CHAPTER (2)

FLUID PROPERTIES

SUMMARY

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FLUID PROPERTIES

System: Is defined as a given quantity of matter.

Surroundings: Anything that is not part of the system is considered to be part of the surrounding.

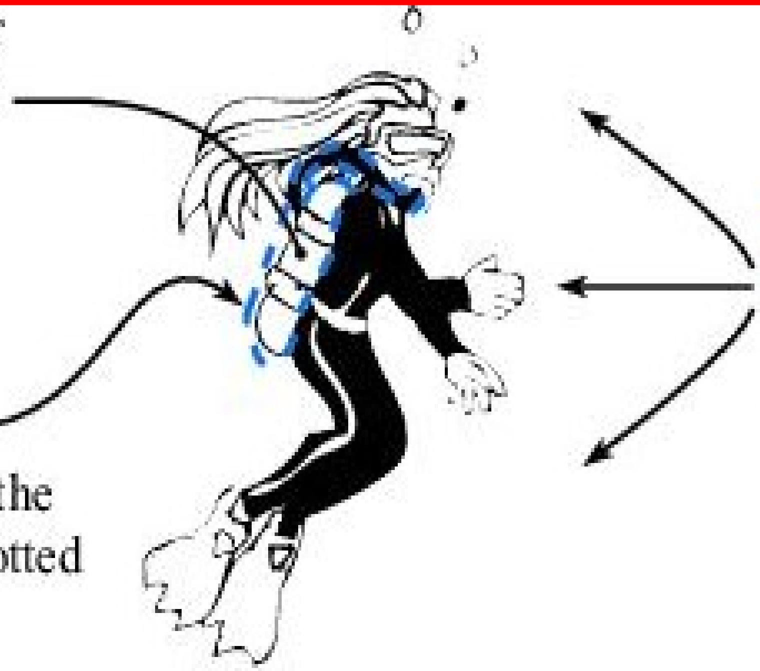
Boundary: Is the real or imaginary surface that seperates the system from its surrounding.

Example (2.2)

EXAMPLE. Suppose an engineer is analyzing the air flow from a tank being used by a SCUBA diver. As shown in Fig. 2.2, the engineer might select a system comprised of the tank and the regulator. For this system, everything that is external to the tank and regulator is the surroundings. Notice that *the system is defined with a sketch* because this is good professional practice.

System: What the engineer selects for study (tank plus regulator in this example)

Boundary: The surface separating the system and the surroundings (shown by dotted blue line in this example)



