CIE A Level Physics

3.2 Non-uniform Motion

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Drag Force & Air Resistance

Drag forces

- Drag forces are forces acting in the **opposite** direction to an object moving through a **fluid** (either gas or liquid)
- Examples of drag forces are **friction** and **air resistance**
- A key component of drag forces is that the magnitude of the drag force **increases** with the **speed** of the object
    - As an object **speeds up**, the drag force **increases**
    - As an object **slows down**, the drag force **decreases**
    - This will be explored further in Terminal Velocity
- Therefore, drag forces have the greatest effect at high speeds

- Consider a car traveling **forward** on a **straight** road
- When the car is **accelerating**:
    - The driving force is **greater** than the frictional force
    - The **resultant force** is acting in the **same direction** as the direction of motion
    - Therefore, the car speeds up
- When the car is traveling at a constant velocity:
    - The driving force is **equal** to the frictional force
    - There is **no resultant force** acting on the car
    - Therefore, the motion of the car remains the same (continues traveling at a constant velocity)
- When the car is **decelerating**:
    - The driving force is **less** than the frictional force
    - The **resultant force** is acting in the direction that **opposes the motion** of the car
    - Therefore, the car slows down

Driving force and frictional force acting on a car at different accelerations

Your notes

Accelerating

Driving force > Drag Force

Drag Force   Driving Force

Constant velocity

Driving force = Drag Force

Drag Force   Driving Force
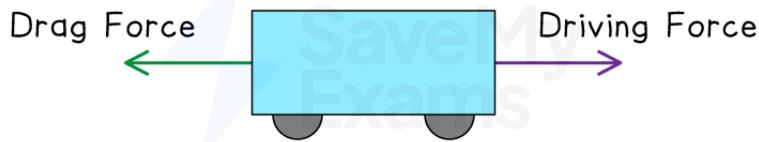
Decelerating

Driving force < Drag Force
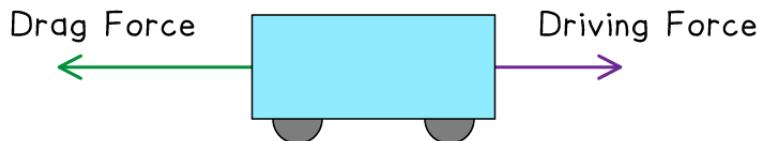
Drag Force   Driving Force

For the car to accelerate, the driving force must be larger than the frictional force; for the car to travel at a constant velocity, the driving force and frictional force must be balanced; for the car to decelerate, the driving force must be less than the frictional force

Your notes

✏️ Worked example

A car of mass 800 kg has a horizontal forward driving force of 3 kN acting on it. The car accelerates at $2.0 \, m \, s^{-2}$.

Determine the magnitude of the frictional force acting on the car.

Frictional force = ?   Driving force = 3 kN

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Answer:

Step 1: List the known quantities and convert to SI units

- Mass, m = 800 kg
- Driving force, F_D = 3000 N

Step 2: Calculate the resultant force acting on the car using Newton's Second Law

$$F = ma$$

$$F = 800 \times 2.0 = 1600 \, \text{N}$$

Step 3: Equate the resultant force to the driving force and frictional force

Resultant force = driving force – frictional force

Step 4: Calculate the magnitude of the frictional force

Frictional force = driving force – resultant force

$$F_F = 3000 - 1600$$

$$F_F = 1400 \, \text{N}$$

💡 Examiner Tip

The key to answering this question correctly is remembering to consider drag forces in your calculation for the resultant force.

Air resistance

- **Air resistance** is an example of a **drag** force
- Objects experience **friction** when moving through the air
- Air resistance depends on the **shape** of the object and the **speed** at which it is travelling
- Since drag force **increases with speed**, air resistance becomes important when objects move faster

Features of a Cyclist that Reduce Air Resistance

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A racing cyclist adopts a more streamlined posture to reduce the effects of air resistance. The bicycle, clothing and helmet are designed to reduce air resistance to allow them to go as fast as possible

Falling objects with air resistance

- When objects fall through a **fluid**, the fluid exerts a **frictional** force on the object as it falls
  - Fluids are liquids or gases
- Frictional forces **oppose** the motion of an object
  - They act to slow it down
- When an object falls through **air**, it experiences **air resistance**
- Air resistance occurs as the object moving through the air **collides** with the air particles
- Air resistance **increases** as the **speed** of the object increases
- When objects fall through air, two forces are exerted on the object:
  - The force of **weight**
  - The force of **air resistance**

