Intermediate Physics for Medicine and Biology - Chapter 1

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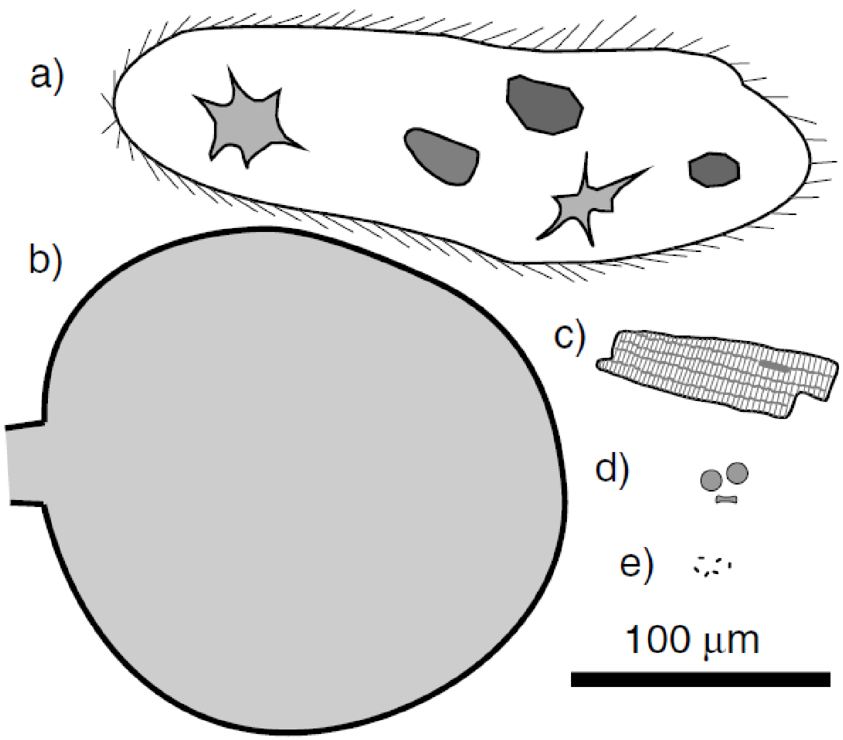
Web: http://ymk.k-space.org/courses.htm

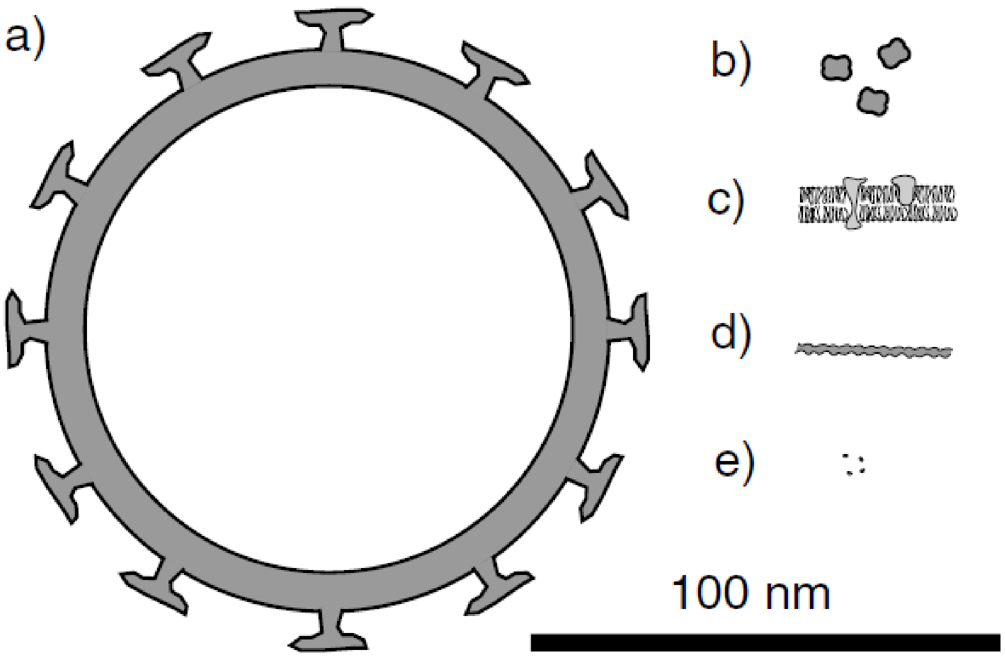
CAIRO UNIVERSITY

Biological Object Sizes



a) A paramecium
b) An alveolus
c) A cardiac cell
d) Red blood cells
e) Escherichia coli bacteria

