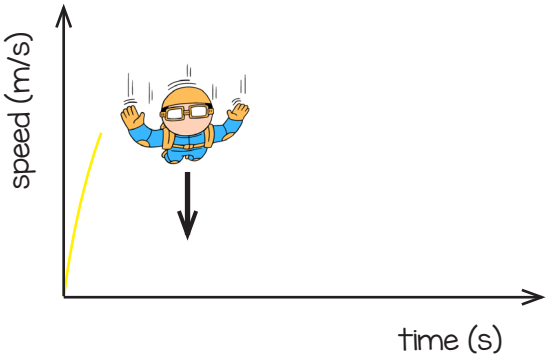
• For an example, a sky diver falling from a plane will experience a downward force due to weight (mass × acceleration of free fall) and an upward acting force frictional force (air resistance).

• When the speed of the diver increases, the force of air resistance acting on him also increases. This is explained below with a speed-time graph.

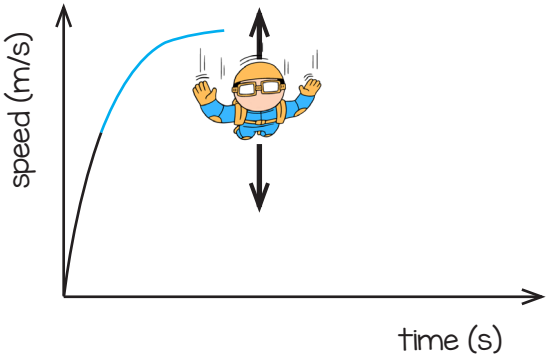


Explanation:

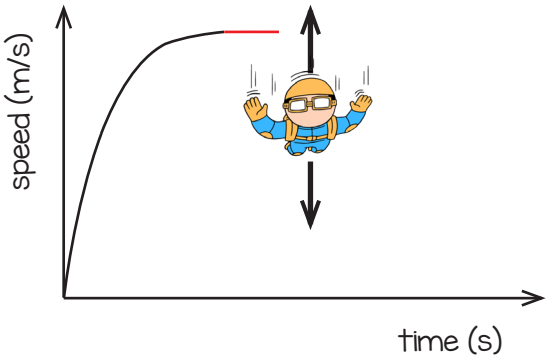
• Initially the upward force of air resistance is very small because the skydiver is not falling very quickly. Therefore, there are unbalanced forces on the skydiver initially.



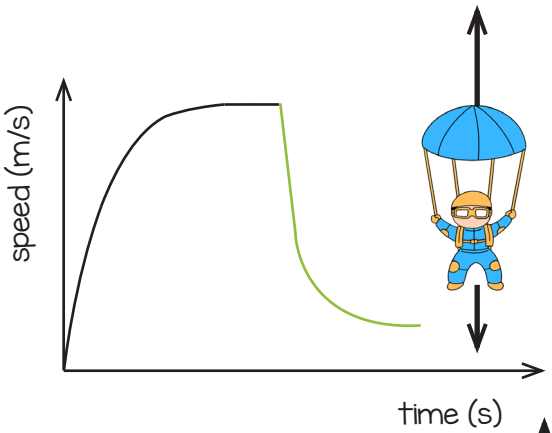
• As the skydiver speeds up, air resistance increases.



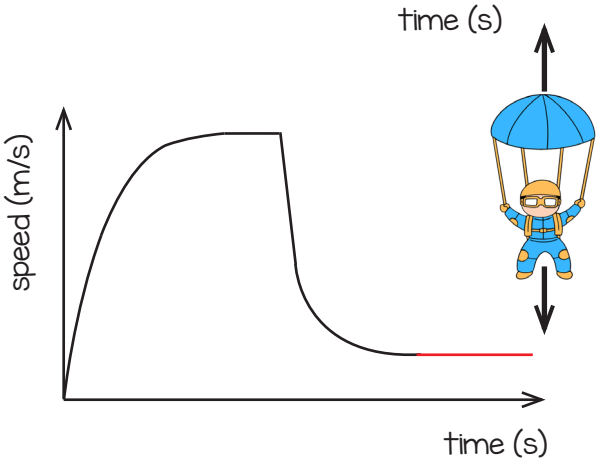
• When the force of air resistance becomes equal to the weight, the forces get balanced and there will be no resultant force.
• As a result, the skydivers acceleration becomes zero, and they fall at a consant speed. This constant speed is called terminal velocity.



• When the skydiver opens the parachute, the air resistance increases because of the increased surface area of the parachute opening.
• The upward force of air resistance on the skydiver increases, slowing the acceleration of the skydivers fall. The skydiver therefore, decelerates.



• Eventually, the forces balance out again, and a new slower terminal velocity is reached.



Sample questions for practice
From 2023 Past papers

Question 1

May/June 2023, P22, Q2

A light ball is held at rest at the top of a tall cliff. It is released and falls through the air, eventually reaching its terminal velocity.

