Medical Equipment I - 2009
Chapter 5

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

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Transport Through Neutral Membranes

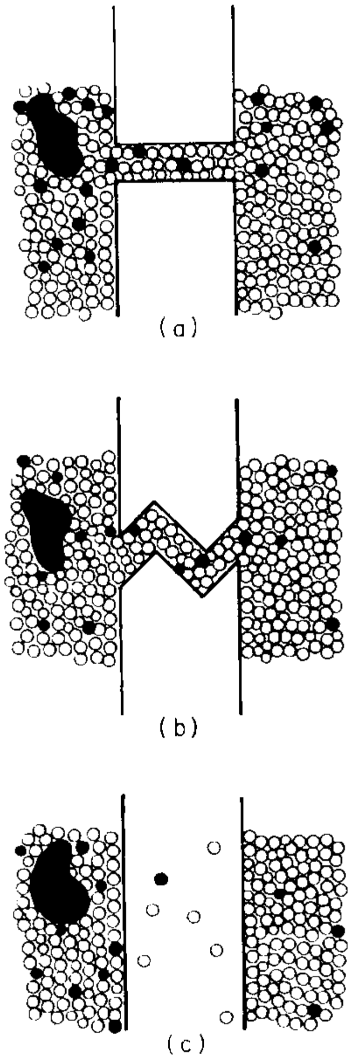
- Definitions
- Continuity equations
- Brownian motion
- Motion in a gas
- Motion in a liquid
- Diffusion
- Applications

Membranes

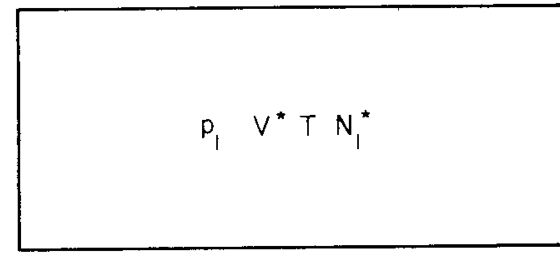
- Cells are surrounded by a membrane 7-10 nm thick
- Permeable to a substance
  - Substance can pass freely through it
- Semipermeable
  - Only certain substances can get through it
- Permeant
  - Substance that can pass through

Membranes

- Examples
  - Straight pores
  - Tortuous pores
  - No pores; molecules dissolve
- Water motion: bulk flow
- Solute motion: random walk
- Effective motion: diffusion superimposed on bulk flow



Osmotic Pressure



- Gas law

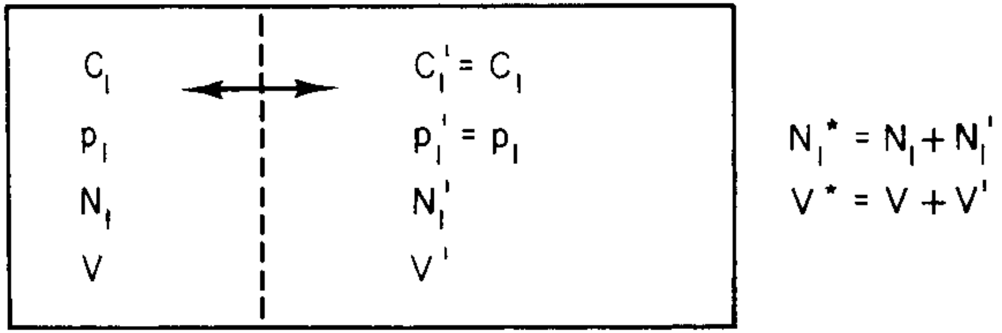
$$p_1 V^* = n_1^* RT = N_1^* k_B T$$

  - N_1^* : # of molecules, n_1^* : # of moles

- Denote,

$$C_1 = \frac{N_1^*}{V^*} \quad , \quad c_1 = \frac{n_1^*}{V^*}$$

Osmotic Pressure



- Imagine volume V* divided into two subvolumes V,V'
  - Pressure remains p_1 in both partitions
  - Average number of molecules remain unchanged

