Physics

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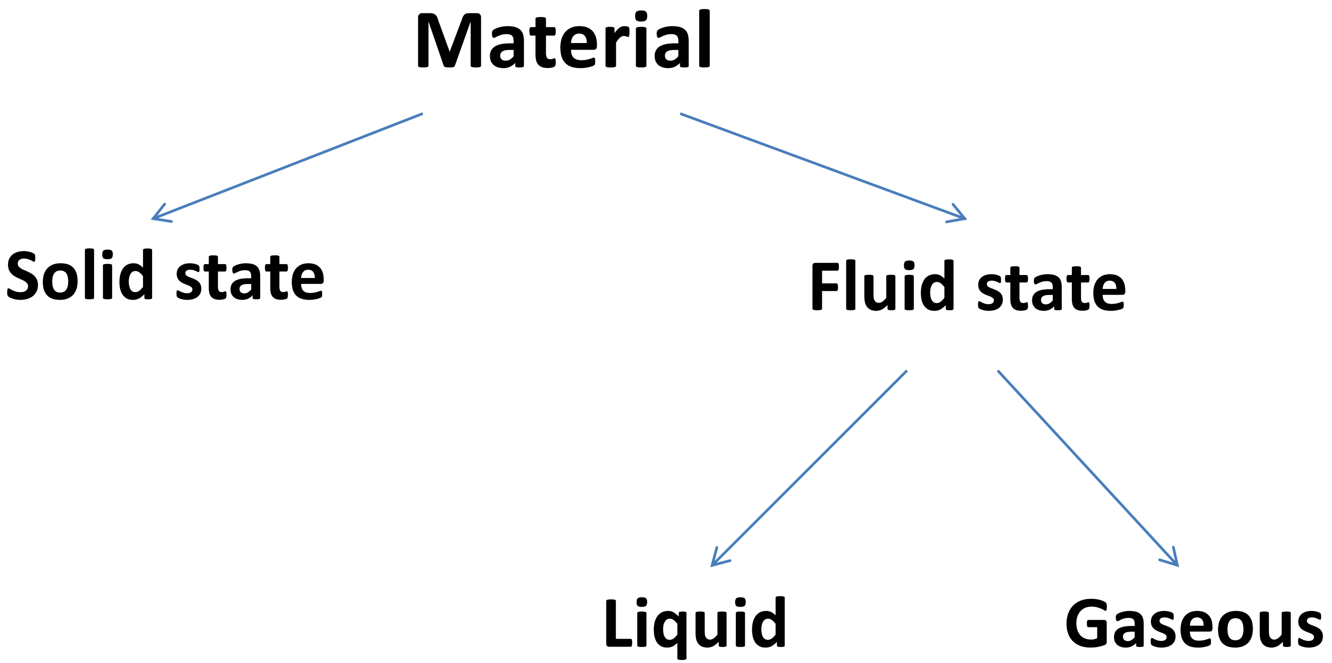
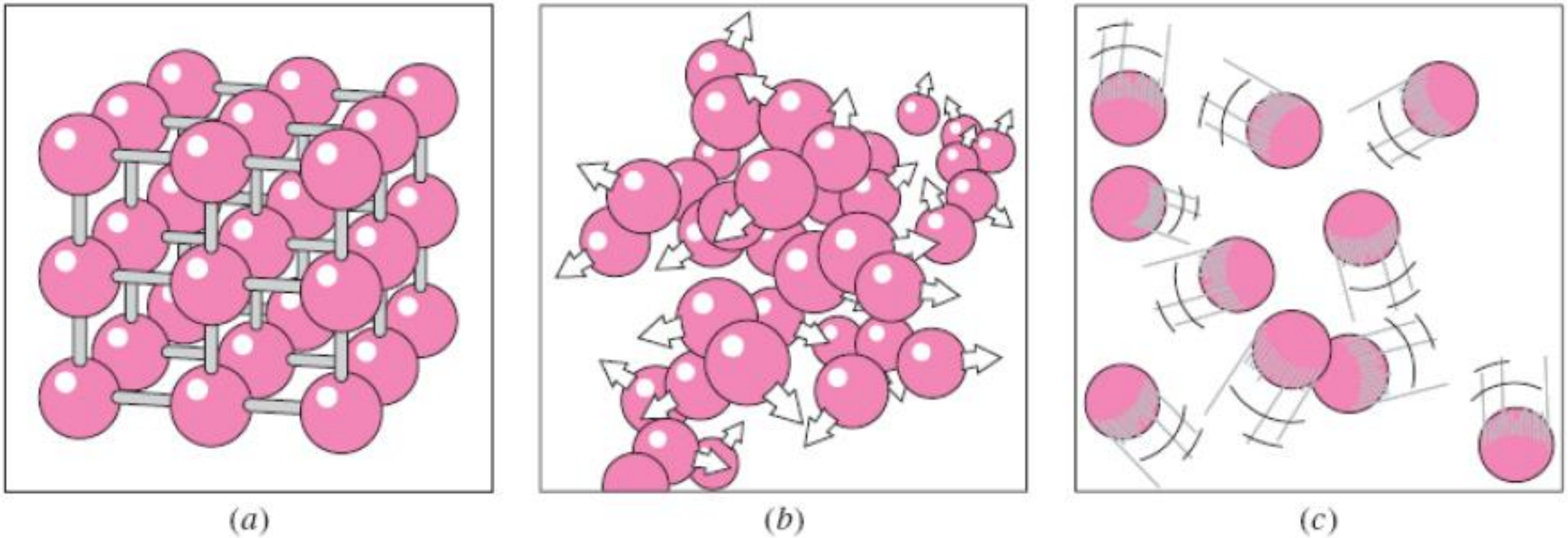
Material Properties