Biological Object Sizes



a) Human immunodeficiency virus (HIV)
b) Hemoglobin molecules
c) Cell membrane
d) DNA molecule
e) Glucose molecules

Approximate Sizes of Biological Objects

Object	Size
Protozoa	100 μm
Cells	10 μm
Bacteria	1 μm
Viruses	100 nm
Macromolecules	10 nm
Molecules	1 nm
Atoms	100 pm

Distances and Sizes

- Valuable skill in physics: ability to make order-of-magnitude estimates
- Example: Calculate number of cells in body
  - Cells ~ 10 μm in size → volume ~ $(10\ \mu m)^3$
  - Adult ~ 2 m tall and 0.3 m wide

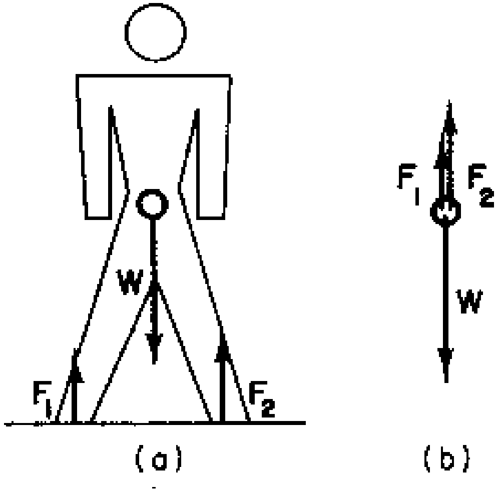
    → volume ~ 2 × 0.3 × 0.3 = 0.18 m^3
  - Assume body is made entirely of cells
  - Number of cells = $0.18/1e^{-15}$ ~ 2 × 10^{14}

Forces and Translational Equilibrium

- Force defined by Newton's second law

$$F = ma$$

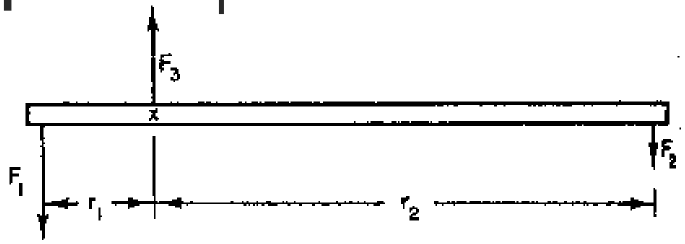
- Translational equilibrium: $\sum_i F_i = 0$
- Equilibrium:
  - remains at rest
  - move at constant speed