- When the force of air resistance becomes **equal** to the force of weight, then the object **stops accelerating** and falls at a **constant** speed
  - This constant speed is called terminal velocity

> 💡 **Examiner Tip**
>
> If a question considers air resistance to be '**negligible**' this means in that question, air resistance is taken to be so small it will not make a difference to the motion of the body. You can take this to mean there are no drag forces acting on the body.
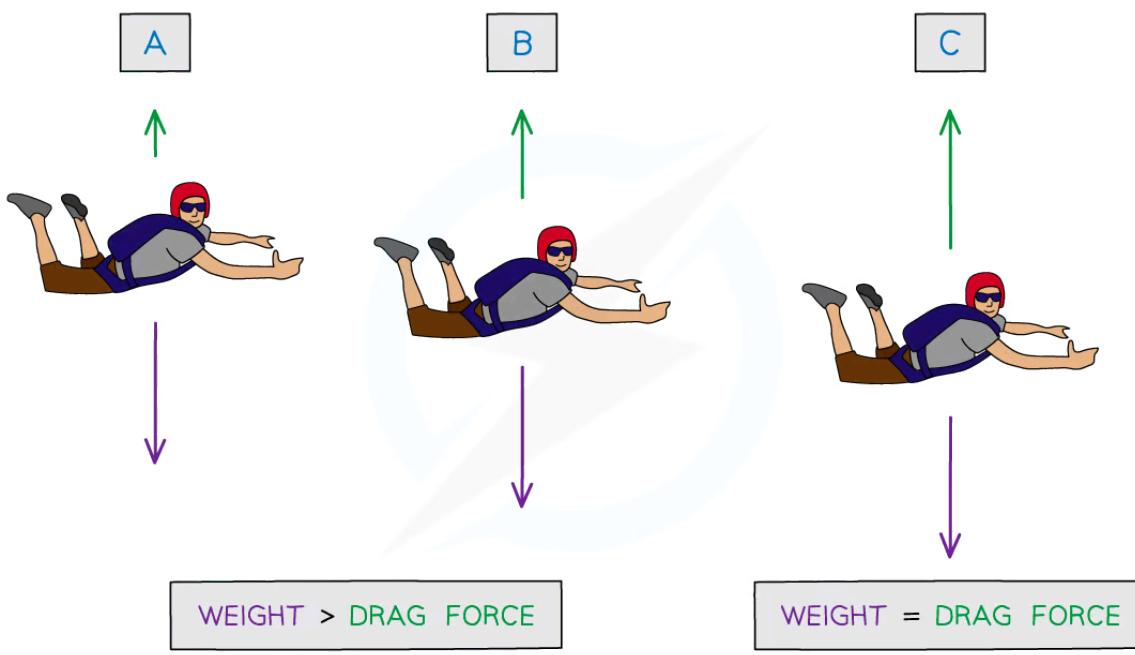
Your notes

Terminal Velocity

Terminal velocity

- For a body in **free fall** with **no effects of air resistance** (for example, on the moon), the **only** force acting on it is **weight**
  - The **resultant force** is equal to weight
  - Therefore, the body accelerates at g, **acceleration of free fall**

- For a body in **free fall**, when **air resistance** is a factor (for example on Earth):
  - **Weight** is **greater** than **air resistance**, so the **resultant force** is in the **direction of motion**
  - The body **accelerates** according to Newton's second law, *F = ma*
  - As the **velocity increases**, the **drag force increases**
  - The **resultant force decreases**, therefore the **acceleration decreases**
  - When the drag force **equals** weight, the resultant force is **zero**
  - The body falls at a **constant** velocity called **terminal velocity**
  - Terminal velocity is the **maximum velocity** the body can reach

The stages of a skydiver reaching terminal velocity

THE SKYDIVER IS IN FREEFALL.

THEIR VELOCITY INCREASES DUE TO THE DOWNWARD FORCE OF THEIR WEIGHT.

THE INCREASE IN VELOCITY MEANS AIR RESISTANCE ALSO INCREASES AND ACCELERATION DECREASES.

EVENTUALLY THE SKYDIVER REACHES A VELOCITY WHERE THEIR WEIGHT EQUALS THE FORCE OF AIR RESISTANCE.

THEIR ACCELERATION IS 0.

THIS IS THE TERMINAL VELOCITY.

