Chemical Engineering 374

Fluid Mechanics

Lecture 2

Fluid Properties

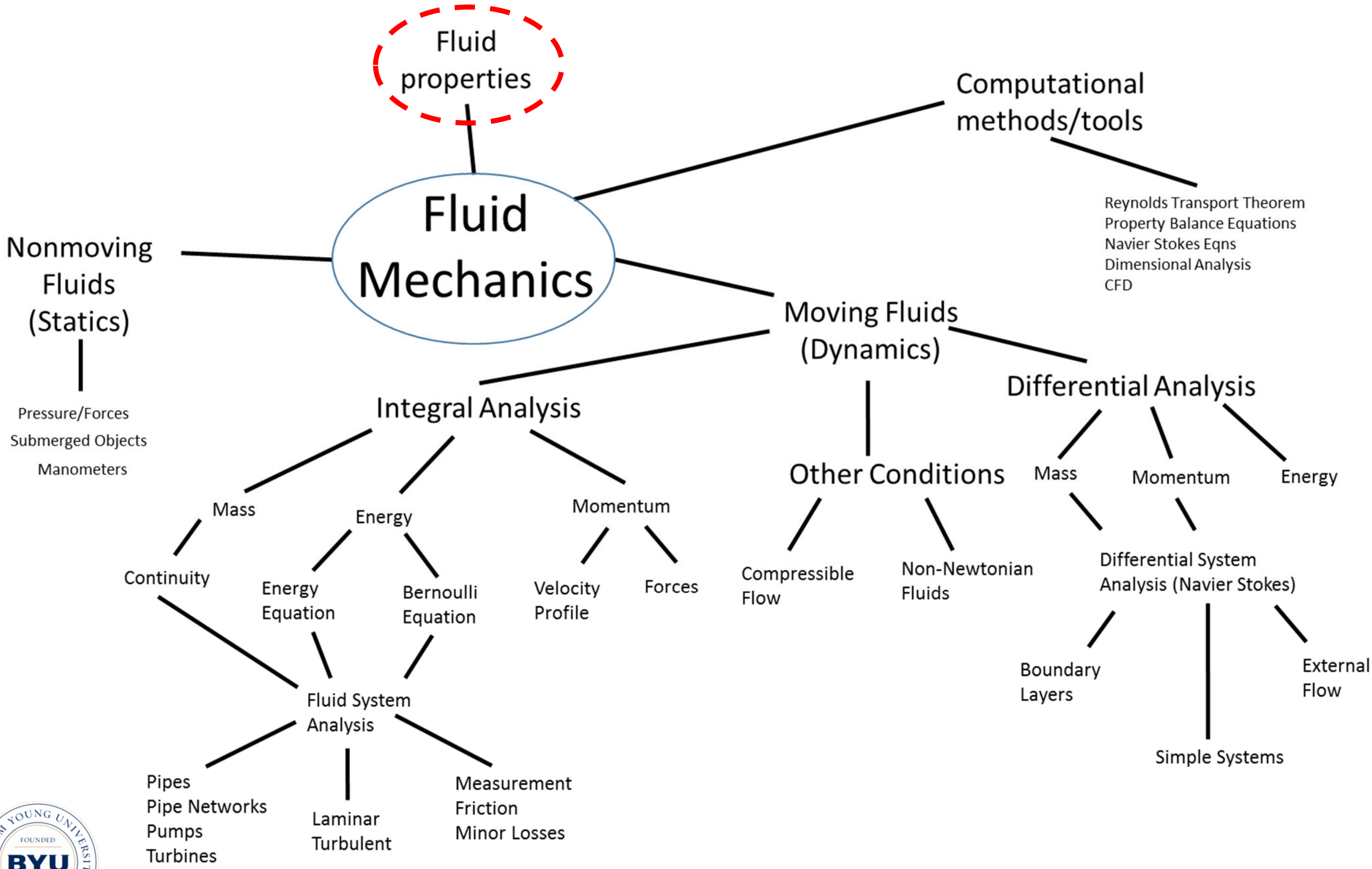
Spiritual Thought

"Many of us miss opportunity when it knocks because it comes to the door dressed in overalls and looks like work."

