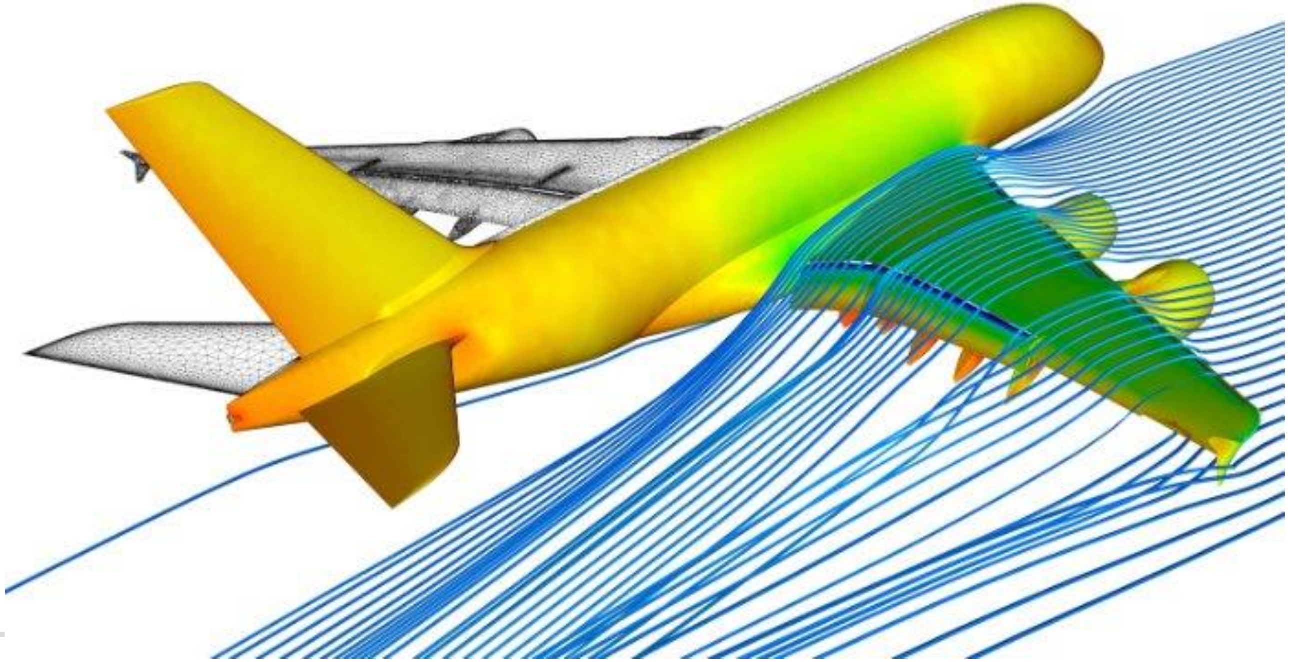
Materials

2015 EdExcel A Level Physics
Topic 4

Fluid dynamics and Stokes' Law

Physics Tutor Online

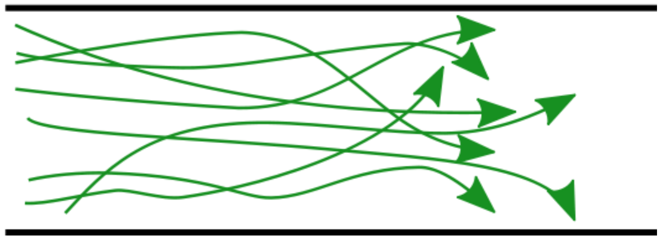
Laminar Flow vs Turbulent Flow



Laminar Flow vs Turbulent Flow

Laminar flow (seen here) is when “adjacent layers of a fluid do not cross over each other”.

Turbulent flow is when “layers of fluid cross over each other”. This can happen when the rate of flow reaches a critical level (or, obviously, when obstacles are put in the way…).