Rotational Equilibrium

- Torques τ_i is defined as

$$\tau_i = r_i F_i$$

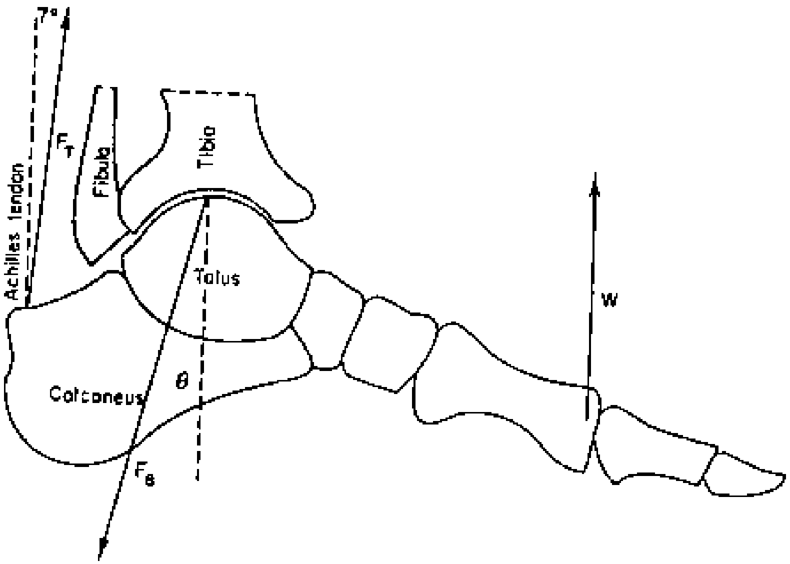


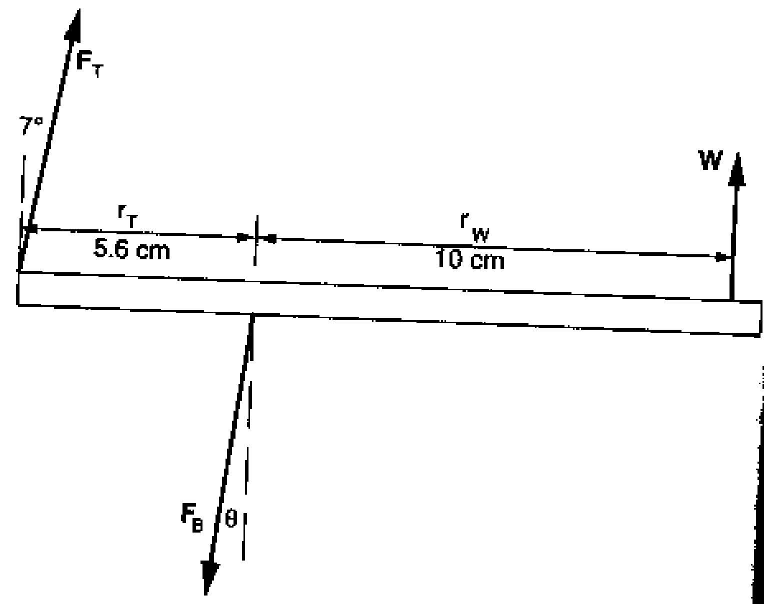
- Rotational equilibrium if,

$$\sum_i \tau_i = 0$$

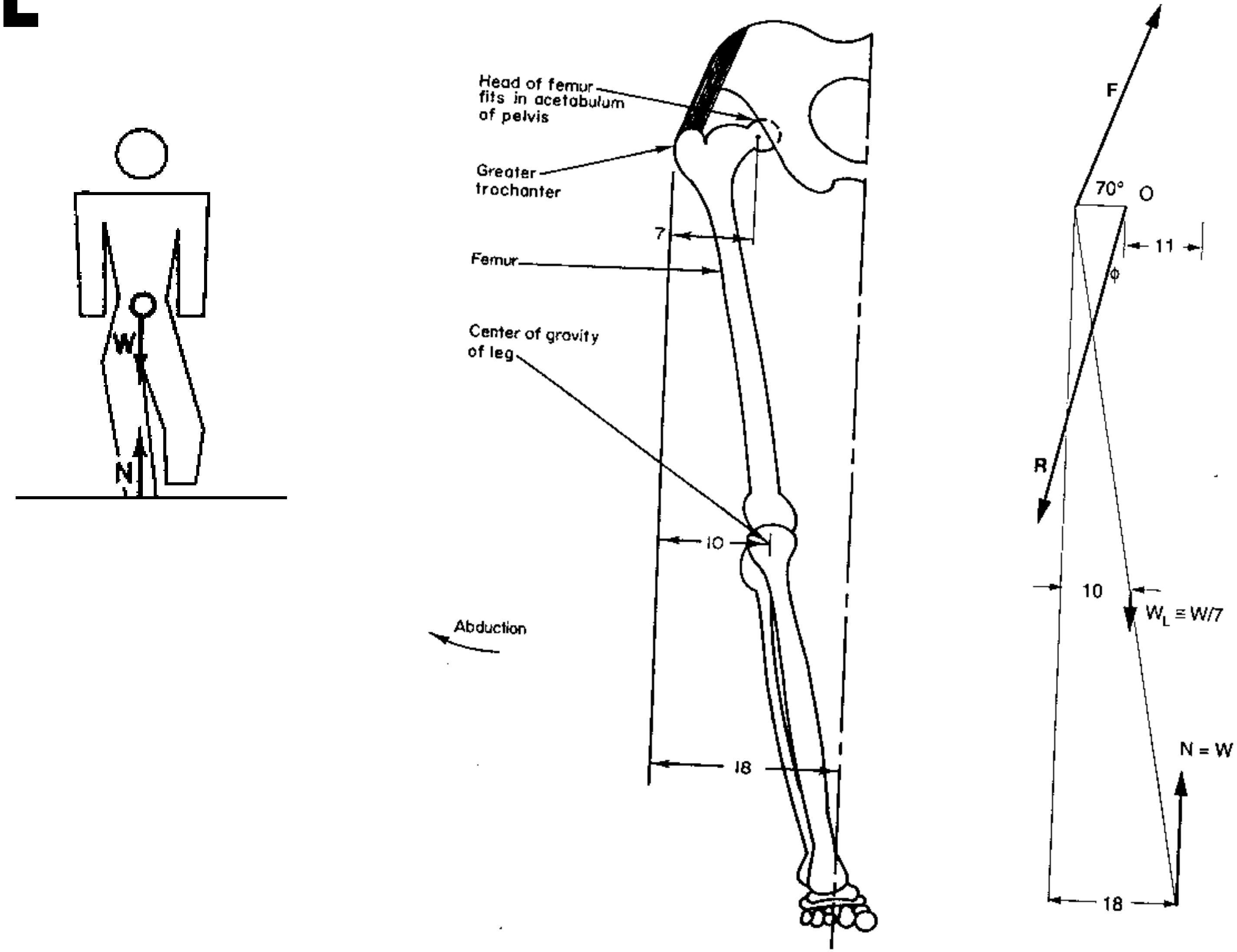