Material
Solid state
Fluid state
Liquid
Gaseous

- **Solid**: The molecules in a solid are arranged in a pattern that is repeated throughout.
- **Liquid**: In liquids molecules can rotate and translate freely.
- **Gas**: In the gas phase, the molecules are far apart from each other, and molecular ordering is nonexistent.



The arrangement of atoms in different phases: (a) molecules are at relatively fixed positions in a solid, (b) groups of molecules move about each other in the liquid phase, and(c) individual molecules move about at random in the gas phase.

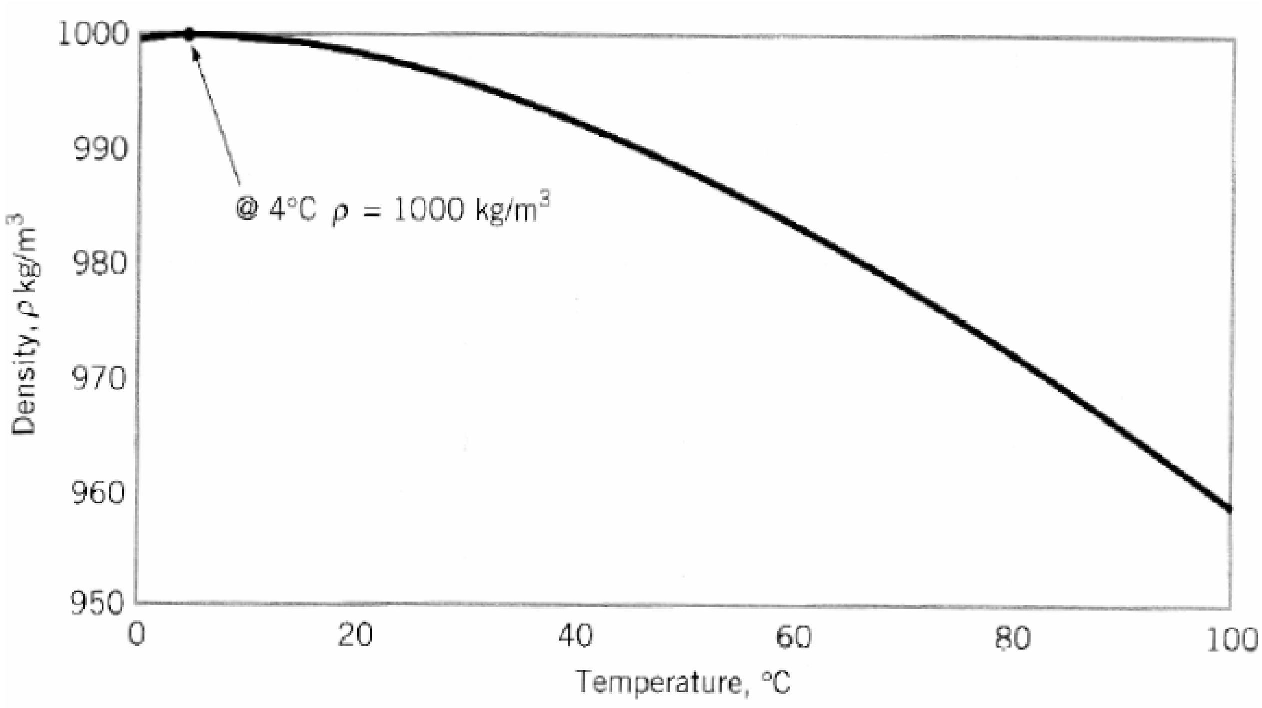
1- Density (ρ):

- **It is defined as a mass per unit volume.**

$$\rho = \text{mass} / \text{volume}$$

In the BG system *"ρ" has units of slugs/ft^3 and in SI the units are kg/m^3.*

✓ The density of a gas is strongly influenced by both pressure and temperature, but for liquids variations in pressure and temperature generally have only a small effect on the value of density.



