Basic Dialysis Theory

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Tuesday

February 10, 2009

Functions of the Kidney

Excretory functions

- **fluid balance**
- **electrolyte balance**
- **acid/base balance**
- **removal of metabolic waste products**

Hormonal functions

- **regulation of blood pressure**
- **red blood cell production**
- **vitamin D metabolism**

Kidney Fluid Balance

Blood flow through the

kidney is about 20% of each

heart beat (about 1200 ml/min.)

A person's total blood supply circulates through the kidneys approximately 12 times/hr.

125 ml/min. of fluid is ***removed*** from the blood, however 124 ml/min. of fluid is ***returned*** to the blood

1 ml/min. of urine is produced (1500 ml/day)

Nephron Structure – Vascular Component

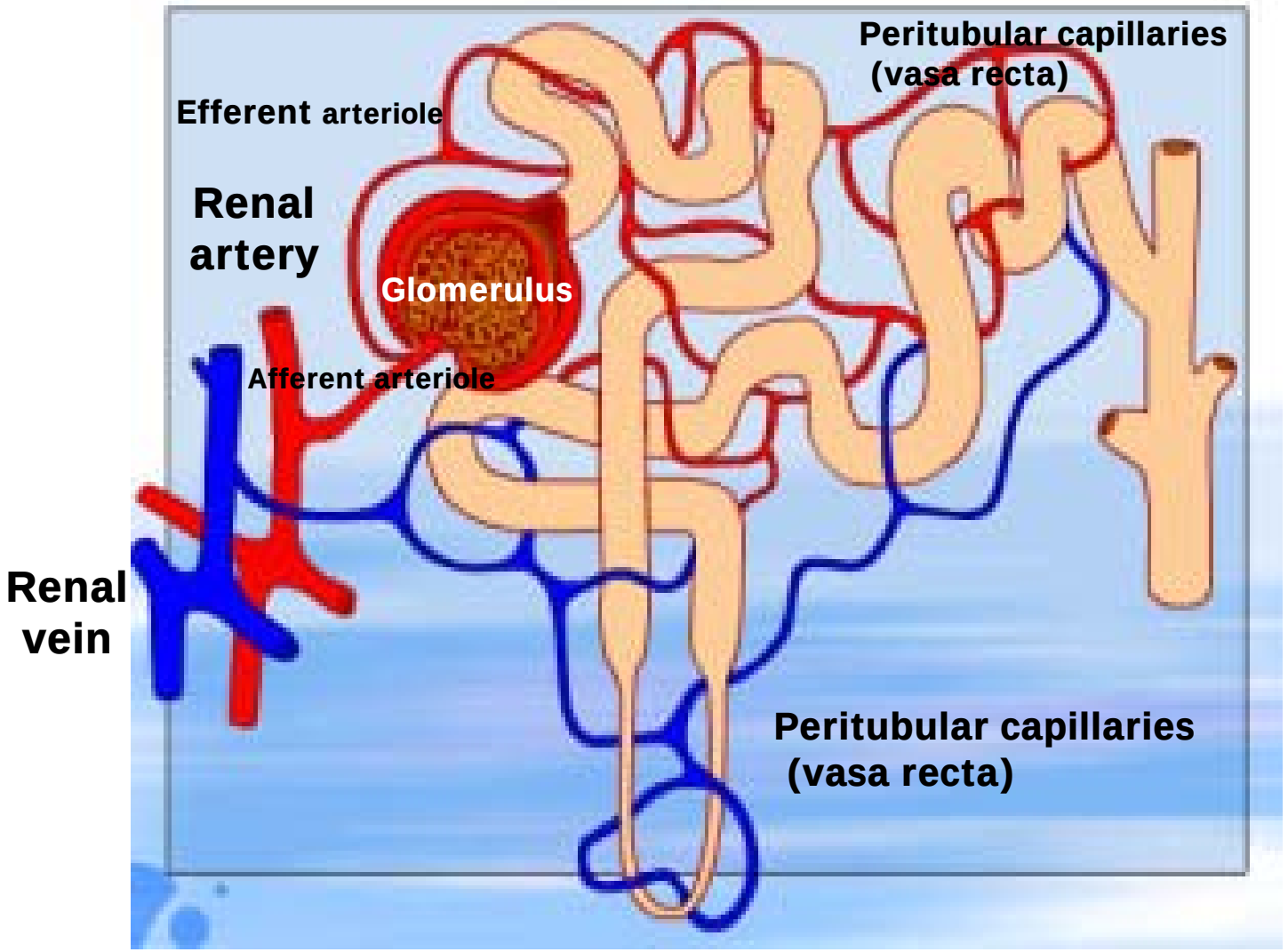


Illustration from Baxter's Aquaduct CD

Nephron Structure – Tubular Component

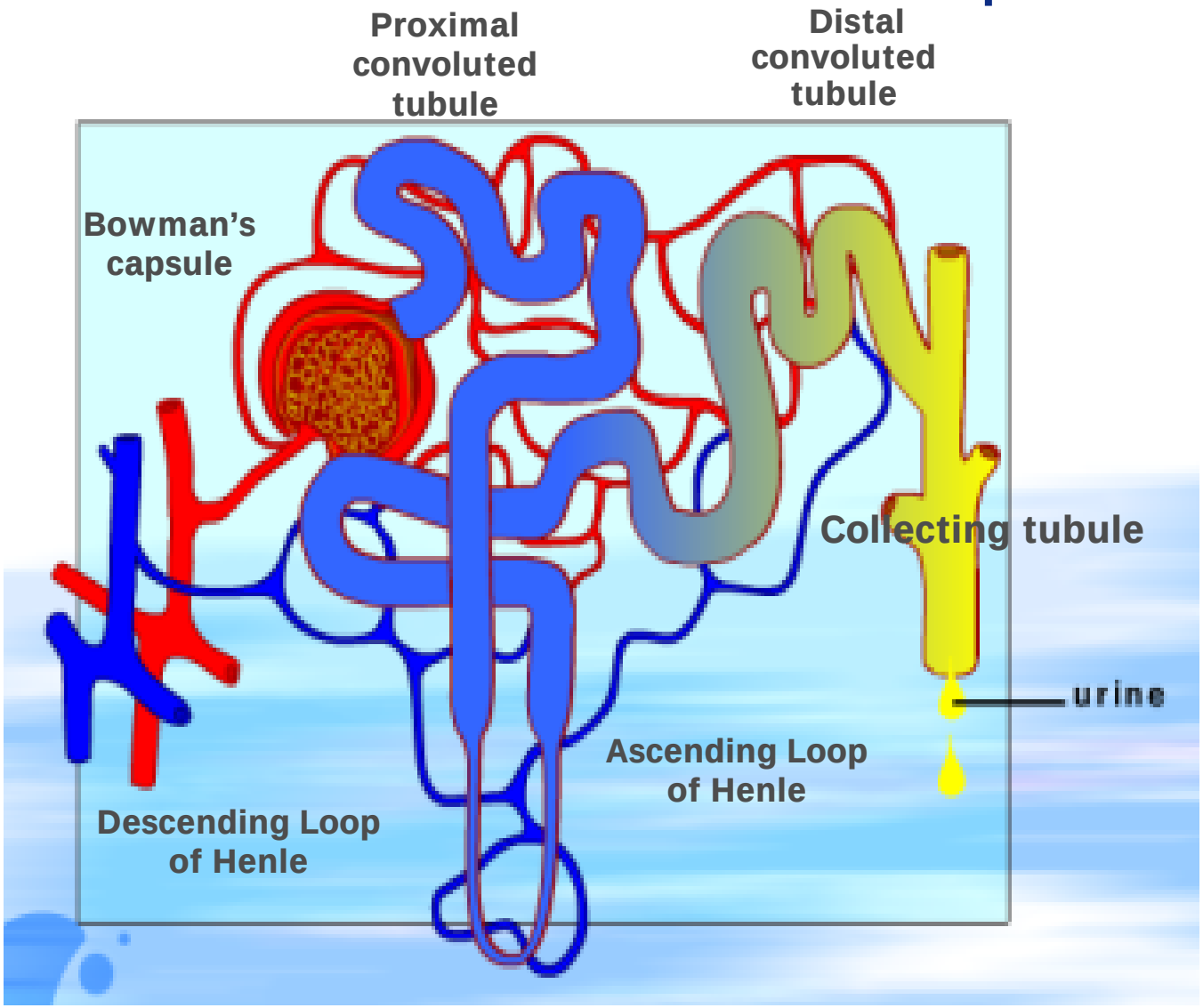


Illustration from Baxter's Aquaduct CD

Nephron Structure – Tubular Component
(continued)

