Medical Equipment I - 2010
Chapter I

Professor Yasser M. Kadah

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

CAIRO UNIVERSITY

Intended Learning Objectives (ILOs)

- Part I (1 lecture every week)
  - To learn theoretical analysis methodologies that serve provide the foundation for the design of medical devices
- Part II (1 Lecture every 2 weeks)
  - To discuss basic ideas of human factors engineering in medical device design

Class Textbook

- Part I:
  - Russell K. Hobbie and Bradley J. Roth, *Intermediate Physics for Medicine and Biology, 4th ed.*, Springer-Verlag, New York, 2007. (Hardcopy)

  - Textbook's official web site: http://www.oakland.edu/~roth/hobbie.htm
- Part II:
  - ANSI/AAMI HE75:2009 - Human factors engineering – Design of medical devices

Grading Policy

- Class Total Grade: **100** points
- Term Exam: **70** points (Open-Book)
- Midterm Exam: **15** Points (Open-Book)
- Class Project: **10** Points
- Other (homework, quizzes, etc.): **5** points
- Coursework grade will be *weighted* by your attendance percentage.
  - Failing to attend at least 80% of the classes will result in a failing grade in this class.

Class Project

- Project statement available on web site
- Due date: January 1, 2010

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 ~ $(10\ \mu m)^3$
  - Adult ~ 2 m tall and 0.3 m wide

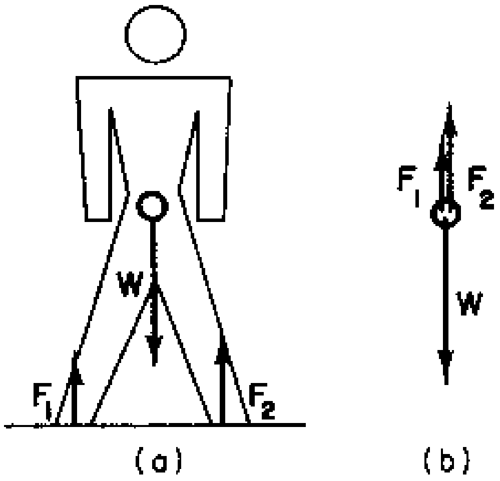
    → volume ~ $2 \times 0.3 \times 0.3 = 0.18\ m^3$
  - Assume body is made entirely of cells
  - Number of cells = 0.18/1e-15 ~ 2×10^{14}

Forces and Translational Equilibrium

- Force defined by Newton's second law

$$F = ma$$

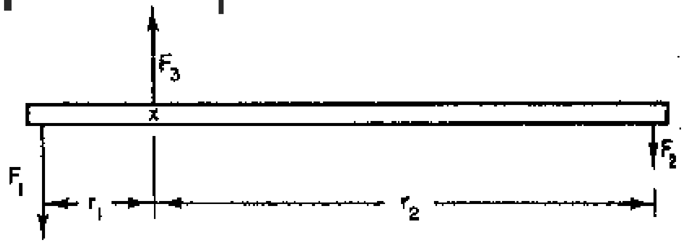
- Translational equilibrium: $\sum_i F_i = 0$
- Equilibrium:
  - remains at rest
  - move at constant speed