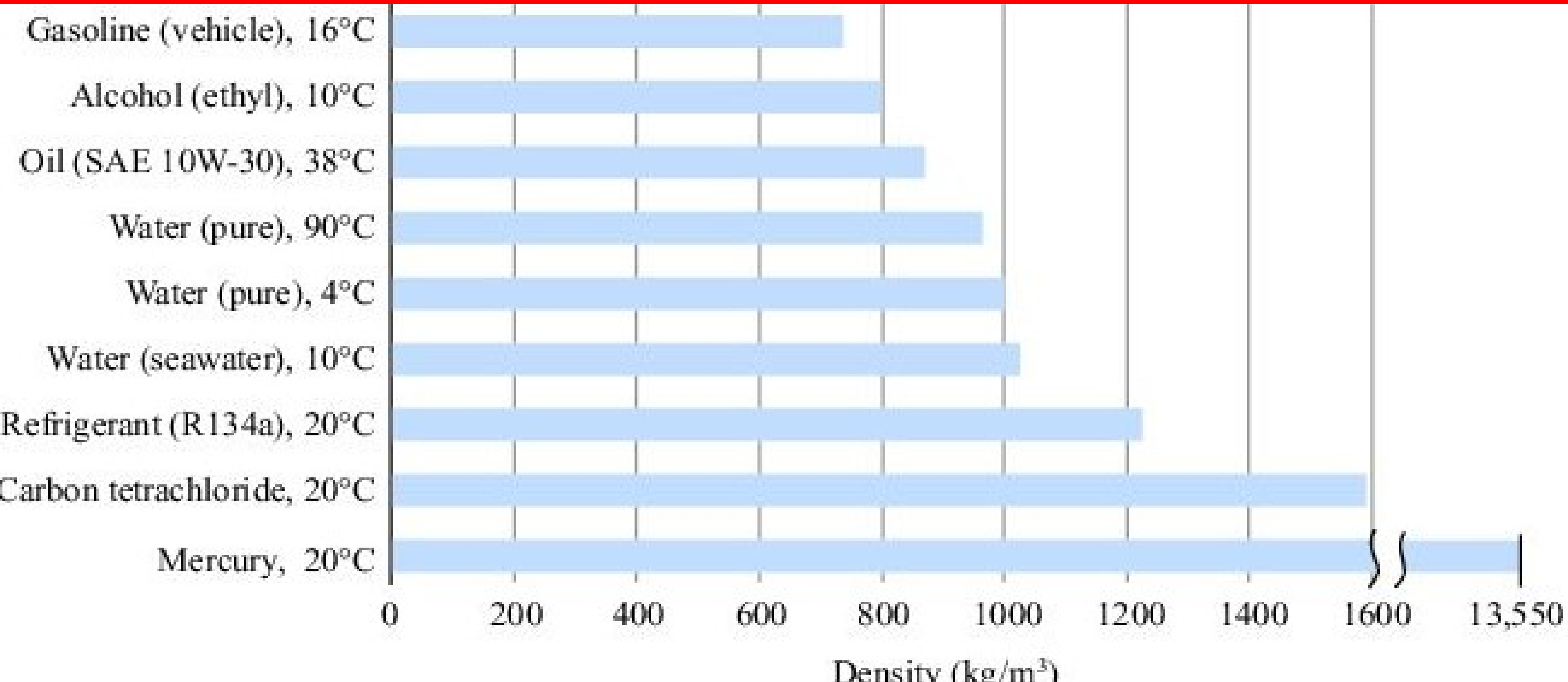
Surroundings: Everything that is not part of the system (in this example, the air bubbles, water, diver, etc.)

$$Desnity = \frac{Mass}{volume}, \quad \rho = \frac{m}{V}$$

Because water is common in application, some useful values to memorize are

$$\rho_{water,\,4°C} = 1000\ kg/m^3 = 1\ kilogram/liter = 1\ gram/milliliter$$

$$\rho_{water,\,59°F} = 62.4\ lbm/ft^3 = 1.94\ slug/ft^3 = 8.345\ lbm/gal\ (US)$$



Specific Weight

$$\frac{Weight}{volume} = \frac{mg}{V} = \rho g = \gamma$$

Specific Gravity

$$\frac{specific\ weight\ of\ fluid}{specific\ weight\ of\ water} = \frac{\gamma_f}{\gamma_w} = \frac{(\rho g)_{fluid}}{(\rho g)_{water}} = \frac{\rho_f}{\rho_w}$$

TABLE 2.2 Summary of Fluid Properties

Property	Units (SI)	Temperature Effects	Pressure Effects (common trends)	Notes
Density (ρ): Ratio of mass to volume at a point	$\frac{kg}{m^3}$	$\rho\downarrow$ as $T\uparrow$ if gas is free to expand	$\rho\uparrow$ as $p\uparrow$ if gas is compressed.	• *Air.* Find ρ in Table F.4 or Table A.3. • *Other Gases.* Find ρ in Table A.2. • *Caution!* Tables for gases are for $p = 1$ atm. For other pressures, find ρ using the ideal gas law.
		$\rho\downarrow$ as $T\uparrow$ for liquids	ρ of liquids are constant with pressure	• *Water.* Find ρ in Table F.5 or Table A.5. • *Note.* For water, $\rho\uparrow$ as $T\uparrow$ for temperatures from 0 to about 4°C. Maximum density of water is at $T \approx 4°C$. • *Other Liquids.* Find ρ in Table A.4.
Specific Weight (γ): Ratio of weight to volume at a point	$\frac{N}{m^3}$	$\gamma\downarrow$ as $T\uparrow$ if fluid is free to expand	same trends as density	• Use same tables as for density. • ρ and γ can be related using $\gamma = \rho g$. • *Caution!* Tables for gases are for $p = 1$ atm. For other pressures, find γ using the ideal gas law and $\gamma = \rho g$.
Specific Gravity (S or SG): Ratio of (density of a liquid) to (density of water at 4°C)	none	SG$\downarrow$ as $T\uparrow$	SG of liquids are constant with pressure	• Find SG data in Table A.4. • SG is used for liquids, not commonly used for gases. • Density of water (at 4°C) is listed in Table F.6.

