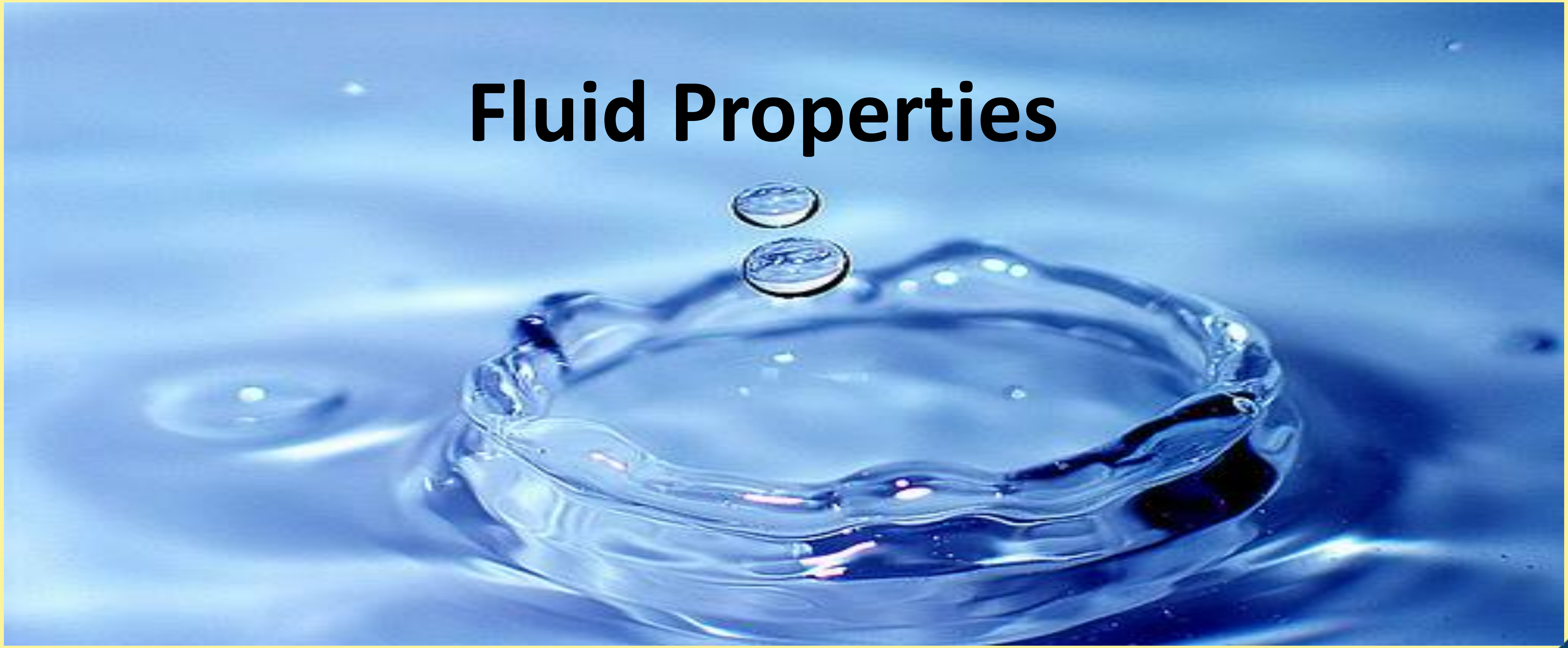
Fluid Properties



Hydraulics

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Dimensions and Units

- The dimensions have to be the same for each term in an equation
- Dimensions of mechanics are
  - length — L
  - time — T
  - mass — M
  - force — $\mathbf{F} = m\mathbf{a}$ → MLT^{-2}
  - temperature — Θ

Dimensions and Units

Quantity	Symbol	Dimensions
Velocity	V	LT^{-1}
Acceleration	a	LT^{-2}
Area	A	L^2
Volume	∀	L^3
Discharge	Q	L^3T^{-1}
Pressure	p	$ML^{-1}T^{-2}$
Gravity	g	LT^{-2}
Temperature	T’	Θ
Mass concentration	C	ML^{-3}

Show this!