-President Thomas S. Monson

(quoting Thomas Edison)

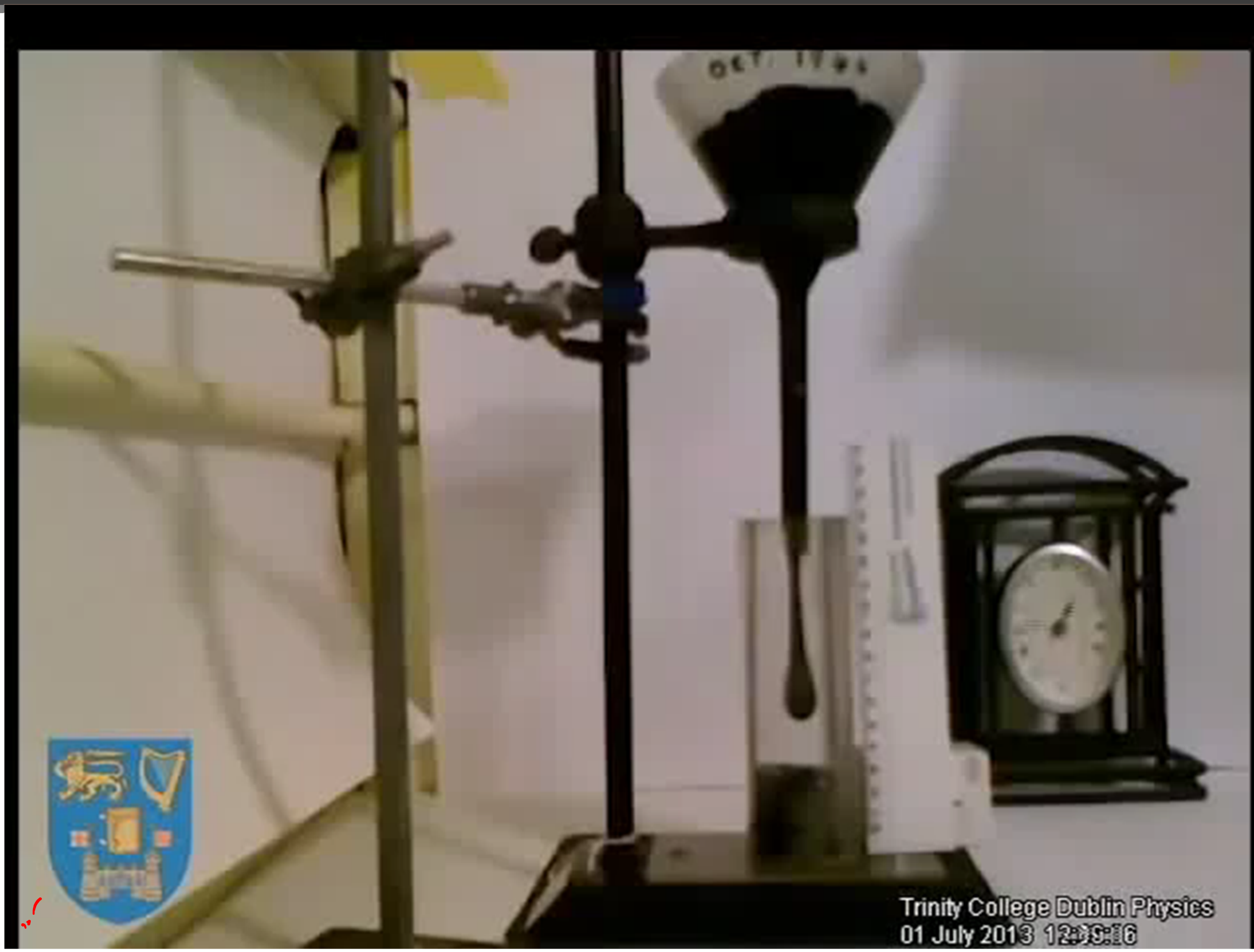
Fluids Roadmap



Key Points

- Fluid Definition
  - Sheer Stress
- Fluid Properties
  1. Density
     - Density variation with P,T
  2. Viscosity (molecular interpretation, equation)
     - Temperature/pressure effect on viscosity
     - Newtonian fluids
     - Non-Newtonian fluids
  3. Kinematic Viscosity

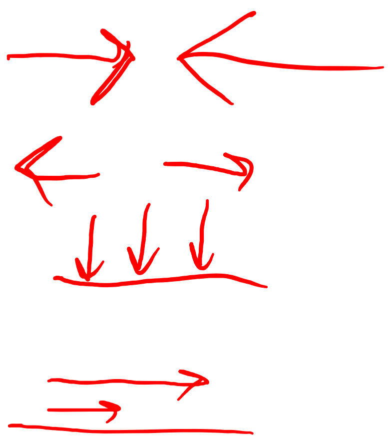
Fluid?



What is a Fluid?