$$p_1 = p_1' = C_1 k_B T = C_1' k_B T$$

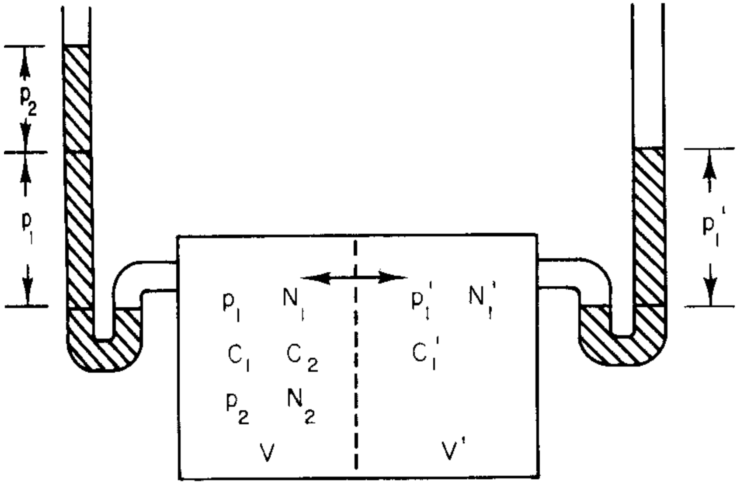
Osmotic Pressure

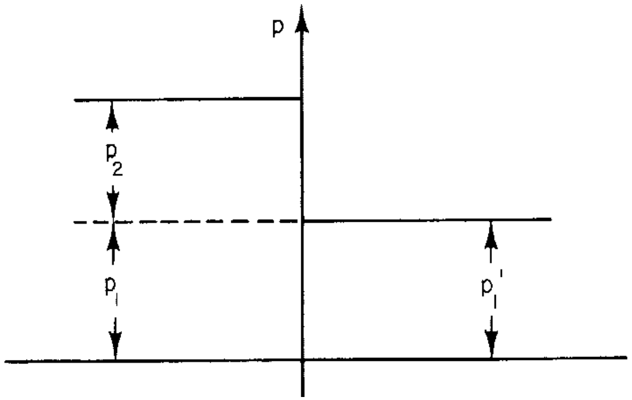
- Second species
  - Cannot pass through

$$p = p_1 + p_2$$

$$p_1 = C_1 k_B T$$

$$p_2 = C_2 k_B T$$





Osmotic Pressure

- Total partial pressure for all species that cannot pass through the membrane is called osmotic pressure and denoted by π

$$\pi_2 = C_2 k_B T$$

Osmotic Pressure

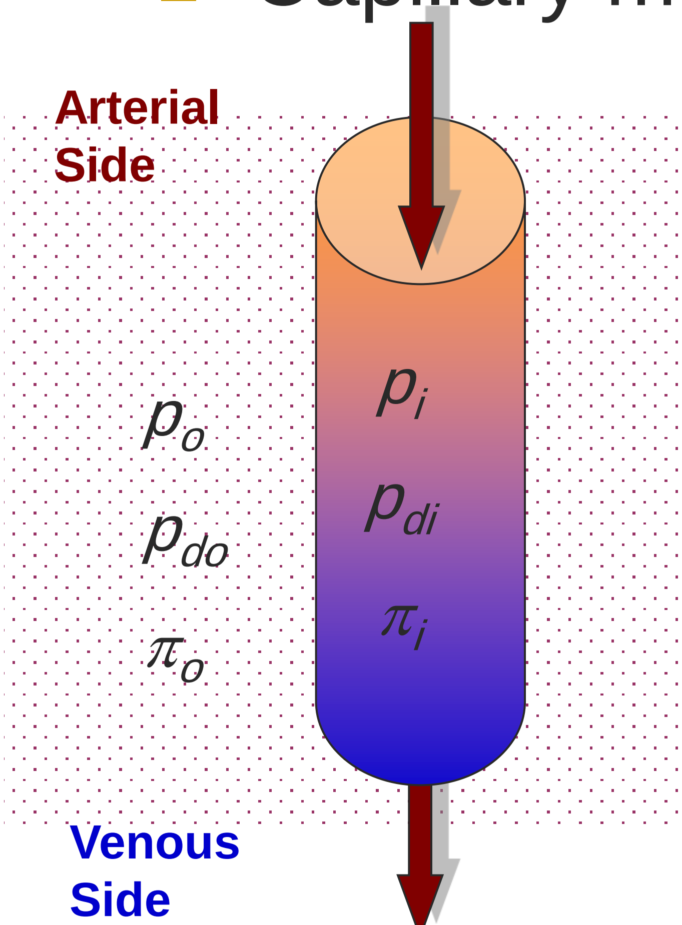
- Total pressure = driving pressure + osmotic pressure

$$p = p_d + \pi$$

- There is no flow if the driving pressure is the same between the two sides of the membrane