Example (2.4)

EXAMPLE. Specific weight for mercury is $\gamma_{mercury} = 133\ kN/m^3$. Calculate the density and specific gravity. Use SI units.

Solution. Applying Eq. (2.3) gives density:

$$\rho_{mercury} = \frac{\gamma_{mercury}}{g} = \frac{(133,000\ N/m^3)}{(9.81\ m/s^2)} = 13,600\ kg/m^3$$

Applying Eq. (2.5) and the reference value for γ_{H_2O} from Table F.6 gives

$$S_{mercury} = \frac{\gamma_{mercury}}{\gamma_{liquid\ water,\ 4^\circ C}} = \frac{(133,000\ N/m^3)}{(9810\ N/m^3)} = 13.6$$

Review. To validate the calculated values of ρ and S, one can consult Table A.4. Note that S has no units because it is a ratio.

Bulk Modulus of Elasticity (E_V)

The elasticity of a fluid is related to the amount of deformation (expansion or contraction) *for a Given Pressure Change*.

The *bulk modulus of elasticity*, E_V, is a property that relates changes in pressure to changes in volume (e.g., expansion or contraction)

$$E_v = -\frac{dp}{d\forall / \forall} = -\frac{\text{change in pressure}}{\text{fractional change in volume}}$$

For an Isothermal Process (Constant temperature)

$$E_V = \rho \frac{dp}{d\rho} = \rho RT = p$$

For an Adiabatic Process (No heat transfer)

$$E_V = kp$$

The Constant Density assumption

High-speed flows of gases, such as the flow around a jet airplane, need to be modeled as compressible flows (see Chapter 12). To distinguish *constant density gas flow* from *variable density gas flow*, engineers use the Mach number M. The Mach number is the ratio of the speed of the flowing fluid V to the speed at which sound travels in the fluid c:

$$\text{Mach number} = M \equiv \frac{V}{c}$$

A *criterion for idealizing a gas as constant density* is:

$$(M < 0.3) \tag{2.8}$$

When flow is steady and Eq. (2.8) is satisfied, the density variation is less than 5% (2).

Viscosity OR Dynamic Viscosity

Viscosity (derives from the Latin word "Viscum") Is a measure of the resistance of a fluid which is being deformed by Shear Stress.

Viscosity : A property that characterize resistance of a fluid to Shear Stress and fluid friction.

