Fluid Properties

CVEN 212

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Fluid Properties

- System, Extensive & Intensive Properties
- Mass and Weight
- Relationships between Pressure and volume
  - Ideal Gas Law
  - Flow of Heat
  - Bulk Modulus of Elasticity
- Viscosity
- Vapor Pressure
- Surface Tension

Viccosity

Definition of a Fluid

- "a substance that deforms continuously when subjected to a shear stress, no matter how small that shear stress may be"
  - *Streeter, Wylie, Bedford*

System, Extensive & Intensive Properties

- System: a given quantity of matter

- Extensive properties
  - related to the total mass of the system
  - represented by upper-case letters
  - e.g., M: mass ; W: weight

- Intensive properties
  - independent of the amount of fluid
  - designated by lowercase letters
  - e.g., p: pressure; ρ: density

* Mass (Kg)
* $W = Mg$ (N)
* Density $\rho = \frac{M}{V}$ $\left(\frac{Kg}{M^3}\right)$
* Specific weight $\gamma = \frac{W}{V}$ $\left(\frac{N}{M^3}\right)$

$= \rho g$

* Specific Volume $(v) = \frac{V}{M} = \frac{1}{\rho}$ $\left(\frac{M^3}{Kg}\right)$
* Specific Gravity $S = \frac{\gamma_F}{\gamma_{H_2O}} = \frac{\rho_F}{\rho_{H_2O}}$

$\gamma_{water} = 9810 \ N/M^3$

$\rho_{water} = 1000 \ Kg/M^3$

Equation of State for Gases

(ideal gas law)

$$PV = RT$$

- P: absolute pressure
- v: specific volume $= 1/\rho$
- R: Gas Constant from tables
- T: absolute temperature, $T(K) = T(C) + 273$

$$\frac{P}{\rho} = RT$$

$$\rho = \frac{P}{RT} \quad \} \text{ Density}$$

Properties involving the flow of heat

- Specific Heat, c
  - describes the capacity of a substance to store thermal energy
  - for gases:
    - c_v: specific volume remains constant
    - c_p: pressure held constant
- Specific Internal Energy, u
  - energy that a substance possesses because of the state of the molecular activity
    - for ideal gas, u is a function of T only
- specific enthalpy, h
  - $h=u+p/\rho$
  - function of T only

