Intermediate Physics for Medicine and Biology - Chapter 1

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

Chapter 1

- Basic concepts of mechanics
  - Equilibrium with biomechanical applications
  - Work
  - Stress, Strain, and shear
  - Hydrostatics
  - Compressibility
  - Viscosity and Viscous Flow
  - Pressure-Volume Work
  - Human Circulatory System as an application

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 μm)^3
  - Adult ~ 2 m tall and 0.3 m wide

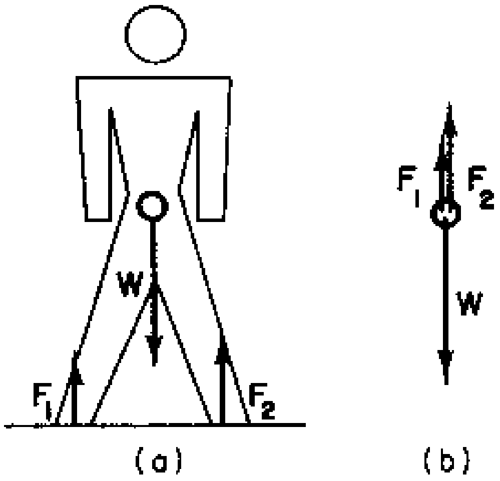
    → volume ~ 2 × 0.3 × 0.3 = 0.18 m^3
  - Assume body is made entirely of cells
  - Number of cells = 0.18/1e-15 ~ 2 × 10^{14}