Bowman's capsule - surrounds the glomerular capillaries and receives the "filtrate"

- Glomerular TMP = Blood Pressure (45 mmHg) – Colloid Osmotic Pressure (28 mmHg) – Back Pressure (10 mmHg) = 7 mmHg
- Kidney K_{UF} = GFR/TMP = 7,500 mL/hr/7 mmHg = 1070

Proximal convoluted tubule

- glucose, amino acids, water, salts and some urea is reabsorbed in this area
- acid/base balance begins here
- drugs are secreted
- volume of filtrate is decreased by 65%

Nephron Structure – Tubular Component
(continued)

Descending Loop of Henle

- water is reabsorbed in this area
- salts (sodium and potassium) are reabsorbed and secreted
- “concentrating” of the filtrate

Ascending Loop of Henle - salts are reabsorbed

Distal convoluted tubule

- water and sodium are reabsorbed
- ammonia and potassium are secreted

Nephron Structure – Tubular Component
(continued)

Collecting tubule

- water is reabsorbed
- acid/base regulation continues
- Aldosterone functions here to regulate sodium, chloride and potassium metabolism
- Antidiuretic hormone (ADH) functions here to increase the resorption of water
- “filtrate” has now changed to “urine”

Excretory Functions

Electrolyte balance

- **Proximal convoluted tubule - glucose, amino acids, water, salts and some urea is reabsorbed**
- ***Aldosterone* is secreted by the adrenal gland which causes sodium retention and secretion of potassium and hydrogen ions in the tubules**
- ***Parathyroid hormone (PTH)* is secreted by the parathyroid glands which causes reabsorption of calcium and phosphorous in the tubules**

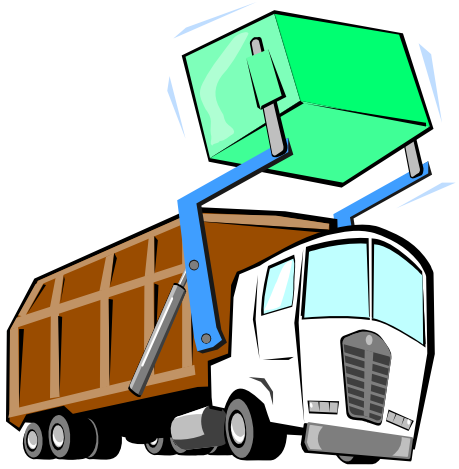
Excretory Functions

Acid/base balance is primarily regulated by the kidneys

- **catabolism increases acid (carbon dioxide) production**
- **acids are produced by metabolism of fats and carbohydrates**
- **some bases are created by protein metabolism**
- **compensation is what the body does to maintain a balance of acid and base**
  - **the kidneys increase or decrease bicarbonate reabsorption and increase or decrease hydrogen ions secretion**
  - **the lungs also compensate by increasing or decreasing respirations to correct**