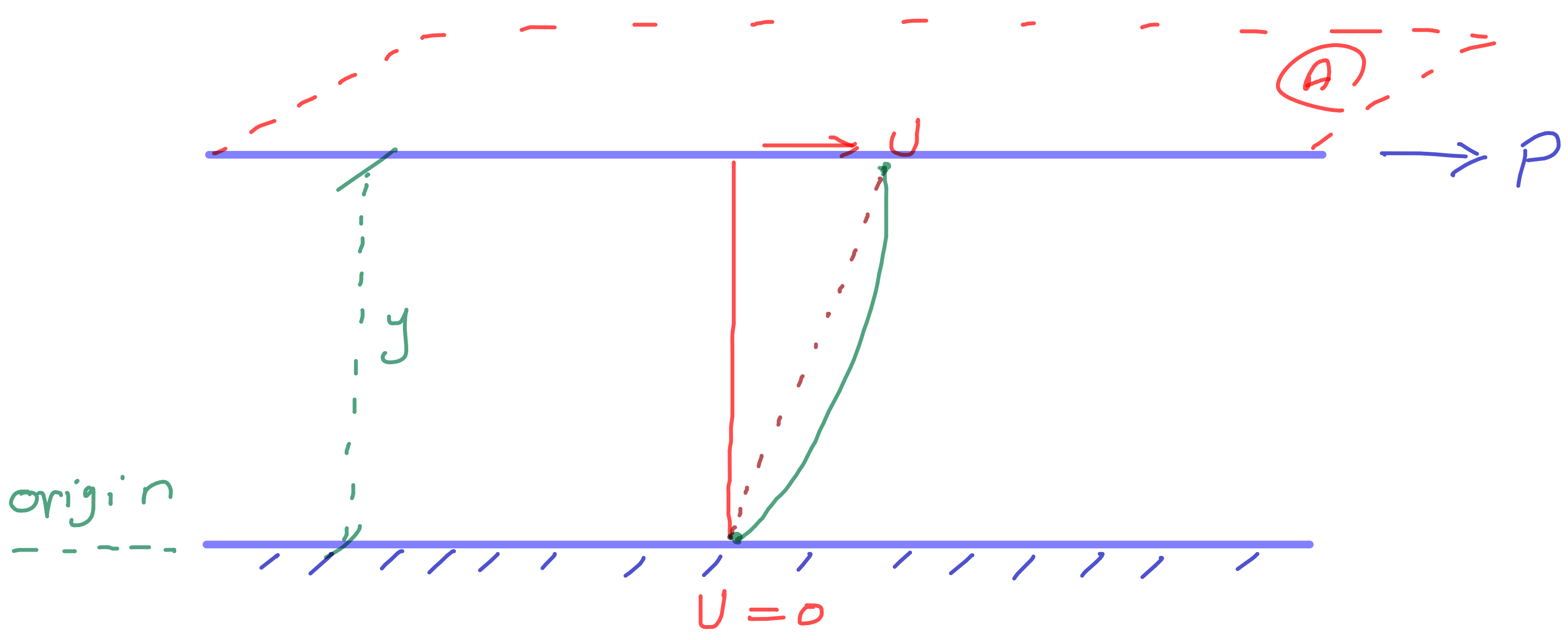
Bulk Modulus of Elasticity

- Relates the change in volume to a change in pressure
- measures the "compressibility" of the fluid
- pressure waves

$$E_v = -\frac{dp}{dV/V}$$

- E_v: bulk modulus of elasticity
- dp: incremental pressure change
- V: fluid volume
- dV: the incremental volume change