$$\mu$$

$$\tau = \mu \frac{dV}{dy}$$

Linear velocity

$$\tau = \mu \frac{d(\omega r)}{dy}$$

Angular velocity

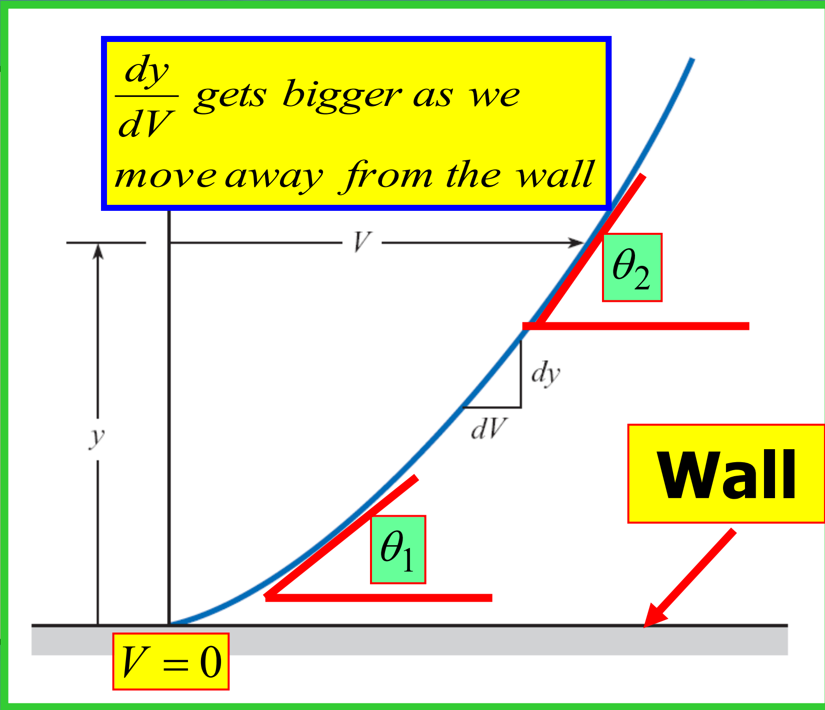
PRINCIPLE VISCOSITY

By definition, $\tau \propto \frac{dV}{dy}$ **, Then** $\tau = \mu \frac{dV}{dy}$

Where:

$\tau =$ **Shear stress applied**

$\frac{dV}{dy} =$ **Velocity gradient (Shear Strain)**



Units of Viscosity:

$$\mu = \frac{\tau}{\left(\frac{dV}{dy}\right)} = \frac{N/m^2}{\frac{m/s}{m}} = \frac{N\,s}{m^2}$$

Common Unit for Viscosity is Poise. (1 poise = $0.1\frac{Ns}{m^2}$ **).**

PRINCIPLE VISCOSITY

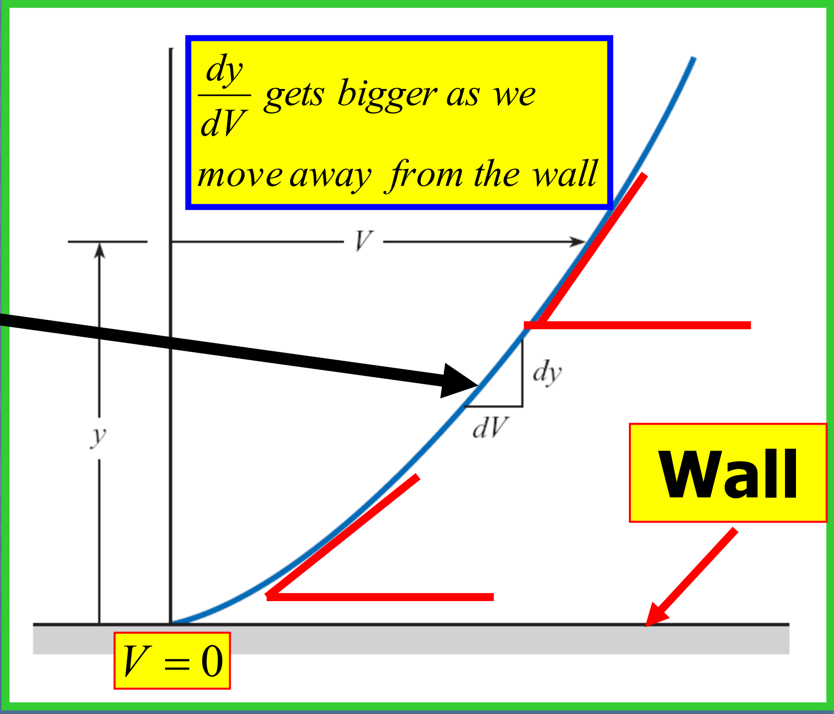
Consider the flow shown Fig. 1 where the velocity distribution is typical of a <u>laminar flow</u> next to a solid boundary. The following <u>observations</u> can be identified which are:

1. **The velocity gradient at the boundary is finite.** $dV/dy \neq 0$

2. **The velocity gradient , becomes smaller, with distance from the boundary.** $\left(\frac{dV}{dy}\right)$

3. **The velocity at the boundary is zero.** $V = 0$

Fig. (1)



