Fluids

AS-Physics-
Topic 2-Materials

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Objectives:

Candidates will be assessed on their ability to:

23	be able to use the equation density $\rho = \frac{m}{V}$
24	understand how to use the relationship upthrust = weight of fluid displaced
25	a be able to use the equation for viscous drag (Stokes' Law), $F = 6\pi\eta rv$. b understand that this equation applies only to small spherical objects moving at low speeds with *laminar flow* (or in the absence of *turbulent flow*) and that viscosity is temperature dependent
26	**CORE PRACTICAL 2: Use a falling-ball method to determine the viscosity of a liquid**

Fluids

- A fluid is defined as any substance that can flow.

Normally this means any gas or liquid, but solids made up of tiny

particles can sometimes behave as fluids; an example is the flow

of sand through an hourglass.

Density

- Density is a measure of the mass per unit volume of a substance.

$$\text{density } (\text{kg m}^{-3}) = \frac{\text{mass (kg)}}{\text{volume } (\text{m}^3)}$$

$$\rho = \frac{m}{V}$$

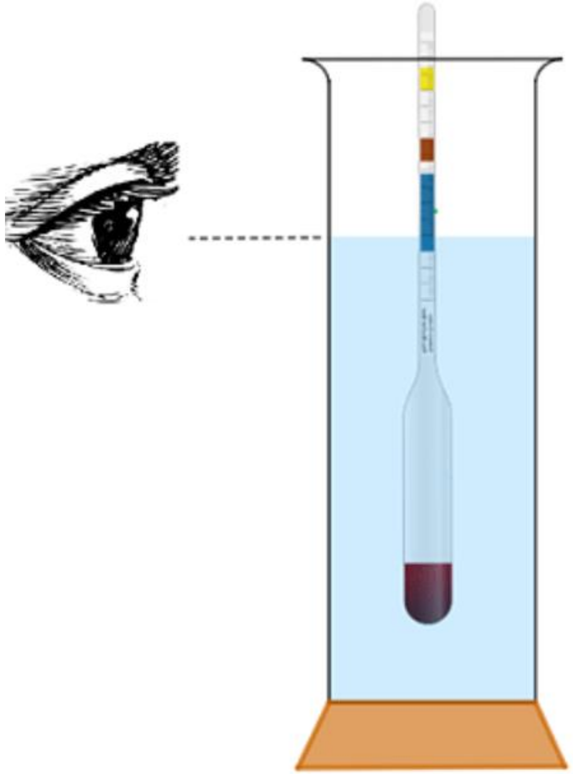
- 1000 $kg\ m^{-3} = 1\ g\ cm^{-3}$

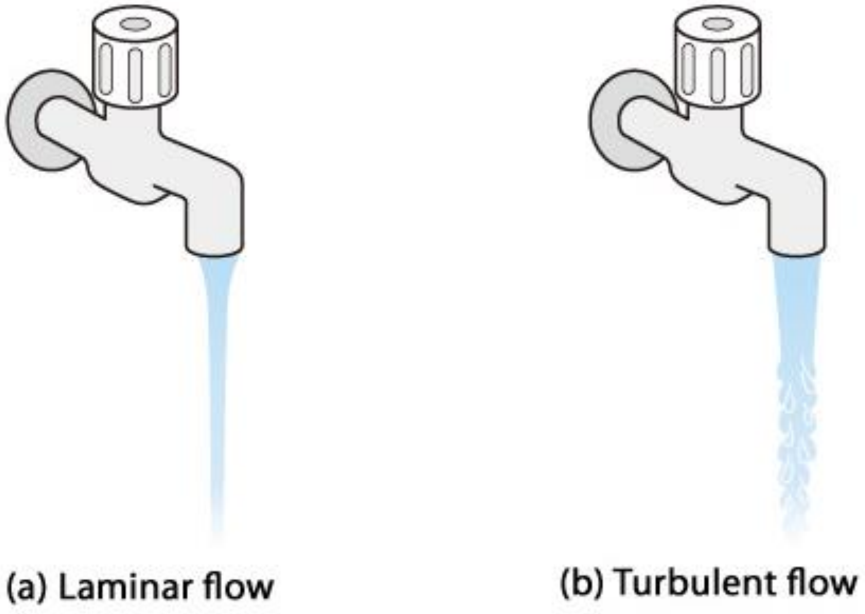
Upthrust

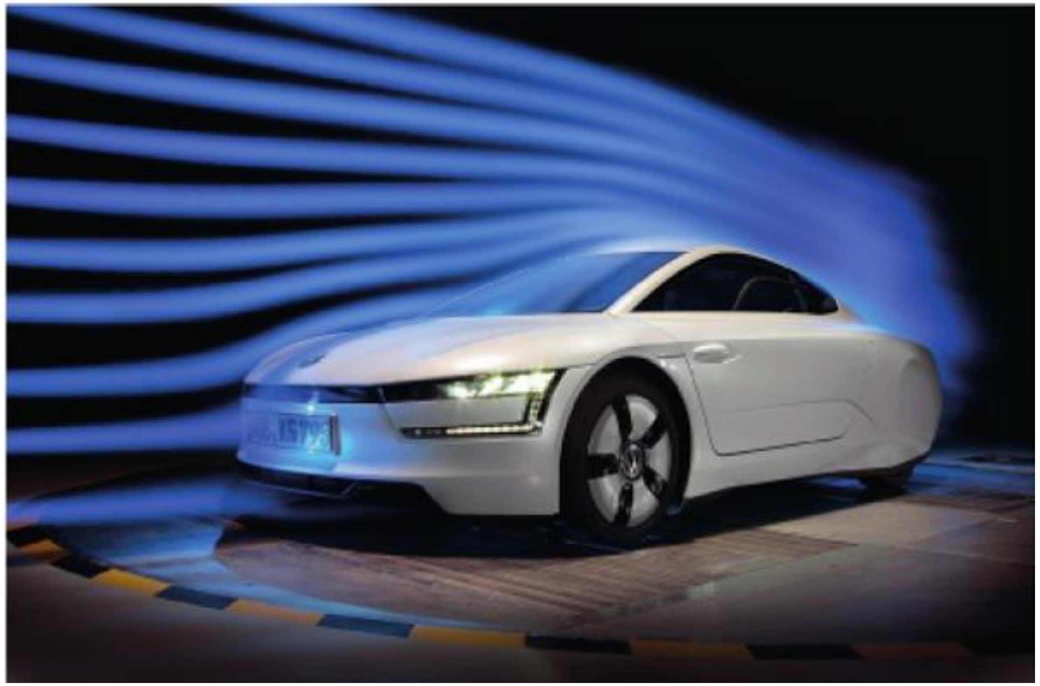
- When an object is submerged in a fluid, it feels an upwards force caused by the fluid pressure - the upthrust.

The hydrometer

- An instrument used to determine the density of a fluid. The device has a constant weight. so it will sink lower in fluids of lesser density.