Viscosity



$P \parallel A$ } Shear Force

$$\tau = \frac{P}{A}$$

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$ } General Eq

$$\tau = \mu \frac{\Delta u}{\Delta y}$$ } Newtonian

$$\frac{P}{A} = \mu \frac{\Delta u}{\Delta y}$$

$\mu \rightarrow \frac{N \cdot s}{m^2}$

Dynamic Viscosity

Fluid Viscosity

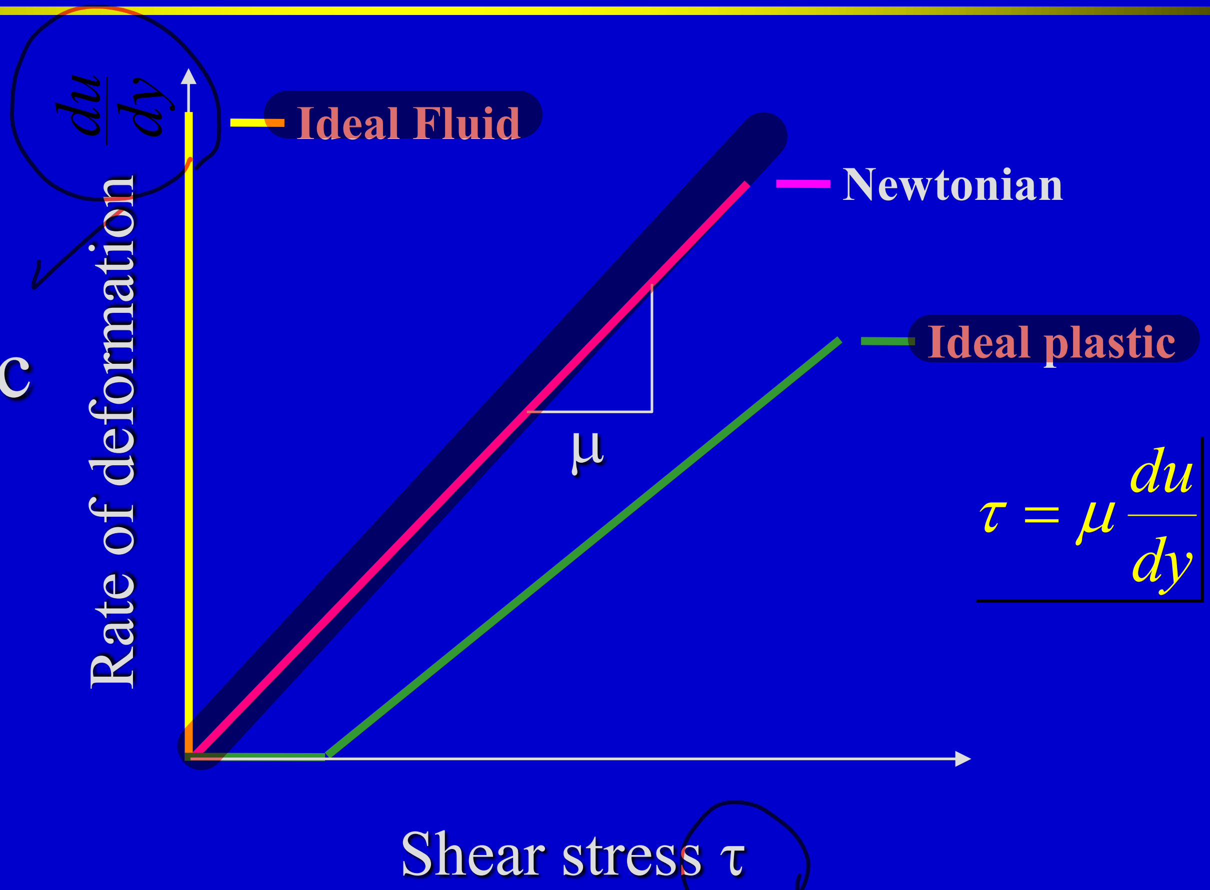
- Examples of highly viscous fluids
  - molasses, tar, 20w-50 oil (Run a Video)
- Fundamental mechanisms
  - Gases - transfer of molecular momentum
    - Viscosity increases as temperature increases.
    - Viscosity increases as pressure increases.
  - Liquids - cohesion and momentum transfer
    - Viscosity decreases as temperature increases.
    - Relatively independent of pressure (incompressible)

Role of Viscosity

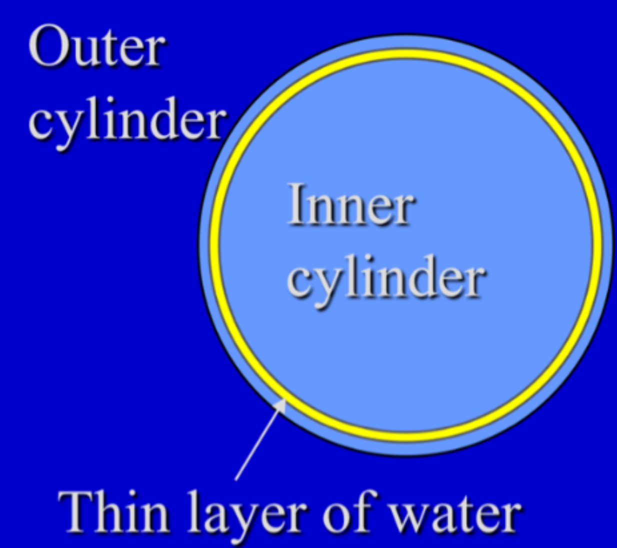
- Statics
  - Fluids at rest have no relative motion between layers of fluid and thus $du/dy = 0$
  - Therefore the shear stress is zero and is independent of the fluid viscosity
- Flows
  - Fluid viscosity is very important when the fluid is moving

Fluid classification by response to shear stress

- Newtonian
- Ideal Fluid
- Ideal plastic



The inner cylinder is 10 cm in diameter and rotates at 10 rpm. The fluid layer is 2 mm thick and 10 cm high. The power required to turn the inner cylinder is 50×10^{-6} watts. What is the dynamic viscosity of the fluid?