Example: Achilles Tendon

- Apply both translational and rotational equilibrium conditions

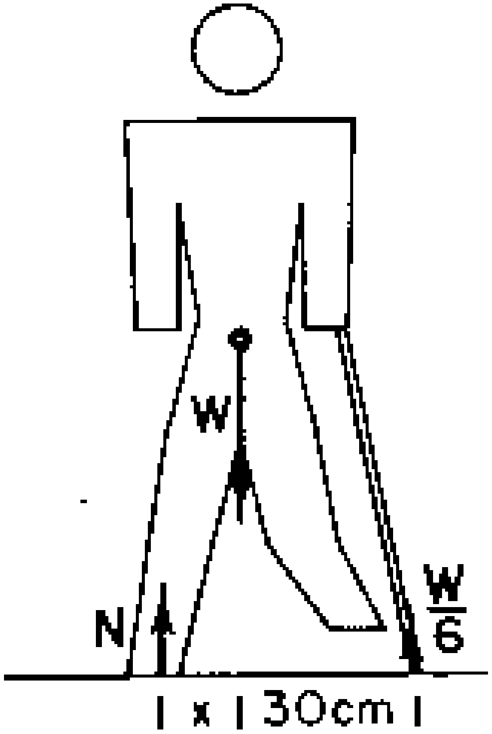


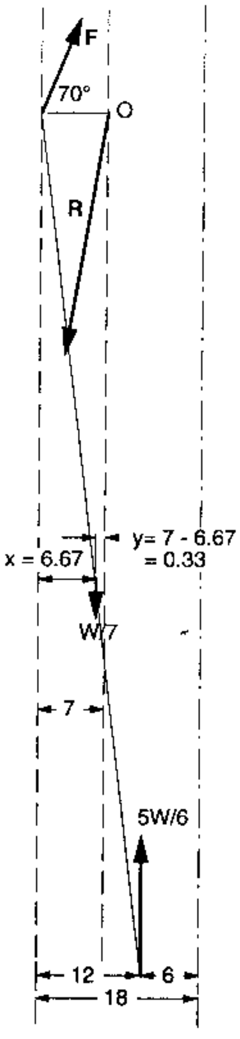


Example: Forces on the Hip



Example: Use of a Cane