– Liquid or Gas

– "deforms continuously under applied shear stress"   stress – $\tau = F/A$



compressive stress

tensile stress

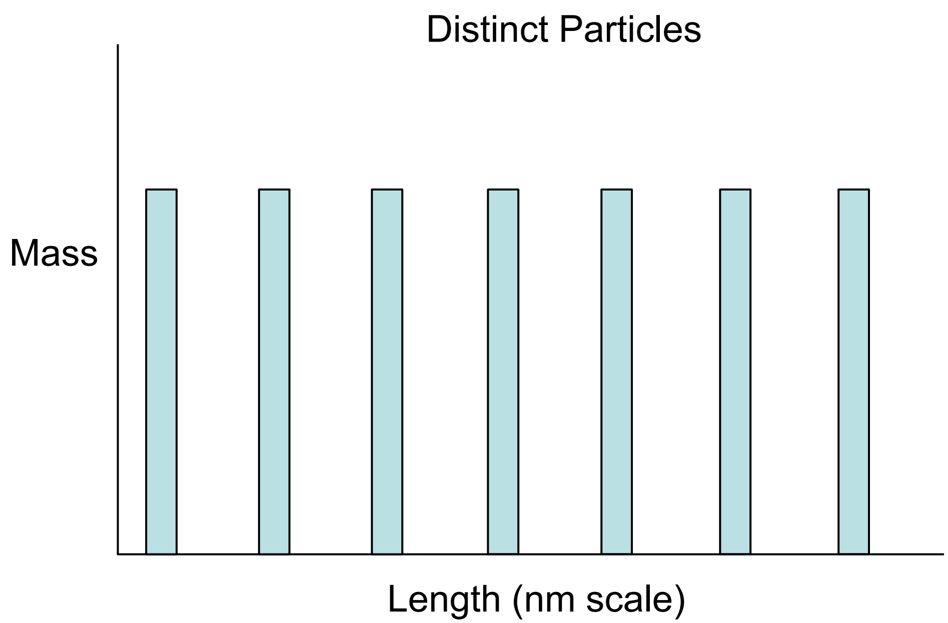
pressure

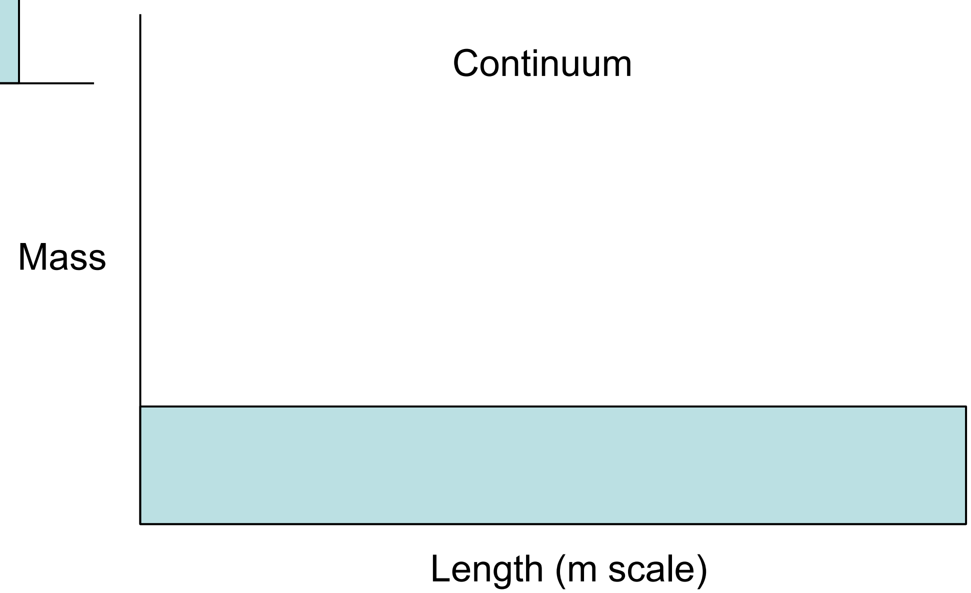
shear stress

– Liquid: form a free surface

– Gases: fill volume, no free surface, mixing

Continuum vs. Particles

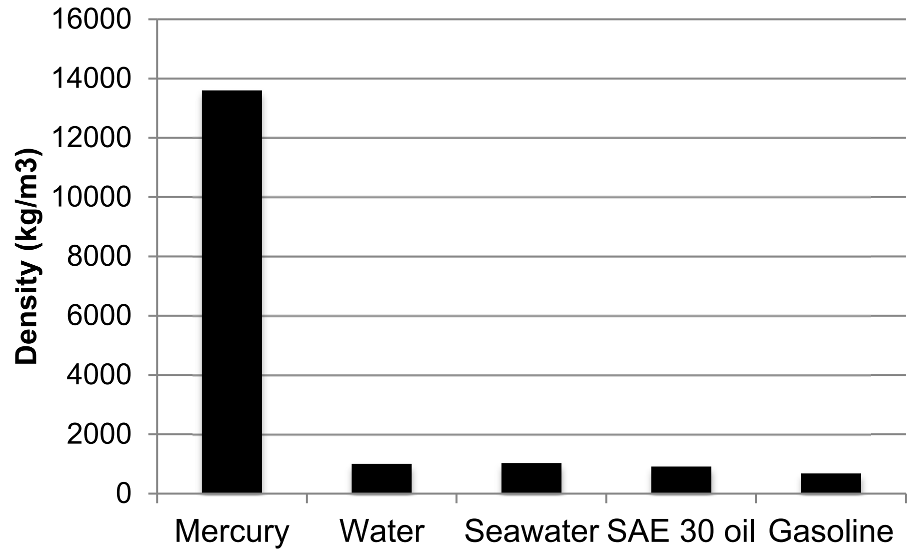