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$$\omega = 10 \text{ rpm} = \frac{10 * 2\pi}{60} = 1.047 \ \text{rad/s}$$

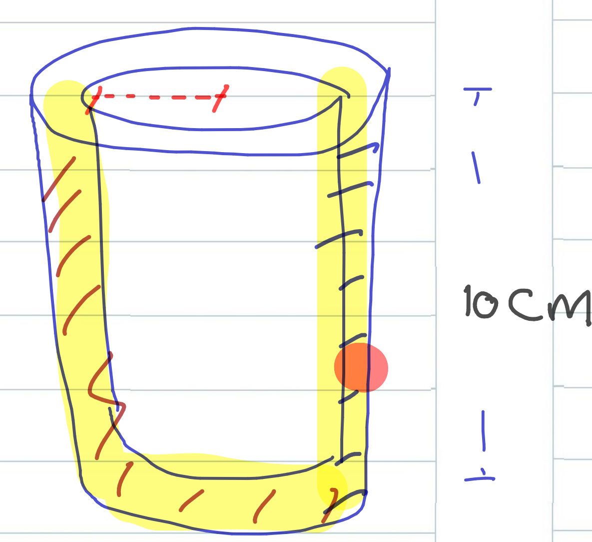
$$U = \omega r = 1.047 * 0.05$$

$$= 0.052 \ \text{m/s}$$

$$y = 2 \text{ mm}$$

$$P = F U$$

$$50 * 10^{-6} = F * 0.052$$



$$F = 9.615 * 10^{-4} \ \text{N}$$

$$\tau = \mu \frac{\Delta U}{\Delta y}$$

$$\frac{F}{A} = \mu \frac{\Delta U}{\Delta y}$$

$$\mu = \frac{F \ \Delta y}{A \ \Delta U} = \frac{F \ \Delta y}{2\pi r h \ \Delta U}$$

$$= \frac{9.615 * 10^{-4} * 2 * 10^{-3}}{2\pi (0.05)(0.1) * 0.052}$$

$$\mu = 1.17 * 10^{-3} \ \text{N·s/m}^2$$

Dynamic and Kinematic Viscosity

- Kinematic viscosity is a fluid property obtained by dividing the dynamic viscosity by the fluid density

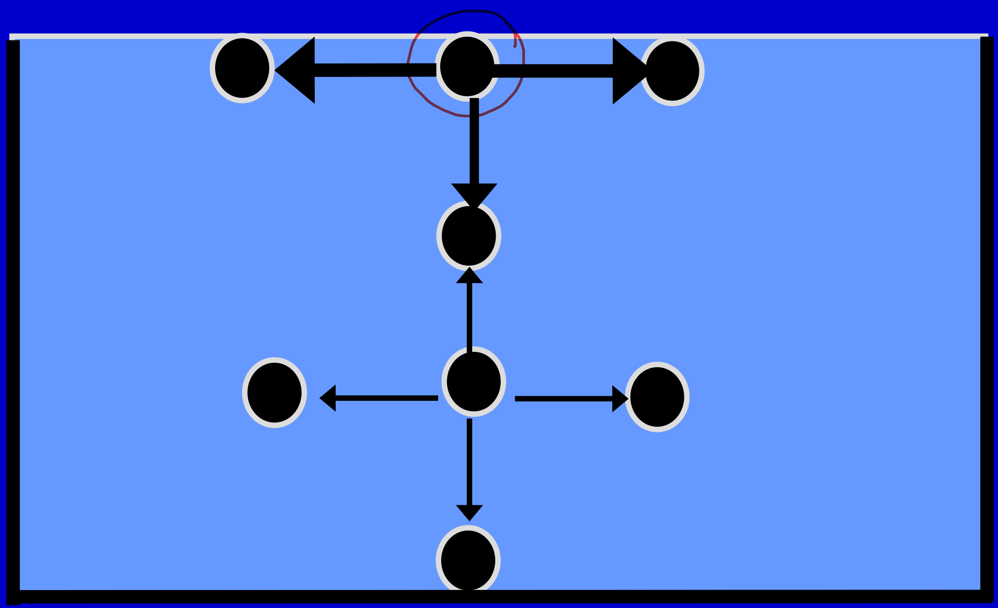
$$\nu = \frac{\mu}{\rho}$$

$$\nu = \frac{\left[\frac{\text{kg}}{\text{m}\cdot\text{s}}\right]}{\left[\frac{\text{kg}}{\text{m}^3}\right]}$$