Excretory Functions

Removal of metabolic waste products

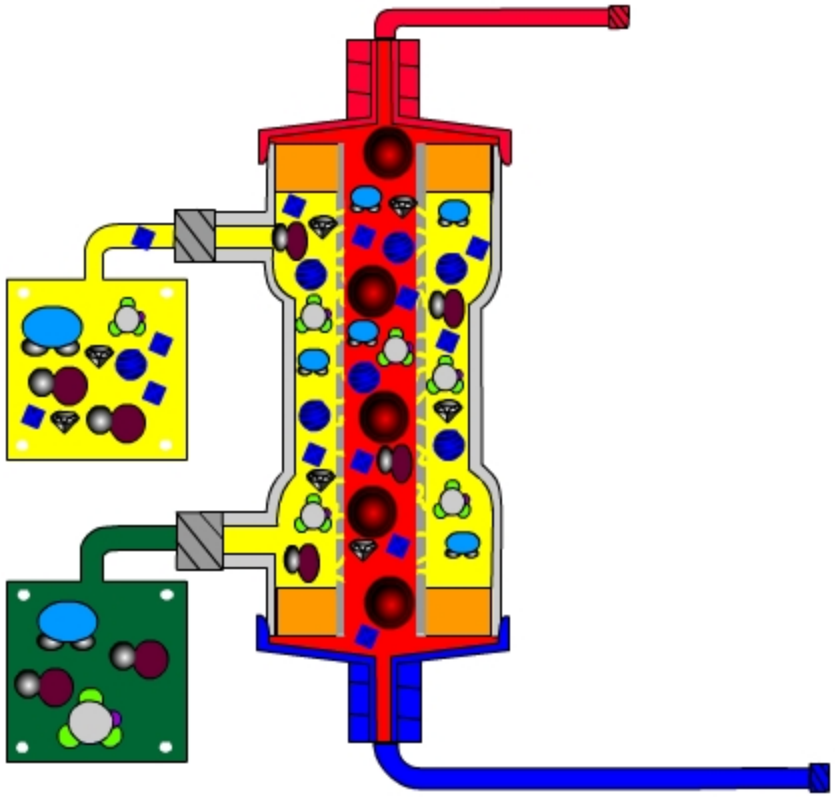


- **Urea (Normal BUN = 10 – 20 mg/dL)**
  - **a by-product of *protein* metabolism**
- **Creatinine (Normal = 0.6 – 1.2 mg/dL)**
  - **a by-product of *muscle* metabolism**
- **Uric Acid (Normal = 2.0 – 7.5 mg/dL)**
  - **a by-product of protein/purine metabolism (which comes from organ meats, fish, beans, alcohol)**