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Kinematic Velocity

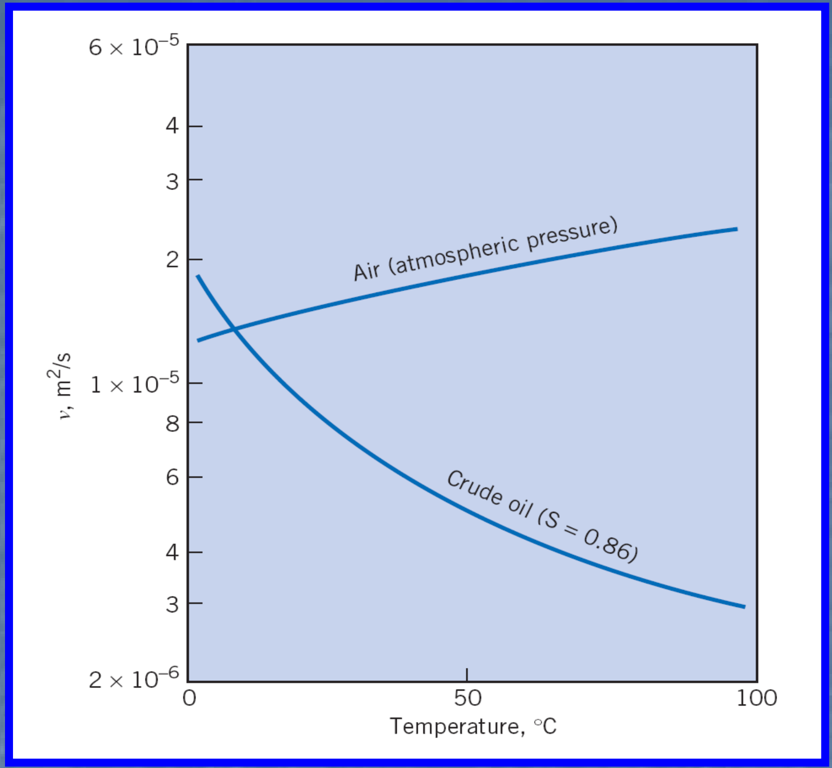
Kinematic viscosity: A property that characterizes the mass and viscous properties of a fluid.

$$\nu = \frac{\mu}{\rho}\left(\frac{m^2}{s}\right)$$

Units of Kinematic Viscosity

$$\nu = \frac{\mu}{\rho} = \frac{Ns/m^2}{kg/m^3} = \frac{m^2}{s}$$

Viscosity Temperature Dependency



1. Variation of viscosity with temperature_*for Liquids*

Viscosity decreases as the temperature increases

2. Variation of viscosity with temperature_*for Gases*

Viscosity increases as the temperature increases

Viscosity Temperature Dependency

An equation for the variation of viscosity with temperature <u>for Liquids:</u>

$$\mu = Ce^{b/T}$$

Sutherland Equation for Gases

$$\frac{\mu}{\mu_0} = \left(\frac{T}{T_0}\right)^{3/2}\left(\frac{T_0 + S}{T + S}\right)$$

Where (S) is Sutherland Constant

Viscosity Pressure Dependency

Viscosity is *<u>minimal</u>* for pressure less *<u>than 10 atmospheres</u>*

Newtonian and Non-Newtonian Fluids

Newtonian Fluids

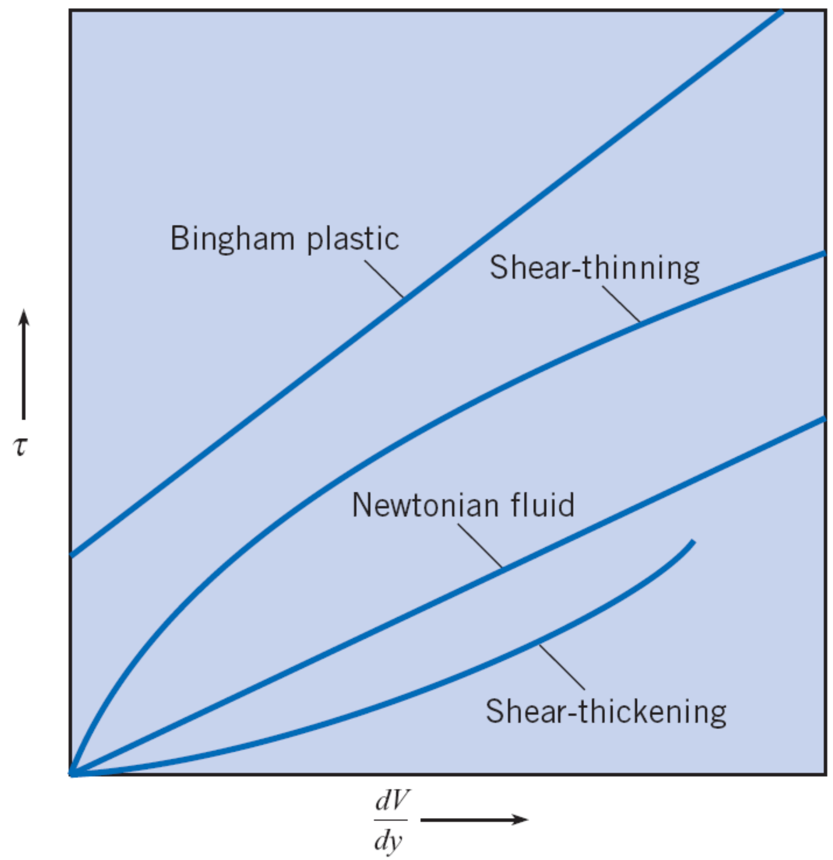
Newtonian fluids are identified when only $\tau \; \alpha \left(\frac{dV}{dy} \right)$