Density of water as a function of temperature.

- The change in the density of water with large variations in temperature.

The specific volume, "v" is the volume per unit mass and is therefore the reciprocal of the density-that is,

$$v = V/m = 1/\rho$$

- ## Specific Weight (γ):

It is defined as a fluid weight per unit volume. Thus, specific weight is related to density through the equation

$$\gamma = \rho g$$

Where g is the gravitational acceleration (9.8 m/s^2).

In the BG system γ ***has units of*** lb/ft^3 ***and in SI the units are*** N/m^3**.**

- **Specific Gravity (SG):**

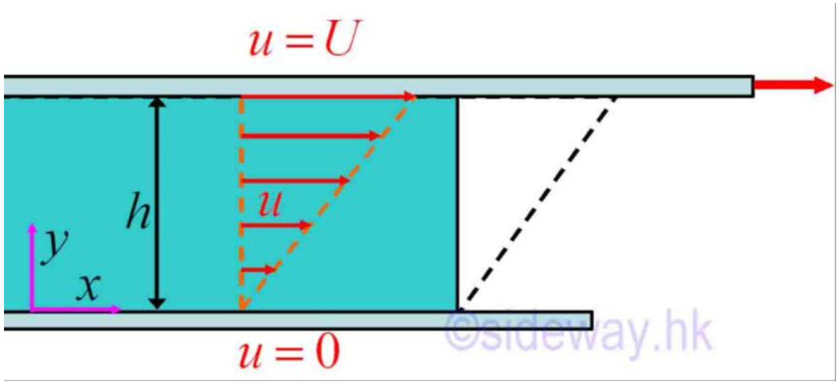
It is defined as the ratio of the density of the fluid to the density of water at 4^{o}C (39.2^{o}F), and at this temperature the density of water is 1.94 slugs/ft^3 or 1000 kg/m^3 . In equation form ,specific gravity is expressed as:

$$SG = \frac{\rho}{\rho_{H_2O@4\,^{\circ}C}} \qquad SG = \rho / 1000$$

Since SG is the ratio of densities, then it is *dimensionless quantity and its value does not depend on the system of units used.*

2- Viscosity

- It is a property describe the resistance of the fluid to the motion either it is internal resistance between the fluid layers or between the fluid and the solid boundaries.



- For liquids, it is found that the shear stress is proportional to the rate of shear strain (Velocity gradient)

Shear stress $\tau \propto \dot{\gamma}$ $\qquad \tau \propto \dfrac{du}{dy}$ $\qquad \tau = \mu \dfrac{du}{dy}$

$$\text{Shear stress} = \tau = \mu \frac{du}{dy}$$

- Where the constant of proportionality is called the **absolute viscosity**, **dynamic viscosity**, or simply the **viscosity** of the fluid

- It can be readily deduced that the dimensions of viscosity are $ML^{-1}T^{-1}$,Thus, in BG units viscosity is given as $lb.s/ft^2$ and in SI as $N.s/m^2$ or $Pa.s$.

Newtonian and non-Newtonian fluids

According to $\tau = \mu \frac{du}{dy}$, plots of τ versus du/dy should be linear with the slope equal to the viscosity as illustrated in Fig. 1.4. The actual value of the viscosity depends on the particular fluid, and for a particular fluid the viscosity is also highly dependent on temperature as illustrated in Fig. 1.4 with the two curves for water.

Fluids for which the shearing stress is linearly related to the rate of shearing strain (also referred to as rate of angular deformation) are designated as Newtonian fluids.

Fortunately most common fluids, both liquids and gases, are Newtonian.