Forces and Translational Equilibrium

- Force defined by Newton's second law

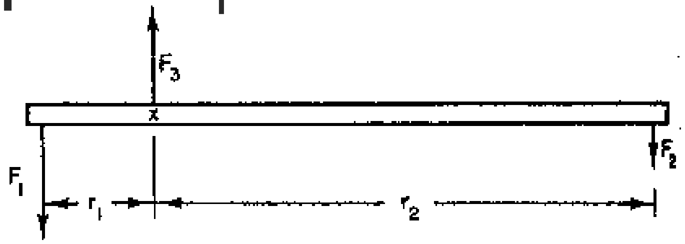
$$\boxed{F = ma}$$

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



Rotational Equilibrium

- Torques τ_i is defined as $\boxed{\tau_i = r_i F_i}$

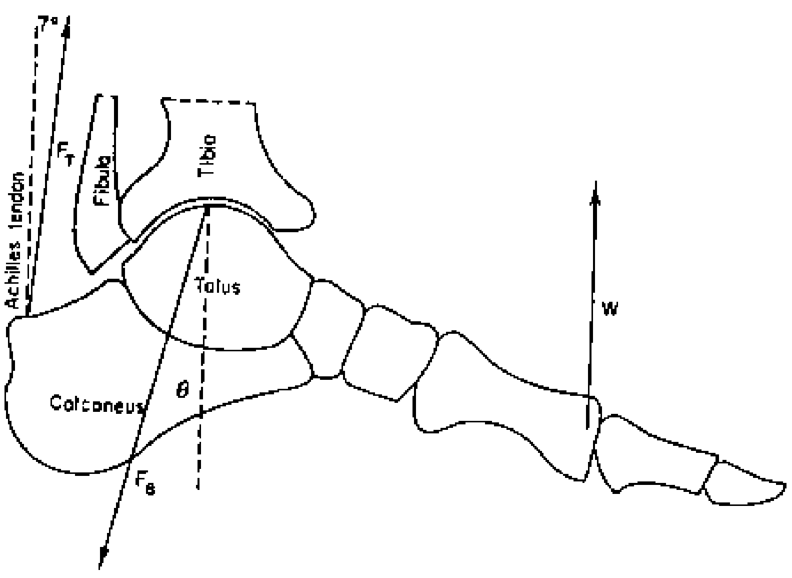


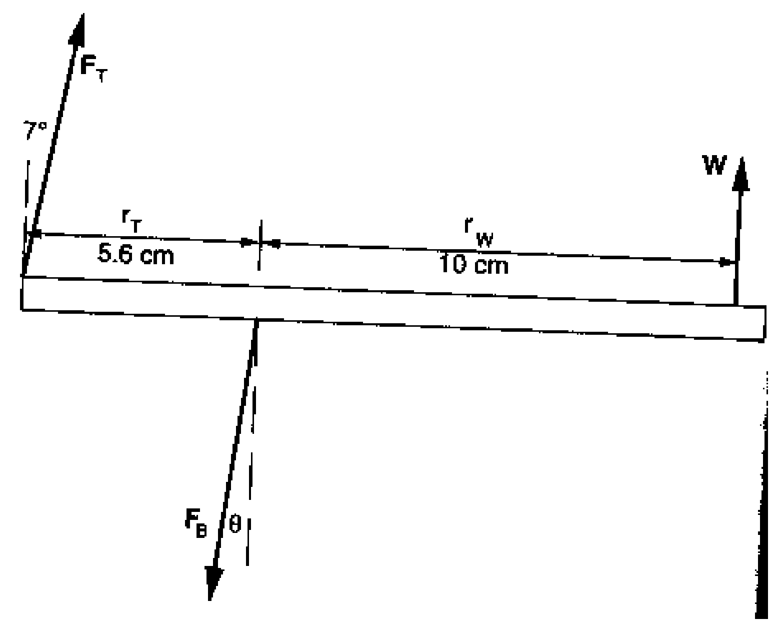
- Rotational equilibrium if,

$$\boxed{\sum_i \tau_i = 0}$$

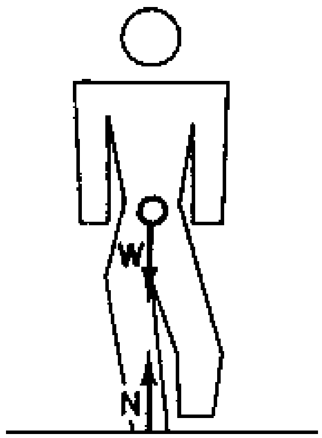
Example: Achilles Tendon

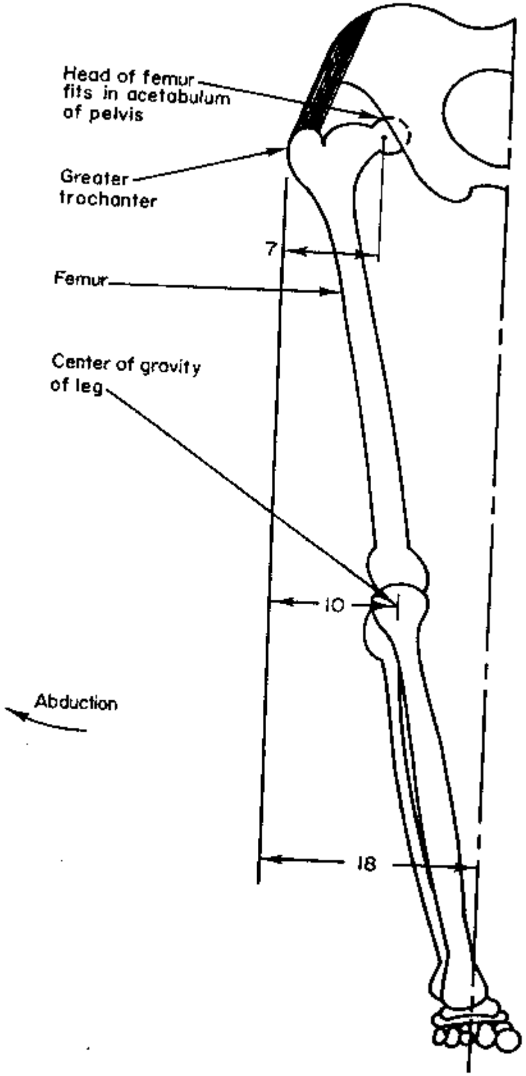
- Apply both translational and rotational equilibrium conditions