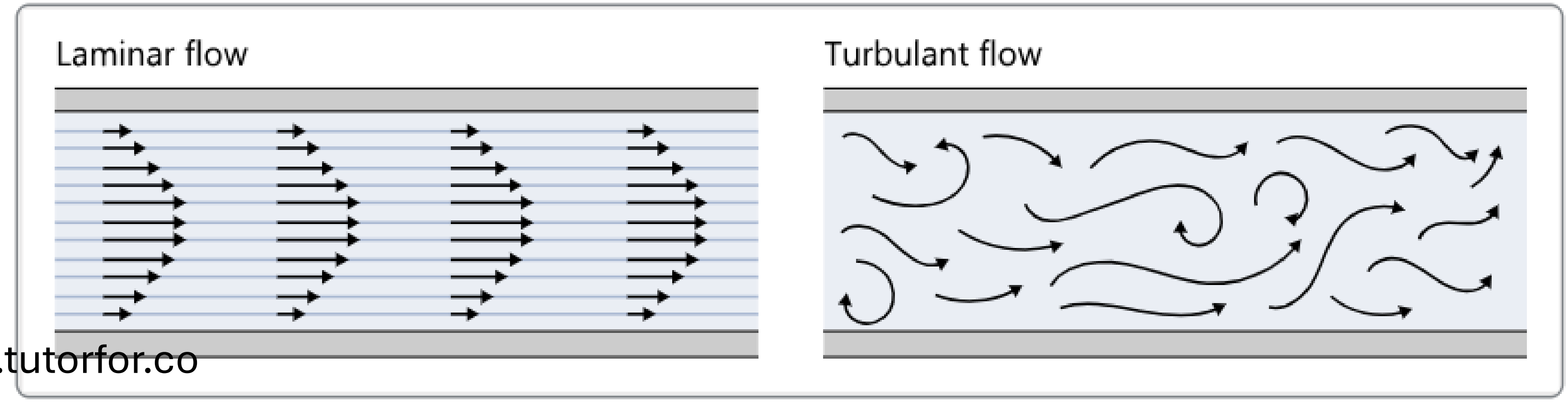


Laminar flow(streamline flow) & Turbulent flow

Laminar flow(streamline flow) & Turbulent flow

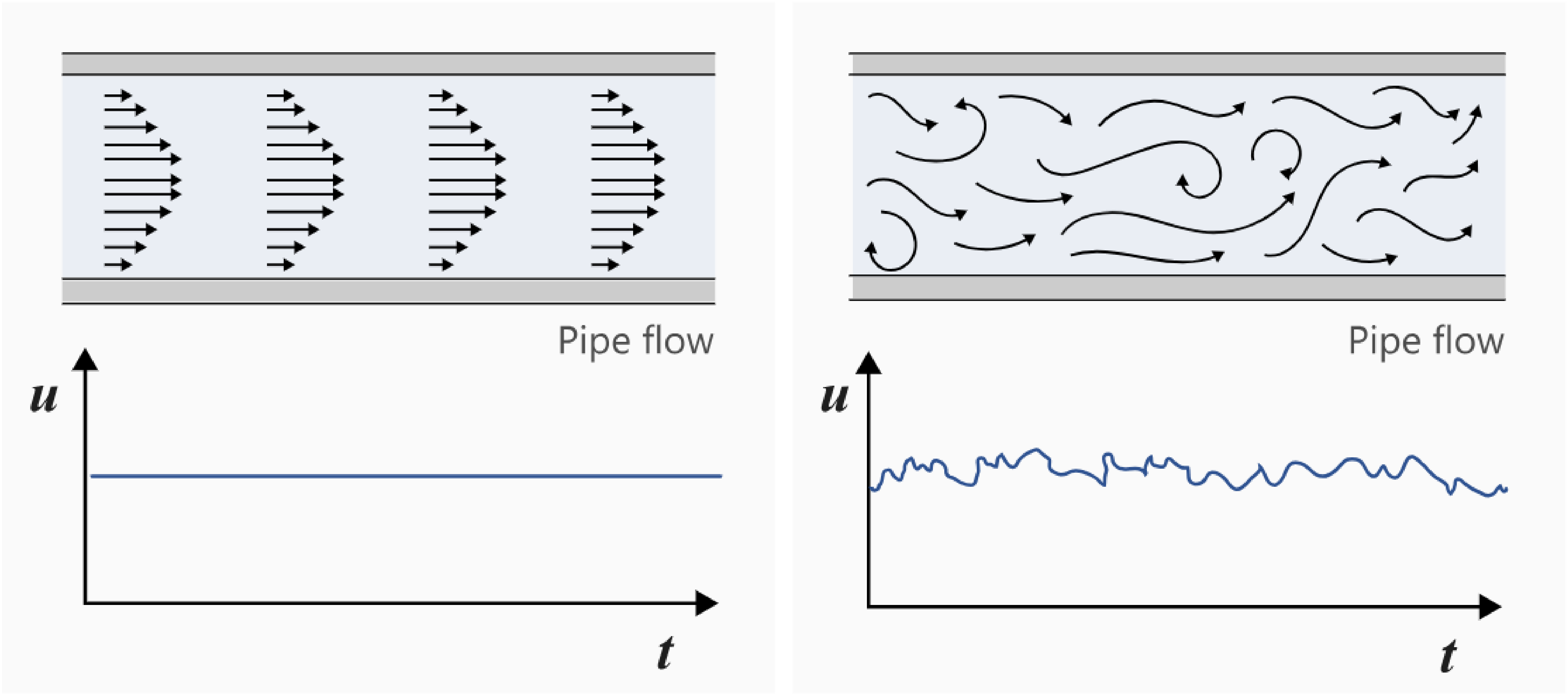
- Laminar flow -smooth, orderly movement in parallel layers, with minimal mixing between adjacent layers. This type of flow occurs at low velocities, resulting in a uniform velocity profile and well-defined streamlines.