Rotational Equilibrium

- Torques τ_i is defined as

$$\tau_i = r_i F_i$$

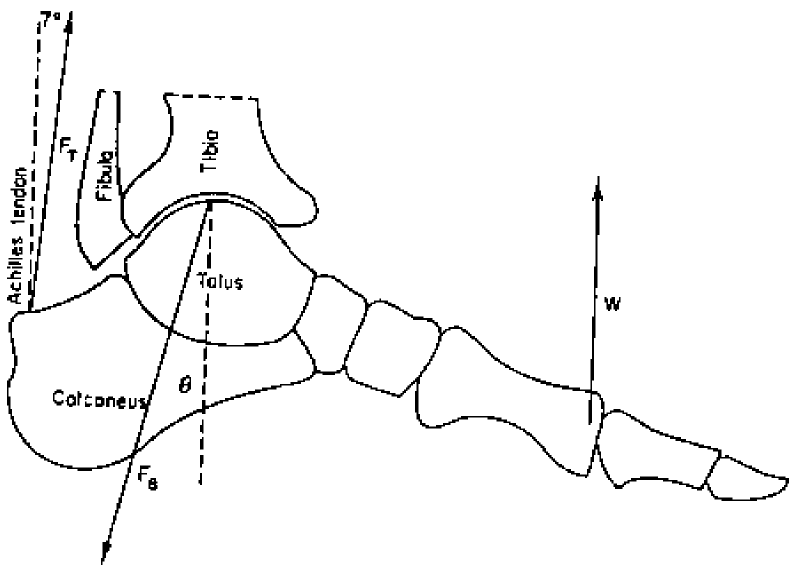


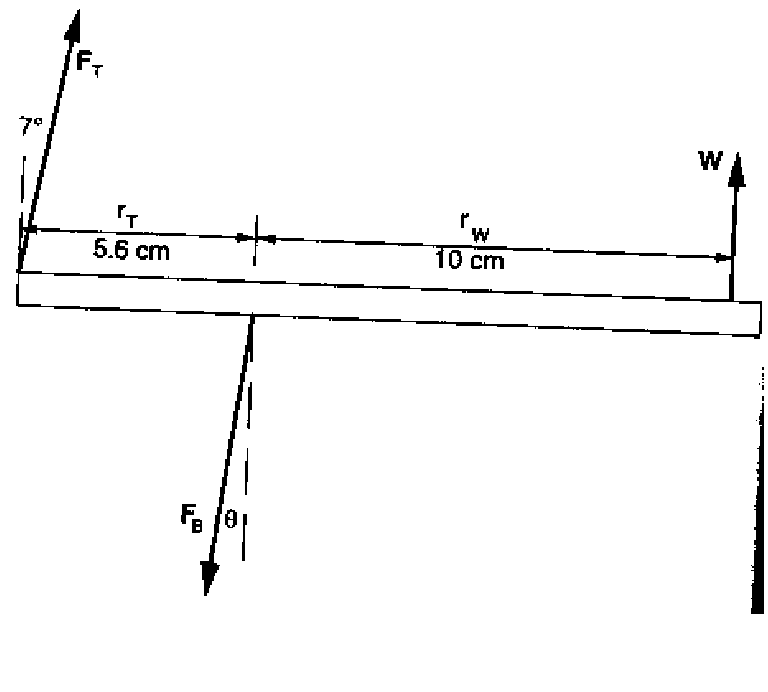
- Rotational equilibrium if,