Non-Newtonian Fluids

- **Shear Thinning** :(paints, printer ink)

  Shear Thickening: (gypsum-water mixture, glass particles in water).

- **Bingham plastic**

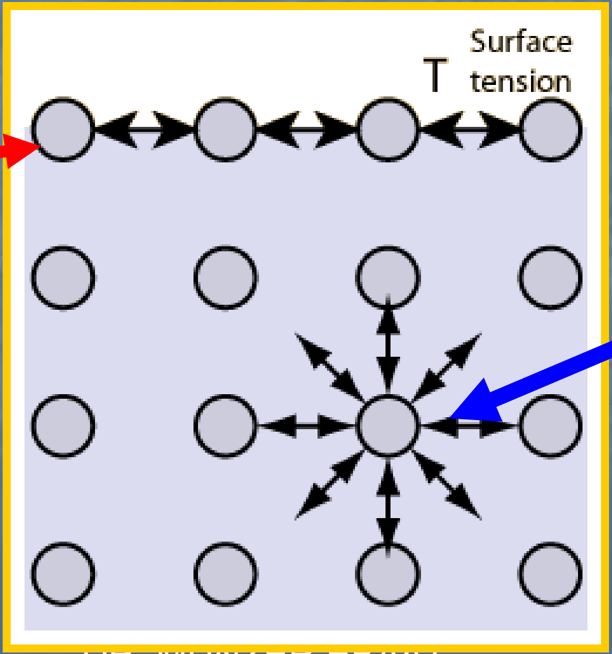


Surface Tension

Surface tension: A property that characterizes the tendency of a liquid surface to behave as a stretched membrane.

The Cohesive Forces between molecules down into a liquid are shared with all neighboring atoms. Those on the surface have no neighboring atoms above, and exhibit stronger attractive forces upon their nearest neighbors on the surface. This enhancement of the intermolecular attractive forces at the surface is called Surface Tension.

Surface Tension



Intermolecular Forces

Examples of Surface Tension

1. **Wicking:** Water will wick into a paper, Ink wick into a paper.
2. **Capillary rise:** A liquid will rise in a small diameter tube.
3. **Drop and bubble formation:** Soap bubbles.
4. **Excess pressure:** Pressure inside a water drop is higher than ambient pressure.
5. **Walking in water:** An insect walking in water, needle, paper clip.
6. **Detergents:** They lower the surface tension of water so that the water can more easily wick into the pores of the fabric.