- Turbulent flow-chaotic, irregular movement with rapid fluctuations in velocity, pressure, and direction. In turbulent flow, eddies and vortices form, leading to significant mixing and energy dissipation throughout the fluid



Laminar flow

Turbulant flow



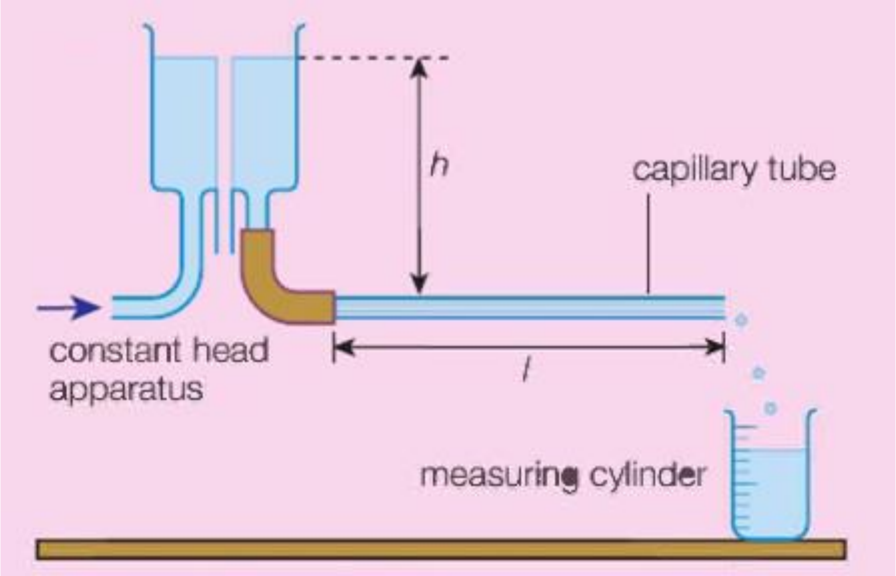
LAMINAR FLOW	TURBULENT FLOW
Smooth, orderly parallel layers	Chaotic, irregular movement with eddies
Uniform velocity within layers	Fluctuating velocity with rapid fluctuations
Minimal mixing between adjacent layers	Significant mixing, resulting in eddies

Differences between laminar & turbulent flow

Viscosity

Viscosity is a measure of a fluid's resistance to flow, or its internal friction. It determines how easily a fluid can deform or move in response to an applied force. Higher viscosity indicates greater resistance to flow, while lower viscosity indicates less resistance

Poiseuille's Law



$$Q = \frac{\pi \cdot r^4 \cdot \Delta P}{8 \cdot \eta \cdot L}$$

- Q is the flow rate (volume of fluid passing through per unit time),
- r is the radius of the pipe,
- ΔP is the pressure difference across the ends of the pipe,
- η is the viscosity of the fluid, and
- L is the length of the pipe.

This equation shows that the flow rate is directly proportional to the fourth power of the radius of the pipe (r^4), the pressure difference (ΔP), and inversely proportional to the viscosity of the fluid (η) and the length of the pipe (L).