$$\sum_i \tau_i = 0$$

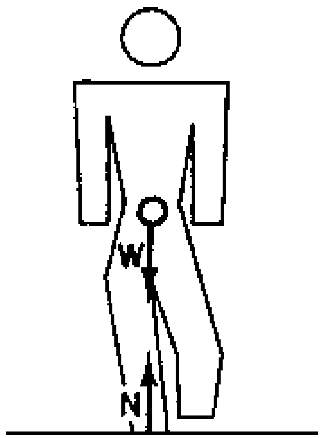
Example: Achilles Tendon

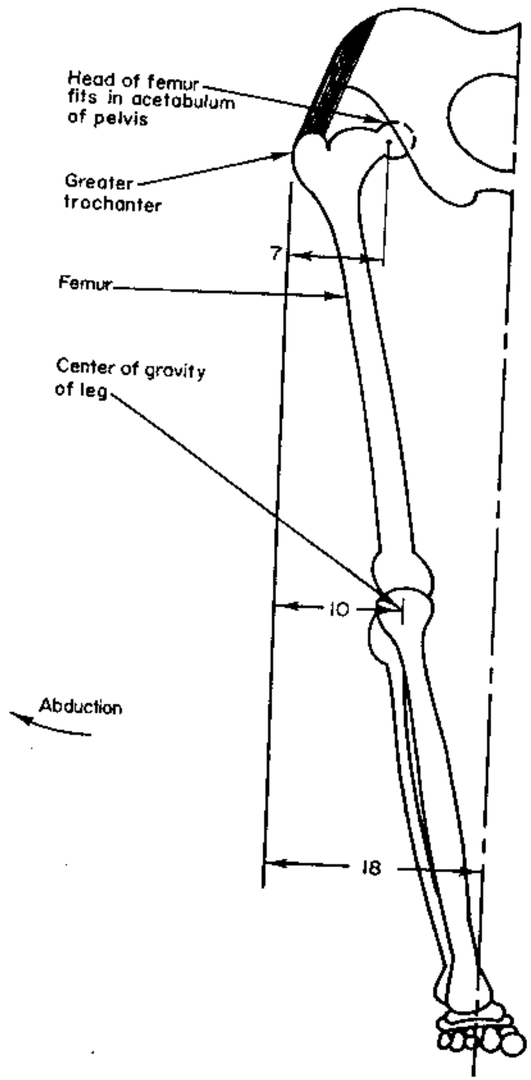
- Apply both translational and rotational equilibrium conditions

