M E 320 Professor John M. Cimbala Lecture 03

Today, we will:

- Continue our discussion about fluid properties from Chapter 2
- Do some example problems – viscosity and surface tension

D. Properties of Fluids (continued)

3. Other (miscellaneous) properties (continued)

b. vapor pressure, P_v

P_v = same as P_{sat} (saturation pressure in thermo)

↓ from steam tables. Our book → Table A-3

E.g. @ 20°C, P_{sat} = 2.339 kPa → @ pressure of 2.339 kPa, water boil @ 20°C (vaporize)

@ 100°C, P_{sat} = 101.3 kPa (standard atm. pressure @ sea level

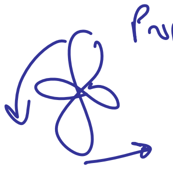
$P < P_{sea\ level}$ → water boils at a lower T

★ CAVITATION → local "boiling" of a liquid in regions of low pressure in a fluid flow

Cavitation bubbles form

★ If $P < P_v$, we form cavitation bubbles

e.g. Propeller



high V, low P } likely to cavitate

★ In general in flows, as V↑, P↓

Cavitation is bad because:

1) noise

2) damage to surfaces (pitting)

3. Other (miscellaneous) properties (continued)
c. viscosity, μ, and kinematic viscosity, ν

"**Viscosity**" typically means "**dynamic viscosity**" μ, also called the "**coefficient of viscosity**". [Some authors call it the "**molecular viscosity**".]

Dimensions of μ are $\boxed{\{\mu\} = \left\{\frac{\text{m}}{\text{Lt}}\right\}}$. Typical units of μ are kg/(m·s) [same as (N·s)/m^2].

Greek "mu"

Kinematic viscosity is defined as $\boxed{\nu = \frac{\mu}{\rho}}$, i.e., dynamic viscosity divided by density.

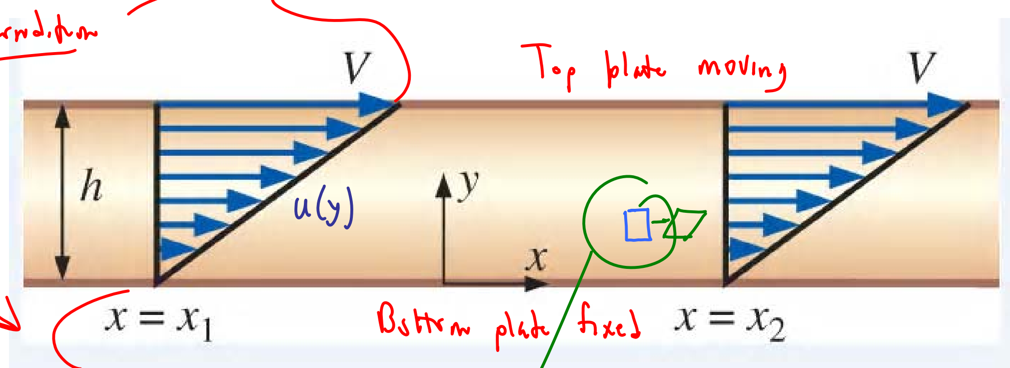
Greek "nu"

Dimensions of ν are $\boxed{\{\nu\} = \left\{\frac{\text{L}^2}{\text{t}}\right\}}$. Typical units of ν are m^2/s.

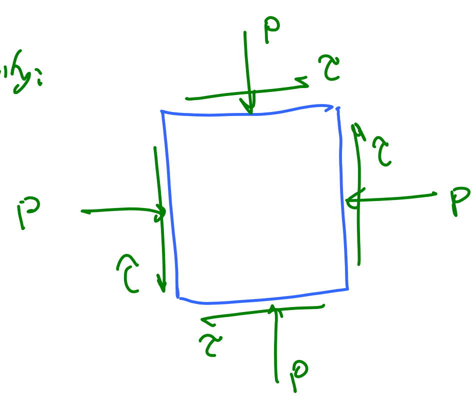
Viscosity is a measure of the importance of friction in a fluid flow [kind of like a coefficient of friction].