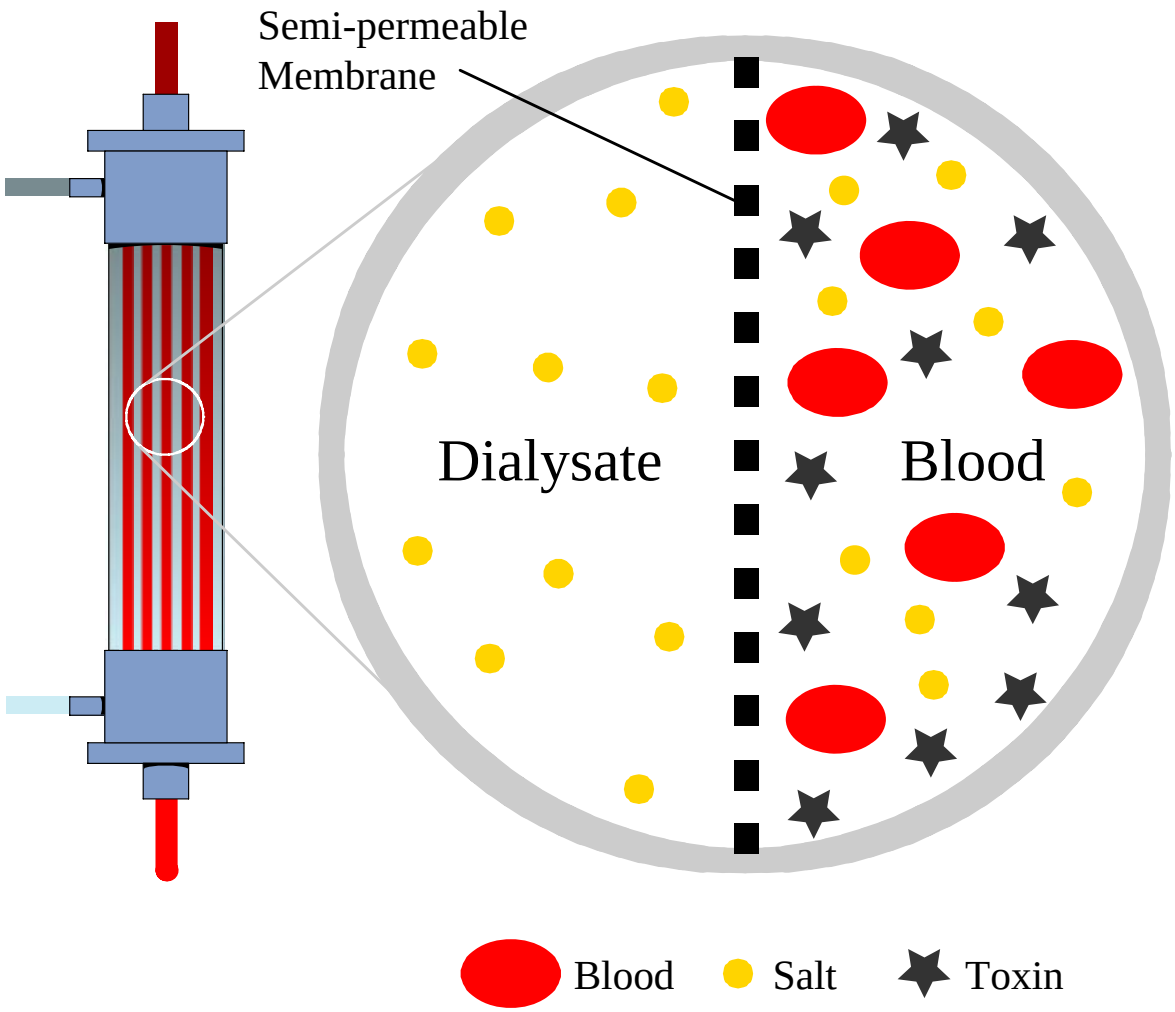
These are just three of a great number of waste substances created in the process of protein metabolism

Gutch, C.F., et.al.: *Review of Hemodialysis for Nurses and Dialysis Personnel, 5th. Ed.*, Mosby, St. Louis, Mo. 1993. p.27

Principals of Hemodialysis



Semi-permeable Membrane (continued)



Designed to keep blood components like red blood cells, platelets and large proteins on the blood side – they cannot pass through the membrane

The membrane has pores, or openings, that are large enough to allow small molecules to pass, and others not

Has the ability to also allow water molecules to pass through

Think “sponge” not “Swiss cheese”.