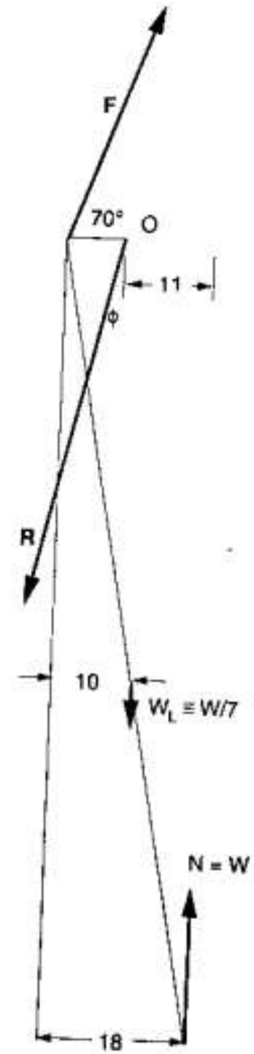




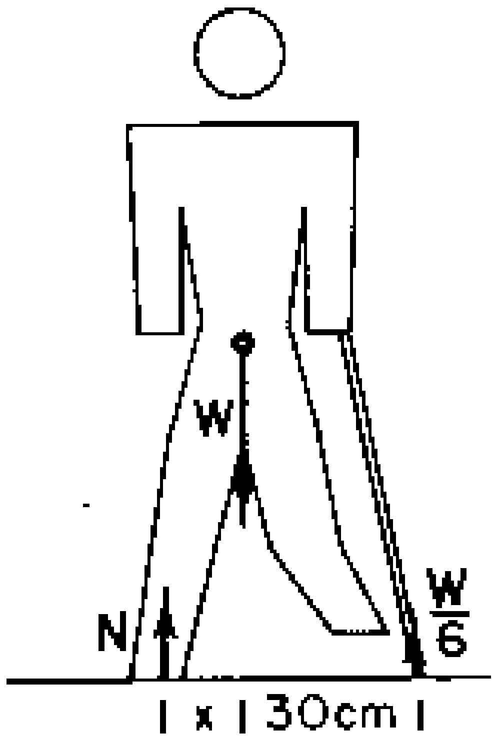
Example: Forces on the Hip

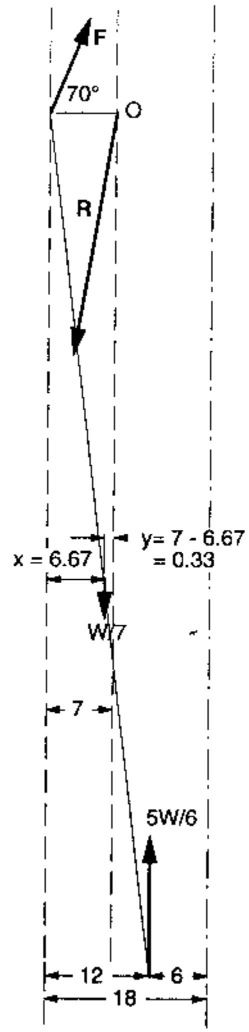






Example: Use of a Cane



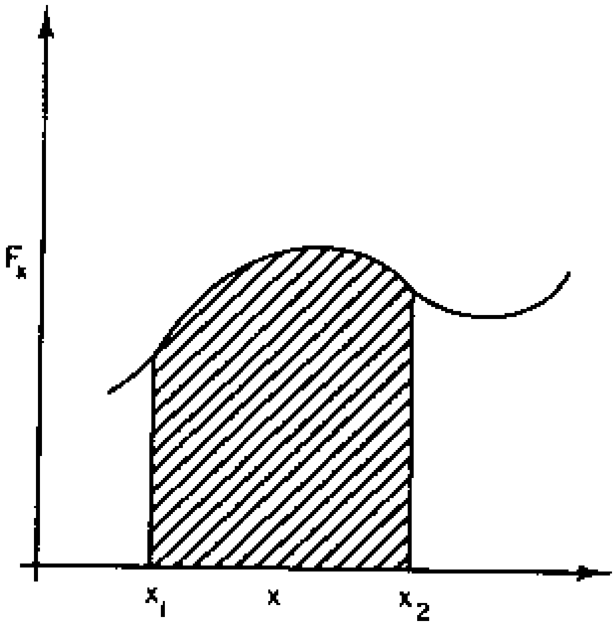


Work

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

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

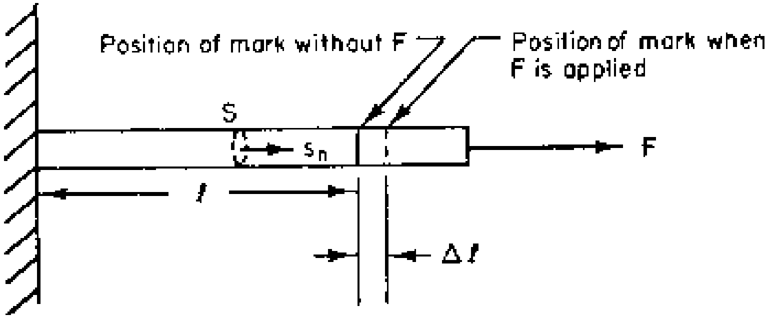
  - Area under curve
  - Equal to increase in K.E.



