- ***Candidates should be able to*** :

  - *Explain that an object travelling in a fluid experiences a resistive or frictional force known as* ***DRAG****.*

  - ***State*** *the factors that affect the magnitude of the* ***DRAG FORCE****.*

  - *Determine the acceleration of an object in the presence of drag.*

  - *State that the* ***WEIGHT*** *of an object is the gravitational force acting on the object.*

  - *Select and use the relationship :*

Weight = mass x acceleration of free fall

$$W = m g$$

  - *Describe the motion of bodies falling in a uniform gravitational field with drag.*

  - *Use and explain the term* ***TERMINAL VELOCITY****.*

- ***MASS (m) AND WEIGHT (W)***

- *The* ***MASS (m)*** *of an object is a measure of its resistance to acceleration or deceleration (i.e. its* ***inertia****).*

The greater the mass, the harder it is to get an object moving or to stop it once it is in motion.

- *The S.I. unit of mass is the* ***KILOGRAM (kg)****.*

- *The mass of an object is* ***the same*** *wherever it may be.*

- *The* ***WEIGHT (W)*** *of an object is the gravitational force which acts on the object (It can also be defined as the force needed to support the object).*

- *The acceleration of a falling object acted on by the gravitational force only is the* ***acceleration due to gravity (g) (= 9.81 m s^{-2})****.*

The value of 'g' varies slightly from place to place on the Earth's Surface because of :

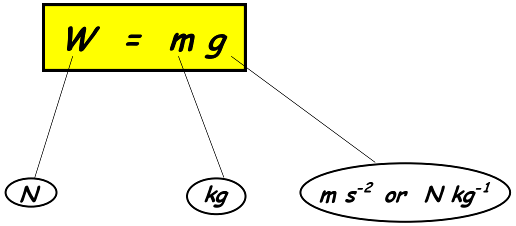
  - *Non-uniformities in the* ***shape*** *and* ***composition*** *of the planet.*
  - *The effect of the* ***Earth's rotation about its axis****.*

- *The force which causes the object's **acceleration of free fall (g)** is the object's **weight** and we can derive an equation for it using:*

$$F = m\,a$$

weight = mass x acceleration of free fall

$$W = m\,g$$



> ***NOTE***
> *The value of the **acceleration of free fall (g)** is an indication of how strong gravity is at a particular place (e.g. The average value of 'g' on the Earth's surface is **9.81 m s^{-2}**, whereas its value is **1. 67 m s^{-2}** on the lunar surface where the gravity is much weaker.*
>
> *So 'g' is also = **GRAVITATIONAL FIELD STRENGTH in N/kg.***
>
> *And, **weight** = **mass** x **gravitational field strength***

*Show that **N kg^{-1}** and **m s^{-2}** are equivalent units.*

- *Any object which is moving through a **FLUID** (i.e. a liquid or a gas) is subject to a resistive **DRAG FORCE** which opposes the motion.*

*The magnitude of the **DRAG FORCE** depends on :*

- *The **SPEED** of the object.*

  *(The **faster** the object is moving, the **greater** the drag force).*

- *The **SHAPE** of the object.*

  *(The **more streamlined** the object is, the **smaller** the drag force).*

- *The **VISCOSITY *** of the fluid.*

  **** VISCOSITY is a measure of the ease with which a fluid flows past a surface.***

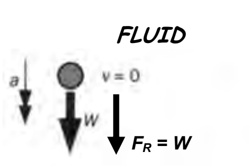
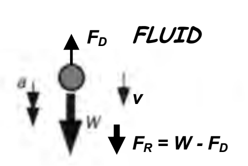
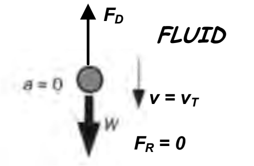
  *(The **greater** the viscosity of the fluid, the **greater** the drag force).*

- ***MOTION OF AN OBJECT FALLING THROUGH A FLUID***

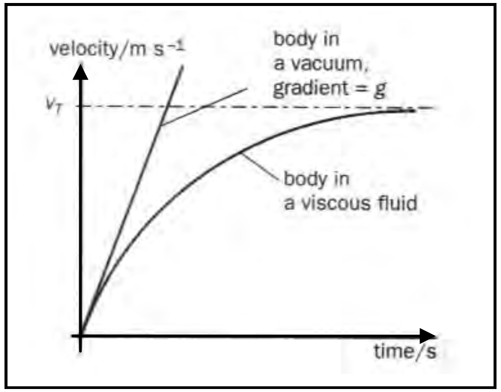
  - *Consider an object released from rest in a fluid (e.g. air, water, oil…).*
  - *At first, the only force acting on it is its **weight** acting downwards.*
  - *As it falls, its **speed increases** and so the resistive **drag force increases.***
  - *The **resultant force (= weight - drag force)** then decreases and so the **acceleration** decreases.*
  - *Eventually, as it continues to fall, the object will reach a velocity (called the **TERMINAL VELOCITY**) for which the **drag force = the weight.** The **resultant force is then zero** and so the **acceleration is zero.***
  - *The object then continues to fall at the constant **TERMINAL VELOCITY.***

