1. STRESS & STRAIN

Stress:

$$\sigma = \frac{F}{A} \ [\text{N/m}^2 = \text{Pa}]$$

Types of Stress:

- **Tensile/Compressive:** Normal force per unit area
- **Shear (Tangential):** Tangential force per unit area
- **Bulk (Volume):** Pressure applied uniformly

Strain (dimensionless):

Longitudinal: $\varepsilon_L = \dfrac{\Delta L}{L}$

Shear: $\varepsilon_s = \dfrac{\Delta x}{L} = \tan\theta \approx \theta$

Volumetric: $\varepsilon_V = \dfrac{\Delta V}{V}$

Elastic limit: Maximum stress beyond which body does not return to original shape.

Plastic behaviour: Permanent deformation beyond elastic limit.

⋆ **Common Pitfall**

- Strain is **dimensionless**; no unit
- Stress has units (Pa); strain does not
- Within elastic limit: Hooke's Law valid; beyond it: plastic deformation

2. ELASTIC MODULI

Young's Modulus (Y):

$$Y = \frac{\text{Tensile Stress}}{\text{Longitudinal Strain}} = \frac{F/A}{\Delta L/L} = \frac{FL}{A\,\Delta L} \ [\text{Pa}]$$

Bulk Modulus (B):

$$B = -\frac{P}{\Delta V/V} = -V\frac{\Delta P}{\Delta V} \ [\text{Pa}]$$

Negative sign: volume decreases with pressure increase.

Compressibility: $k = \dfrac{1}{B}$ $[\text{Pa}^{-1}]$

Modulus of Rigidity / Shear Modulus (η or G):

$$\eta = \frac{\text{Shear Stress}}{\text{Shear Strain}} = \frac{F/A}{\theta} \ [\text{Pa}]$$

Typical values:

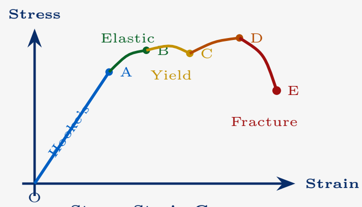
Steel: $Y \approx 2 \times 10^{11}$ Pa
Rubber: $Y \approx 5 \times 10^{6}$ Pa
Water: $B \approx 2 \times 10^{9}$ Pa

⋆ **Common Pitfall**

- Y is defined only for solids; gases/liquids have no Y
- Gases have only B (no Y or η)
- Higher $Y \Rightarrow$ more rigid (less deformation for same force); steel > rubber

3. HOOKE'S LAW & STRESS-STRAIN CURVE

Hooke's Law: $\sigma \propto \varepsilon$
$F = -kx$ (for spring/wire)



Stress–Strain Curve

- **O→A:** Proportional limit (Hooke's Law)
- **A→B:** Elastic limit (no permanent deformation)
- **B→C:** Yield point (permanent deformation begins)
- **C→D:** Strain hardening
- **D→E:** Necking → Fracture

Elastic Potential Energy in wire:

$$U = \tfrac{1}{2} \times \text{Stress} \times \text{Strain} \times V = \tfrac{1}{2} \times Y\varepsilon^2 \times V$$

$$\text{Energy density:} \quad u = \frac{U}{V} = \frac{\sigma^2}{2Y} = \tfrac{1}{2}Y\varepsilon^2$$

⋆ **Common Pitfall**

- Elastic limit $\neq$ proportional limit; elastic limit is slightly beyond proportional limit
- Breaking stress < Ultimate stress (stress at D) for ductile materials
- Brittle materials fracture before yield point

4. POISSON'S RATIO & RELATIONS

$$\nu = -\frac{\text{Lateral Strain}}{\text{Longitudinal Strain}} = -\frac{\Delta D/D}{\Delta L/L}$$

Range: $-1 \le \nu \le 0.5$
Practical range: $0 < \nu < 0.5$
For rubber: $\nu \approx 0.5$ (incompressible)
For steel: $\nu \approx 0.3$

Relations between elastic constants:

$$Y = 2\eta(1+\nu)$$
$$Y = 3B(1-2\nu)$$
$$\eta = \frac{3BY}{9B - Y}$$
$$\nu = \frac{3B - 2\eta}{6B + 2\eta}$$