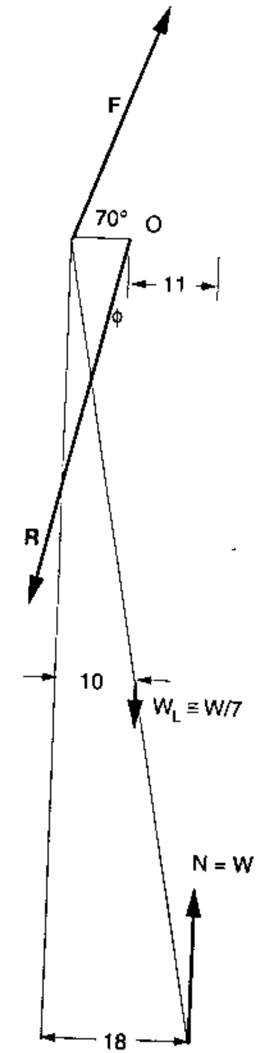




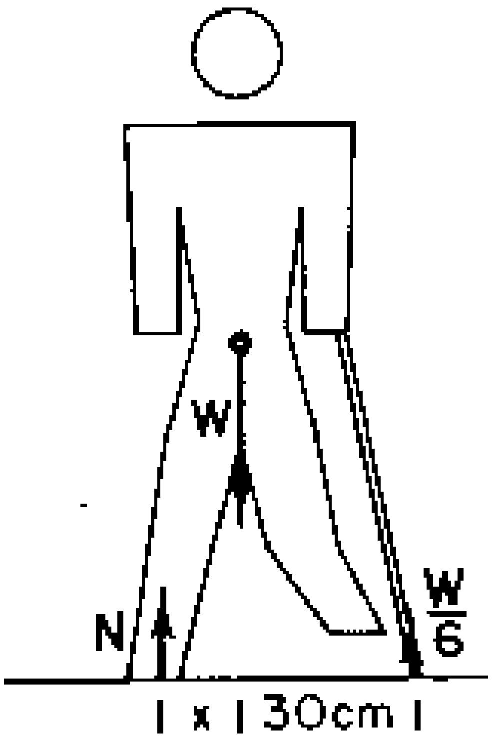
Example: Forces on the Hip

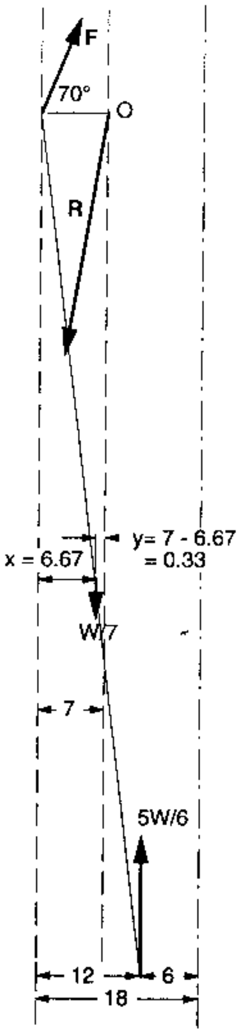






Example: Use of a Cane



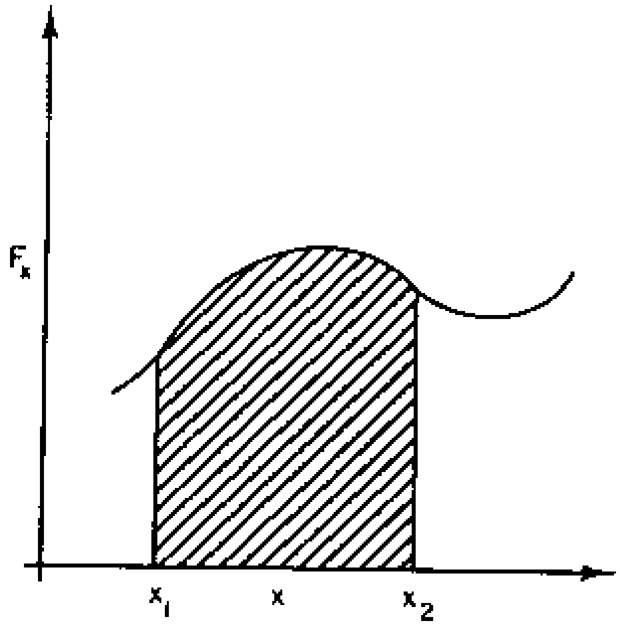


Work

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

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

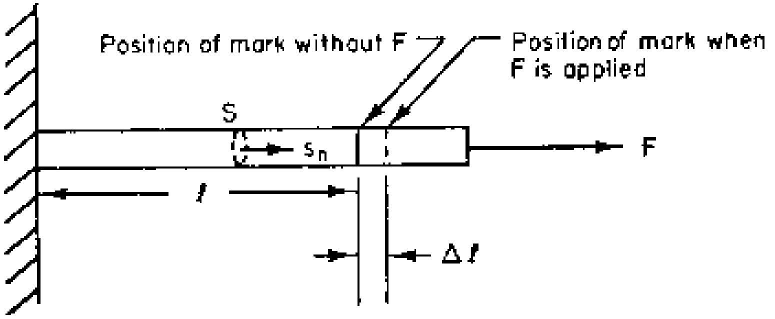
  - Area under curve
  - Equal to increase in K.E.