Example: Consider the fully developed simple 1-D flow field of a viscous fluid sandwiched between two infinite parallel plates. The upper plate is moving and the lower plate is stationary.

$u = u(y)$ only



Magnify:



For simple one-D shear flow like this, $\boxed{\tau = \mu \frac{du}{dy}}$ ★ (we prove in Ch. 9)

Also, τ = constant in this simple flow

$\mu \frac{du}{dy} = \text{const} \rightarrow$ $\boxed{u \text{ is linear in } y}$

$\left[\frac{du}{dy} = \frac{V}{h} \text{ for this case}\right]$

∴ $\boxed{\tau = \mu \frac{V}{h}}$ $\boxed{u = V \frac{y}{h}}$

Details: $\tau = \mu \frac{du}{dy} = \text{constant}$

$\frac{du}{dy} = \frac{\text{constant}}{\mu}$ → Integrate

$u = \frac{\text{const}}{\mu} y + C$

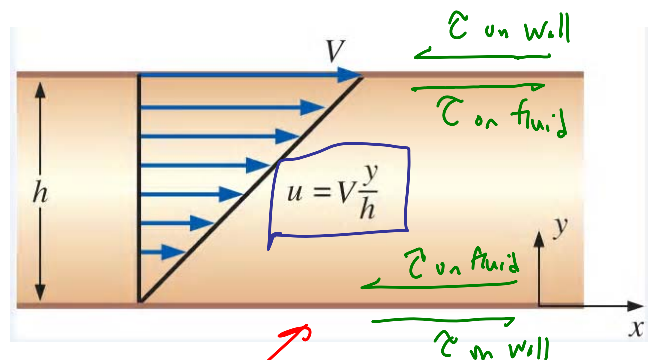
But @ $y=0$, $u=0 \rightarrow C=0$

@ $y=h$, $u=V \rightarrow \frac{\text{const}}{\mu} = \frac{V}{h}$

∴ $\boxed{u = \frac{V}{h} y}$ ✓

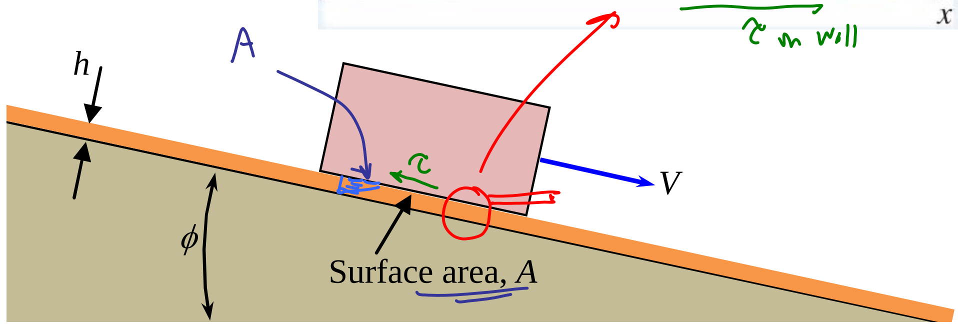
This simple flow turns out to have many practical applications, since