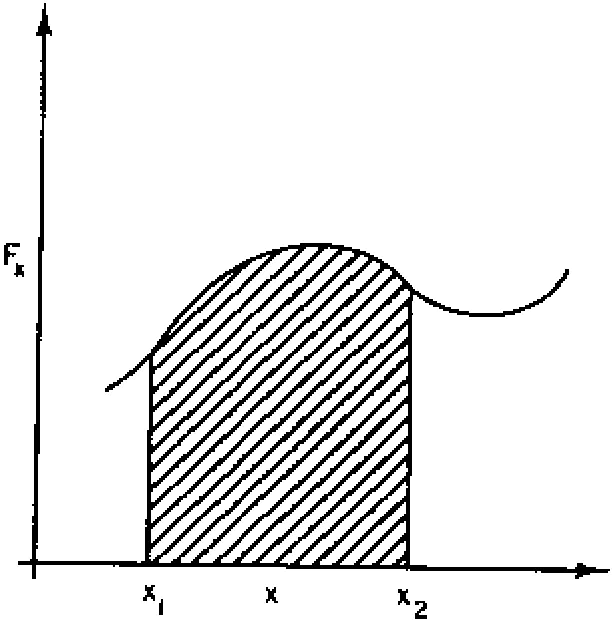


Work

- Work done by a force F_x as it moves from x_1 to x_2

$$W = \int_{x1}^{x2} F_x(x)\,dx$$

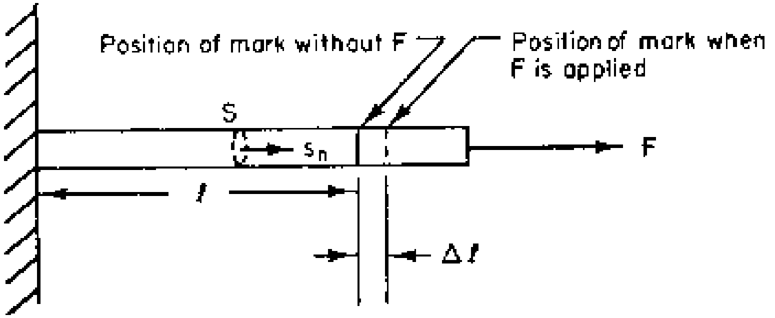
  - Area under curve
  - Equal to increase in K.E.