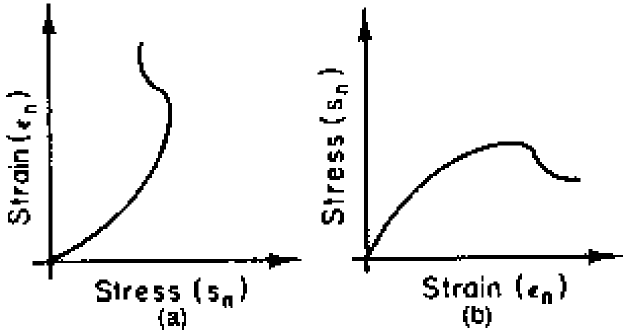
Stress and Strain

- Normal stress: tensile/compressive

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



  - *E*: Young's modulus



Shear

- Force parallel to surface

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

  - *G*: shear modulus

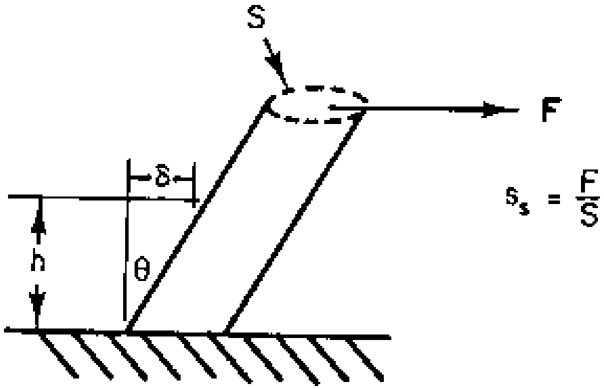


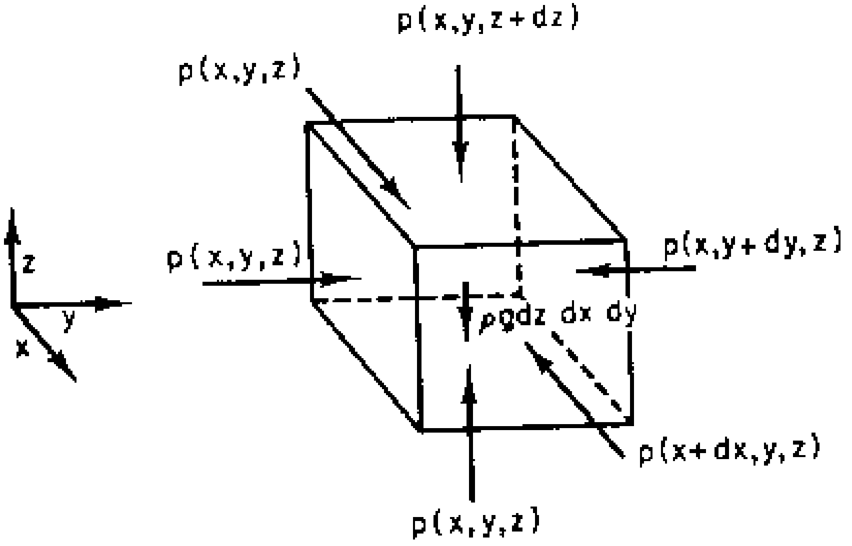
FIGURE 1.23. Shear stress and strain.