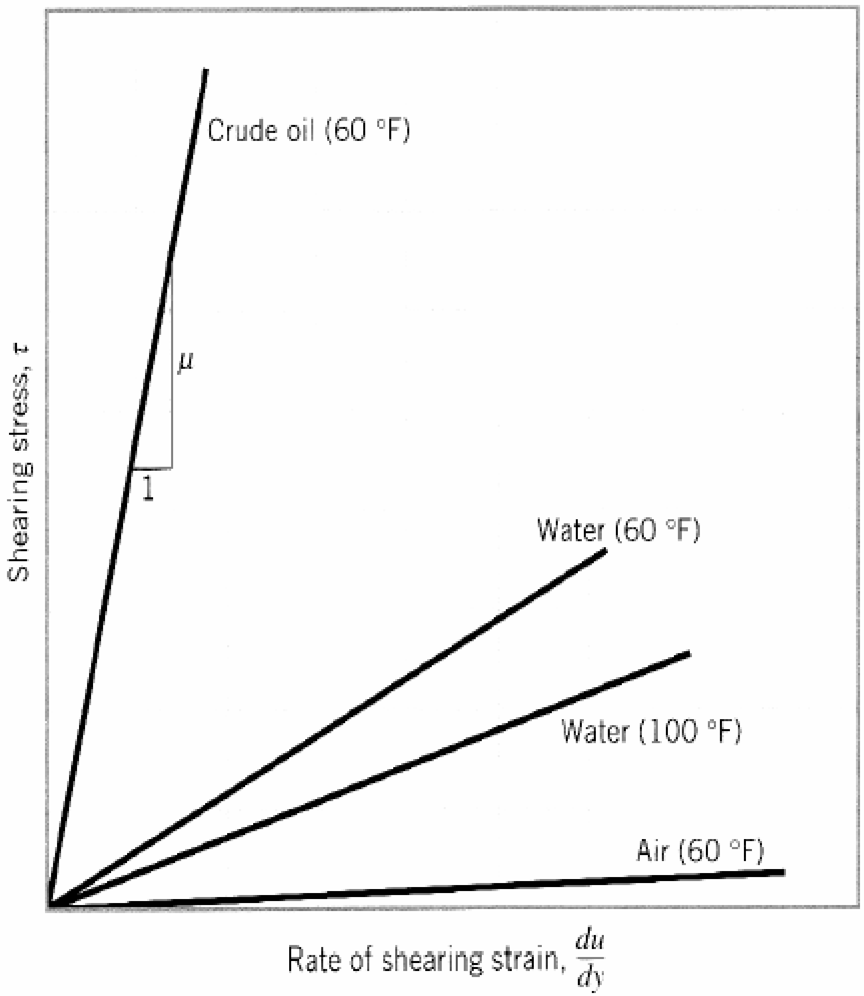


FIGURE 1.4 Linear variation of shearing stress with rate of shearing strain for common fluids.

Fluids for which the shearing stress is not linearly related to the rate of shearing strain are designated as non-Newtonian fluids. The simplest and most common of non-Newtonian fluids are shown in Fig. 1.5. The slope of the shearing stress versus rate of shearing strain graph is denoted as the apparent viscosity, μ_{ap}.

For Newtonian fluids the apparent viscosity is the same as the viscosity and is independent of shear rate.

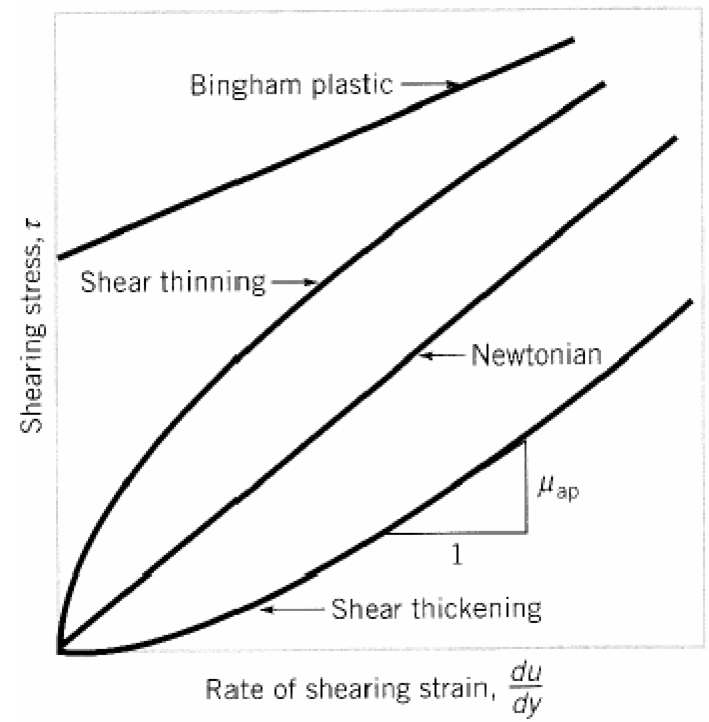


FIGURE 1.5 Variation of shearing stress with rate of shearing strain for several types of fluids, including common non-Newtonian fluids.