It's important to note that this equation assumes laminar flow, where the fluid flows smoothly in parallel layers.

Viscosity and temperature

FLUID	TEMPERATURE / °C	VISCOSITY / Pa S
air	0	0.000017
air	20	0.000018
air	100	0.000022
water	0	0.0018
water	20	0.0010
water	100	0.0003
glycerine	-40	6700
glycerine	20	1.5
glycerine	30	0.63
chocolate	30	100
chocolate	50	60

For liquids:

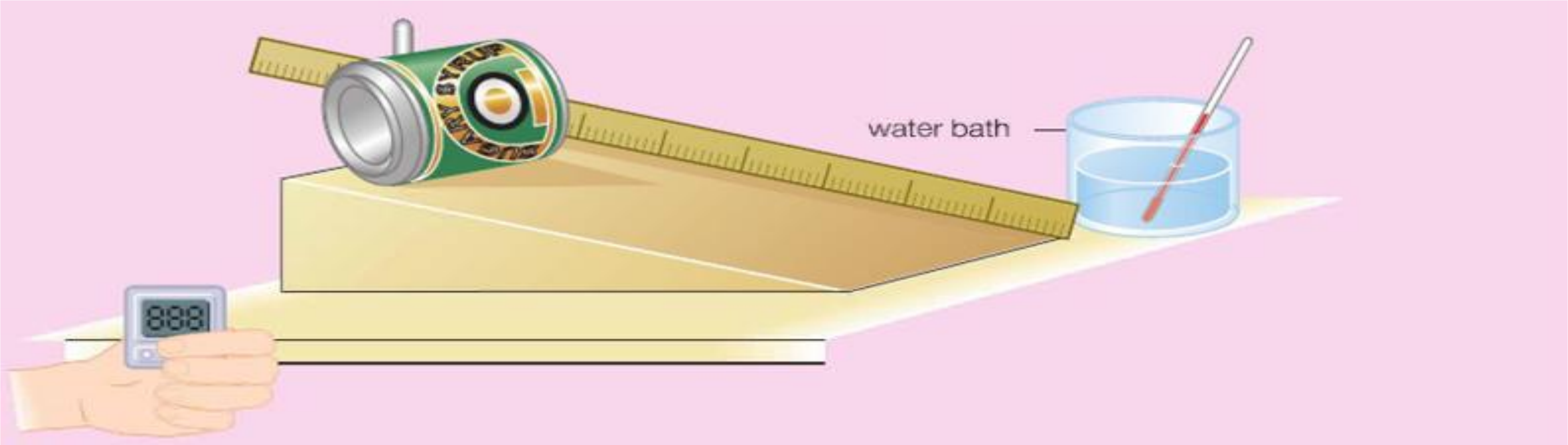
An increase in temperature usually leads to a decrease in viscosity.

This is because higher temperatures increase the kinetic energy of the molecules, causing them to move more freely and reducing the intermolecular forces that contribute to viscosity.

For gases:

The viscosity of gases increases with temperature due to increased molecular collisions, but this relationship can be influenced by factors such as pressure and the specific gas molecules involved.