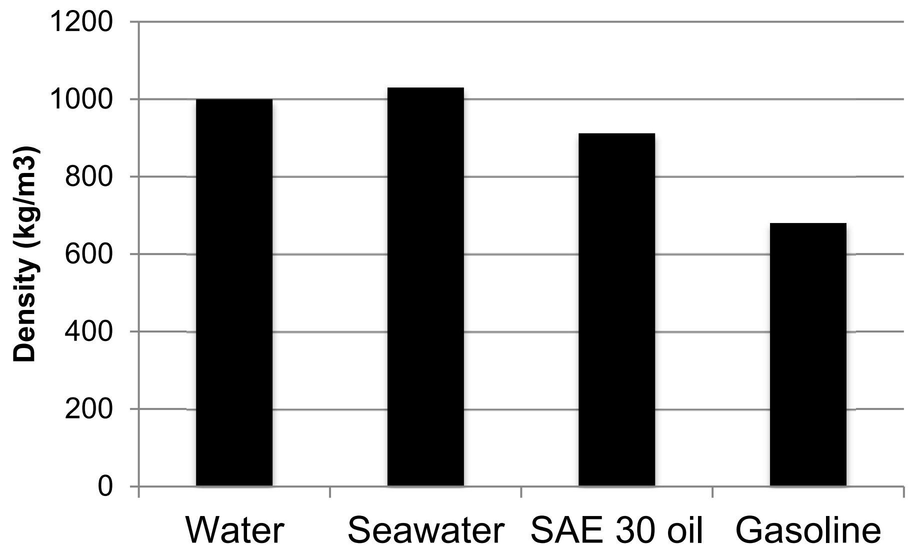


Density

- mass/volume
  - metric vs. British?
    - » 1000 kg/m^3,   1.2 kg/m^3
    - » 62.3 lb_m/ft^3,   0.0752 lb_m/ft^3
- Specific Gravity $= \frac{\rho}{\rho_w}$
- Specific Weight $\rho \cdot g$
- Industry Specific
  - Degrees API, Brix Gravity, Degrees Baume, etc.

Density


16000
14000
12000
10000