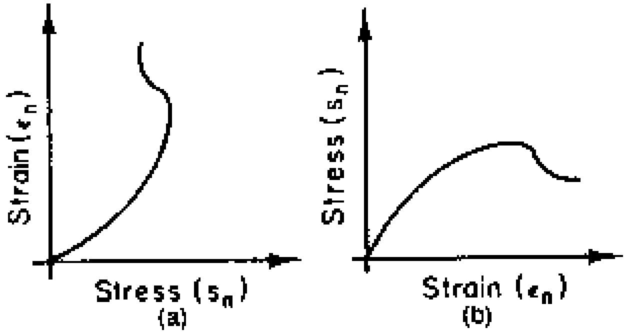
Stress and Strain

- Normal stress: tensile/compressive

$$s_n = \frac{F}{S} = E\varepsilon_n = E\frac{\Delta l}{l}$$



  - *E*: Young's modulus



Shear

- Force parallel to surface

$$s_s = \frac{F}{S} = G\varepsilon_s = G\frac{\delta}{h}$$

  - *G*: shear modulus

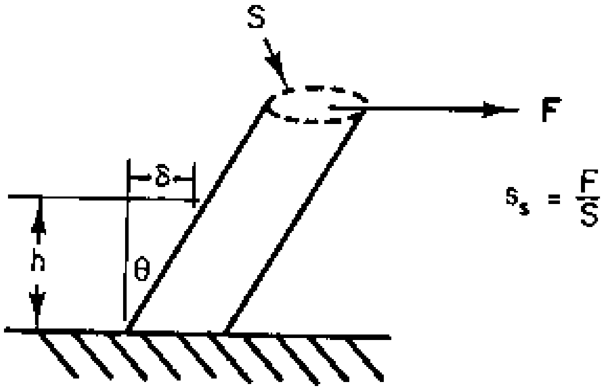


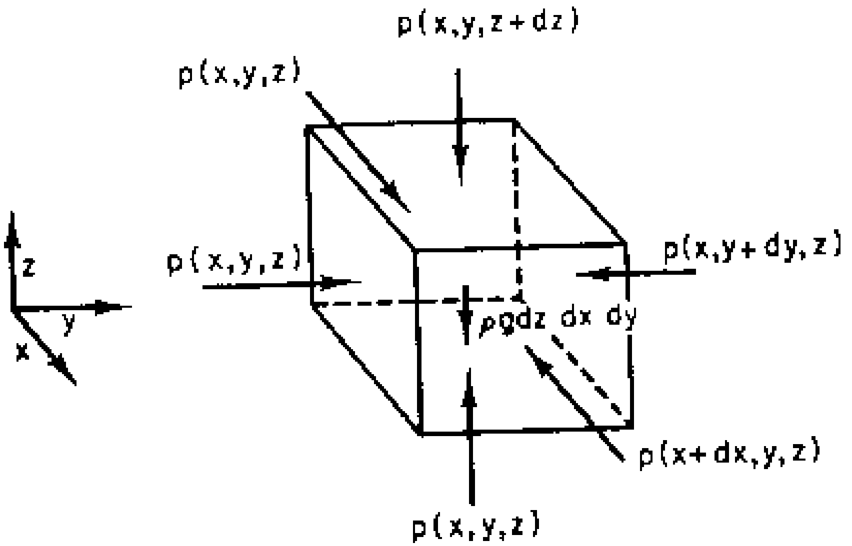
FIGURE 1.23. Shear stress and strain.

Hydrostatics

- Equilibrium:

$$\frac{dp}{dz} = -\rho g$$

$$p = p_o - \rho g z$$



Buoyancy

- Object immersed in fluid

$$F = (\rho_{fluid} - \rho) \cdot g \cdot V$$

- Example: Terrestrial animals
  - Very small *buoyancy* because $\rho_{fluid} << \rho$
- Example: Aquatic animals
  - Very small *F* because $\rho_{fluid} \approx \rho$
  - "Weightless" in water

Compressibility

- Pressure on a fluid

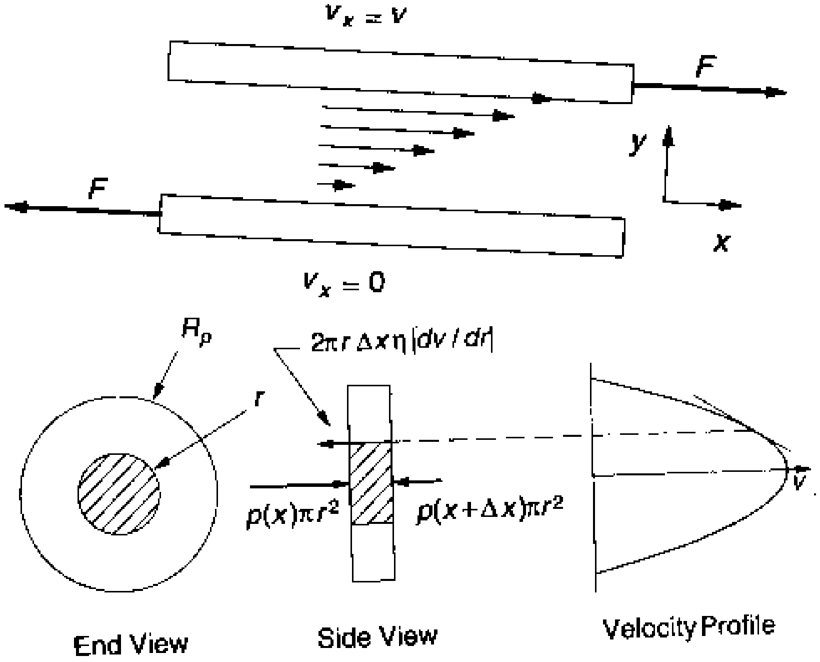
$$\frac{\Delta V}{V} = -\kappa \cdot \Delta p$$

- Compressibility κ negligible in many cases (e.g., $\kappa = 5\times10^{-10}\ \mathrm{Pa}^{-1}$ for water)
- Important for such phenomena as ultrasound transmission