Surface Tension

$$\text{Surface tension} = \frac{\text{Force along an interface}}{\text{Area of the interface}}$$

$$\frac{N}{m}$$

$$\sigma = \frac{F}{A_s} \rightarrow F = \sigma \times A_s$$

$$\text{Surface tension} = \frac{\text{Energy } \textit{required to} \text{ increase the surface area of a liquid}}{\text{unit area}}$$

$$\frac{J}{m^2}$$

Surface tension typically has a magnitude ranging from (1 – 100 mN/m)

Adhesion and Cohesion Forces

Adhesion: **Attractive forces between dissimilar materials**

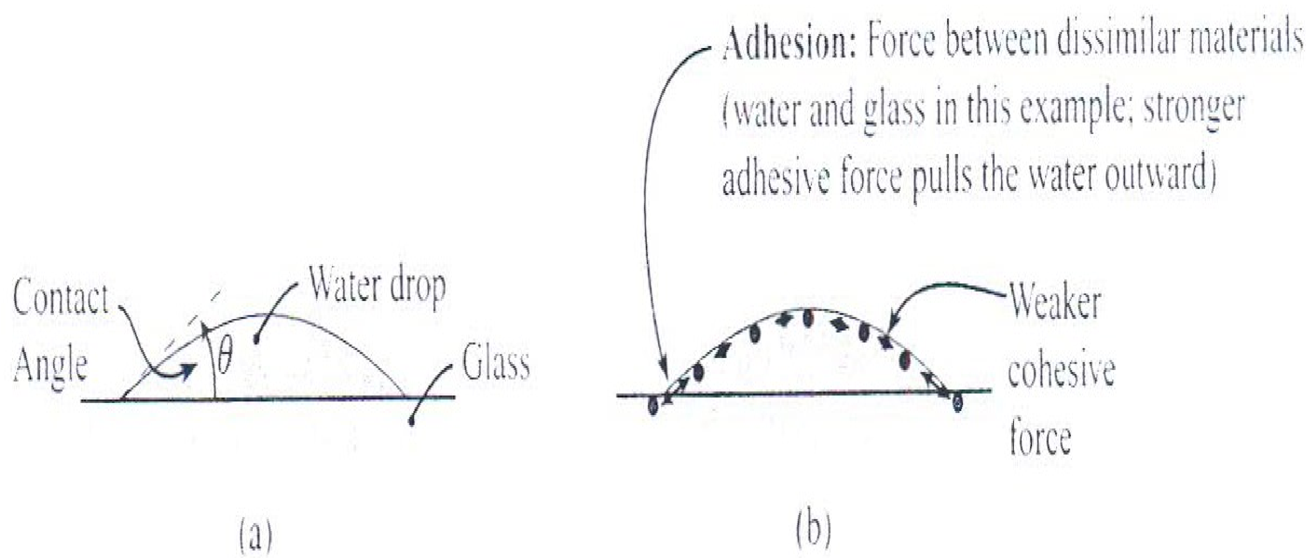
Cohesion: **Attractive forces between molecules of the same materials.**

Hydrophillic phenomena (Water loving)

Ex: Water spreads on glass

FIGURE 2.17

Water wets glass because adhesion is greater than cohesion. Wetting is associated with a contact angle less than 90°.