⋆ **Common Pitfall**

- $\nu > 0.5$ violates thermodynamics (impossible)
- $\nu = 0.5$: no volume change on stretching
- If $\nu = 0$: no lateral strain (cork bottle cap)

5. THERMAL STRESS & WIRE FORMULAS

Thermal stress (rod fixed at ends):

Thermal stress $= Y\alpha\Delta T$
Thermal force $= YA\alpha\Delta T$

α = coefficient of linear expansion

Elongation under own weight:

$$\Delta L = \frac{\rho g L^2}{2Y} = \frac{WL}{2AY}$$

W = weight of wire, ρ = density

Work done in stretching wire:

$$W = \frac{1}{2}F \cdot \Delta L = \frac{YA(\Delta L)^2}{2L}$$

⋆ **Common Pitfall**

- Thermal stress exists only when expansion is **prevented**; free expansion ⇒ no stress
- For hanging wire under own weight, the *maximum* stress is at the top (not middle or bottom)

6. FLUID PRESSURE & PASCAL'S LAW

$$P = \frac{F}{A} \; [\text{Pa} = \text{N/m}^2]$$
$$P = P_0 + \rho g h \quad (\text{at depth } h)$$

$P_{atm} = 1.013 \times 10^5$ Pa $= 76$ cm Hg $\approx 10^5$ Pa

Pascal's Law: Pressure applied to enclosed fluid is transmitted equally in all directions.

Hydraulic Press:

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \Rightarrow F_2 = F_1\frac{A_2}{A_1}$$

Gauge pressure: $P_{gauge} = P - P_{atm} = \rho g h$

Absolute pressure: $P_{abs} = P_{atm} + \rho g h$

⋆ **Common Pitfall**

- Pressure is a scalar; force is a vector
- P at same horizontal level is equal in connected fluids (even with different cross-sections)
- Gauge pressure can be negative (vacuum)

7. ARCHIMEDES' PRINCIPLE & BUOYANCY

Buoyant force: $F_b = \rho_{fluid} \cdot V_{submerged} \cdot g$

Floating condition: $\rho_{body} \leq \rho_{fluid}$

Fraction submerged:

$$\frac{V_{sub}}{V_{total}} = \frac{\rho_{body}}{\rho_{fluid}}$$

Apparent weight:

$$W_{app} = W_{true} - F_b = V\,g(\rho_{body} - \rho_{fluid})$$

Law of floatation: Weight of body = Weight of fluid displaced

⋆ **Common Pitfall**

- Buoyant force depends on $V_{submerged}$, not on shape or mass of object
- A body floats even if $\rho_{body} > \rho_{fluid}$ if it is hollow (effective density consideration)
- Buoyancy does not depend on depth of submersion

8. FLUID DYNAMICS & BERNOULLI'S THEOREM

Equation of Continuity:

$$A_1v_1 = A_2v_2 \quad (\text{Volume flow rate} = \text{const.})$$
$$\dot{m} = \rho A v = \text{const}$$

Bernoulli's Equation:

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{const}$$

Applications:

Torricelli's theorem (hole in tank):

$$v = \sqrt{2gh}$$

Venturimeter:

$$v_1 = A_2\sqrt{\frac{2\Delta P}{\rho(A_1^2 - A_2^2)}}$$

Dynamic lift (aerofoil): $\Delta P = \frac{1}{2}\rho(v_2^2 - v_1^2)$

Volume flow rate: $Q = Av$ [m^3/s]

⋆ **Common Pitfall**

- Bernoulli applies to **streamline flow** of **ideal** (non-viscous, incompressible) fluid
- Higher speed ⇒ lower pressure (not higher); counter-intuitive but correct
- Continuity: Av = const means narrow section has *higher* velocity

9. VISCOSITY & STOKES' LAW

Newton's Law of Viscosity:

$$F = \eta A\frac{dv}{dy}$$

η = coefficient of viscosity [Pa · s = Poise/10]
1 Poise = 0.1 Pa · s

Stokes' Law: (sphere of radius r, velocity v)

$$F_{viscous} = 6\pi\eta r v$$

Terminal Velocity: ($F_{viscous} + F_b = W$)

$$v_t = \frac{2r^2(\rho - \sigma)g}{9\eta}$$

ρ = density of sphere; σ = density of fluid

Poiseuille's Formula (pipe flow):

$$Q = \frac{\pi r^4 \Delta P}{8\eta L}$$

$Q \propto r^4$ (radius has huge effect!)