8000
6000
4000
2000
0
Density (kg/m3)
Mercury
Water
Seawater
SAE 30 oil
Gasoline


1200
1000
800
600
400
200
0
Density (kg/m3)
Water
Seawater
SAE 30 oil
Gasoline

Density Changes

- Gas: Ideal Gas

$n = \text{moles}$

$pV = nRT$

$M = MW = \frac{\text{mass}}{\text{moles}}$

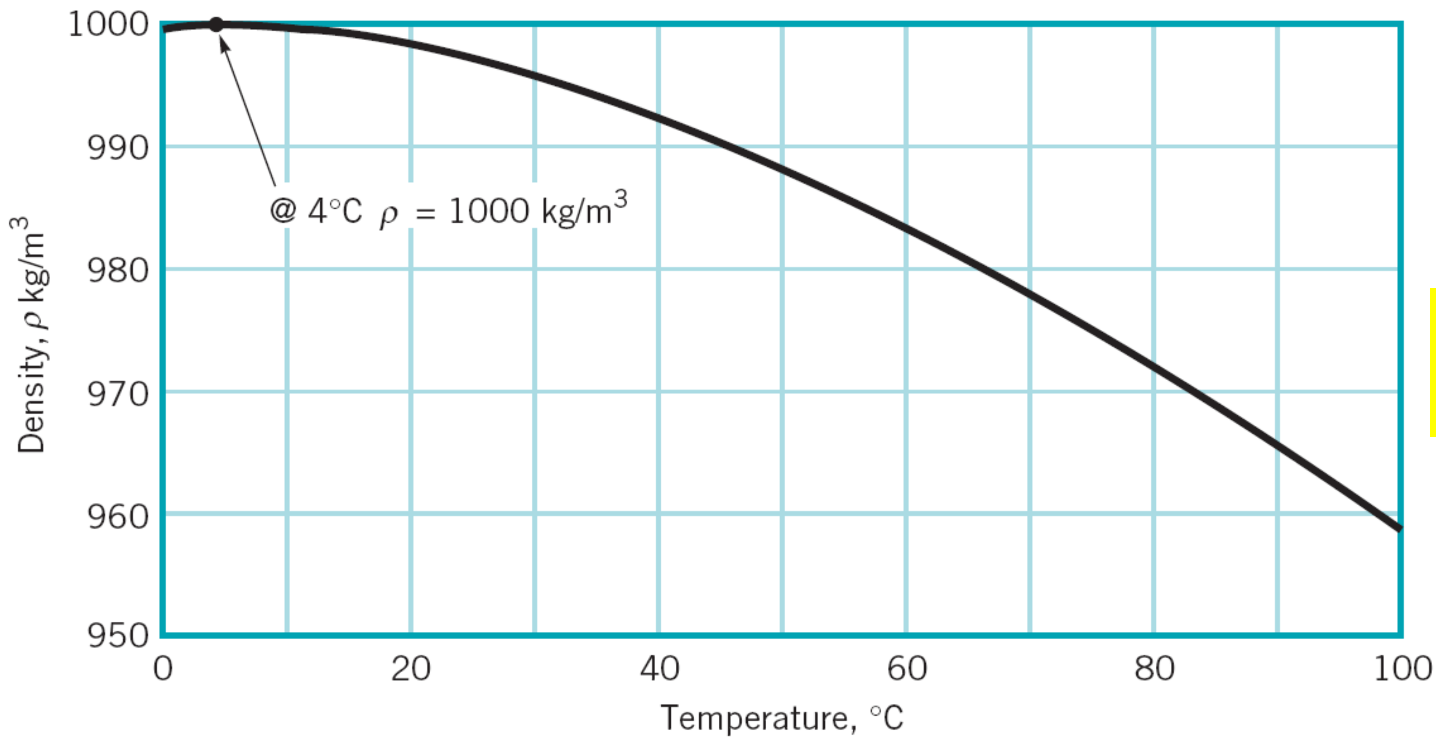
$MpV = \overset{\text{mass}}{\widehat{nM}}RT$