Membrane Transport Mechanisms

Solute + Solvent = Solution

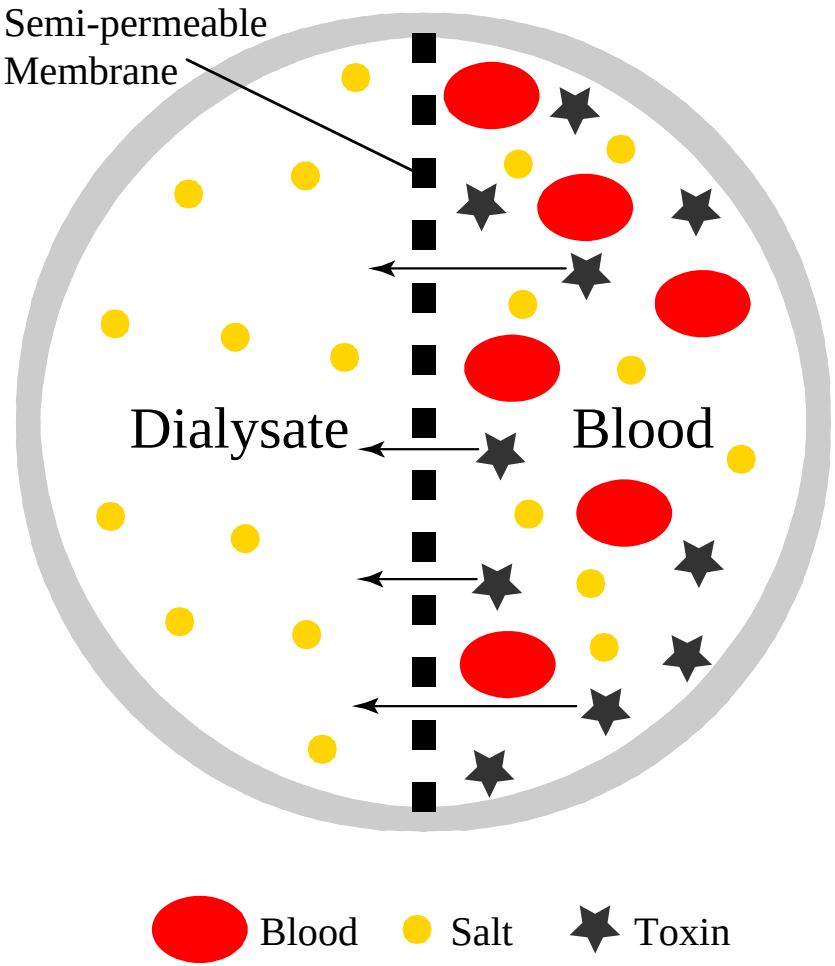
Toxin/salt removal (solute)

- Diffusion (toxins and electrolytes)
- Convection (larger molecules > 1,000 daltons)

Water removal (solvent)

- Osmosis (body fluid shifts)
- Ultrafiltration (plasma water removal)