Practical: Viscosity and temperature

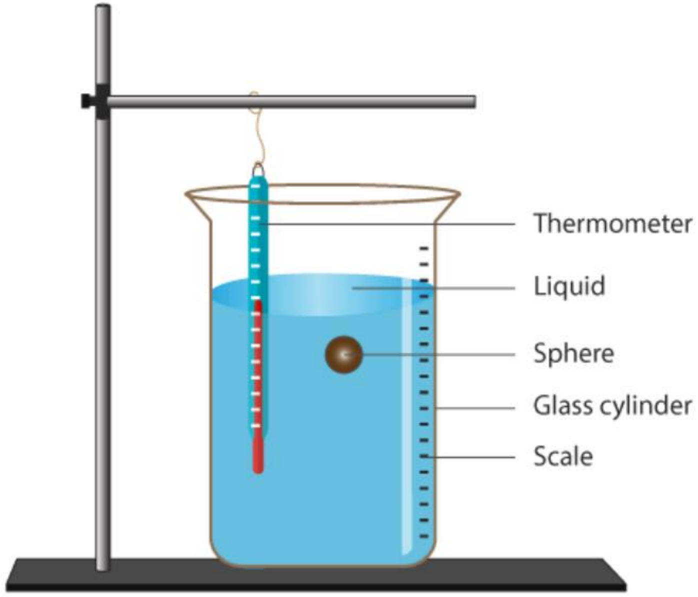


The temperature of the liquid is varied using a water bath. The viscosity of the liquid will affect the rate at which the tin or bottle rolls down a fixed ramp.

Higher viscosity fluids will offer more resistance to the motion of the object rolling down the ramp, thus slowing it down. Conversely, lower viscosity fluids will offer less resistance, allowing the object to roll more easily and quickly.

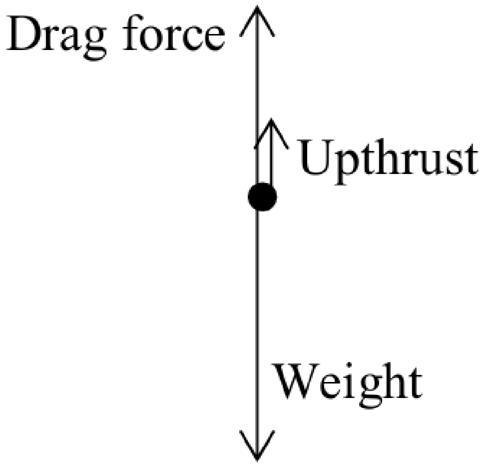
Strokes’ law

Strokes’ law states that the viscous drag on a small sphere at low speed is directly proportional to the velocity of the particle, the radius of the particle, and the viscosity of the fluid,



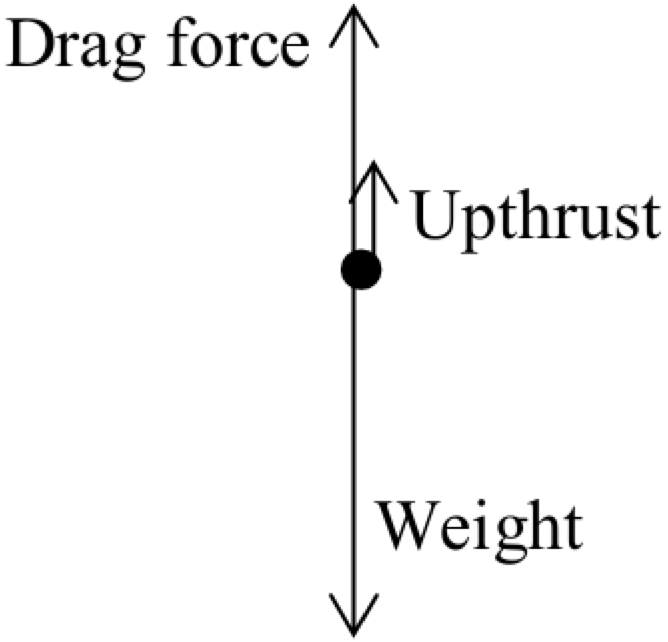
Small sphere falling in a long glass cylindrical jar