$\frac{R_g}{M} = R$

$Mp = \rho \cdot RT$

- Liquid: nearly constant
  - 4% variation in T → 0 ˚C to 100 ˚C
  - 1% variation in P → 1 atm to 200 atm

Density of water versus temperature



4% variation

Fundamentals of Fluid Mechanics, 5/E by Bruce Munson, Donald Young, and Theodore Okiishi

Density changes w/ Pressure

- Coefficient of Compressibility

$$K = \rho\left(\frac{dP}{d\rho}\right)_T \approx \rho\frac{\Delta P}{\Delta\rho} \quad \frac{\Delta P}{\Delta \rho} \quad \frac{1}{K}\cdot\Delta P$$

$$K_w = 21{,}000\,atm$$

$$\frac{\Delta V}{V} = -\frac{\Delta P}{K}$$

Density changes w/ Temperature

- Coefficient of Volume Expansion

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_p \Rightarrow \frac{\Delta \rho}{\rho} \cdot \frac{1}{\Delta T}$$

$$\therefore \frac{\Delta \rho}{\rho} = \beta \Delta T$$

Examples

Harry potter, when transmuting a tank of water ($3m^3$ at 1 atm) accidentally shrinks the walls of the tank (while not changing the mass of water inside) to 2 m^3. How much additional pressure is exerted on the walls of the tank as a result? (κ = 21,000 atm)