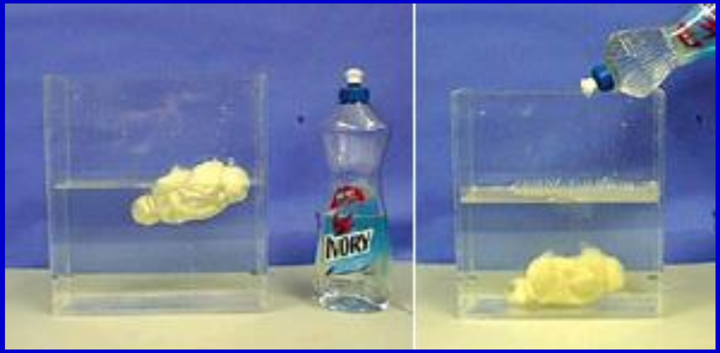
$[\text{m}^2/\text{s}]$

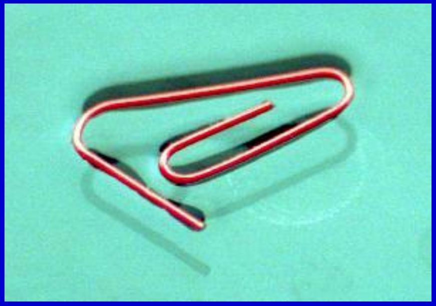
Surface Tension

- molecules below the surface act on each other through forces that are equal in all directions
- molecules near the surface have a greater attraction for each other than they do for molecules below the surface