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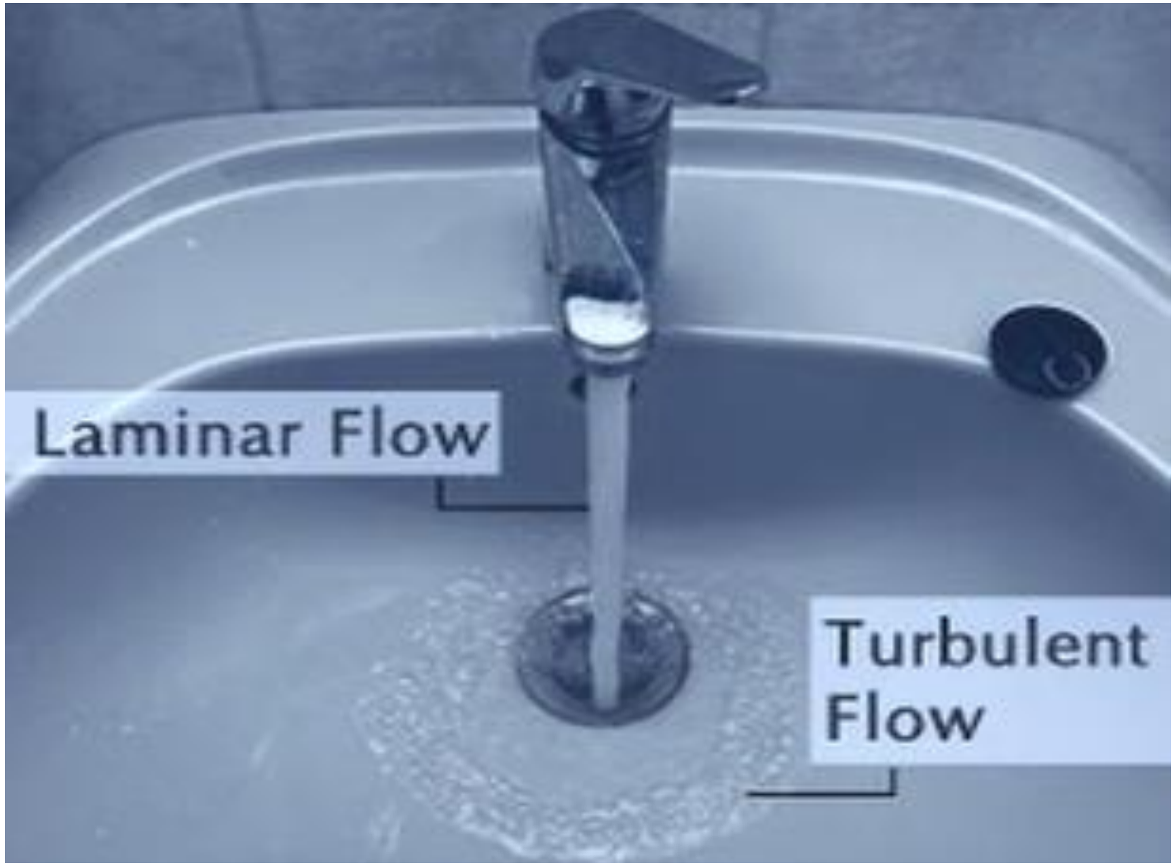
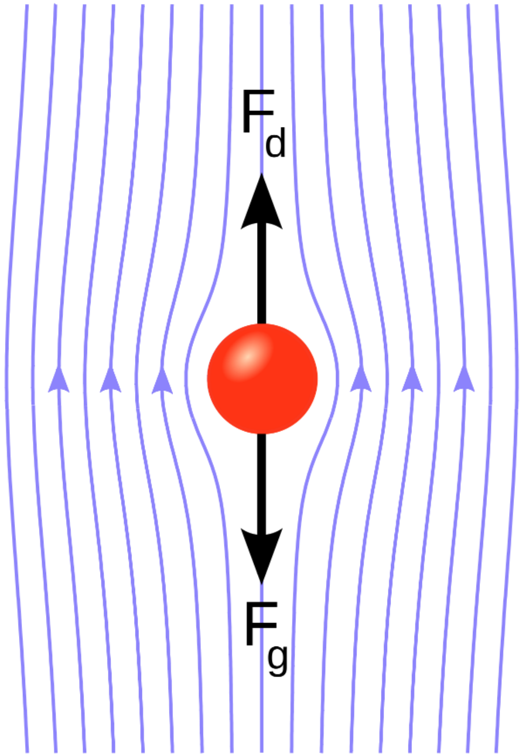