• <u>The Kinematic Viscosity</u>

- **It is defined as the ratio of the absolute viscosity to the fluid density .i.e.,**

$$\nu = \frac{\mu}{\rho}$$

- **The dimensions of kinematic viscosity are *L^2/T and the BG system are ft^2/s and SI are m^2/s.***

<u>Important Note:</u>

Dynamic viscosity is often expressed in the metric CGS (centimeter-gram - second) system with units of dyne. s/cm^2. This combination is called a "poise".

In the CGS system, kinematic viscosity has units of cm^2/s, and this combination is called a "stoke".

Units Kinematic Viscosity

$$\text{Kinematic viscosity} = \nu = \mu / \rho$$

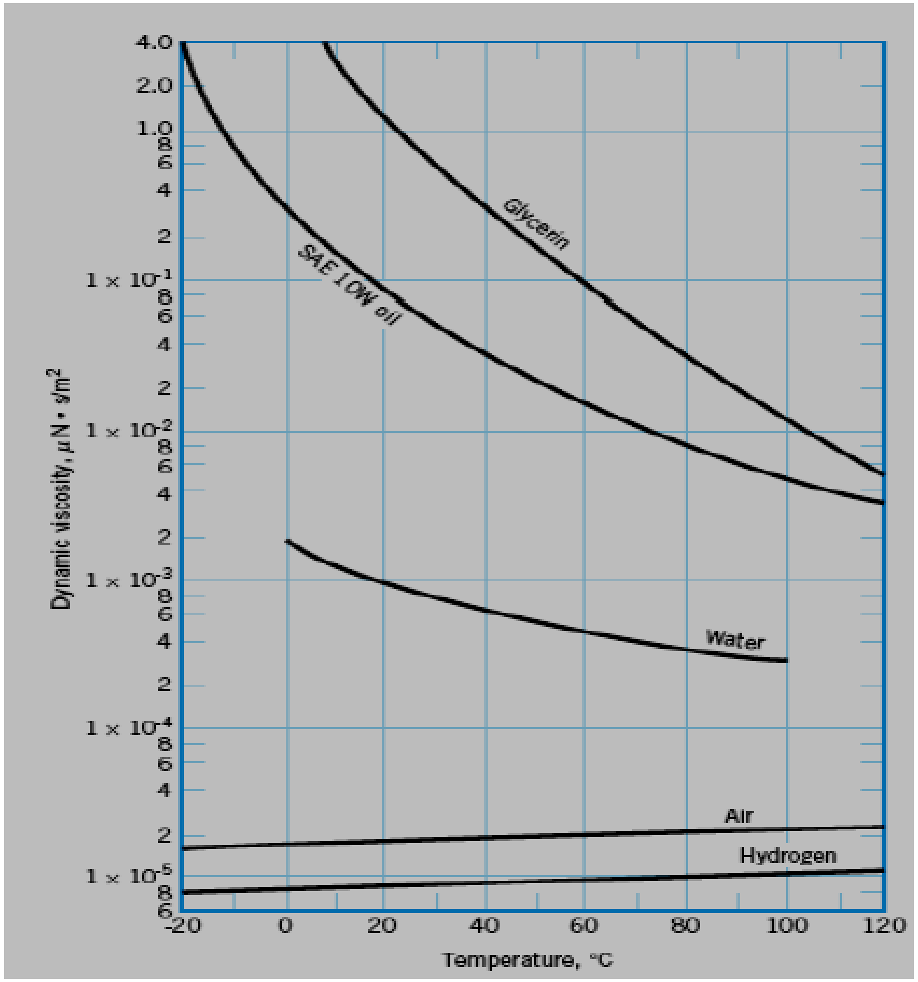
The most common unit of kinematic viscosity is the centistoke (cSt)