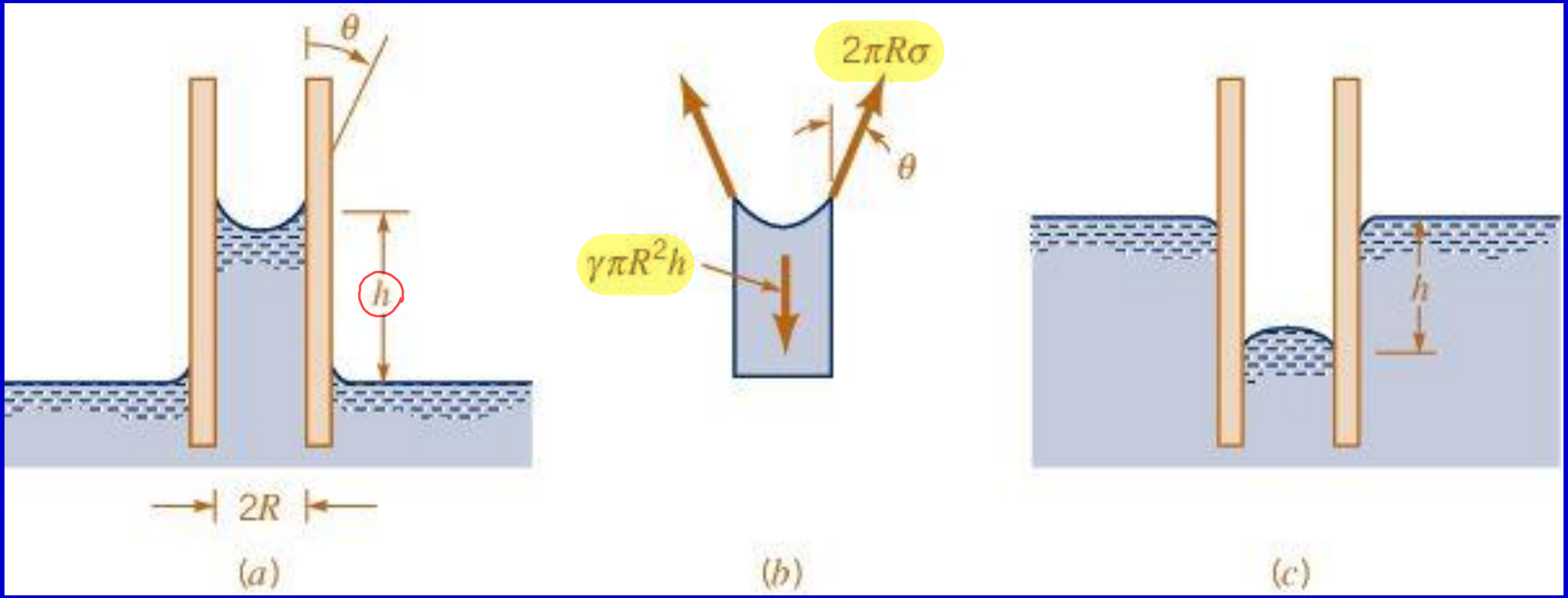


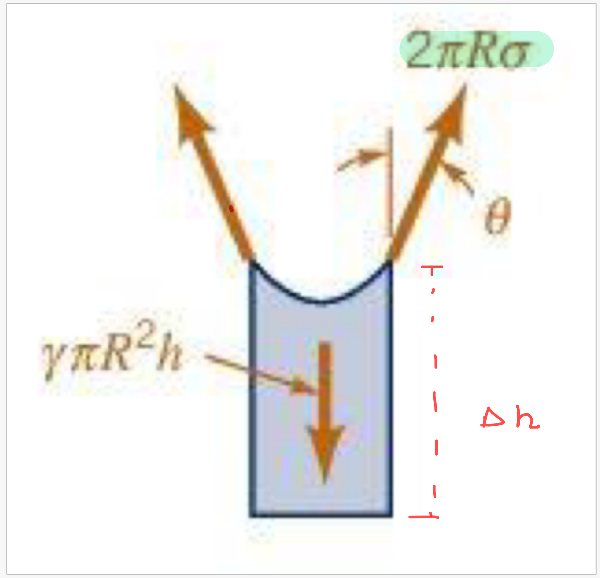
Surface Tension - Examples





Surface Tension and Capillary Rise



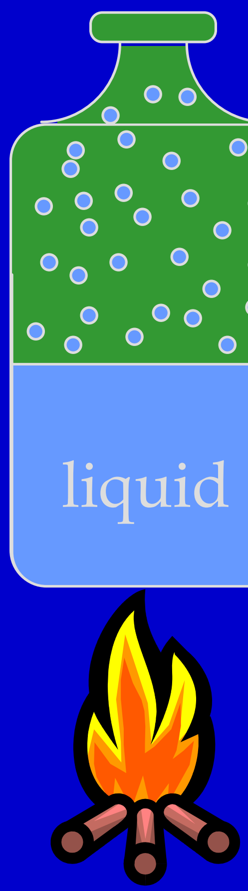


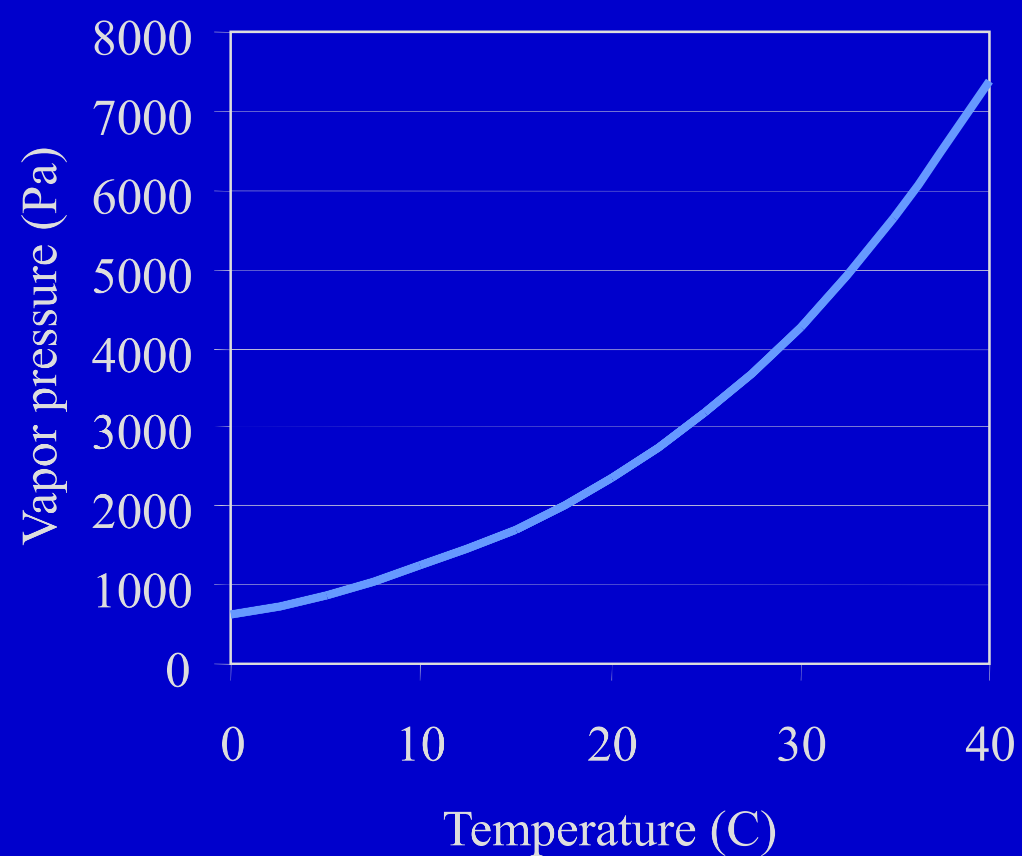
$$\Delta h = \frac{4\sigma \cos\theta}{\gamma d}$$