Dimensions and Units

Quantity	Symbol	Dimensions
Density	ρ	ML^{-3}
Specific Weight	γ	$ML^{-2}T^{-2}$
Dynamic viscosity (m)	μ	$ML^{-1}T^{-1}$
Kinematic viscosity(n)	ν	$L^{2}T^{-1}$
Surface tension	σ	MT^{-2}
Bulk mod of elasticity	E	$ML^{-1}T^{-2}$

$\gamma = \rho g$

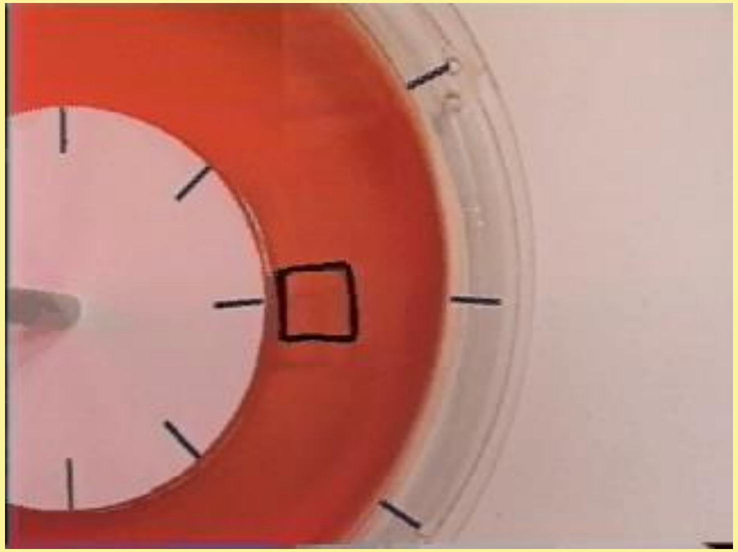
$n = \frac{m}{\rho}$

These are __fluid__ properties!

How many independent properties? _4_

Definition of a Fluid

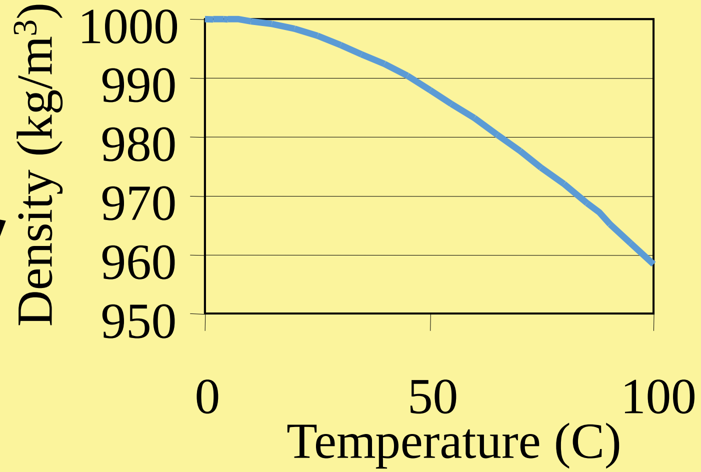
- "a fluid, such as water or air, deforms continuously when acted on by shearing stresses of any magnitude."
  \- *Young, Munson, Okiishi*

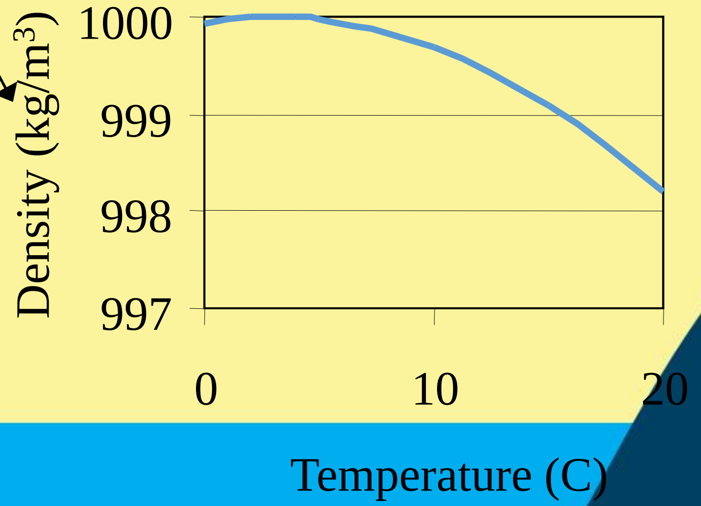


Why isn't steel a fluid?