$$\frac{\Delta V}{V} = -\frac{\Delta P}{\kappa}$$

$$\frac{2m^3 - 3m^3}{3m^3} \cdot -21{,}000atm = 7000atm$$

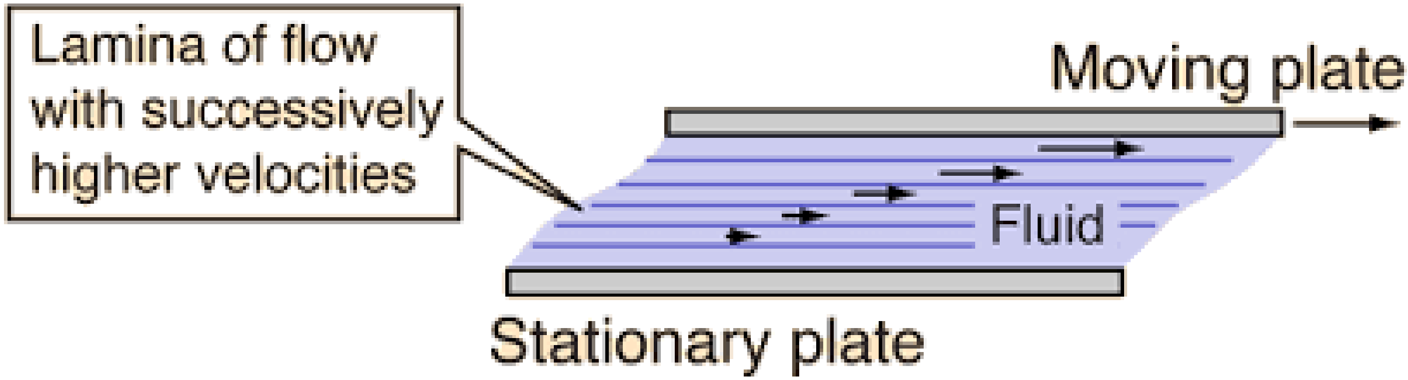
On his next attempt he uses less water (only 1 m^3) in the same tank, but he increases the temperature by 300 ˚C. How much volume does the water now take up? ($\beta = 2.61\text{x}10^{-4}/K$)

$$\beta \cdot \Delta T = \frac{\Delta V}{V}$$

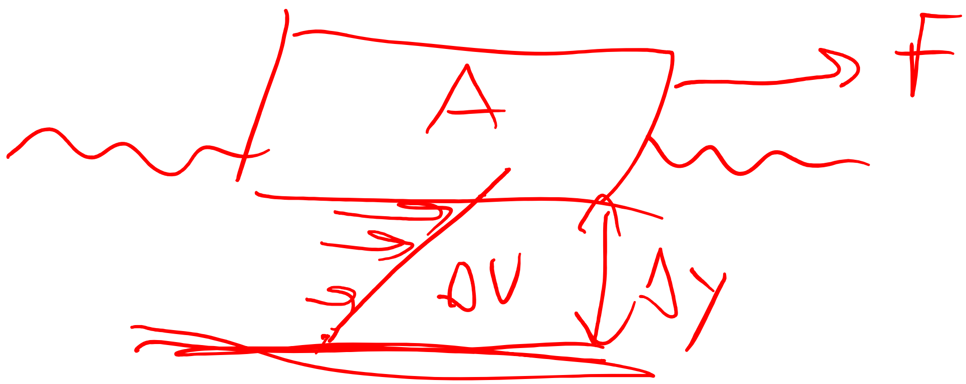
$$\Delta V = \beta \cdot \Delta T \cdot V = .0783m^3$$

V_f=1.0783m^3

Viscosity


Lamina of flow with successively higher velocities
Moving plate
Fluid
Stationary plate

Viscosity II



$F \propto A$ $\quad F \propto \Delta v$ $\quad F \propto \frac{1}{\Delta y}$

μ = viscosity

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

$$F = -\mu A \frac{dv}{dy}$$

$$\tau = -\mu \frac{dv}{dy}$$

Viscosity III

Viscosity Changes with T & P

- Liquids: molecules are everywhere, constantly getting in way of motion
  - T up, molecules move faster…
    - μ decreases
- gases: molecules are sparce, rarely hit each other
  - T up, molecules move faster…
    - more frequent collisions, μ increases
- Pressure:
  - Small effect for both