Vapor Pressure

- Def'n: pressure at which a liquid will boil
  - the vapor pressure of water at 212 °F is 14.7 psia (i.e., atmospheric pressure)
  - at 70 °F, the vapor pressure is 0.363 psia
- Cavitation: "boiling" in flowing liquids; e.g., suction side of a pump

Vapor Pressure





What is vapor pressure of water at 100°C? 101 kPa

Problem 1:

(1.13) Make use of Table 1.2 to express the following quantities in SI units: **(a)** 10.2 in./min, **(b)** 4.81 slugs, **(c)** 3.02 lb,**(d)** 73.1 ft/s^2, **(e)** 0.0234 $lb \cdot s/ft^2$.

Problem 2:

(1.15) Water flows from a large drainage pipe at a rate of 1200 gal/min. What is this volume rate of flow in **(a)** m^3/s, **(b)** liters/min, and **(c)** ft^3/s?

	length	time	Mass	Force	Gravity
SI	M	Sec	Kg	N	$9.81\ M/s^2$
US	Ft	Sec	Slug	Ib	$32.2\ Ft/s^2$

Problem 3:

(1.19) The density of a certain liquid is 2.15 slugs/ft^3. Determine its specific weight and specific gravity.

$$\gamma = \rho g = 2.15 * 32.2 = 69.2\ \frac{Ib}{Ft^3}$$

$$S.G = \frac{\rho}{\rho_{H_2O}} = \frac{2.15}{1.94}$$

$$= 1.11$$

Problem 4:

(1.31) Nitrogen is compressed to a density of 4 kg/m^3 under an absolute pressure of 400 kPa. Determine the temperature in degrees Celsius.

$$\rho = 4\ Kg/M^3$$

$$P = 400\ KPa$$

$$\frac{P}{\rho} = RT$$

$$T = \frac{P}{\rho R}$$

$$= \frac{400 * 10^3}{4 * 296.8} = 337\ (K)$$

$$T(c) = 337 - 273 = 64^\circ C$$

Problem 5:

(1.41) The viscosity of a certain fluid is $5 \text{ X } 10^{-4}$ poise. Determine its viscosity in both SI and BG units.

$$1 \text{ Poise} = 10^{-1} \frac{N \cdot s}{m^2}$$

$$\mu = 5 * 10^{-4} * 10^{-1} \frac{N \cdot s}{m^2} = 5 * 10^{-5} \frac{N \cdot s}{m^2}$$

$$\mu = 5 * 10^{-5} * \frac{0.2248}{(3.28)^2} \frac{lb \cdot s}{ft^2} = 10.4 * 10^{-7} \frac{lb \cdot s}{ft^2}$$

End of class ①