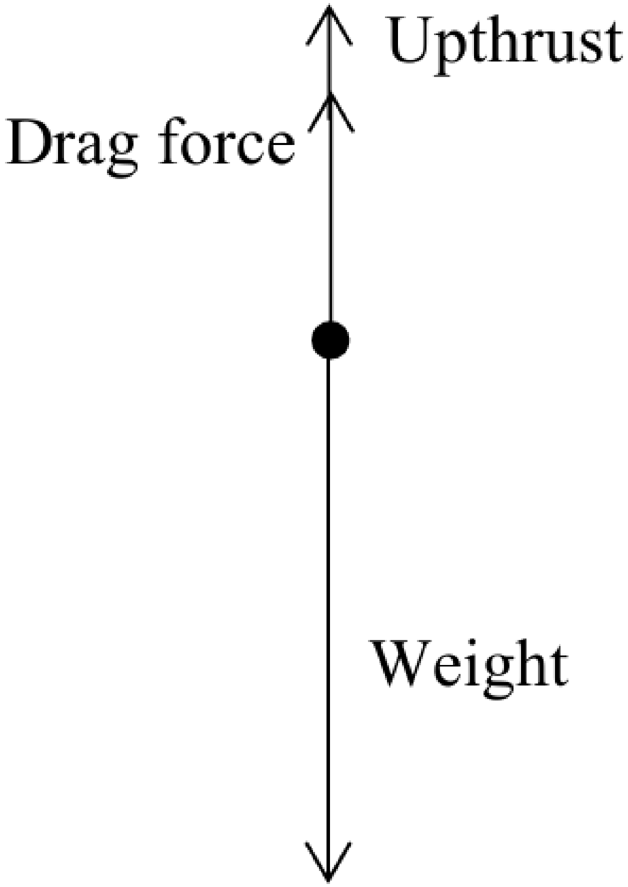
$$F_d = 6\pi\eta r v$$

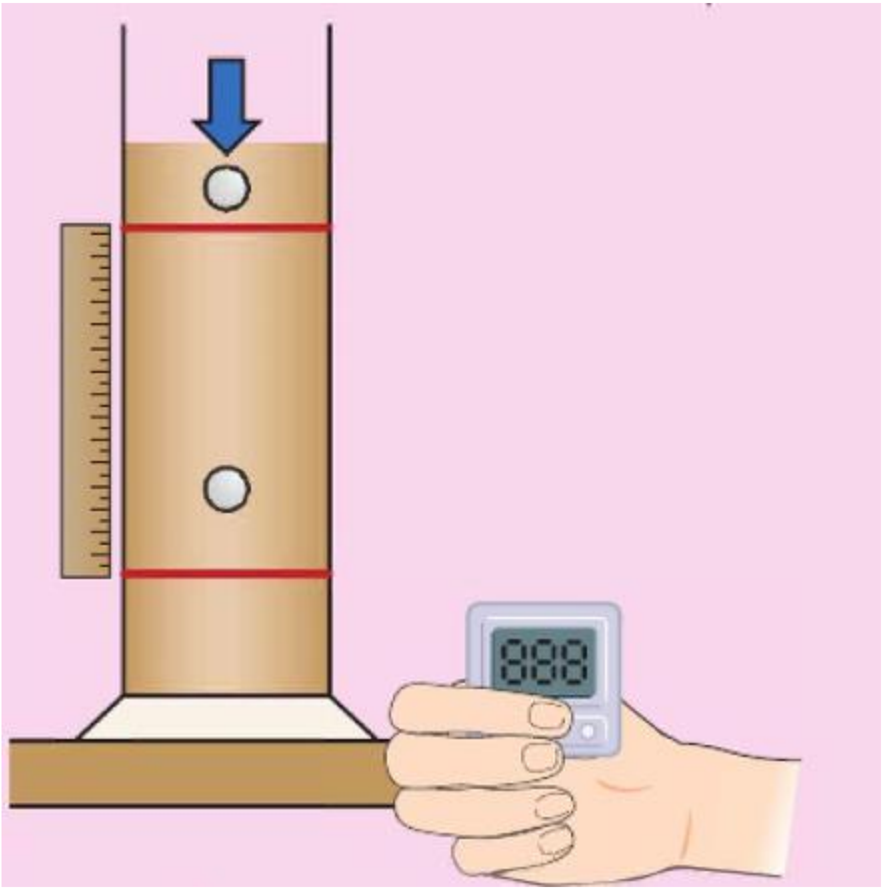


- F_d is the drag force acting on the particle,
- η is the viscosity of the fluid,
- r is the radius of the particle,
- v is the velocity of the particle