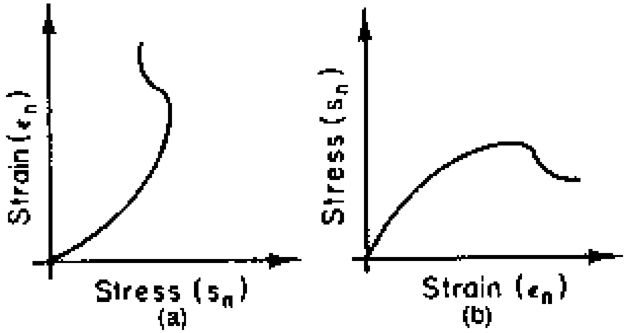
Stress and Strain

- 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

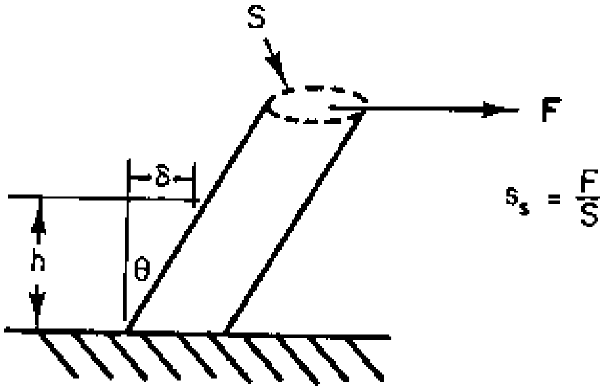
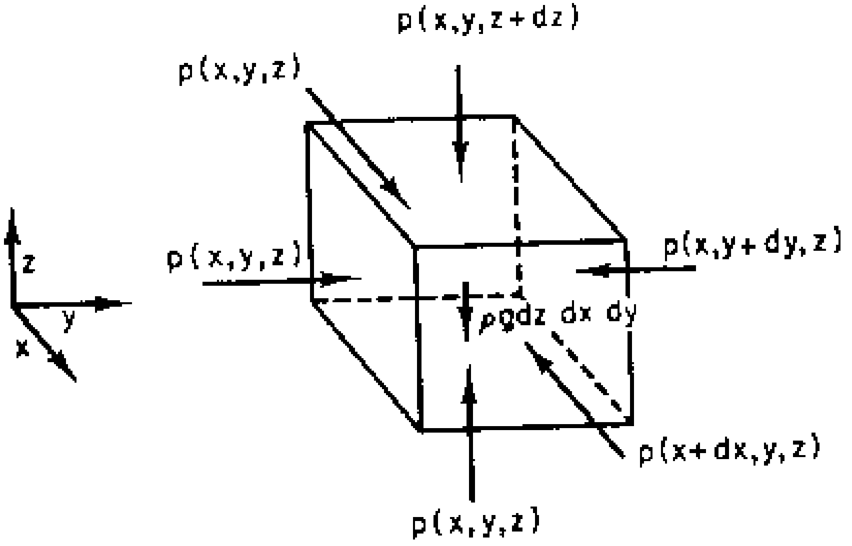


FIGURE 1.23. Shear stress and strain.

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

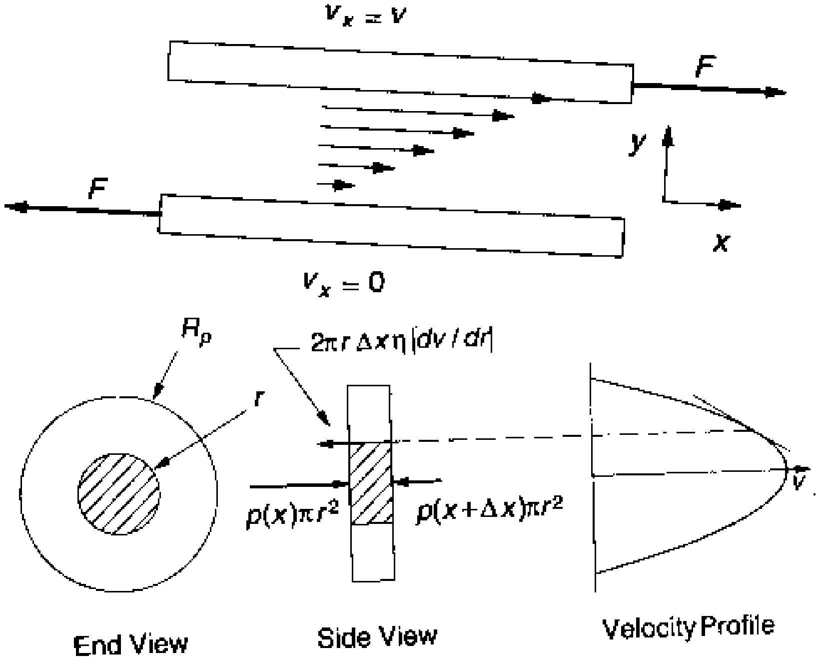
$$\frac{\Delta V}{V} = -\kappa \cdot \Delta p$$