Which row describes the behaviour of the ball as it descends?

	the initial acceleration of the ball	the final acceleration of the ball
A	0	0
B	0	*g*
C	*g*	0
D	*g*	*g*

Question 2

May/June 2023, 23, Q2

Which statement about a falling object accelerating close to the Earth's surface is correct?

A The weight of the object is increasing and the force of air resistance on the object is decreasing.

B The weight of the object and the force of air resistance on the object are of equal magnitude, but act in opposite directions.

C The weight of the object is constant, but the force of air resistance on the object is increasing.

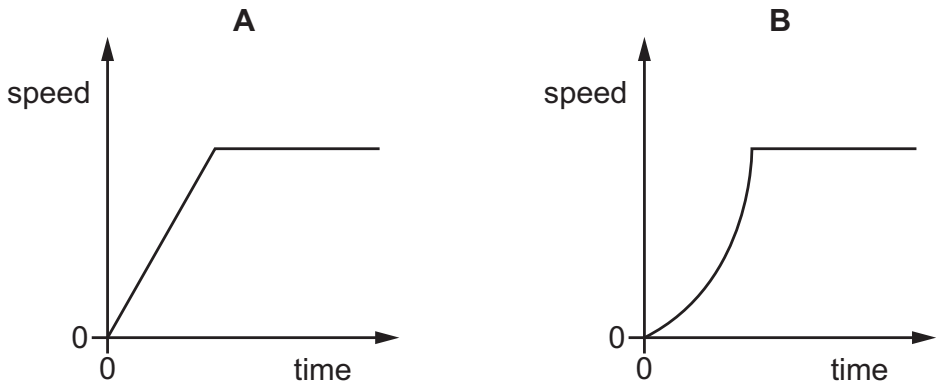
D The weight of the object is less than the force of air resistance.

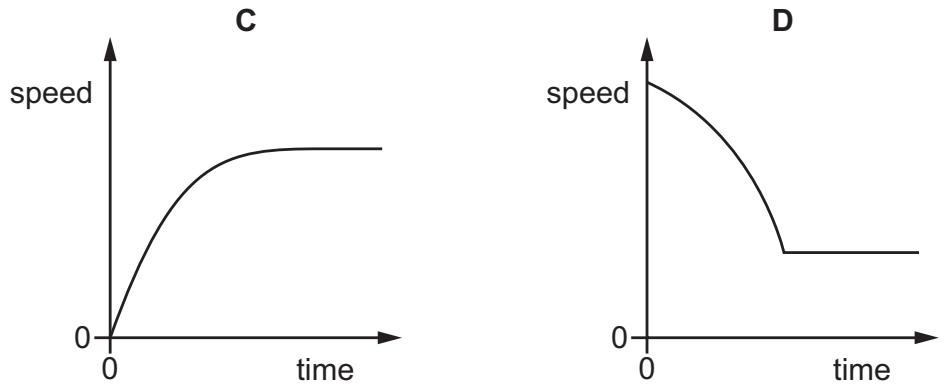
Question 3

October/November 2023, 21, Q3

An object reaches terminal velocity after being dropped and falling through air.

Which graph shows how its speed varies with time?





Question 4

May/June 2023, P42, Q1, (b)

Fig. 1.2 shows a vertical speed-time graph for a parachutist who jumps from a hot-air balloon.

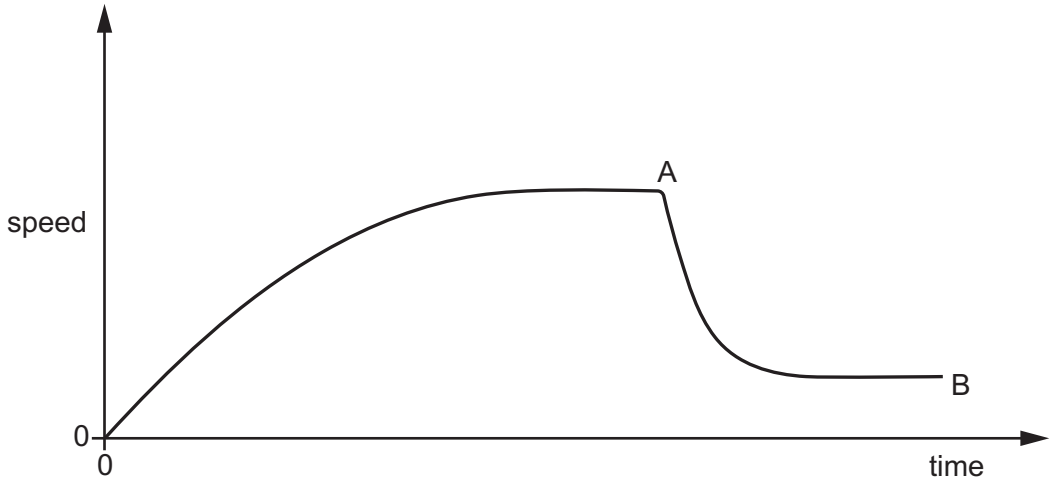


Fig. 1.2

The parachutist jumps from the balloon at time = 0 and reaches the ground at B. The point A indicates when the parachute opens.