Terminal velocity & Strokes’ law

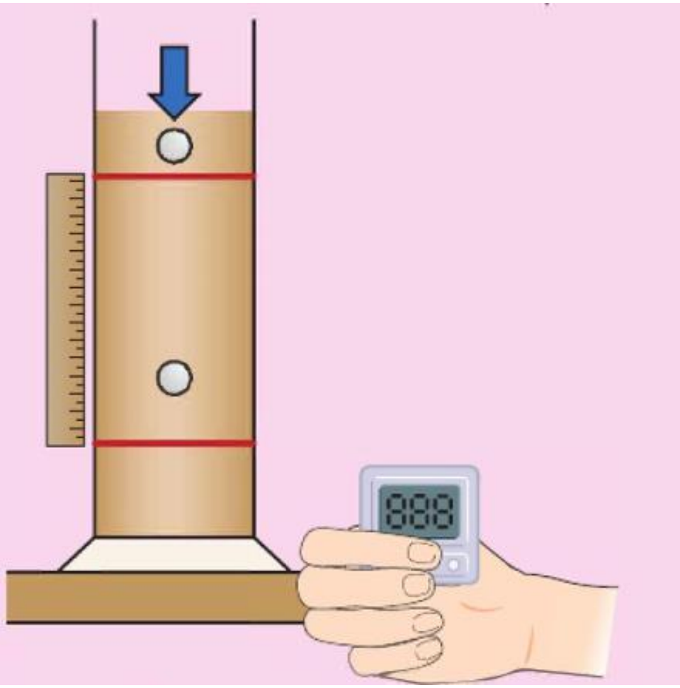


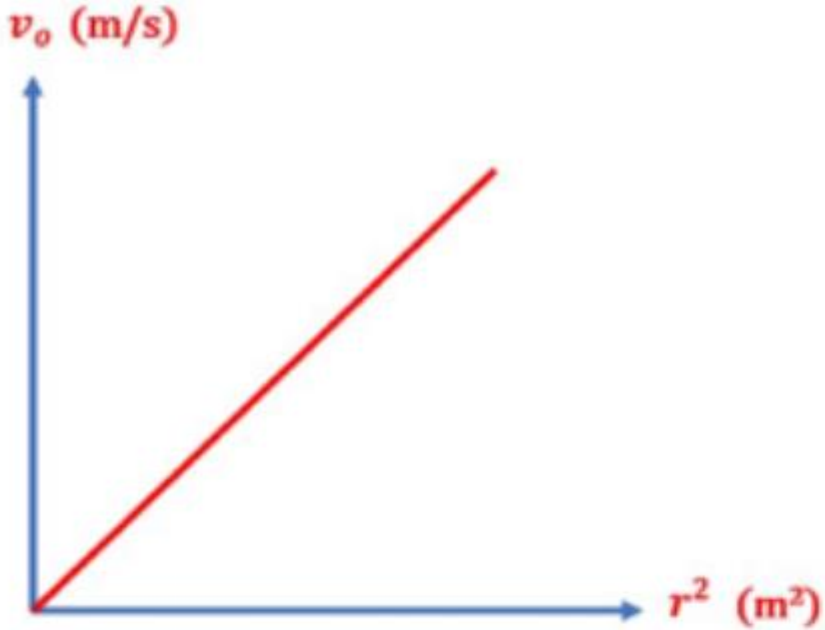




Length of weight arrow ≈ length of drag arrow + length of upthrust arrow

Practical: Terminal velocity of a small sphere





You can plot a graph of the terminal velocity, v_{term}, against the square of the sphere radius, r^2, and hence calculate the viscosity of water, η.

Stokes' law tells us that the gradient of the graph = $\frac{2g(\rho_s - \rho_f)}{9\eta}$

Show that the terminal velocity of a small sphere at low speed is given by:

$$v_{term} = \frac{2r^2 g(\rho_s - \rho_f)}{9\eta}$$

weight = upthrust + viscous drag

viscous drag= $6\pi\eta r v$