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

Viscosity

- Laminar flow of a Newtonian fluid

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



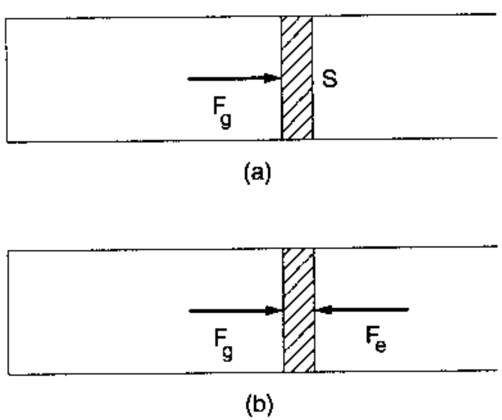
- Application: clean room isolation

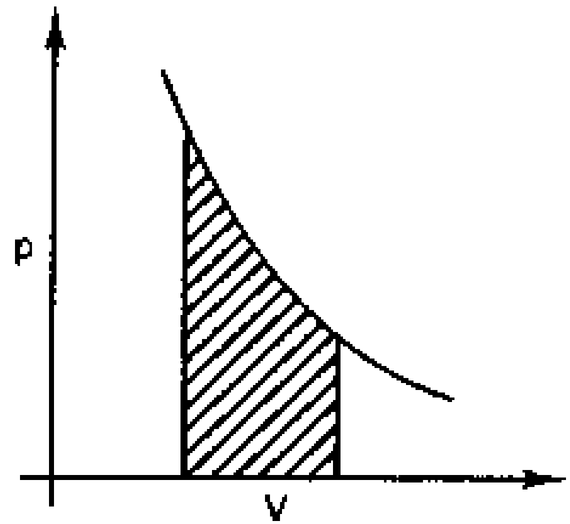
Pressure-Volume Work

- Work done by a gas

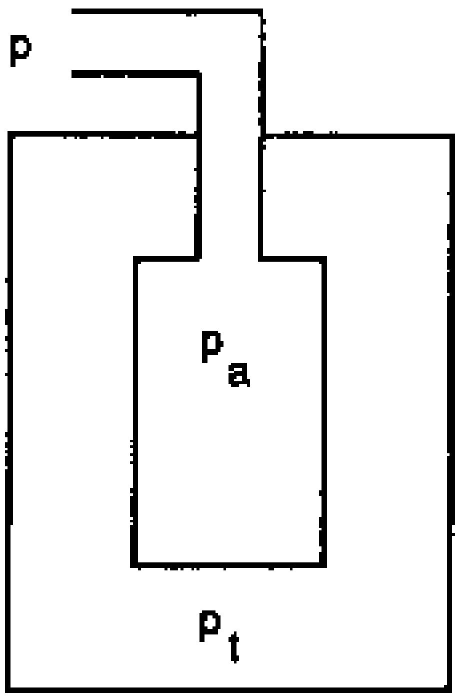
$$W_{by\,gas} = F \cdot dx = p \cdot S \cdot dx = p \cdot dV$$

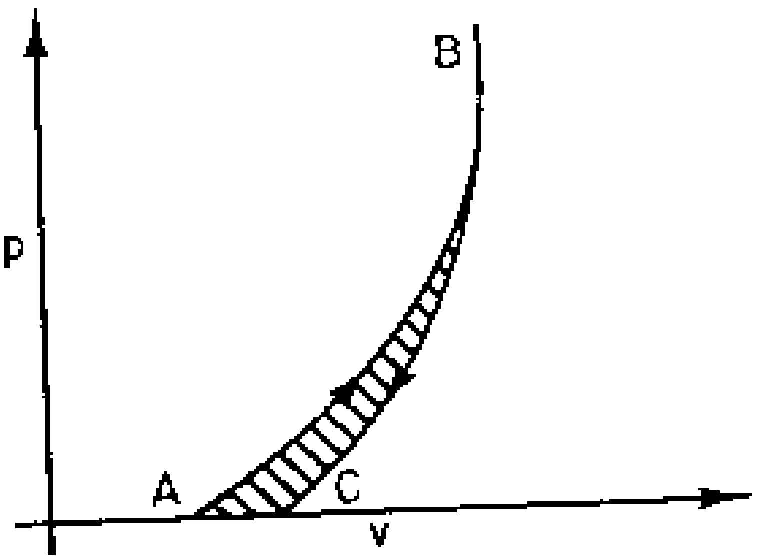
$$W_{by\,gas} = \int_{V1}^{V2} p \cdot dV$$