Viscosity

- Laminar flow of a Newtonian fluid

$$F = \eta S \frac{dv_x}{dy}$$



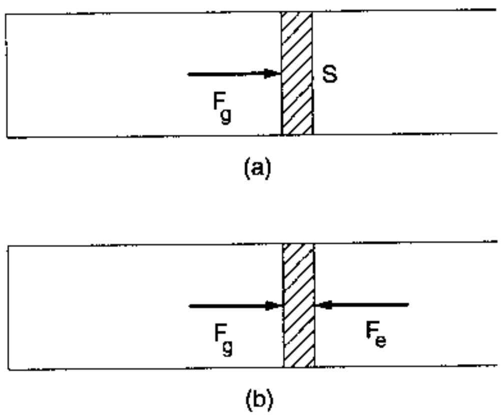
- Application: clean room isolation

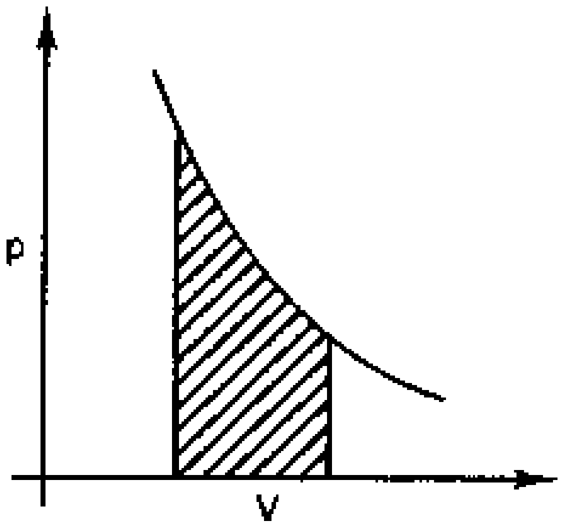
Pressure-Volume Work

- Work done by a gas

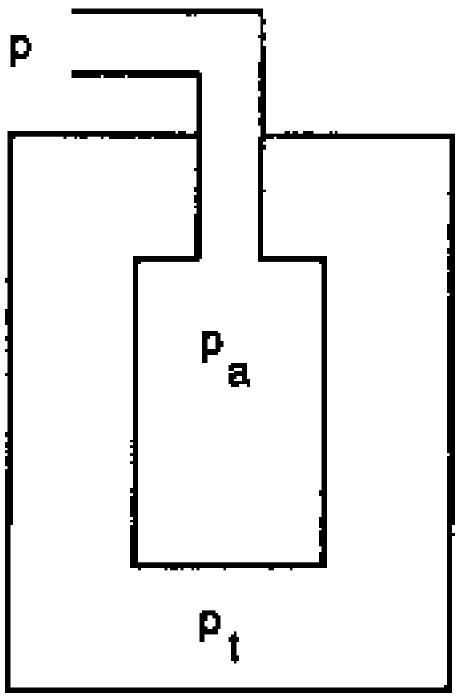
$$W_{by\,gas} = F \cdot dx = p \cdot S \cdot dx = p \cdot dV$$

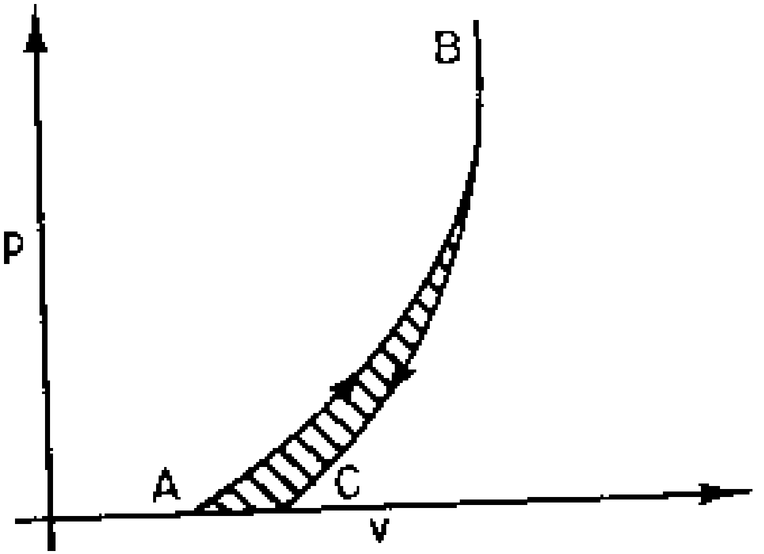
$$W_{by\,gas} = \int_{V1}^{V2} p \cdot dV$$