$$\boxed{\tau = \mu \frac{du}{dy} = \mu \frac{V}{h} = \text{constant}}$$



Example: Viscosity

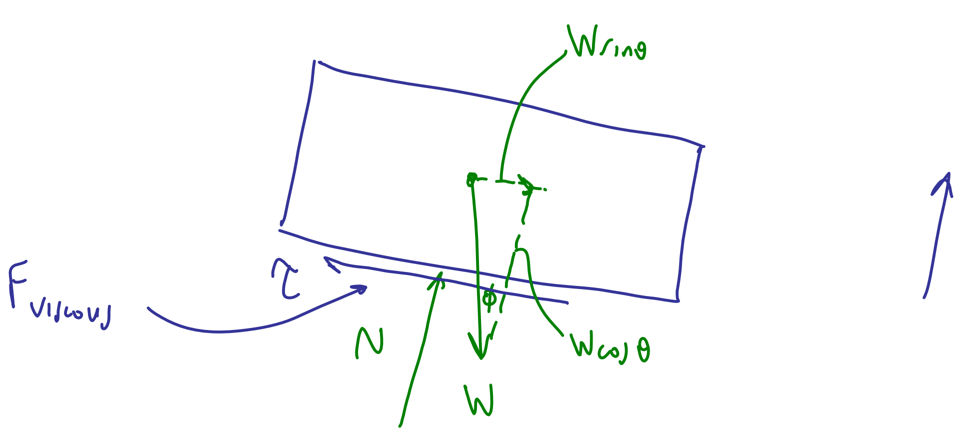
Given: A block of weight W and bottom surface area A slides steadily down an incline at speed V, riding on a thin film of oil of viscosity μ. The oil film thickness is h and the incline angle is ϕ as sketched.



To do: Calculate V as a function of the other variables (stay in variable form).

Solution:

Draw a F.B.D. of block



Const velocity $\rightarrow$ no accel. $\therefore$ $\sum \vec{F} = 0$

- direction normal to wall, $N = W\cos\phi$
- " // to " $F_{visc} = W\sin\phi$

But $\tau = \mu \frac{V}{h}$, $F_{visc} = \tau \cdot A$

$$\frac{\mu V A}{h} = W\sin\phi$$

$$\boxed{V = \frac{W h \sin\phi}{\mu A}}$$

μ is a fnc. of T, but typ. not a fnc. of P

In general,

$$\boxed{\begin{array}{l} \mu \uparrow \text{ as } T \uparrow \text{ in a gas} \\ \mu \downarrow \text{ as } T \uparrow \text{ in a liquid} \end{array}}$$

We are talking about Newtonian fluids $\left[\tau = \mu \frac{du}{dy} \text{ holds only for Newtonian fluids} \right]$

3. **Other (miscellaneous) properties (continued)**

d. surface tension, σ_s Greek "Sigma"

Surface tension applies to the surface of liquids. Think of it as an imaginary infinitesimally thin "skin" on the surface of the liquid, like the skin of a balloon that has been stretched and is in tension.

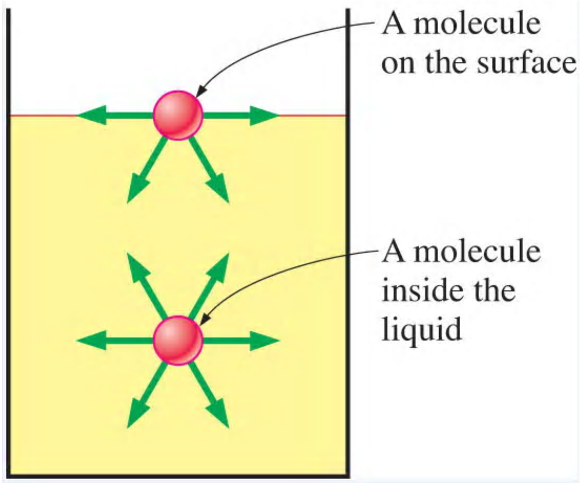
Dimensions of σ_s are $\boxed{\{\sigma_s\} = \left\{\frac{\text{force}}{\text{length}}\right\}}$.

express $\{\sigma_s\}$ in primary dims (m, L, t)

$$\{\sigma_s\} = \left\{\frac{mL/t^2}{L}\right\} = \left\{\frac{m}{t^2}\right\}$$

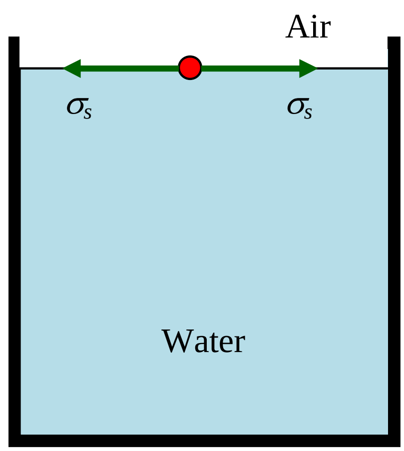
Typical units of σ_s are N/m.