Stokes' Law

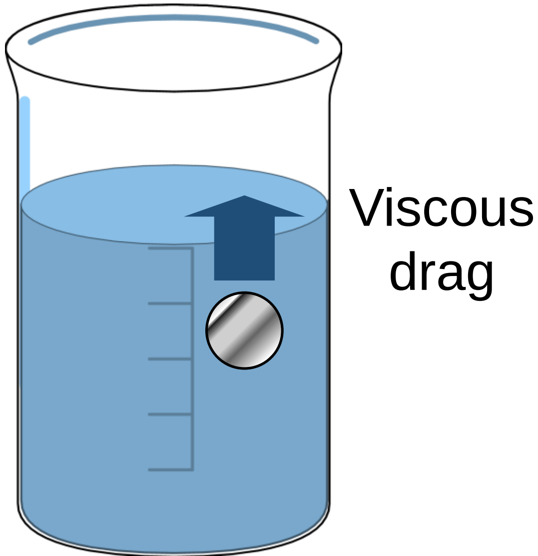


When a sphere moves through a liquid the movement of the liquid relative to the sphere is laminar. This can be expressed mathematically……

Consider a sphere of radius r moving with a velocity v relative to a fluid with viscosity η:

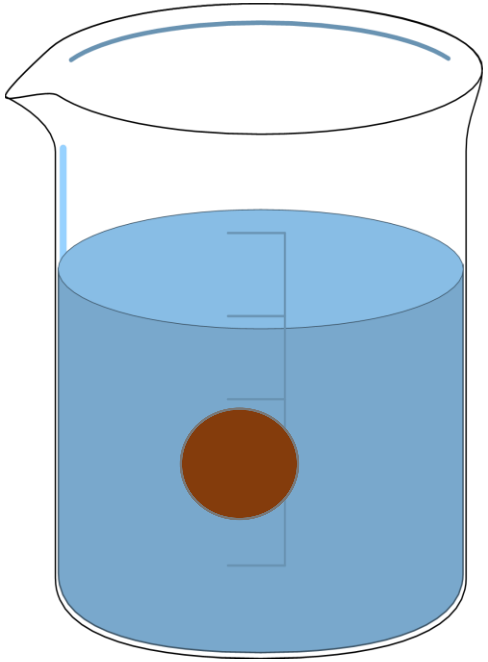
Viscous drag $F_d = 6\pi\eta r v$

This is called Stokes' Law, after me. It ONLY works for spheres moving at low speeds (i.e. laminar flow)



Example

Calculate the drag force on a sphere of radius 5 cm an it is travelling in a liquid having viscosity 2.2×10^{-3} N s m^{-2} with a velocity 25 ms^{-1}.



Example

Calculate the drag force on a sphere of radius 5 cm an it is travelling in a liquid having viscosity $2.2\text{x}10^{-3}$ N s m^{-2} with a velocity 25 ms^{-1}.

Solution:

$r=0.05$ m

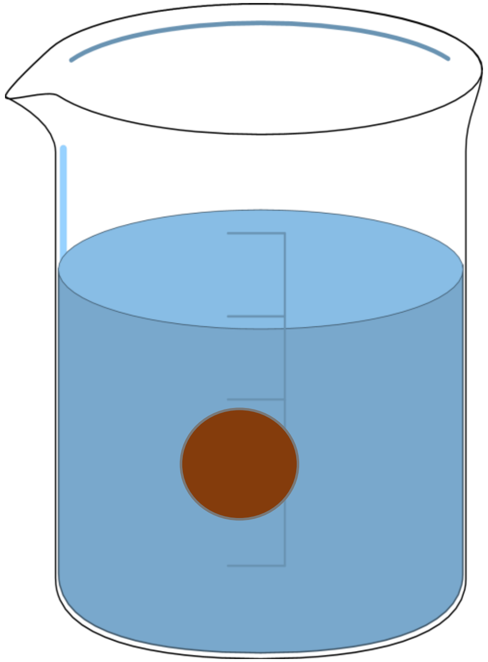
$v= 25\ ms^{-1}$

$\eta= 2.2\text{x}10^{-3}\ Nsm^{-2}$

Viscous drag $F = 6\pi\eta rv$

By putting in the values

$F = 6 \times 3.14 \times 2.2\text{x}10^{-3} \times 0.05 \times 25=51.81\text{x}10^{-3}$ N