Density and Specific Weight

- Density (mass/unit volume) ρ Specific mass
  - density of water: 1000 kg/m^3
  - density of air at atmospheric pressure and 15 °C

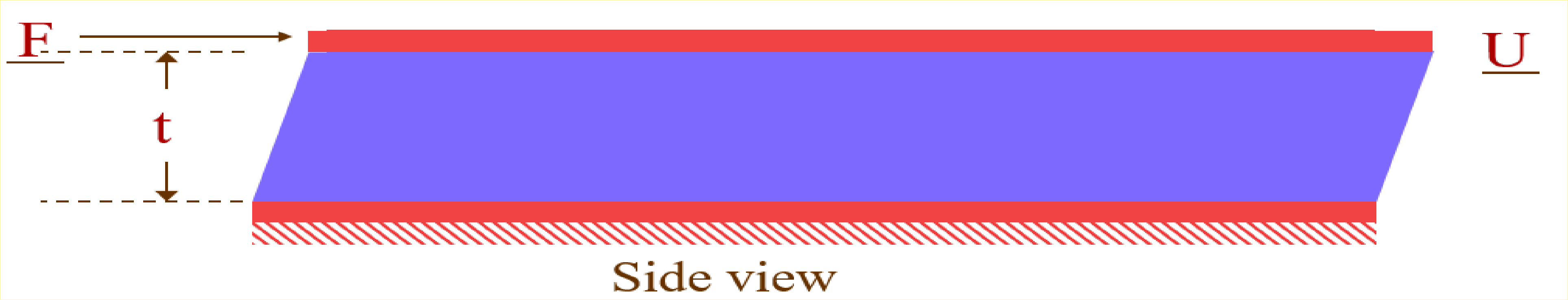




- Specific Weight of water (weight per unit volume) γ
  - 1.22 kg/m^3

$$\gamma = \rho g = 9806 \text{ N/m}^3$$

Fluid Deformation between Parallel Plates



Force F causes the top plate to have velocity U. What other parameters control how much force is required to get a desired velocity?

$$F = \mu \frac{AU}{t}$$

↑ ↓

If this parameter increases, what does F do?

Parameter		
Distance between plates (t)	↑	↓
Area of plates (A)	↑	↓
Viscosity! (μ)	↑	↓

Shear Stress

$$F = \mu \frac{AU}{t}$$

$$\mu = \frac{Ft}{AU}$$ dimension of $\left[\frac{N \cdot s}{m^2}\right]$

$$\tau = \frac{F}{A}$$ Tangential force per unit area $\left[\frac{N}{m^2}\right]$

$$\tau = \mu \frac{U}{t}$$ $\frac{U}{t}$ Rate of angular deformation $\left[\frac{1}{s}\right]$

$$\tau = \mu \frac{du}{dy}$$ $\frac{du}{dy}$ change in velocity with respect to distance