Hydrostatics

- Equilibrium:

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

$$\boxed{p = p_o - \rho g z}$$



Buoyancy

- Object immersed in fluid

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

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

Compressibility

- Pressure on a fluid

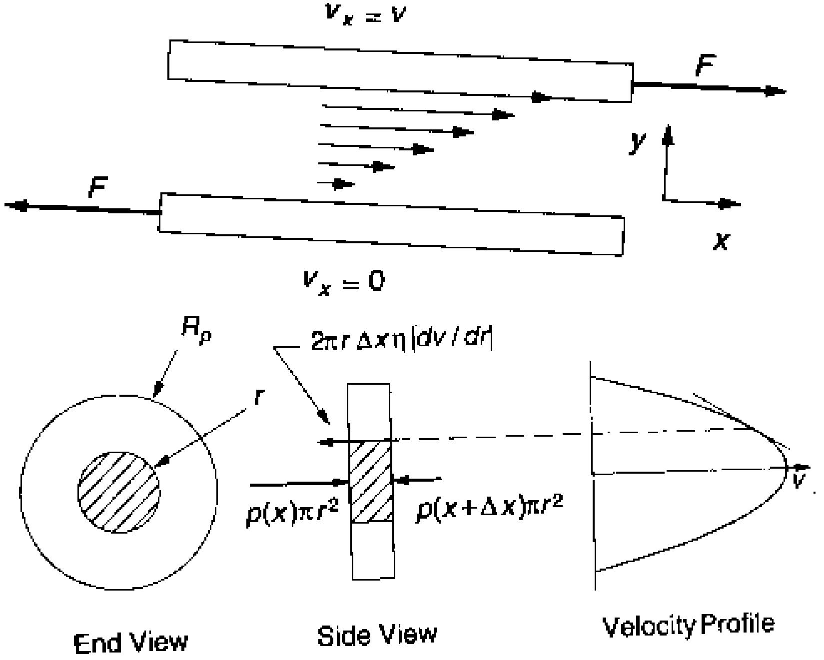
$$\boxed{\frac{\Delta V}{V} = -\kappa \cdot \Delta p}$$