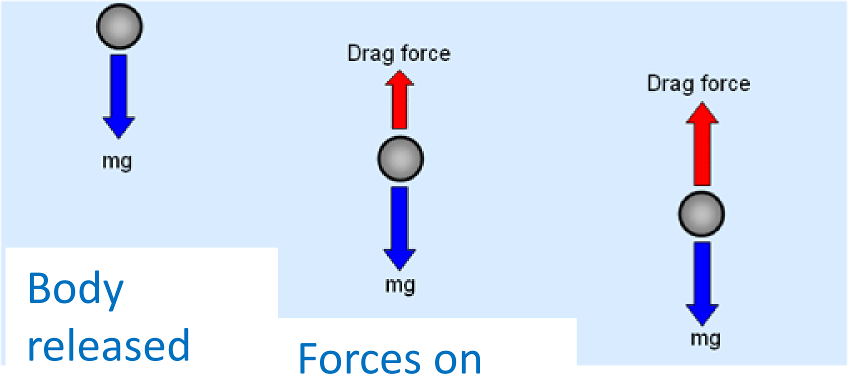


Terminal Velocity

When vehicles and free-falling objects first move they have much more force accelerating them than resistance which is trying to slow them

As speed increases resistance builds up – gradually reducing the resultant force and so the acceleration also reduces

Eventually the resistance forces are equal to the accelerating force and the object remains at a constant speed (**terminal velocity**).



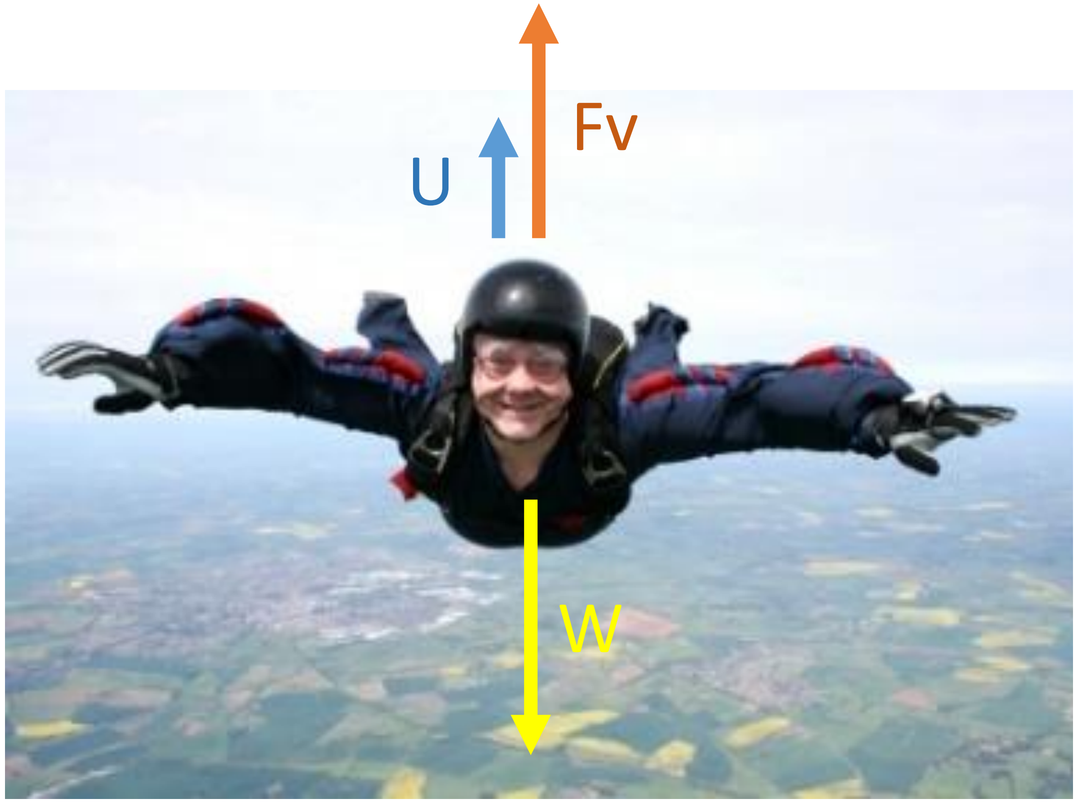
Body released from rest

Forces on body during acceleration

Forces on body at terminal velocity

Terminal Velocity

Forces acting on a skydiver



Weight, W=mg
Upthrust, U
Viscous drag, Fv

At terminal velocity the resultant force $\Sigma F=0$

$$\Sigma F = 0 = W - (U + Fv)$$

$$a = \Sigma F/m = 0$$

acceleration is zero!