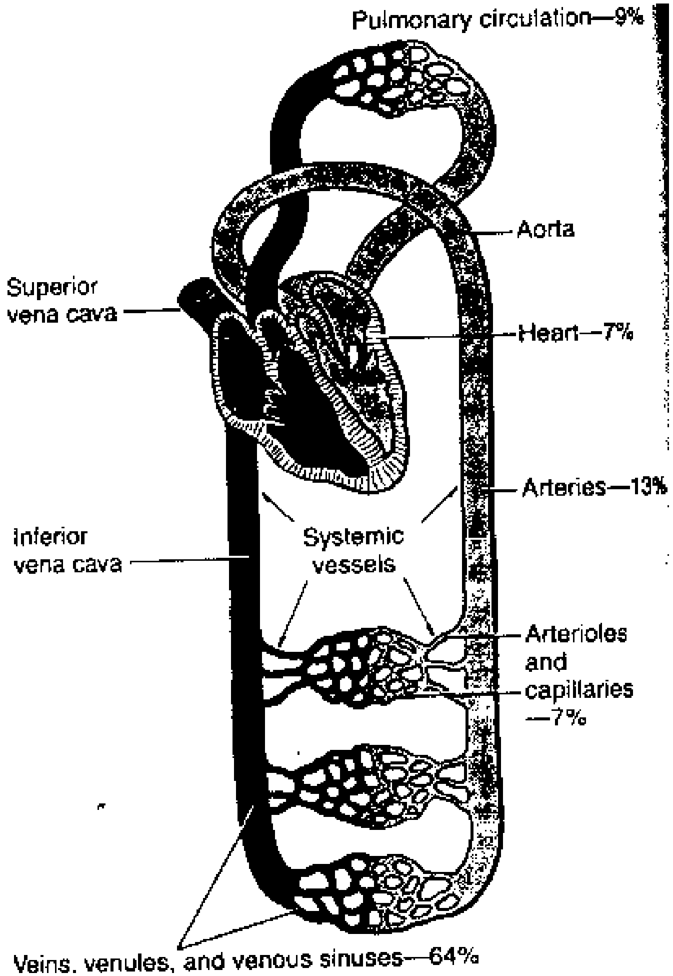


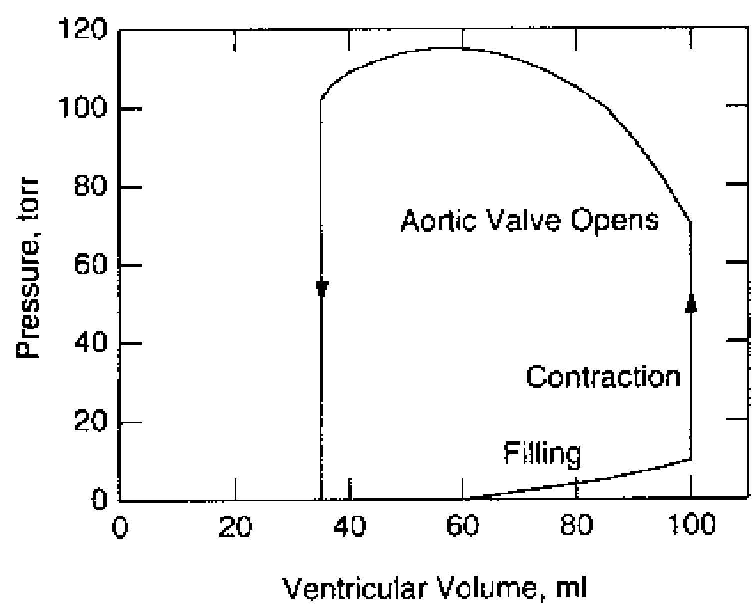
Example: Respiration Work





Circulatory System





Turbulent Flow and Reynolds Number

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

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

Circulatory System Values

TABLE 1.4. Typical values for the average pressure at the entrance to each generation of the major branches of the cardiovascular 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
- Solution manual is available from TA

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