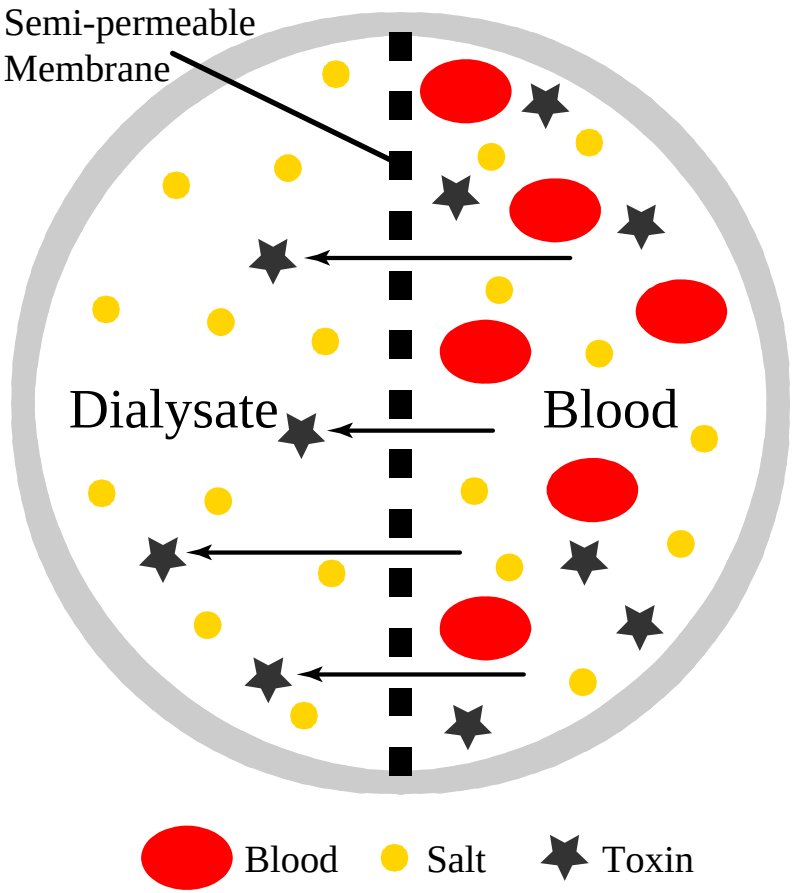
Toxin Removal



Removal of toxins from the blood is accomplished by:

- Diffusion
  - Toxins and electrolytes
- Convection
  - Large molecules (> 1,000 daltons)
- Adsorption
  - Largest molecules (beta-2-microglobulin)

Toxin Removal - Diffusion



Graham's Law:

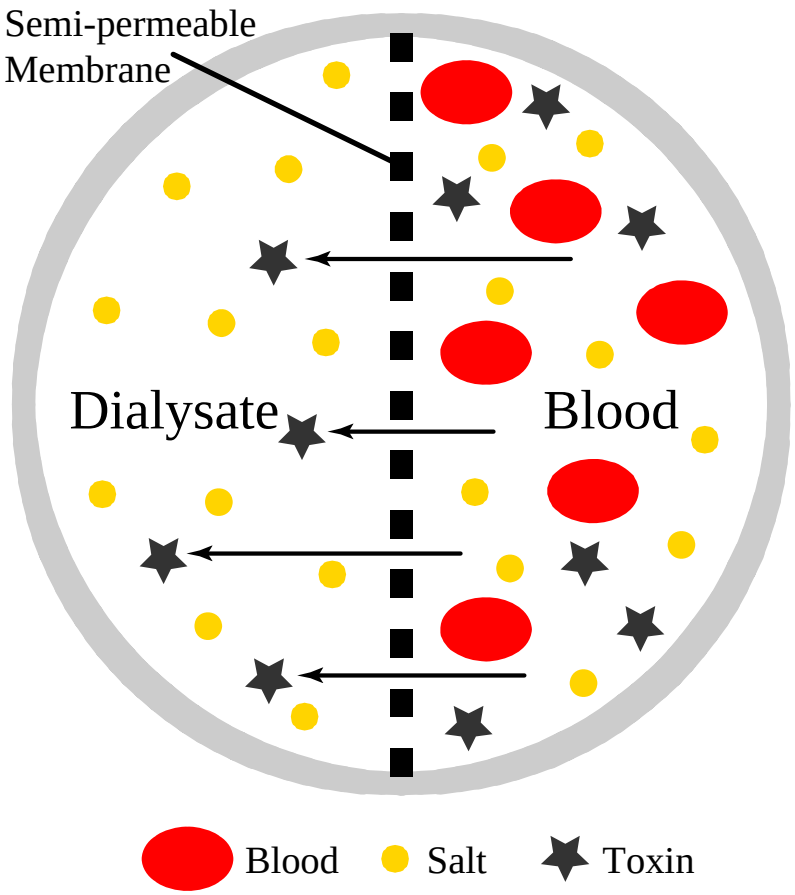
The rate of diffusion of molecules is inversely proportional to the square root of their masses

Fick's Law:

Diffusion is the movement of a solute from an area of greater to lesser concentration of solute until the concentration is equal

The amount of blood that is completely "cleared" of a solute/toxin in a specific amount of time is called the 'clearance' measured in mL/min