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

Viscosity

- Laminar flow of a Newtonian fluid

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



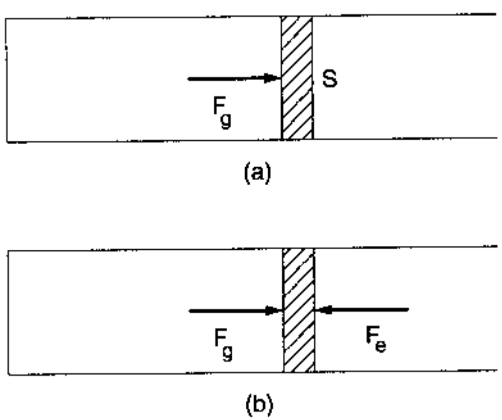
- Application: clean room isolation

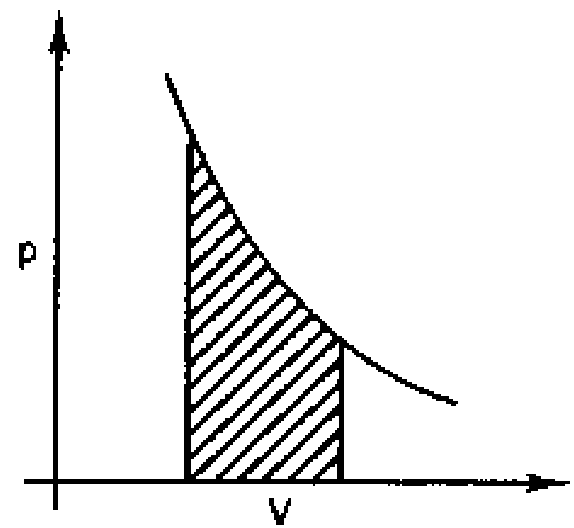
Pressure-Volume Work

- Work done by a gas

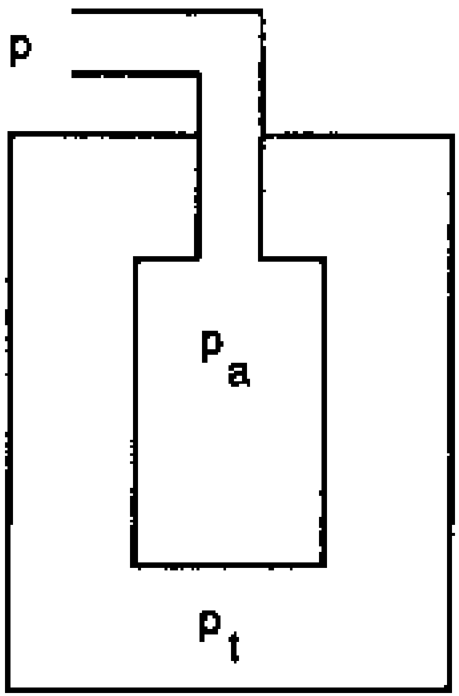
$$\boxed{W_{by\,gas} = F \cdot dx = p \cdot S \cdot dx = p \cdot dV}$$

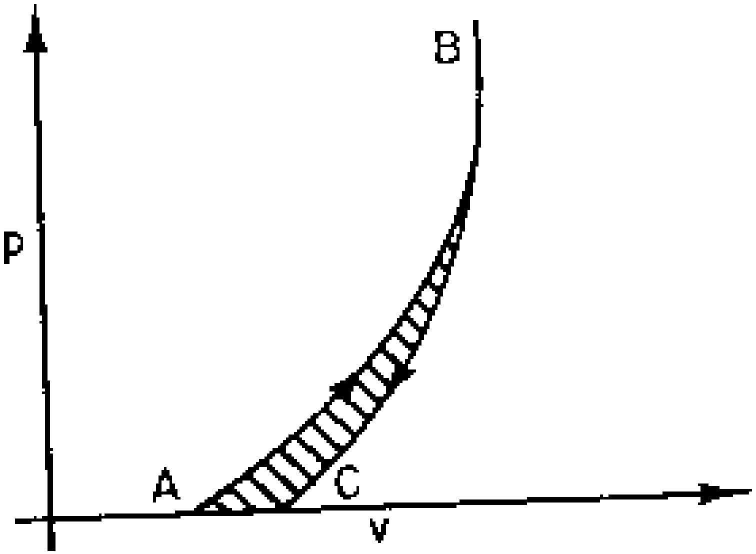
$$\boxed{W_{by\,gas} = \int_{V1}^{V2} p \cdot dV}$$