rate of shear

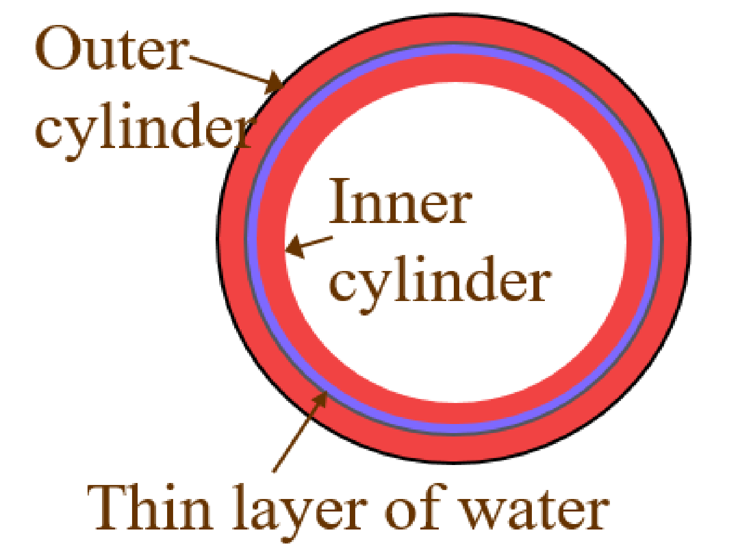
Our general equation relating shear and viscosity

Fluid Viscosity

- Examples of highly viscous fluids
  molasses, tar, 20w-50 oil, glycerin ____________
- Fundamental mechanism
  - 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)

Example: Measure the viscosity of water

The inner cylinder is 10 cm in diameter and rotates at 10 rpm. The fluid layer is 2 mm thick and 20 cm high. The power required to turn the inner cylinder is 100×10^{-6} watts. What is the dynamic viscosity of the fluid?



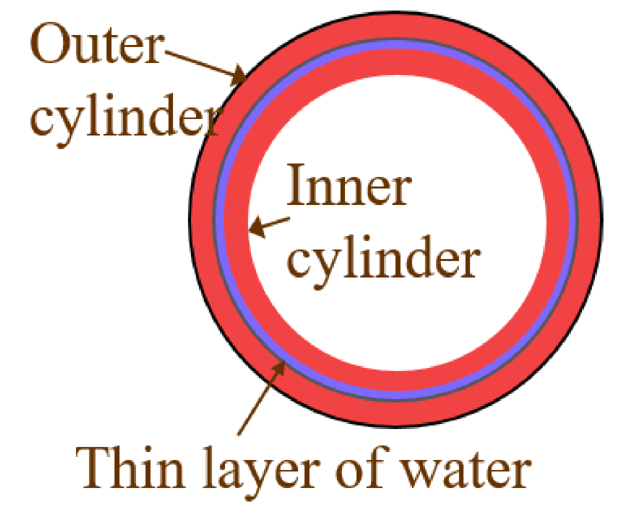
$$\tau = \mu \frac{du}{dy} \qquad F = \mu \frac{AU}{t}$$

Viscosity Measurement: Solution

$$F = \mu \frac{AU}{t} \qquad U = \omega r \qquad A = 2\pi r h$$

$$\omega = \frac{10 rev}{\min}\frac{2\pi rad}{rev}\frac{\min}{60 s} = 1.047 rad/s$$

r = 5 cm
t = 2 mm
h = 20 cm
P = 100 x 10^{-6} W
10 rpm



$$F = \mu \frac{2\pi\omega r^2 h}{t}$$

$$P = F\omega r$$

$$P = \mu \frac{2\pi\omega^2 r^3 h}{t} \qquad \mu = \frac{Pt}{2\pi\omega^2 r^3 h}$$

$$m = \frac{(100x10^{-6} W)\ (0.002\ m)}{2p\,(1.047/s)^2 (0.05\ m)^3 (0.2\ m)} = 1.16x10^{-3}\ N \times s/m^2$$

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 <u>zero</u> and is independent of the fluid viscosity

- Dynamics
  - Fluid viscosity is very important
    - when the fluid is moving

Dynamic and Kinematic Viscosity

- Kinematic viscosity (nu) is a fluid property obtained by dividing the dynamic viscosity (mu) by the fluid density

$$\nu = \frac{\mu}{\rho} \qquad \nu = \frac{\left[\frac{\text{kg}}{\text{m}\cdot\text{s}}\right]}{\left[\frac{\text{kg}}{\text{m}^3}\right]} \qquad [\text{m}^2/\text{s}]$$

Connection to Reynolds number!

$$Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$$

Practice Problem

The velocity distribution in a viscous flow over a plate is given by

$$u = 4y - y^2 \text{ for } y \leq 2 \text{ m}$$

where u = velocity in m/s at a point distant y from the plate. If the coefficient of dynamic viscosity is 1.5 Pa.s determine the shear stress at y = 0 and at y = 2.0 m.