Reynolds Number:

$$R_e = \frac{\rho v d}{\eta}$$

$R_e < 1000$: laminar; $R_e > 2000$: turbulent

⋆ **Common Pitfall**

- $v_t \propto r^2$: doubling radius $\Rightarrow$ 4× terminal velocity
- Viscosity of liquids **decreases** with temperature; gases **increase** with temperature
- At terminal velocity: acceleration = 0; net force = 0

10. SURFACE TENSION & CAPILLARITY

Surface Tension (T):

$$T = \frac{F}{l}\ [\text{N/m}]$$

$$T = \frac{W}{\Delta A}\ (\text{work per unit area})\ [\text{J/m}^2]$$

Excess Pressure inside curved surfaces:

Liquid drop: $\Delta P = \dfrac{2T}{R}$

Air bubble in liquid: $\Delta P = \dfrac{2T}{R}$

Soap bubble (2 surfaces): $\Delta P = \dfrac{4T}{R}$

Capillarity (Jurin's Law):

$$h = \frac{2T\cos\theta}{\rho g r}$$

$h \propto \dfrac{1}{r}$ (finer tube: higher rise)

θ = contact angle; r = radius of tube

Contact angle:
Water–glass: $\theta \approx 0$ (wetting; rises)
Mercury–glass: $\theta \approx 135$ (non-wetting; falls)

Merging of droplets (n drops of radius $r \to 1$ drop of radius R):

$R = n^{1/3} r$

Energy released $= 4\pi T r^2 (n - n^{2/3})$

$= 4\pi T R^2 (n^{1/3} - 1)$

⋆ **Common Pitfall**

- Soap bubble has **two** surfaces $\Rightarrow \Delta P = 4T/R$; liquid drop has one surface $\Rightarrow \Delta P = 2T/R$
- Surface tension decreases with temperature
- Capillary rise: liquid level *inside* tube is higher for water (wetting), lower for mercury (non-wetting)
- If tube is short (length $< h$): liquid spreads at top, does NOT overflow

11. QUICK REVISION TABLE – MODULI

Modulus	Formula	For
Young's Y	$\frac{FL}{A\Delta L}$	Solids only
Bulk B	$-\frac{P}{\Delta V/V}$	Solids, liquids, gases
Rigidity η	$\frac{F/A}{\theta}$	Solids only

General order: $Y > B > \eta$ (for most metals)

Formula	Use
$P = P_0 + \rho g h$	Fluid pressure
$F_b = \rho_f V_s g$	Buoyancy
$v = \sqrt{2gh}$	Torricelli
$v_t = \frac{2r^2(\rho-\sigma)g}{9\eta}$	Terminal vel.
$h = \frac{2T\cos\theta}{\rho g r}$	Capillarity
$\Delta P = 4T/R$	Soap bubble
$\Delta P = 2T/R$	Liquid drop
$Q = \frac{\pi r^4 \Delta P}{8\eta L}$	Poiseuille

12. MASTER: COMMON MISTAKES NEET

1. **Soap vs. drop:** Soap bubble $= 4T/R$ (two surfaces); liquid drop $= 2T/R$ (one surface)
2. **Terminal velocity:** $v_t \propto r^2$, not r; doubling radius gives 4× v_t
3. **Bernoulli:** High speed $\Rightarrow$ low pressure (NOT high pressure)
4. **Elastic moduli:** Y and η only for solids; B for all states
5. **Capillarity:** Rise $\propto 1/r$; narrow tube gives higher rise
6. **Viscosity vs. temperature:** Liquids ↓; gases ↑
7. **Floating:** $F_b = W_{\text{body}}$ (not $F_b = W_{\text{displaced}}$ for partly submerged)
8. **Pascal's law:** Pressure, not force, is equal throughout; $F_2/F_1 = A_2/A_1$
9. **Poisson's ratio:** $\nu \leq 0.5$ always; $\nu = 0.5$ means incompressible
10. **Stress–strain:** Breaking stress (E) < Ultimate tensile strength (D) for ductile material