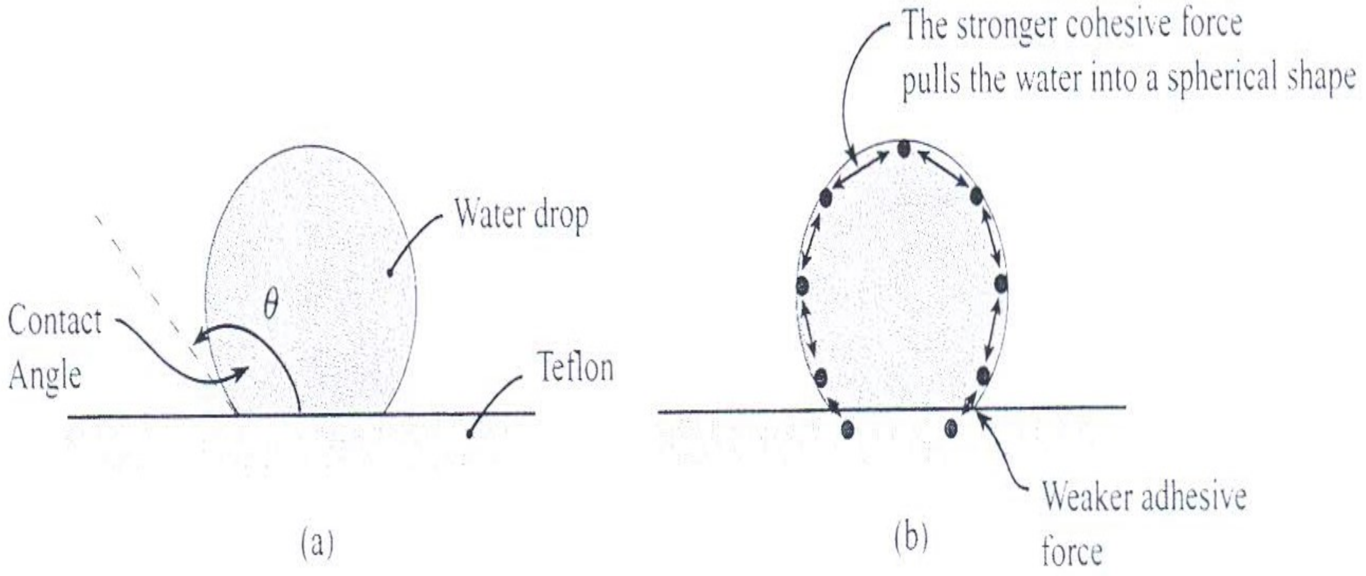
Adhesion and Cohesion Forces

Hydrophobic phenomena (Water hating)

Ex: Water on Teflon or Wax paper

FIGURE 2.18

Water beads up a hydrophobic material such as Teflon because adhesion is less than cohesion. A nonwetting surface is associated with a contact angle greater than 90°.



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Surface Tension Forces for some cases

$$F_\sigma = \sigma L = pA$$

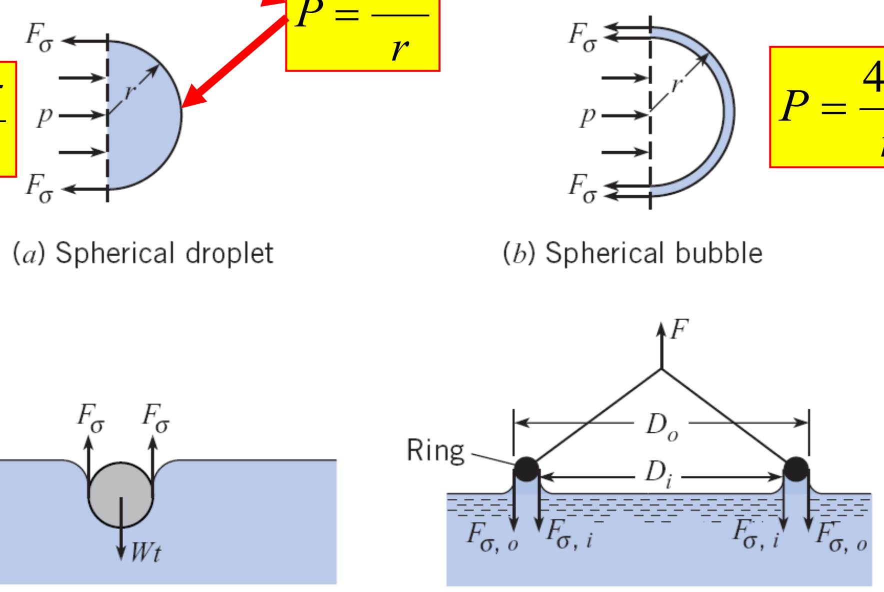
$$2\pi r\sigma = \pi p r^2$$

Gauge pressure

$$P = \frac{2\sigma}{r}$$

$$2F_\sigma = 2\sigma 2\pi r = p\pi r^2$$

$$P = \frac{4\sigma}{r}$$



(a) Spherical droplet

(b) Spherical bubble

(c) Cylinder supported by surface tension (liquid does not wet cylinder)

(d) Ring pulled out of liquid (liquid wets the ring)

$$2F_\sigma = 2\sigma L = Wt$$

$$F_\sigma = F_{\sigma,i} + F_{\sigma,o}$$

Vapour Pressure

The pressure exerted by a vapor; often understood to mean saturated vapor pressure.

(The pressure of a vapor in contact with its liquid form and increases with temperature).

<u>Vapor pressure depends on various factors which are:</u>

- **The nature of the liquid.**
- **Temperature.**
- **The presence of dissolved substances.**

End of

Chapter (2)