(i) On Fig. 1.2 label a point on the graph where the acceleration is:

- zero with '1'
- negative with '2'
- decreasing with '3' [3]

(ii) Explain, interms of forces, the changes in motion which occur from when the parachutist leave the hot-air balloon until point A. [4]

Sample answers and explanations:

Question 1:

C When an object falls from above, it initially accelerates with an acceleration called the acceleration of free fall. Which is represented by g . When the object starts to speed up, the opposing air resistance starts to increase. Finally when the downward force of weight and the upward force of air resistance becomes equal, the resultant force becomes zero and the object starts to move at a constant velocity. This velocity is called terminal velocity. Since this velocity is constant the object is no longer accelerating. So, the final acceleration of the ball is zero.

Question 2:

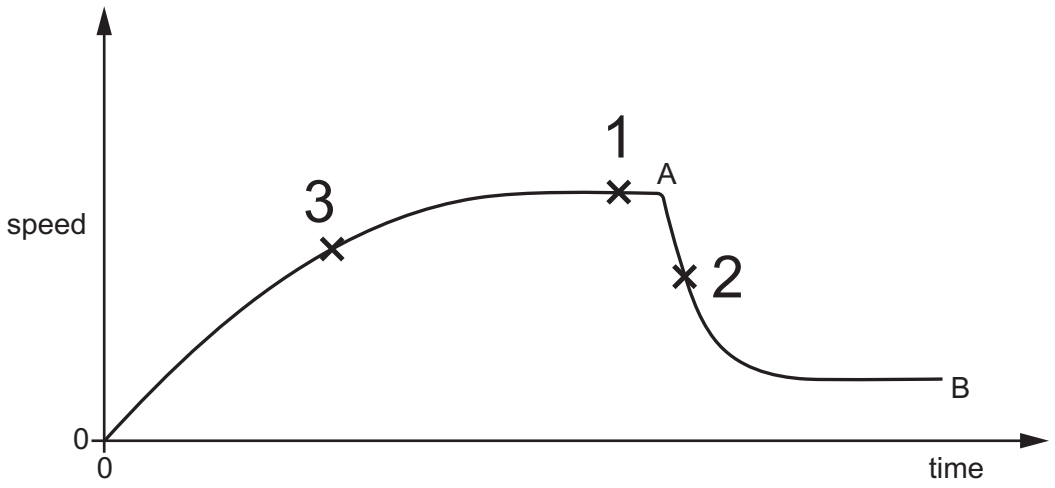
C As the object falls, it keeps accelerating at the rate of 9.8 m/s^2. But as it falls, the force of air resistance acting on the object keeps on increasing until it becomes equal to the downward force of weight, and thus acceleration becomes zero and the object is said to be in terminal velocity. Since the question mentions that the object is accelerating, it implies that the object has not yet reached its terminal velocity. So at this stage the force of air resistance will keep on increasing until it becomes equal to weight of the object and the object reaches terminal velocity.
The weight of the object should not change at all (i.e. it should remain constant) since neither its mass or the gravitational field strength changes.

Question 3

C Terminal velocity for a falling object is the maximum velocity reached by the object when the force due to air resistance becomes equal to the weight of the falling object.
On graph A, a straight line can be observed. This is constant acceleration. But this is not true for the current situation since air resistance will not allow for a constant increase in speed. Whenever air resistance is involved, the acceleration will not be constant.
On graph B, the graph shows that the acceleration increases before reaching terminal velocity. This is also incorrect since air resistance will prevent the acceleration from increasing. Note that even if the speed seems to increase, the rate at which increases (i.e. its acceleration) must decrease inorder to reach terminal velocity.
Graph D is incorrect as it shows deceleration before reaching terminal velocity.
The speed of the object should increase (i.e. accelerate) but this acceleration should decrease as air resistance starts to increase. Finally, the acceleration should become zero, as the object reaches constant/terminal velocity. This is correctly shown on graph C.

Question 4

(b) **(i)**



'1' should be labelled where acceleration is zero, which is any point on the speed-time graph where the speed is constant (i.e. horizontal). There are two correct points; horizontal sections just to the left of A, and just to the left of B. '2' should be labelled where acceleration is negative, which means a point which shows deceleration. '3' should be labelled where acceleration is decreasing, which means a region where speed is increasing, but not at a steady rate, therefore it will be a curve of decreasing gradient on the graph. When asked to label a point, the point should be clearly shown as a point with a dot or a cross.

(ii) Immediately after jumping, the parachutist accelerates due to the gravitational force downwards. As the velocity increases, the air resistance also increases. As the air resistance increases, the resultant force downwards decreases. Eventually, when the air resistance equals the downward gravitational force, the resultant force becomes zero, and the parachutist falls at a constant velocity until point A on the graph.

References to gravity, instead of the "force or gravity" or "gravitational force" or "weight", are insufficient.