- ***OBJECT FALLING THROUGH A FLUID - MATHEMATICAL ANALYSIS***

- *Consider a ball bearing released from rest to fall through a fluid.*

			
WHAT IS HAPPENING	***Ball bearing has just been released in a fluid.***	***Ball bearing has been falling through the fluid for a short time.***	***Ball bearing has fallen through the fluid for long enough to achieve its terminal velocity (v_T)***
VELOCITY (v)	*zero*	*Some value less than the terminal velocity*	*Equal to the terminal velocity (v_T)*
SIZE OF THE DRAG FORCE F_D	*zero*	*Some value less than W*	*Equal to W*
RESULTANT FORCE (F_R)	*Equal to the weight (W)*	*Equal to the weight - the drag force. ($F_R = W - F_D$)*	*Equal to zero. ($F_R = W - F_D = 0$)*
ACCELERATION (a)	*Has its maximum value (= g)*	*Has decreased to some value less than g*	*Has decreased to zero*

- *The diagram opposite shows the v/t graph for an object falling :*



- ***Under gravity in the absence of any resistive DRAG FORCE** (i.e. in a vacuum).*

*The straight line graph indicates **CONSTANT acceleration** and the gradient = the acceleration of free fall, 'g'.*

- ***Under gravity through a fluid which gives rise to a resistive DRAG FORCE** (e.g. through oil or air).*

The initial gradient (and therefore acceleration) is the same as for an object falling in a vacuum, but it decreases gradually as the velocity increases (this is shown by the decreasing gradient of the v/t graph).

*Eventually, a velocity is reached at which the **DRAG FORCE = the WEIGHT**, meaning that there is **zero RESULTANT FORCE** on the object and hence **zero ACCELERATION** (indicated by zero gradient of the v/t graph). The object has reached its constant TERMINAL VELOCITY (v_T).*

• MAXIMUM SPEED OF A POWERED VEHICLE

• **1967 — Bonneville Salt Flats, Utah.**

*New Zealander Burt Munroe set the World land speed record for engines below 1000 cc when he rode his self customized Indian Scout motorbike and clocked an amazing **184 mph.** This record still stands today! The 2005 film, **"The World's Fastest Indian"**, tells the story of Burt's lifelong quest to make his bike go as fast as it could possibly go.*

1997 — Black Rock Desert, Nevada.

*The **Thrust SSC rocket car** broke the World land speed record when it reached the incredible top speed of **763 mph** (faster than sound) over a distance of 1 mile.*

1969 — 100 km above the Pacific ocean

*The **Apollo 10 command capsule** reached a top speed of **24,790 mph** on re-entry into the Earth's atmosphere.*

This is not a powered vehicle, unless we consider the Earth's gravitational pull to be the provider of a constant motive force.

• WHY DOES ANY POWERED VEHICLE HAVE A TOP SPEED ?

*The **maximum speed** achievable by an engine-powered vehicle depends on :*

- *The **maximum forward force** which the engine can provide.*
- *How quickly the **drag force** value will increase to equal the **engine force.** This depends on the shape of the vehicle (i.e. how streamlined it is).*

*The **RESULTANT FORCE (F_R)** which gives the vehicle its forward Acceleration is given by :*

RESULTANT FORCE = ENGINE FORCE - DRAG FORCE

$$F_R = F_E - F_D$$

INITIALLY : **vehicle speed = 0,** so **drag force = 0**

Therefore, **resultant force,** $F_R = F_E - F_D = F_E$

So the **vehicle has maximum acceleration.**

As the vehicle's speed increases, the drag force on it (due to air resistance) also Increases, and :

EVENTUALLY : **vehicle speed** = v_T (its **TERMINAL** or **'TOP'** speed)

Then, **drag force,** $F_D = F_E$

Therefore, **resultant force,** $F_R = F_E - F_D = 0$

So the **vehicle acceleration is zero.**

The vehicle has then achieved its maximum speed and it will carry on moving at this constant speed

- **PRACTICE QUESTIONS**

1 A car of mass ***1050 kg*** is travelling along a straight, flat road. The forward force provided by the car's engine is ***775 N*** and the drag force due to air resistance is ***325 N.***

Calculate the ***acceleration*** of the car.

2 Skydivers jump from a plane at intervals of a few seconds. If two divers want to join up as they fall, the second diver has to catch up with the first.