Practice Problem

A 90 N rectangular solid block slides down a 30° inclined plane. The plane is lubricated by a 3 mm thick film of oil of relative density 0.90 and viscosity 8.0 poise. If the contact area is 0.3 m^2, estimate the terminal velocity of the block.

Fluid Properties contd.

Hydraulic Engineering

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Perfect Gas Law

- PV = nRT
  - R is the universal gas constant
  - T is in Kelvin

$$R_{text} = \frac{R}{M_{gas}} \qquad R = 8.314\ \frac{Nm}{mol\ K}$$

M_{gas} is molecular mass

M_{gas} for air is 0.029 kg/mole

Why is this M_{gas} for air reasonable

N_2 28 g/mol, O_2 32 g/mol

Bulk Modulus of Elasticity

- Relates the change in volume to a change in pressure
- changes in density at high pressure
  - pressure waves
    - Sound
    - Water hammer

$$E_v = -\frac{dp}{d\forall / \forall}$$

$$E_v = \frac{dp}{d\rho/\rho}$$

Pv = Constant

On differentiation we get

Pdv+vdp=0

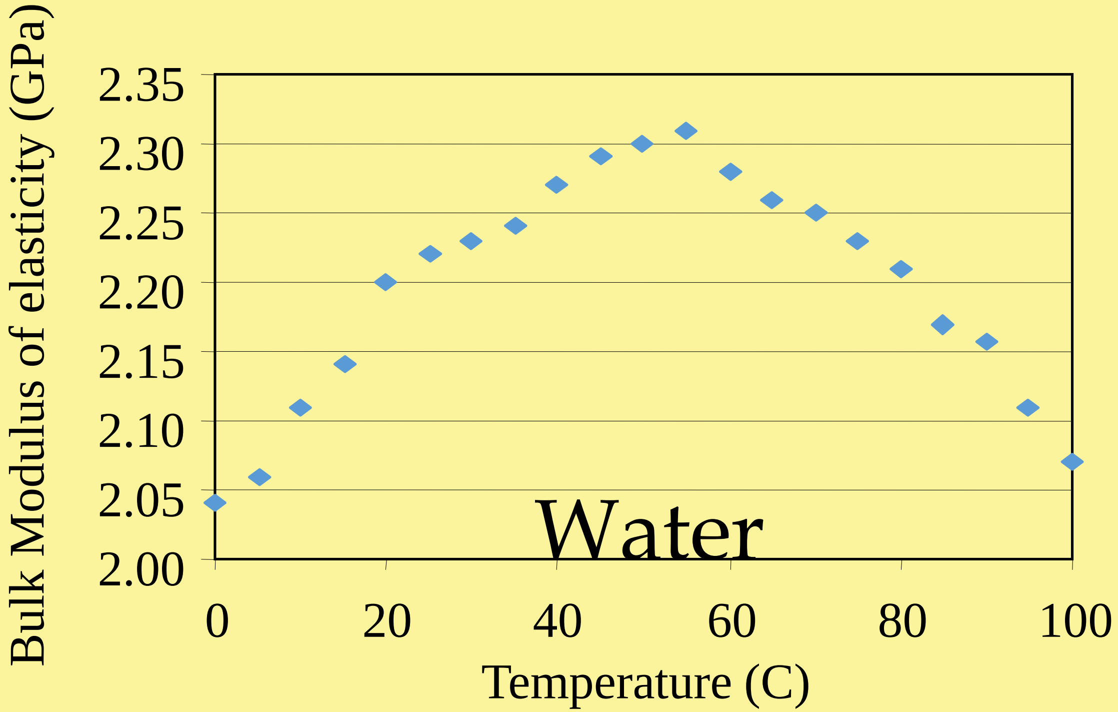
$$\frac{dp}{dv} = -\frac{p}{v}$$

Hence $E_v = -v\left(-\frac{p}{v}\right)$ $E_v = p$

How much does water compress?

$$\frac{d\forall}{\forall} = -\frac{dp}{E_v}$$

Bulk Modulus of Elasticity



Compression and Expansion of Gases: What is E_v?