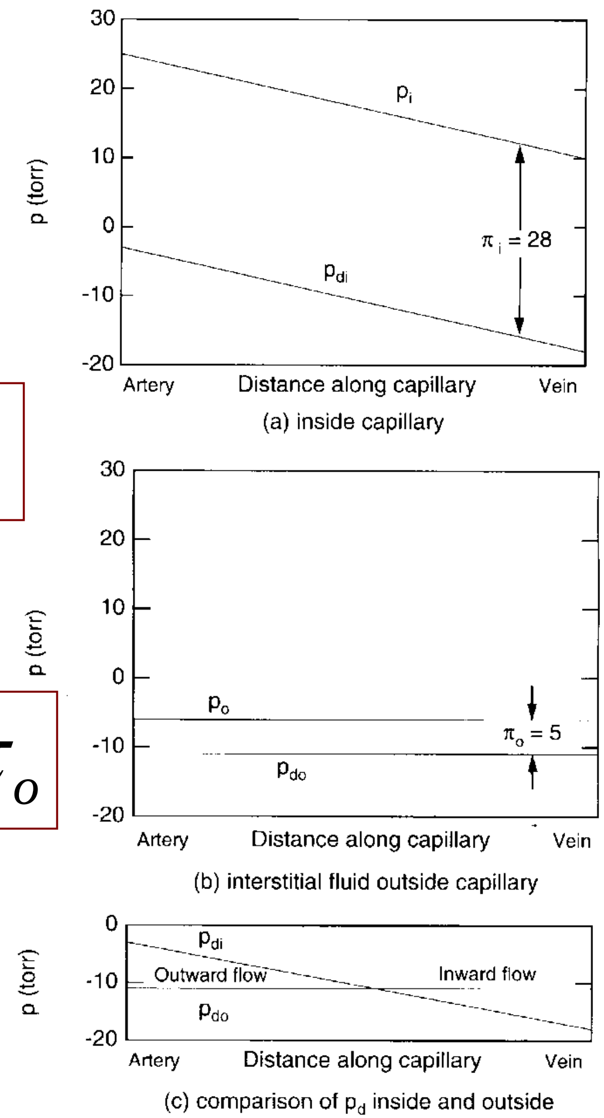
Clinical Examples

- Capillary model



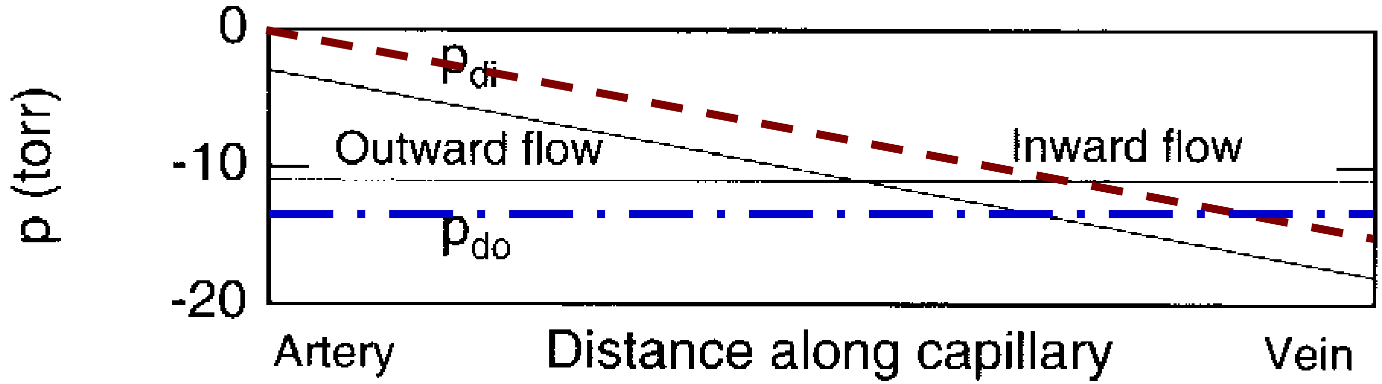
$$p_i = p_{di} + \pi_i$$

$$p_o = p_{do} + \pi_o$$



Edema

- Abnormal collection of fluid inside tissue