(a) If diver ***A*** has a total mass of ***110 kg*** and diver ***B*** has a total mass of ***85 kg***, use the idea of ***forces and terminal velocity*** to explain which diver needs to jump first.

(b) If the two divers are of the ***same mass***, ***explain*** what the second diver can do so as to catch up with the first.

3 A steel ball bearing of mass ***0.05 kg*** released from rest in oil falls through a vertical distance of ***0.18 m*** in ***4.0 s.*** Assuming the ball reaches its terminal velocity instantaneously, calculate :

(a) Its ***terminal velocity.***

(b) The value of the ***drag force*** acting on the ball when it is falling at its terminal velocity.

(Assume that the ***acceleration of free fall, g = 9.81 m*** s^{-2})

- **HOMEWORK QUESTIONS**

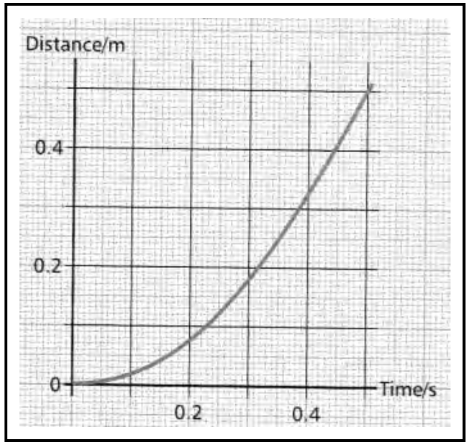
1 A mobile crane of mass ***60 000 kg*** has an engine which can provide a motive force of 6.0×10^3 ***N*** and a maximum speed of ***24 m*** s^{-1}. Calculate :

(a) The vehicle's ***maximum acceleration from rest.***

(b) The ***distance travelled*** by the vehicle at maximum acceleration to reach a speed of ***15 m*** s^{-1} from ***rest.***

2 A steel ball bearing was released from rest to fall through water in a tall measuring cylinder.

The diagram opposite shows a graph of the ***distance*** fallen by the ball bearing plotted against ***time taken.***



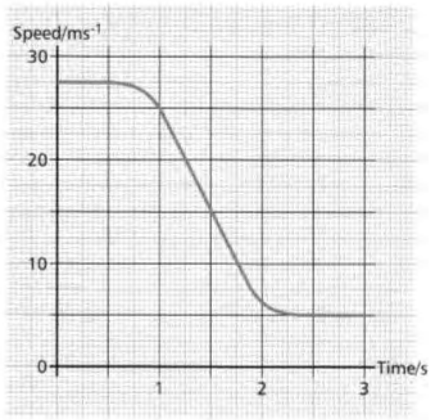
(a) What feature of the graph gives the ***speed*** of the ball bearing at any instant.

(b) ***Describe*** the motion of the ball bearing from the moment it was released until time = 0.5 s.

(c) Sketch a ***speed/time*** graph for the ball bearing's descent.

(d) Explain, in terms of the forces acting on the ball bearing, why its acceleration decreased to zero during its descent. What happens when the ball's acceleration is zero ?

3



A skydiver of total mass ***80 kg*** is falling freely at ***constant speed*** when she opens her parachute.

(a) Calculate : (i) The skydiver's ***weight.***

(ii) The ***drag force*** on the skydiver before she opened her parachute.

(b) The graph shows how the skydiver's speed changed after the parachute was opened.

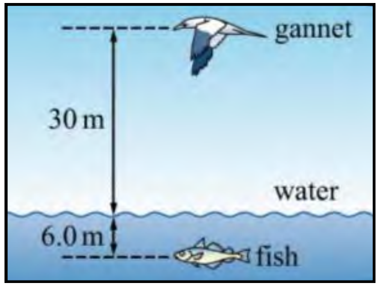
(i) ***Explain*** why her speed decreased suddenly when the parachute was opened.

(ii) Use the graph to estimate her ***maximum deceleration*** after opening the parachute.

(iii) Sketch a graph to show how the ***drag force*** on the skydiver changed as a result of opening the parachute.

4

The diagram opposite shows a gannet hovering above a water surface.



The gannet is ***30 m*** above the surface of the water. It folds its wings and falls vertically in order to catch a fish that is ***6.0 m*** below the surface.

Assume air resistance to be negligible and take the ***acceleration of free fall, $g = 9.81 \text{ m s}^{-2}$.***

(a) Calculate : (i) The ***speed*** at which the bird enters the water.

(ii) The ***time taken*** for the bird to fall to the water surface.

(b) The bird does ***not*** continue to travel at the acceleration of free fall when it enters the water.

State and ***explain*** the effect of the forces acting on the bird as it falls :

(i) Through ***the air.***

(ii) Through ***the water.***

(OCR AS Physics - Module 2821 - June 2006)