Surface tension always acts *parallel* to the liquid surface. Why? The molecular attractive forces on a liquid molecule deep inside the liquid are uniform all around. However, on the *surface*, only the *lower half* of the molecule experiences attractive forces, as sketched.

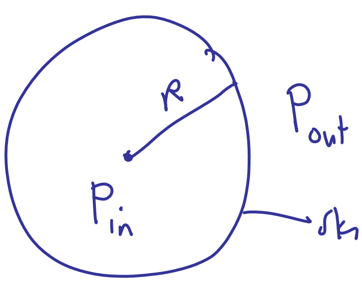


like a membrane on the surface

Example: A glass of water



Example → a soap bubble, analogous to a balloon

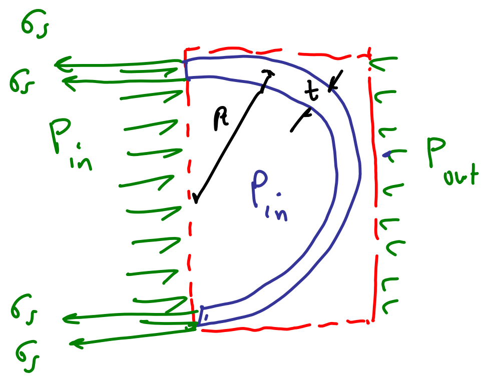


$(P_{in} > P_{out})$

skin is in tension like a balloon

Calculate ΔP for the soap bubble

F.B.D. of half of bubble



x-dir_ $\sum F_x = 0$

$t << R$

2 surfaces

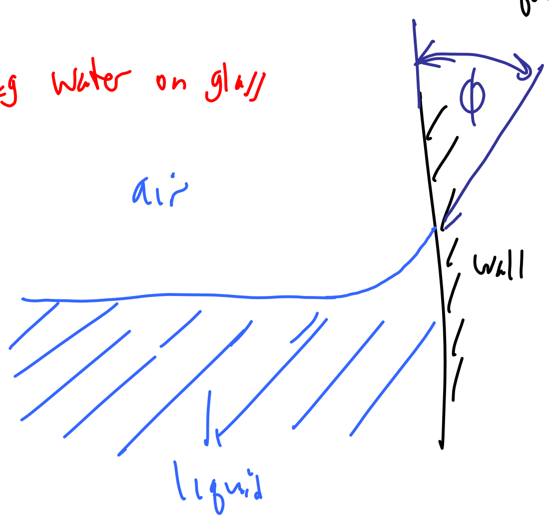
$$P_{in}(\pi R^2) = P_{out}(\pi R^2) + 2\sigma_s \cdot \underbrace{2\pi R}_{\text{circumference}}$$

Right   Left

$$\boxed{\Delta P = P_{in} - P_{out} = \frac{4\sigma_s}{R}}$$ ☆

Capillary Effect — When a liquid surface meets a wall, the liquid curves to some contact angle ϕ

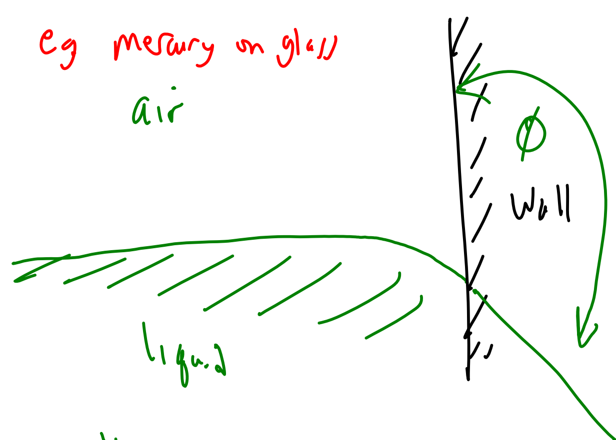
eg water on glass



"Wetting fluid"

$\phi < 90°$

eg mercury on glass



"Nonwetting fluid"

$\phi > 90°$