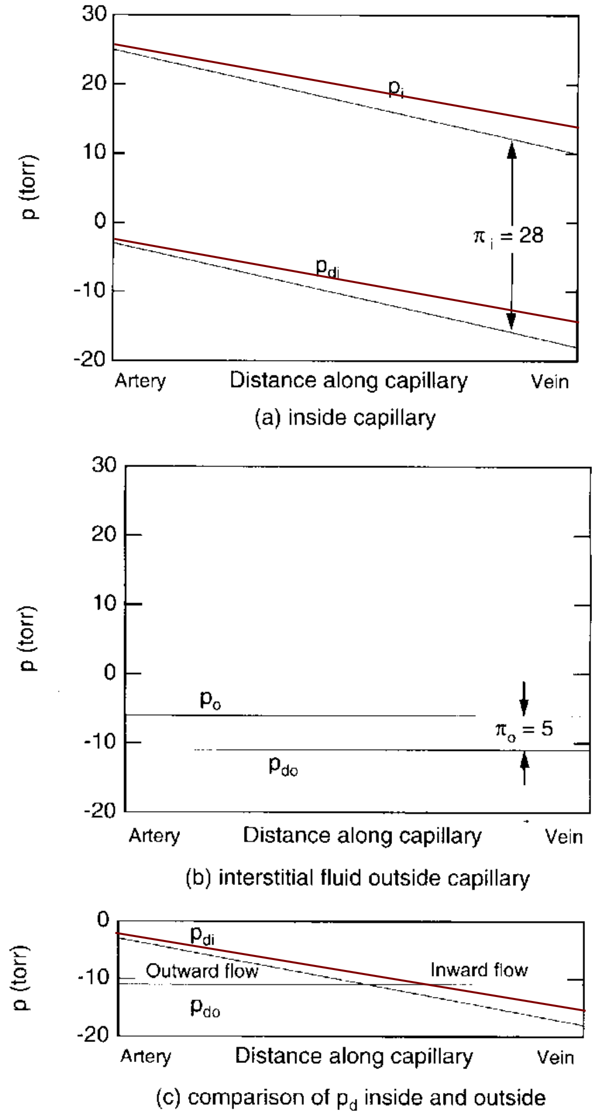


(c) comparison of p_d inside and outside

Edema due to Heart Failure

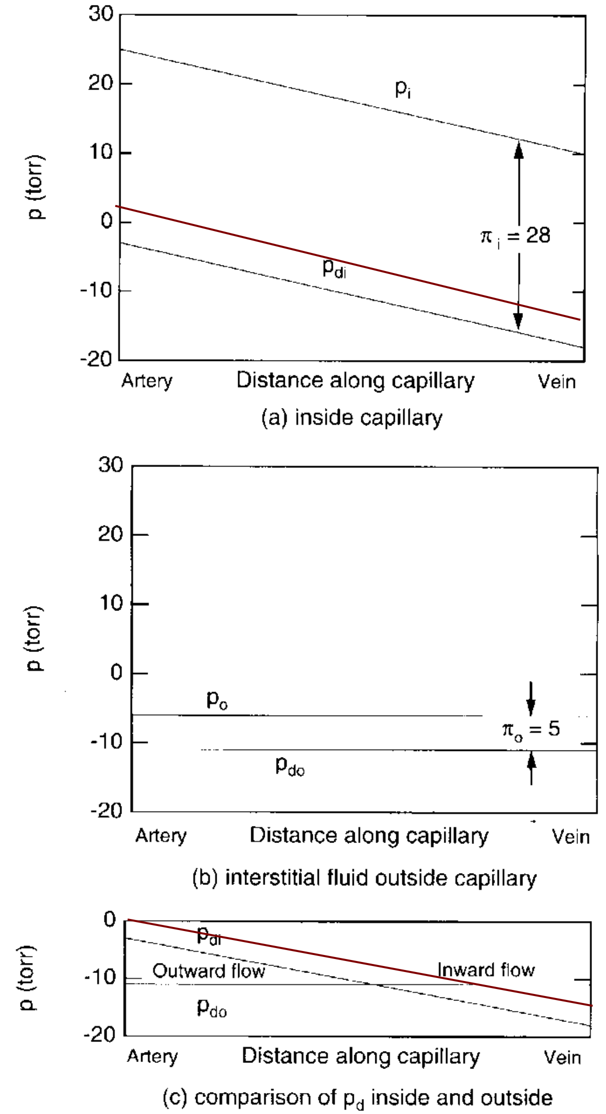
- Right heart failure
  - Swelling of legs
- Left heart failure
  - Pulmonary edema
- Root cause:

Rising venous pressure



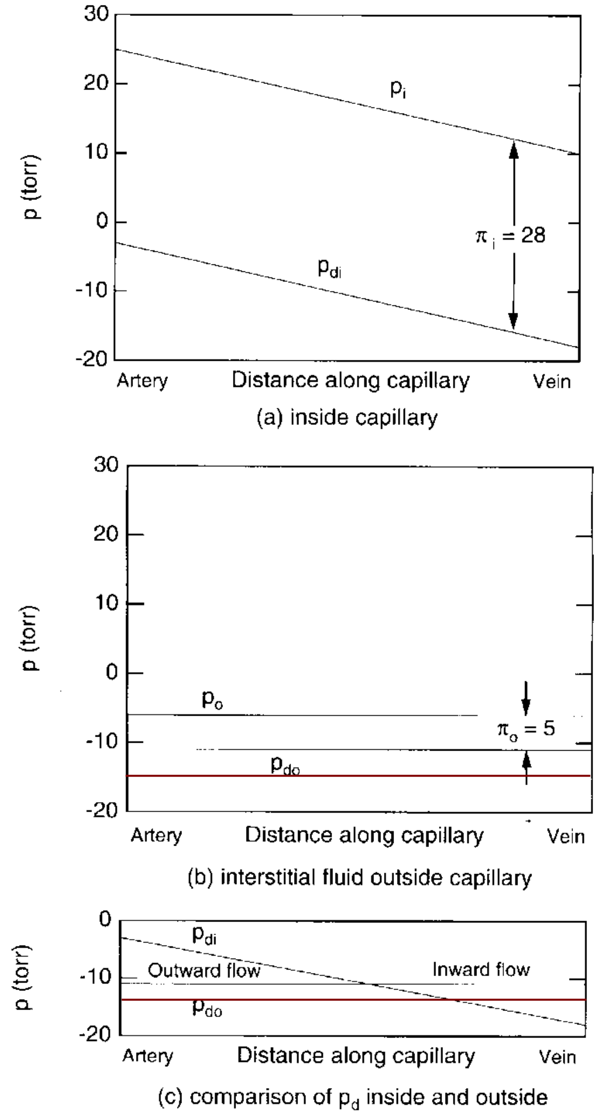
Nephrotic Syndrome, Liver Disease and Ascitis

- Lower protein in blood
  - Hypoproteinemia
- Several causes
  - Nephrons leaking proteins
  - Liver malfunction
  - Ascitis (blocking of veins in the liver)



Edema of Inflammatory Reactions

- 3 Steps
  - Vasodilation
  - Fluid exodation (plasma)
  - Cellular migration
- Rise in osmotic pressure in extracellular space



Headaches in Renal Dialysis

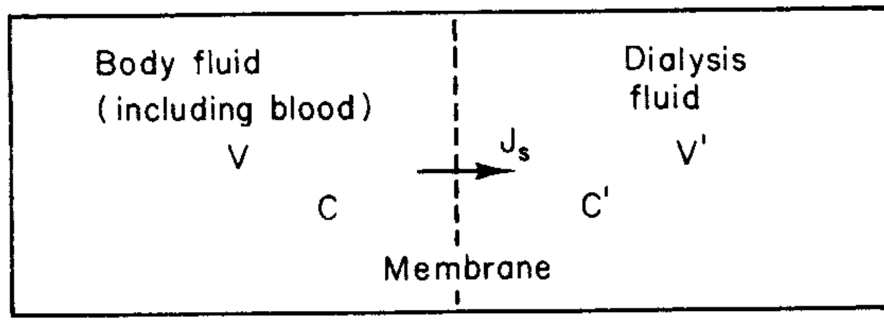
- Capillary-brain barrier
  - Low permeability to urea
- Plasma urea ↓, temporary urea osmotic pressure inside brain ↑
- Water flows into brain causing cerebral edema, which can cause severe headache.
- Converse: inject into blood urea/manitol
  - Water flows from brain to blood
  - Emergency treatment for cerebral edema

Osmotic Diuresis

- Water and many solutes pass into nephron from the blood
- Net reabsorption occurs through the rest of the nephron
  - Most of water and variable for solutes
- Medium-weight molecules are not reabsorbed at all (e.g., manitol, glucose)
  - If they are present, water reabsorption is less
  - Increase in urine volume

The Artificial Kidney

- No solvent drag



$$J_s = \omega RT\left(C - C'\right)$$

$$\frac{dN}{dt} = -S\omega RT\left(C - C'\right) \Rightarrow \frac{dC}{dt} = \frac{-S\omega RT}{V}\left(C - C'\right)$$