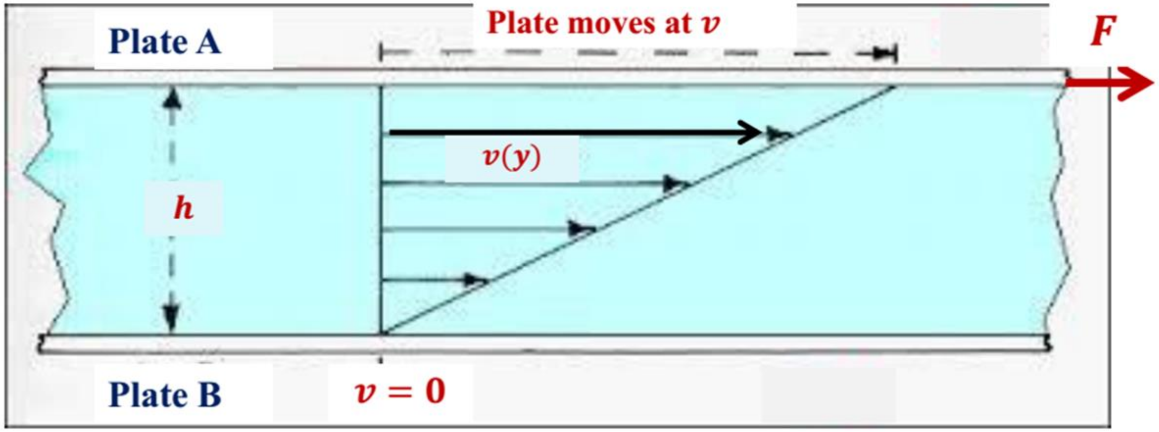
$$1 \text{ cSt} = \frac{1 \text{ cP}}{1 \text{ g/cm}^3} = 10^{-6} \frac{\text{m}^2}{\text{s}} = 1.08 \times 10^{-5} \frac{\text{ft}^2}{\text{s}}$$

at 68°F = 20°C, water has a kinematic viscosity of 1.004 ≈ 1 cSt. To

For Dynamic viscosity : 1 pa.s = 10 poise = 1000 cp
For kinematic viscosity : 1 m^2/s = 10^4 St = 10^6 cSt

The effect of temperature on viscosity





Shear stress = F/A

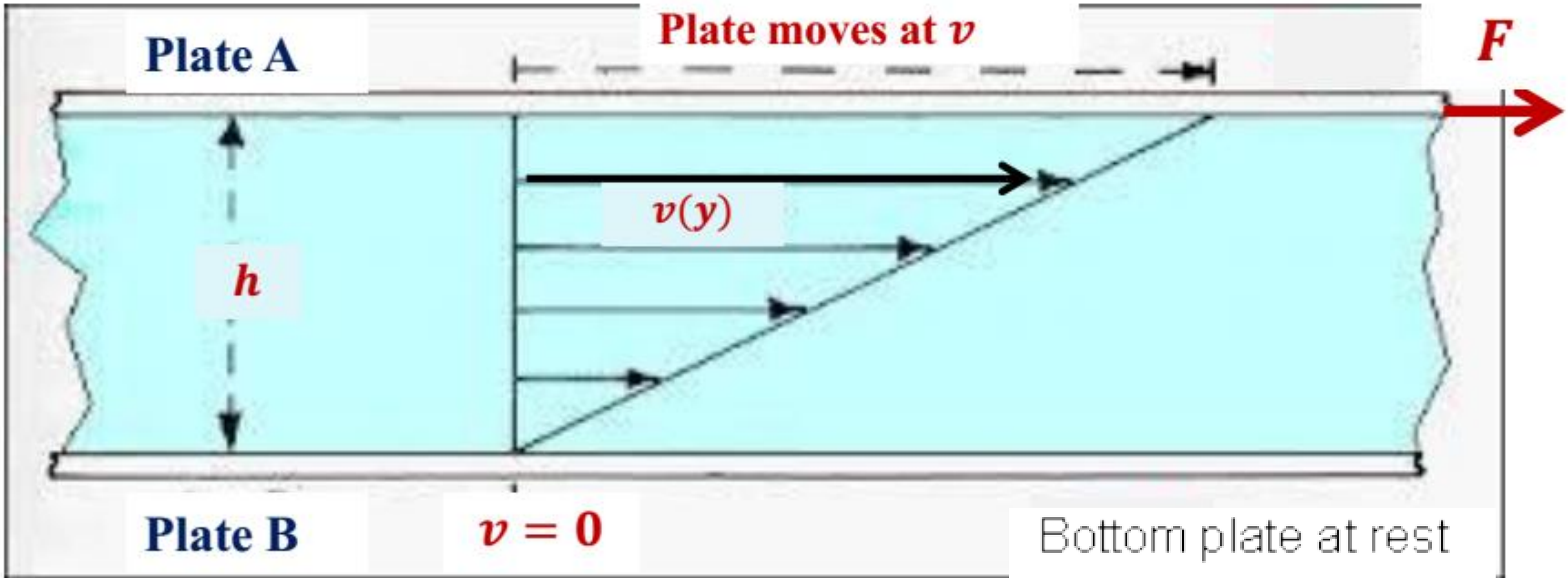
$$\text{Shear stress} = \tau = \mu \frac{du}{dy} = F/A$$

