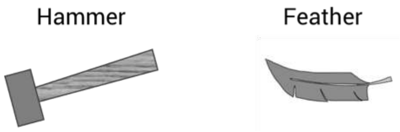
**0 1**

On the Apollo 15 mission in 1971, Commander David Scott famously dropped a hammer and feather from the same height of 1.6 m above the lunar surface. Both objects were dropped at the same time, and went on to hit the ground at exactly the same time.




**0 1 . 1**

Estimate the velocity at which both objects would have struck the lunar surface. The acceleration due to gravity at the surface of the Moon is approximately 1.6 m/$s^2$.

$v^2 - u^2 = 2\ a\ s$
$v^2 - 0 = 2\ (1.6)\ (1.6)$
$v^2 = 5.12$
v = **2.26 m/s**

**0 1 . 2**

Intrigued by this experiment, a student tries to repeat it at home. When they drop both objects from the same height however, they find that the feather takes over three seconds longer to reach the ground than the hammer.

Explain their findings, making full reference to the forces involved.

The Moon has no atmosphere, but the Earth does [1]. As a result, an object that is falling through the air will experience the force of air resistance opposite to the direction in which it is moving (and opposite to the direction in which its weight acts) [1]. This decreases the resultant (net) downwards force acting on the object, which decreases its downwards acceleration (until the point at which both forces are balanced) [1].

(In this case, the feather will almost certainly stop accelerating and will reach its terminal velocity long before it hits the ground. This occurs when the air resistance acting on it becomes equal to its weight so that the resultant downwards force acting on it falls to zero.)

**0 2**

A stone is thrown into a deep lake from the side of a rowing boat.

**0 2 . 1**

At least three forces act on the stone as it falls through the water. By drawing labelled arrows onto the above diagram, write down the names of two of these forces and indicate the direction(s) in which they act.

Any TWO of: weight, drag and upthrust.

(Remember that the upthrust force acting is equal to the weight of water displaced by the stone.)

**0 2 . 2**

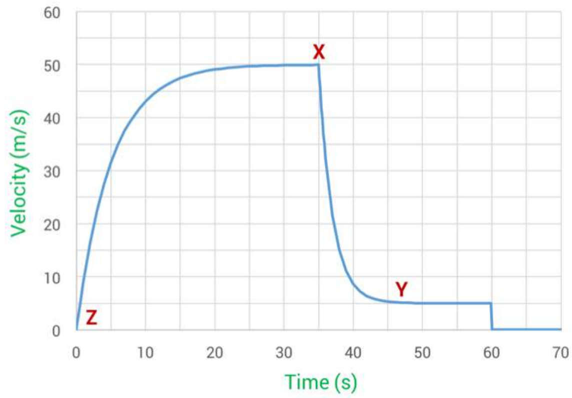
Which of the following statements best describes the motion of the stone before it reaches the bottom of the lake?

- It descends with constant velocity ☐
- It accelerates downwards ☐
- It accelerates downwards then descends with constant velocity ☑
- It accelerates downwards ☐
- It decelerates downwards then descends with constant velocity ☐

The above question is a slightly tricky one! Remember that only the drag force will change after the stone is dropped into the water. When it is travelling slowly, the drag force is small, so there is a net (resultant) downwards force which causes it to accelerate downwards. As its speed increases, the drag force acting on it will increase. Eventually, when the total downwards force is equal to the total upwards force, the resultant force falls to zero, and the stone will stop accelerating – it will have reached its **terminal velocity**.

**0 3**

The below velocity-time graph describes the motion of a skydiver from the moment they jump out of their plane.




**Remember** here that the acceleration of the skydiver is only equal to g (9.8 $m/s^2$) the moment they jump out of the plane. As soon as they start travelling downwards, the air resistance acting on them increases, which decreases the resultant downwards force, which causes their acceleration to decrease.

**03.1** On the above graph:

- mark with the letter **X** the point at which they open their parachute;
- mark with the letter **Y** the point at which they reach their second (lower) terminal velocity;
- mark with the letter **Z** the point at which their acceleration is equal to 9.8 $m/s^2$.

**03 2** Describe and explain the motion of the skydiver for the first 35 seconds of their jump.

Description: from 0 seconds, they accelerate from rest [1]. Over (approximately) the next 25 seconds, their acceleration (rate of change of velocity) decreases (but their velocity continues to decrease) [1]. They reach their terminal velocity at 25 seconds, and continue travelling at this velocity for 10 seconds [1].

Explanation: the forces acting on the skydiver are their weight (↓) and the force of air resistance (↑). As their velocity increases, the air resistance acting on them increases [1]. This decreases the resultant force acting on them (↓) which decreases the acceleration [1]. When the forces acting on them are balanced, the resultant force is zero [1] which means that they will no longer accelerate downwards.

**03.3** Describe and explain the motion of the skydiver from t = 35 seconds until the point at which they strike the ground.

Description: their parachute is opened at 35 seconds. This causes them to decelerate [1] at a non-uniform / decreasing rate [1] until they reach a new, lower terminal velocity (of 5 m/s) [1]. They reach the ground and stop moving at 60 seconds.

Explanation: when they open their parachute, the air resistance acting on them increases (to a magnitude which is greater than their weight) [1]. The resultant force acting on them is then in the upwards direction [1] which causes them to decelerate (if a positive acceleration is taken as being one which occurs in the downwards direction). Between 45 and 60 seconds the air resistance is once again equal to their weight, which means that the resultant force acting on them is (again) zero [1] and they will no longer accelerate (or decelerate).

**Acceleration, deceleration and motion**: these are fairly solid 6-markers which should really test your understanding of the main concepts of free-fall and terminal velocity. Note here that, when the resultant force exerted on the skydiver is *upwards* (after they have opened their parachute), they decelerate from their first terminal velocity of 50 m/s (this may also be looked at as an *upwards* acceleration). It is important to realise however that the skydiver never actually moves upwards during their descent – the resultant upwards force acting on them is only acting to decrease their velocity.