Terminal Velocity in a liquid

Consider a ball falling through a liquid:

Some questions to consider:

1) What forces are acting on the ball?
2) How do those forces change when the ball gets faster?
3) Will the ball keep getting faster? Explain your answer in terms of forces

Terminal Velocity

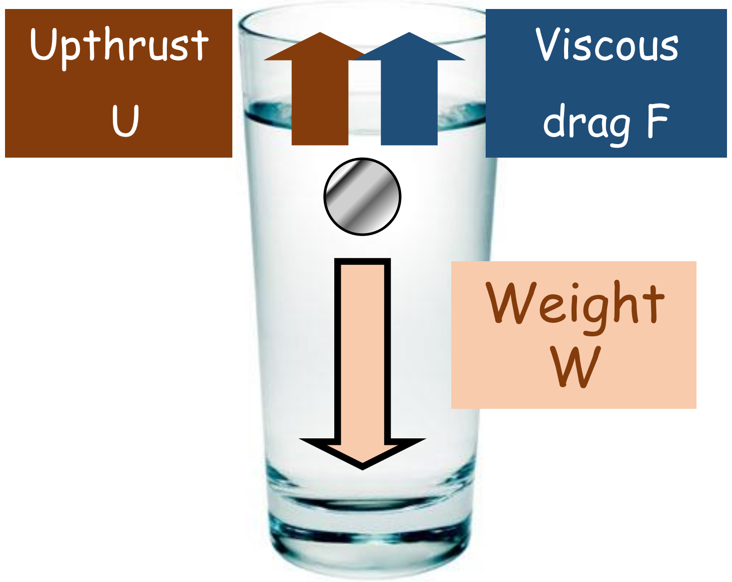
What forces are acting on the ball?

Some facts about the sphere falling through a fluid:

1) The weight, obviously, stays constant

2) Upthrust = weight of fluid displaced, so that stays constant after the sphere becomes totally immersed

3) Viscous drag is proportional to velocity so it increases as the ball gets faster



Clearly, terminal velocity is reached when the following condition is met:

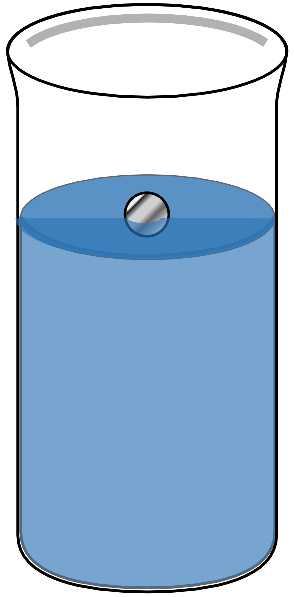
$$\Sigma F = 0 = W - (U + F)$$

$$W = U + F$$

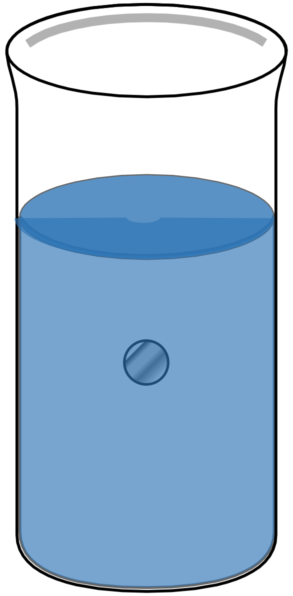
Free body force diagrams

Draw free body force diagrams and write a force equation for the following objects:

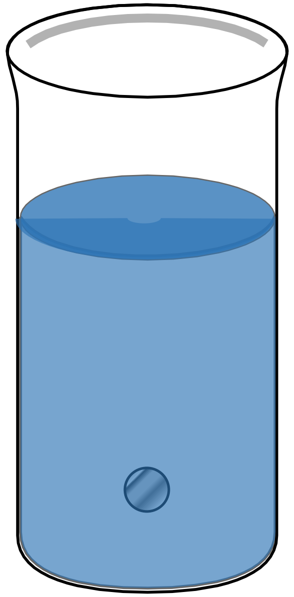
1) A ball bearing with a density just less than water floating on its surface:



2) A more dense ball bearing accelerating through a liquid:



3) The same ball bearing later when it has reached terminal velocity:



Free body force diagrams

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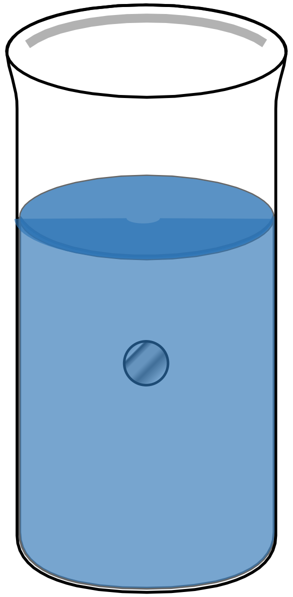
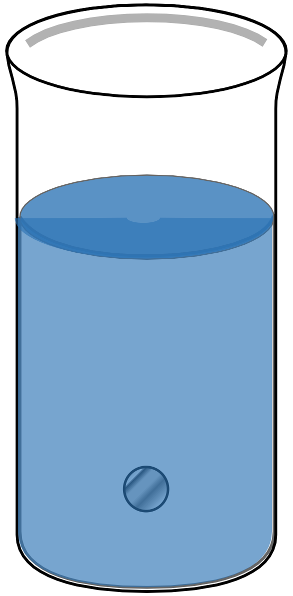
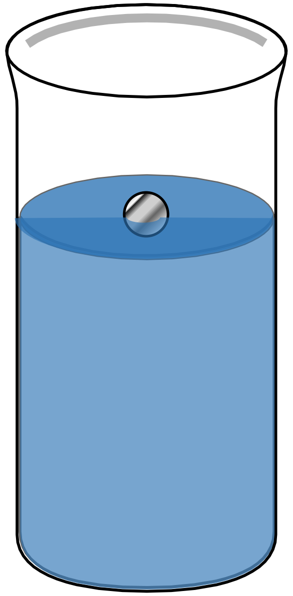


1) A ball bearing with low density that's accelerating towards the surface:



2) The same ball bearing when it has reached terminal velocity while rising:

3) The same ball bearing later when it has reached the surface:

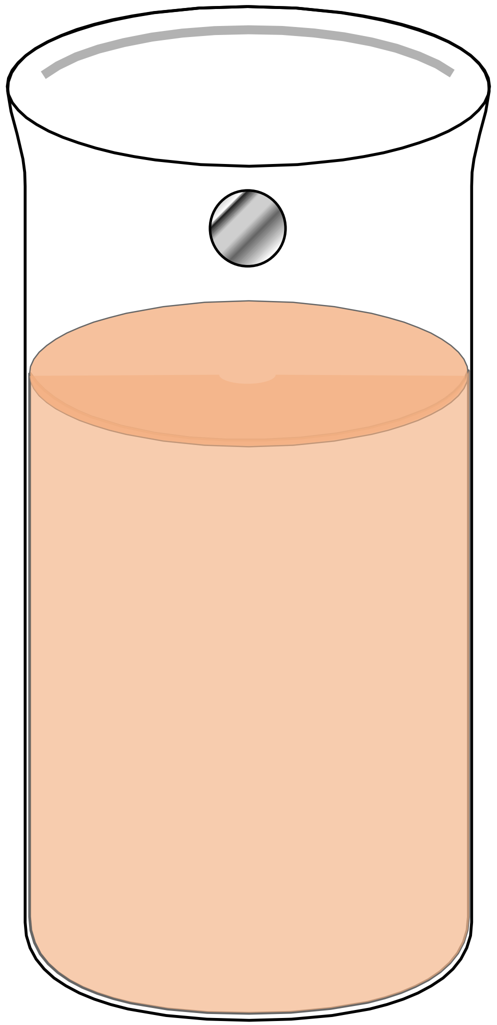


Core Practical 4 - Viscosity

The viscosity of a fluid can be defined as its “resistance to flow”, i.e. a viscous fluid is one that would be thick and sticky (like syrup).