$$F = \eta A \frac{d\,v}{d\,y}$$

F : The force required **to move a plate**

A : Area of the plate

$\frac{d\,v}{d\,y}$ **:the velocity gradient**



$$F = \eta A \frac{dv}{dy}$$

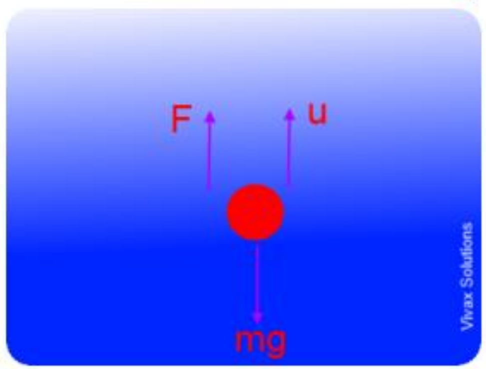
$$F = \eta A \left(\frac{v - 0}{h}\right)$$

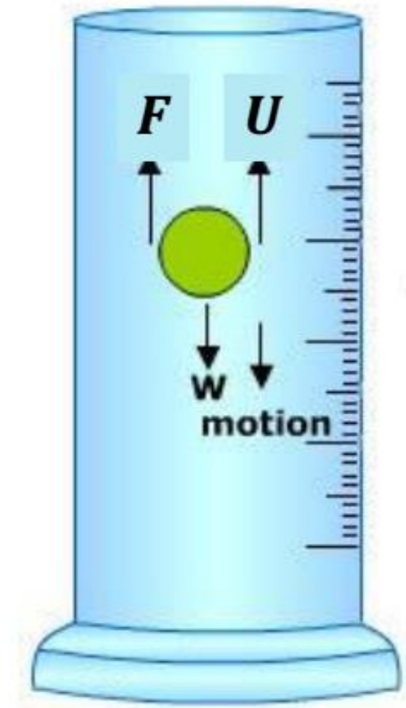
Stoke’s Law

Stoke’s Law

- **Stokes' law** and terminal velocity. When any object rises or falls through a fluid it will experience a viscous drag, whether it is a parachutist or spacecraft falling through air, a stone falling through water or a bubble rising through fizzy lemonade.

- Consider the movement of a ball inside a viscous fluid:
- **Radius : r**
- **Coefficient of Viscosity : η**
- Density of the ball : ρ_s
- **Density of the liquid : ρ_l**
- **Acceleration due to Gravity : g**





Stoke's Law

The ball is subjected to the influence of three forces: they are the **weight, up thrust** and the viscous force - drag or liquid friction.

W: Weight of the ball :

$\mathbf{W = mg = 4/3\ \pi\ r^3}\ \rho_S\ \mathbf{g}$

U: Up thrust on the ball by the liquid
(Buoyancy force)

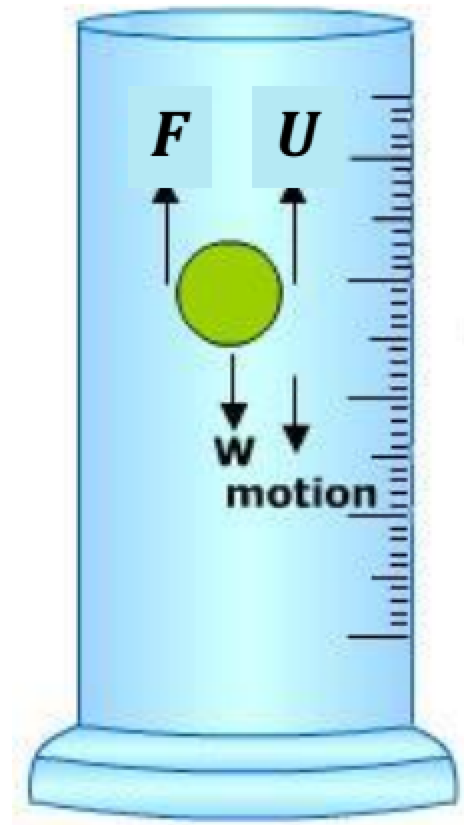
$U = v\ \rho_L\ g = 4/3\ \pi\ r^3\ \rho_L\ \mathbf{g}$