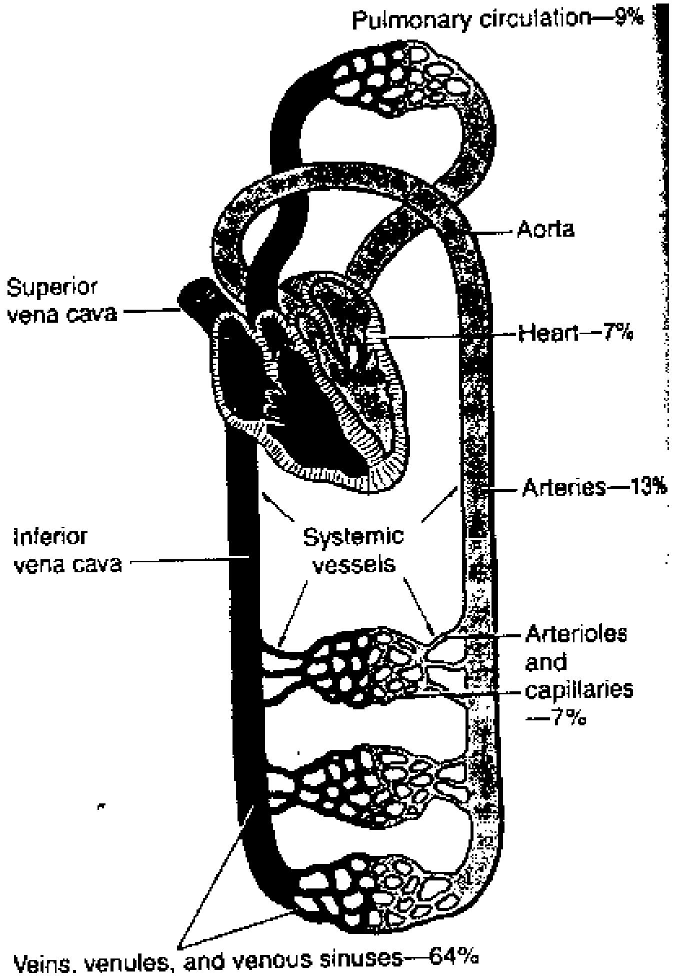


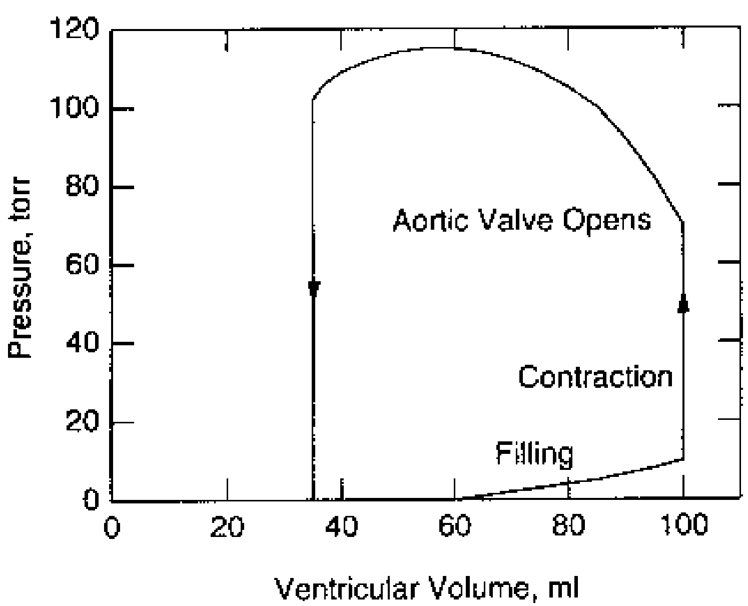
Example: Respiration Work





Circulatory System





Turbulent Flow and Reynolds Number

- Turbulent flow when Reynolds number is more than a few thousands

$$N_R = \frac{LV\rho}{\eta}$$

Problem Assignment

- Posted on class web site

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