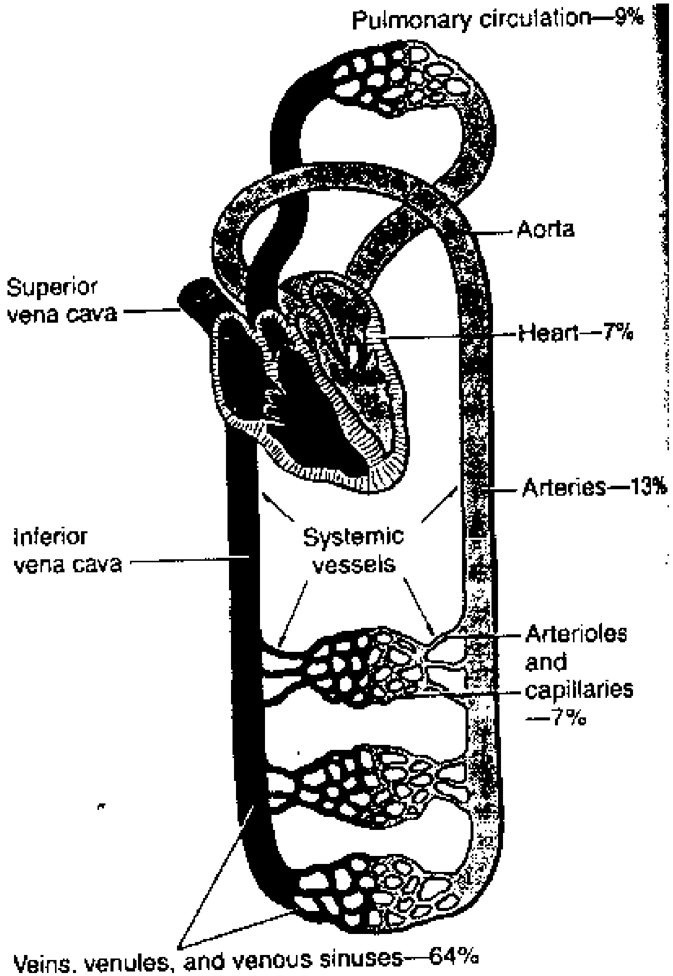


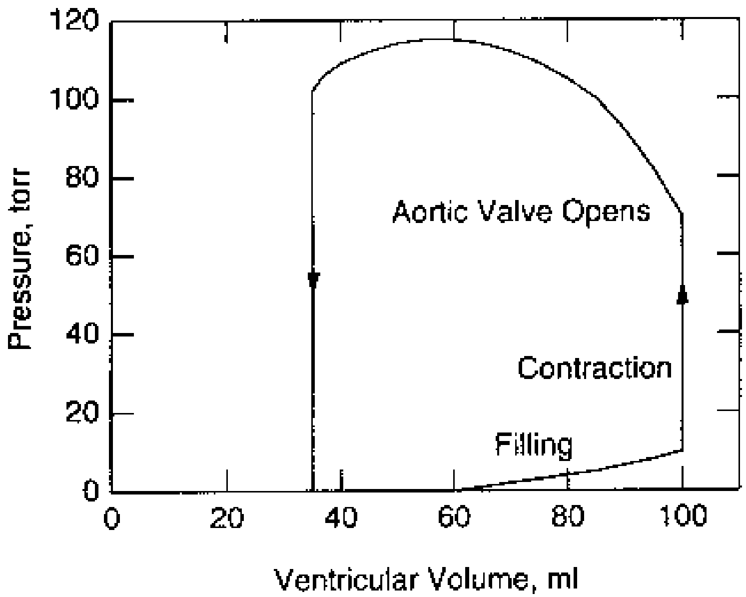
Example: Respiration Work





Circulatory System





Turbulent Flow and Reynolds Number

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

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

Circulatory System Values

TABLE 1.4. Typical values for the average pressure at the entrance to each generation of the major branches of the cardio-vascular tree, the average blood volume in certain branches, and typical dimensions of the vessels.

Location	Average pressure (torr)	Blood volume[a] (ml)	Diameter[b] (mm)	Length[b] (mm)	Wall thickness[b] (mm)	Avg. velocity[b] ($m\ s^{-1}$)	Reynolds number at maximum flow [c]
			Systemic circulation				
Left atrium	5						
Left ventricle	100						
Aorta	100	156	20	500	2.00	4.80×10^{-1}	9 400
Arteries	95	608	4	500	1.00	4.50×10^{-1}	1 300
Arterioles	86	94	0.05	10	0.2	5.00×10^{-2}	
Capillaries	30	260	0.008	1	0.001	1.00×10^{-3}	
Venules	10	470	0.02	2	0.002	2.00×10^{-3}	
Veins	4	2682	5	25	0.5	1.00×10^{-2}	
Vena cava	3	125	30	500	1.5	3.80×10^{-1}	3 000
Right atrium	3						
			Pulmonary Circulation				
Right atrium	3						
Right ventricle	25						
Pulmonary artery	25	52					
Arteries	20	91					7 800
Arterioles	15	6					
Capillaries	10	104					
Veins	5	215					2 200
Left atrium	5						

Problem Assignment

- Posted on class web site

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