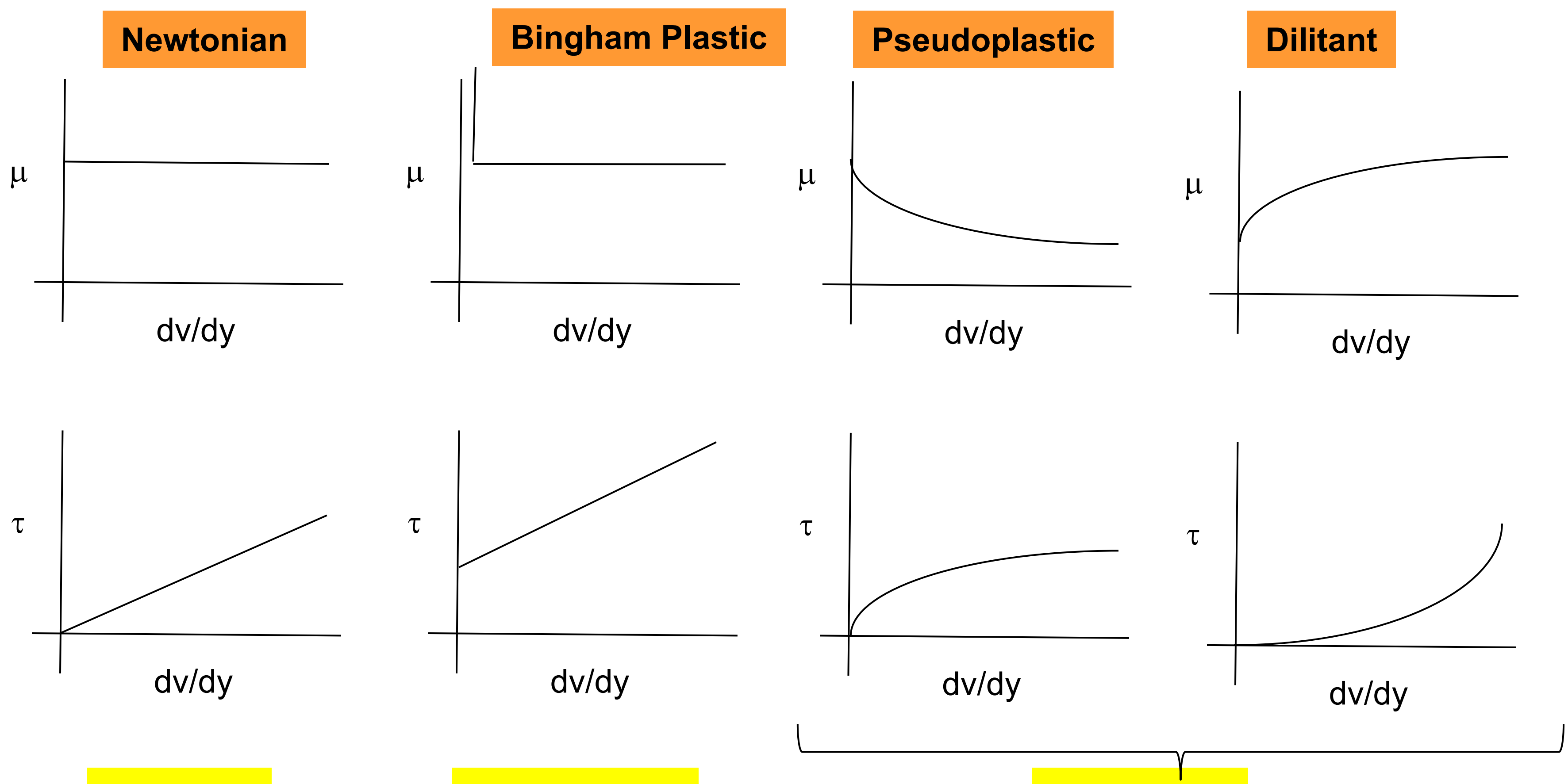
Kinematic Viscosity

- ν (units of m^2/s)

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

- μ steam vs. water is factor 100 different
- ρ steam vs. water is factor 1000 different

Non-Newtonian Fluids



$\tau = \mu * dv/dy$

$\tau = \mu * dv/dy + \tau_y$

$\tau = \kappa * |dv/dy|^n$