Comparing viscosities

The viscosity of different fluids can be compared by using a viscometer or by dropping a ball bearing through the liquid:



Example

A steel ball-bearing of mass 2.6×10^{-4} kg and radius 4.0mm is allowed to fall through water until it reaches terminal velocity. Calculate this terminal velocity if the viscosity of water is 2.2×10^{-3} N s m^{-2}.

Solution:

$m = 2.6 \times 10^{-4}$ kg

$r = 4.0$ mm $= 4 \times 10^{-3}$ m

$\eta = 2.2 \times 10^{-3}$ Nsm^{-2}

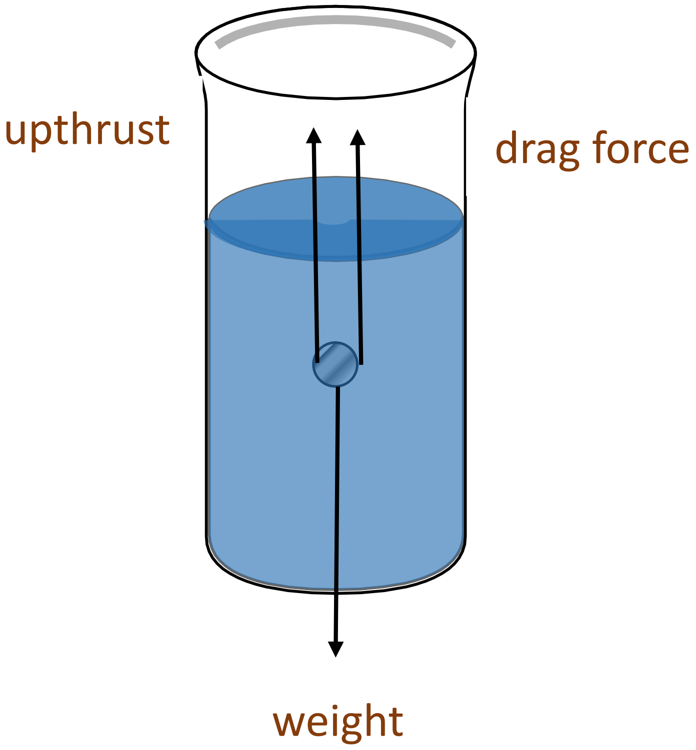
$v = ?$

Drag Force:

$F = 6\pi\eta r v$

By putting values

$F = 6 \times 3.14 \times 2.2 \times 10^{-3} \times 4 \times 10^{-3} \times v = 1.66 \times 10^{-4}\, v$ Newton



Example cont.

upthrust

$upthrust = density\ of\ water\ x\ volume\ of\ water\ displaced\ xg$

$volume\ of\ water\ displaced = \frac{4}{3}\pi r^3$

$volume\ of\ water\ displaced = \frac{4}{3}x3.14x(4x10^{-3})^3 = 2.717x10^{-8}m^3$

$upthrust = 1000\ x2.717x10^{-8}x\ 9.8 = 2.66x10^{-4}N$

Weight of ball

$w = mg$

$w = 2.6\ x10{-}4x9.8 = 2.548x10^{-3}kgms^{-2}$

terminal velocity is reached when the following condition is met:

$W = U + F$

$2.548x10^{-3} = 2.66x10^{-4} + 1.66\ x10^{-4}v$

$2.282x10^{-3} = 1.66\ x10^{-4}v$

$v{=}13.75ms^{-1}$

Practice Questions

1) A steel ball-bearing of mass 1.1×10^{-4}kg and radius 1.8mm is allowed to fall through water until it reaches terminal velocity. Calculate this terminal velocity if the viscosity of water is 1.1×10^{-3} N s m^{-2}.

2) A ball of density 8000 kgm^{-3} and radius 1.2mm is allowed to fall through water until it reaches terminal velocity. Calculate this terminal velocity if the viscosity of water is 1.1×10^{-3} N s m^{-2}.