Stoke's Law

- According to **Stokes Law**,
  Viscous force: $F = 6\pi\eta r v$,
- where v is the velocity at a given a time.

$$W = U + F$$

$$\frac{4}{3}\pi r^3 \rho_s g = \frac{4}{3}\pi r^3 \rho_L g + 6\pi\eta r v$$



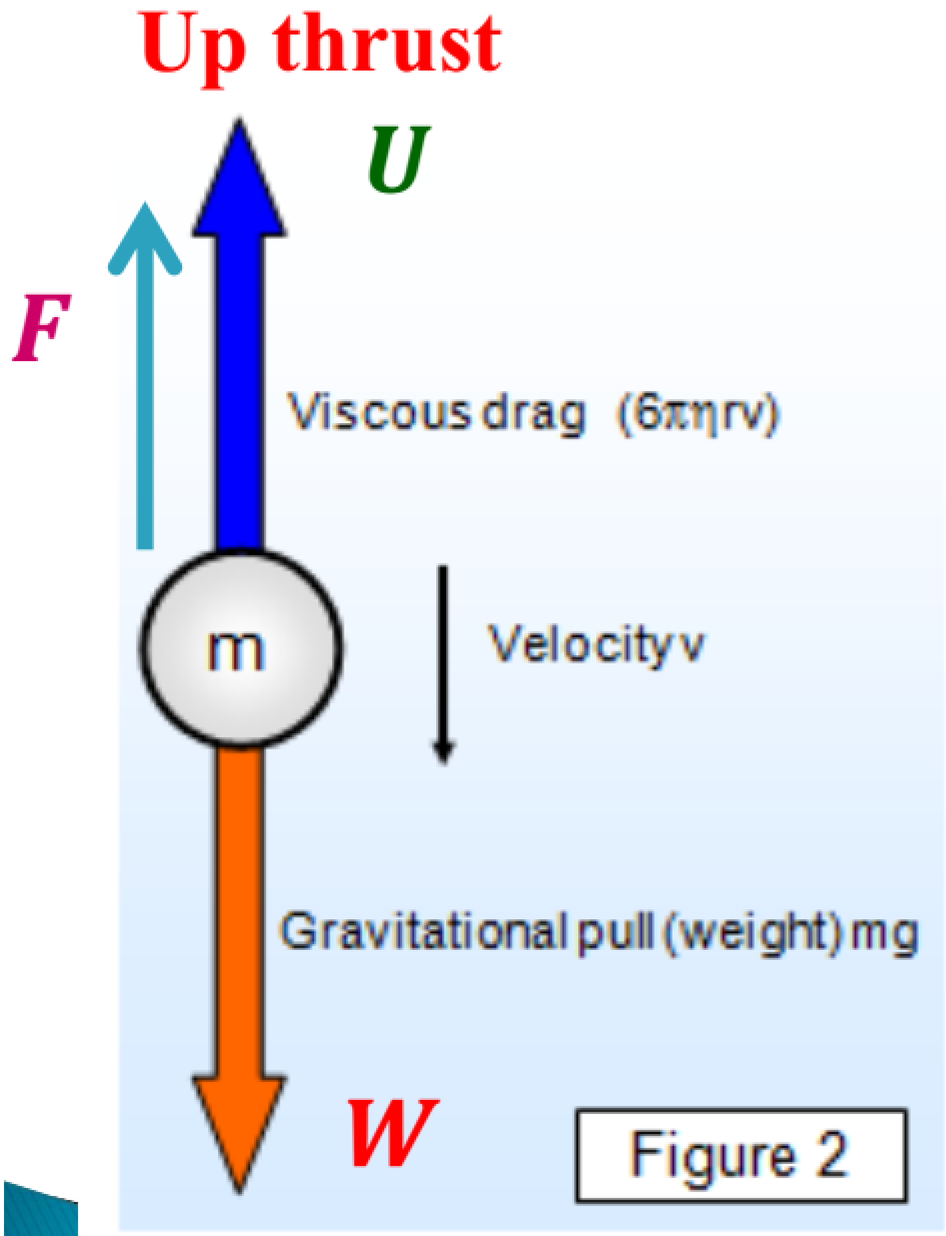


Figure 2

$$W = U + F$$

$$\eta = \frac{2}{9}\frac{r^2}{v}(\rho_s - \rho_L)\,g$$