As the velocity of the skydiver increases, the drag force due to air resistance also increases, until the skydiver can no longer accelerate and a maximum, terminal velocity is reached

Graph of the stages of the skydiver reaching terminal velocity
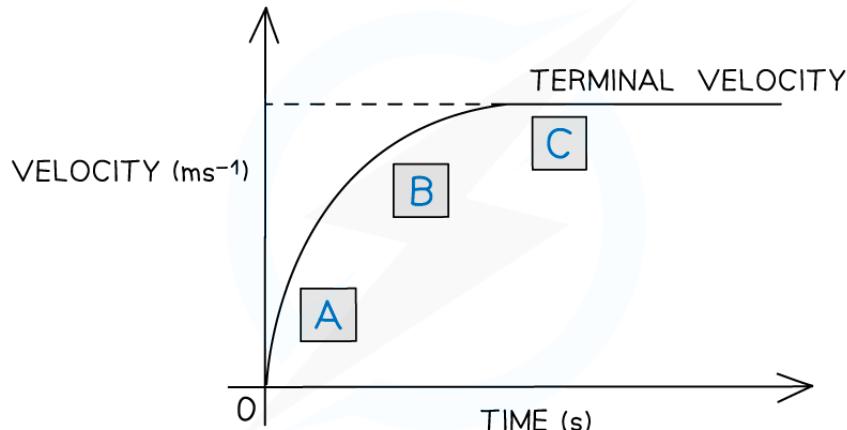
The gradient decreases with time, showing that acceleration decreases with time until terminal velocity is reached and acceleration reaches zero

- The graph shows how the **velocity** of the skydiver varies with **time**
- Since the **acceleration** is equal to the **gradient** of a velocity-time graph, the acceleration **decreases** and eventually becomes **zero** when **terminal velocity** is reached
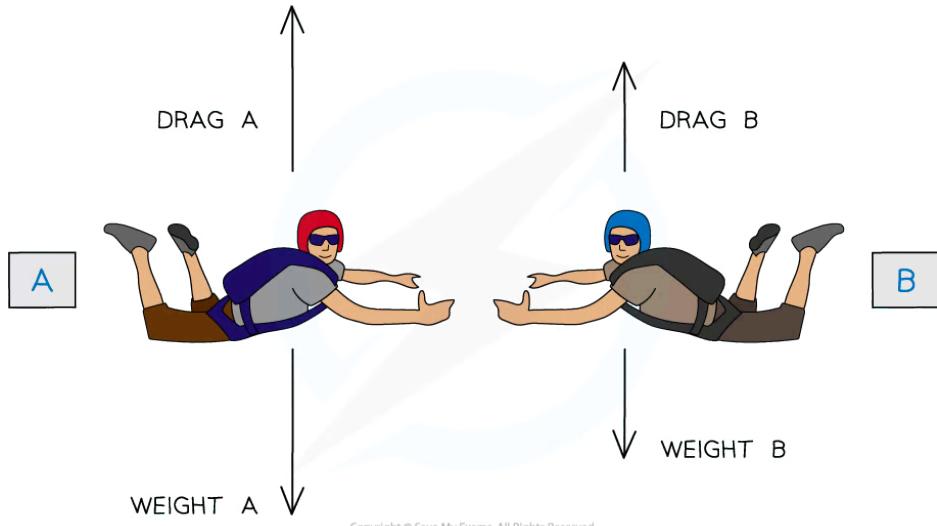
✏️ Worked example

Skydivers A and B jump out of a plane at intervals of a few seconds. The mass of Skydiver A is greater than the mass of Skydiver B. Skydivers A and B want to join up as they fall.

Explain who should jump first, in order for them to meet up as they fall.

DRAG A

DRAG B

A

B

WEIGHT B

WEIGHT A

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Answer:

Step 1: Determine which skydiver will have the greatest terminal velocity

- Skydiver A has a greater **mass**
- Because **F = ma**, Skydiver A also has a **greater** force of **weight** acting on them
- Since **terminal velocity** is reached when **air resistance equals weight**, Skydiver A will have a **greater** terminal velocity

Step 2: Determine who should jump first

- Skydiver A has a greater terminal velocity and will therefore fall at a **greater** speed
- In order for Skydiver B to catch up to Skydiver A during the fall, **Skydiver B needs to jump first**

💡 Examiner Tip

- Exam questions about terminal velocity tend to involve the motion of skydivers as they fall
- A common misconception is that skydivers move upwards when their parachutes are deployed – however, this is not the case, they are in fact **decelerating** to a lower terminal velocity