- Isothermal (constant temperature)

$$\frac{pV}{n} = constant \qquad V \propto \frac{1}{\rho}$$

$$RT$$

$$\frac{p}{\rho} = constant \qquad \frac{dp}{d\rho} \qquad E_v = \frac{dp}{d\rho/\rho} \qquad E_v = p$$

Where, p = absolute pressure

v = specific volume

Compression and Expansion of Gases: What is E_v?

- Isentropic (no heat exchanged)

$$\frac{p}{\rho^k} = C \qquad \text{where} \qquad k = \frac{c_p}{c_v} \text{ (specific heat ratio)}$$

$$\frac{dp}{d\rho} = Ck\rho^{k-1} \qquad \frac{dp}{d\rho} = \frac{p}{\rho^k}k\rho^{k-1} \qquad \frac{dp}{d\rho} = k\frac{p}{\rho} \qquad \underline{E_v = kp}$$

Speed of Sound (c)

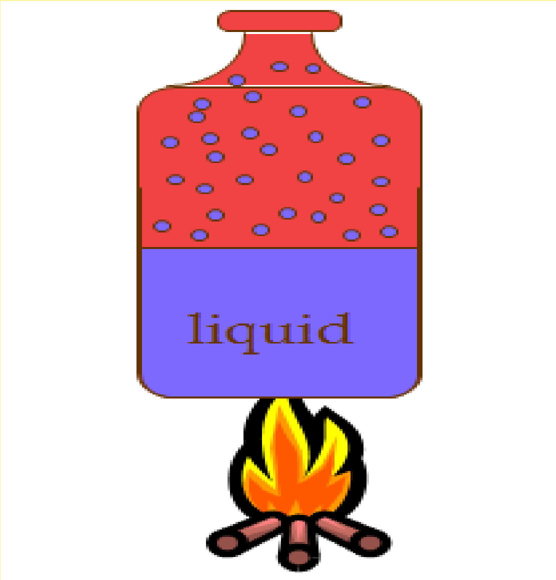
$c = \sqrt{\frac{dp}{d\rho}}$ and $E_v = \frac{dp}{d\rho/\rho}$. Solve for $\frac{dp}{dr}$