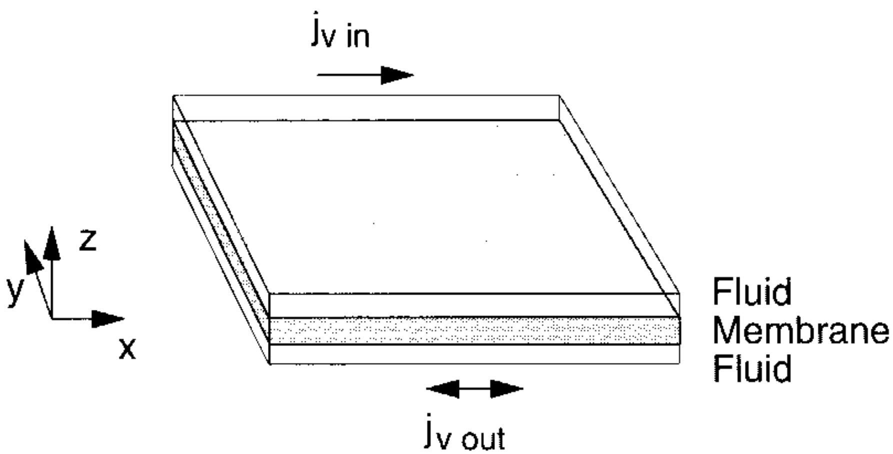
$$C(t) = \left[C(0) - C'\right]e^{-t/\tau} + C'$$

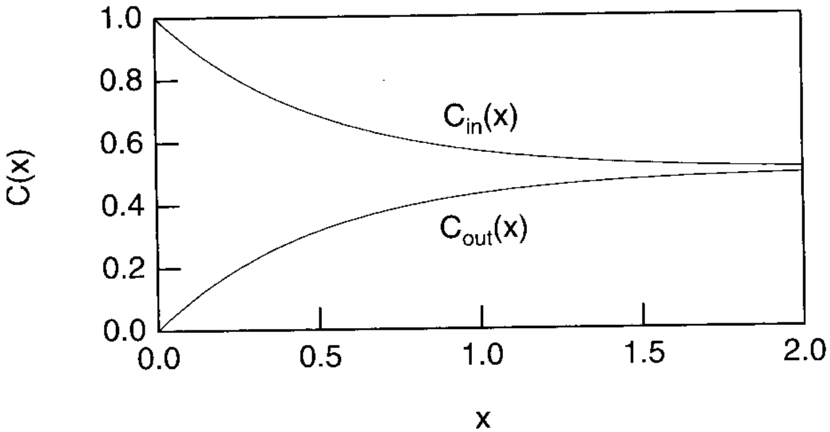
where $$\tau = \frac{V}{S\omega RT}$$

The Artificial Kidney: Example

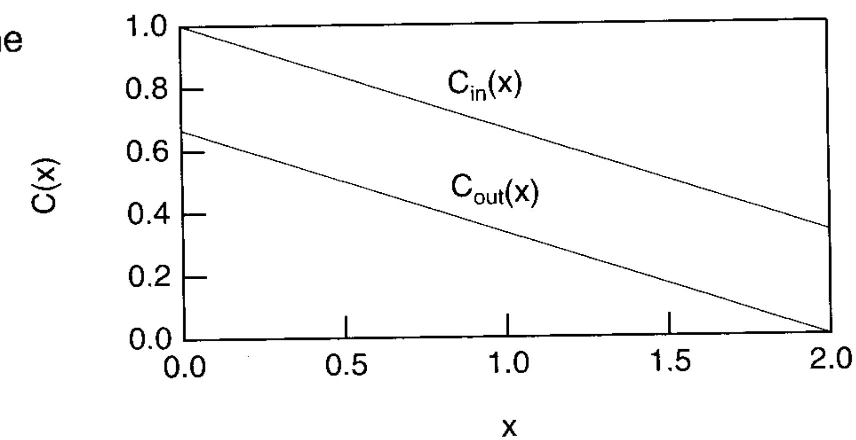
- Let:
  - $\omega RT = 5\times10^{-6}$ m/s
  - $S = 2$ m^2
  - $V = 40$ L
- Then,
  - $\tau = 1.1$ h
- Dialysis typically takes hours
  - A number of τ must elapse
  - Larger molecules are slower
  - Not to cause cerebral edema and headache

Countercurrent Transport





(a) Both flows are to the right.



(b) The flows are in opposite directions.

Problem Assignments

- Information posted on web site
- Problems 1, 2, 3, 4, 5, 6, 14