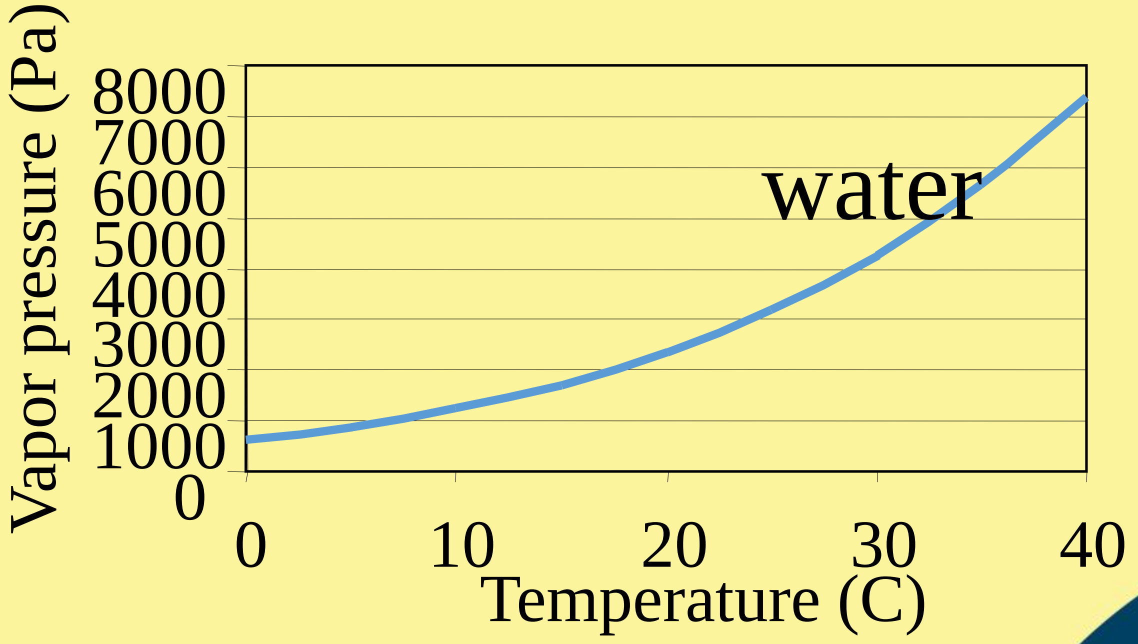
$$\frac{E_v}{\rho} = \frac{dp}{d\rho}$$

$$c = \sqrt{\frac{E_v}{\rho}}$$

c is large for difficult to compress fluids

Vapour Pressure

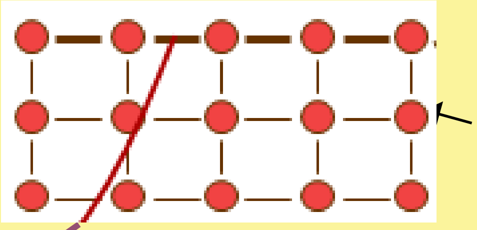


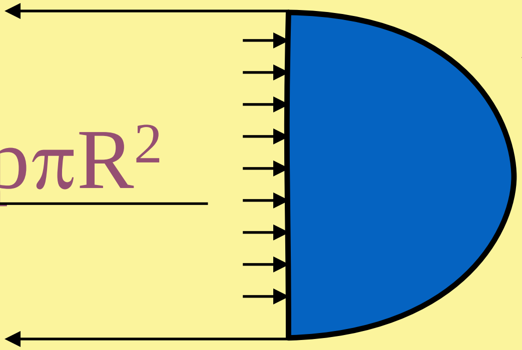


What is vapor pressure of water at 100°C? 101 kPa

Surface Tension

- Pressure increase in a spherical droplet





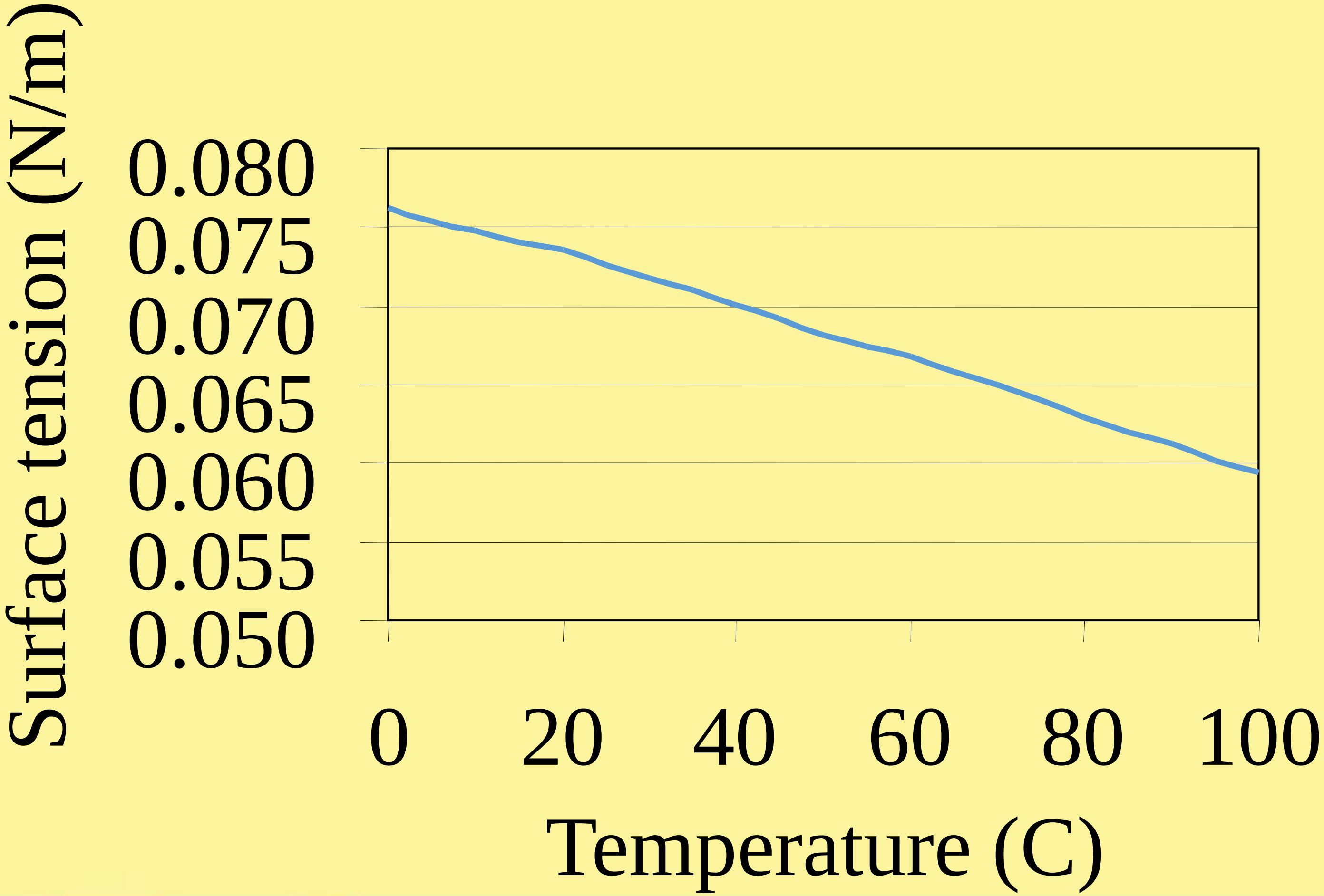
$F_p = \Delta p \pi R^2$

$F_\sigma = 2\pi R\sigma$

$\Delta p \pi R^2 = 2\pi R\sigma$

$$\Delta p = \frac{2\sigma}{R}$$

Surface Tension



Example: Surface Tension

- Estimate the difference in pressure (in Pa) between the inside and outside of a bubble of air in 20ºC water. The air bubble is 0.3 mm in diameter. $\sigma = 0.073\ \text{N/m}$, $R = 0.15 \times 10^{-3}\ \text{m}$

$$\Delta p = \frac{2\sigma}{R} \qquad \Delta p = \frac{2(0.073 N/m)}{0.15 x 10^{-3} m}$$

$$\Delta p = 970\ \text{Pa}$$

What is the difference between pressure in a water droplet and pressure in an air bubble?

Review: Fluid Properties

- Viscosity

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

- Density and Specific Weight
- Elasticity

$$E_v = \frac{dp}{d\rho/\rho} \qquad c = \sqrt{\frac{E_v}{\rho}}$$

- Vapor Pressure
- Surface Tension

$$\Delta p = \frac{2\sigma}{R}$$

Practice Problem

In an experiment, the tip of a glass tube with an internal diameter of 2.0 mm is immersed to a depth of 1.50cm in to a liquid of specific gravity 0.85. Air is forced in to the tube to form a spherical bubble just at the lower end of the tube. Estimate the surface tension of the liquid if the air pressure in the bubble is 200 N/m^2

Practice Problem

A very small quantity of a liquid having a surface tension σ forms a circular spot of diameter D between two glass plates separated by a small distance h. Obtain an expression for the force required to pull the plates apart.

Practice Problem

Air at 20°C and 200 kPa (abs) contained in a cylinder is compressed to half its volume. Find the pressure and temperature inside the cylinder if the process is (a) isothermal, and (b) isentropic with k = 1.4

Practice Problem

The velocity of propagation of sound in air is calculated by assuming the process to be isentropic. What is the velocity of sound at 80°C?