Concentration Gradient

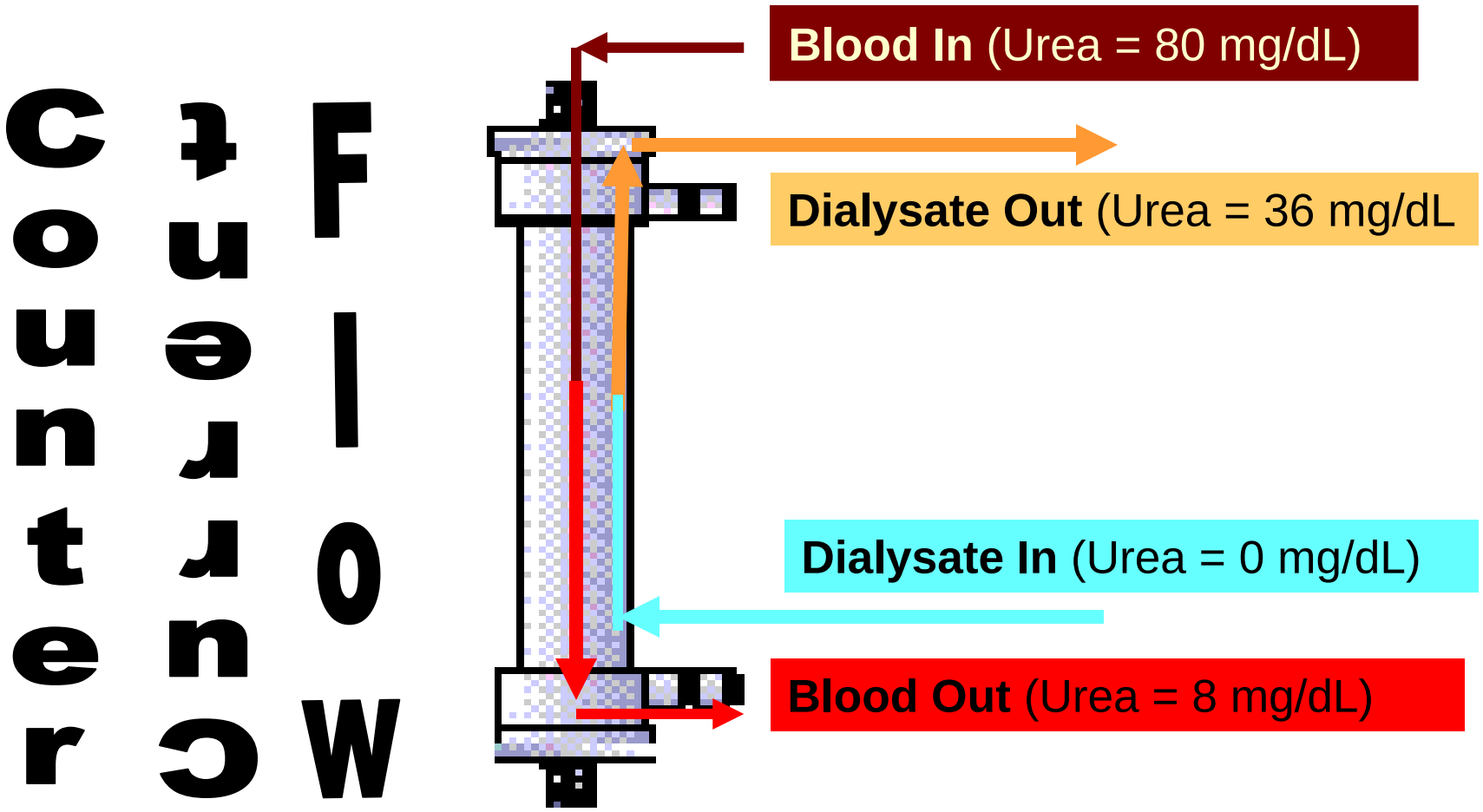


The difference in concentration of solute from one solution to another

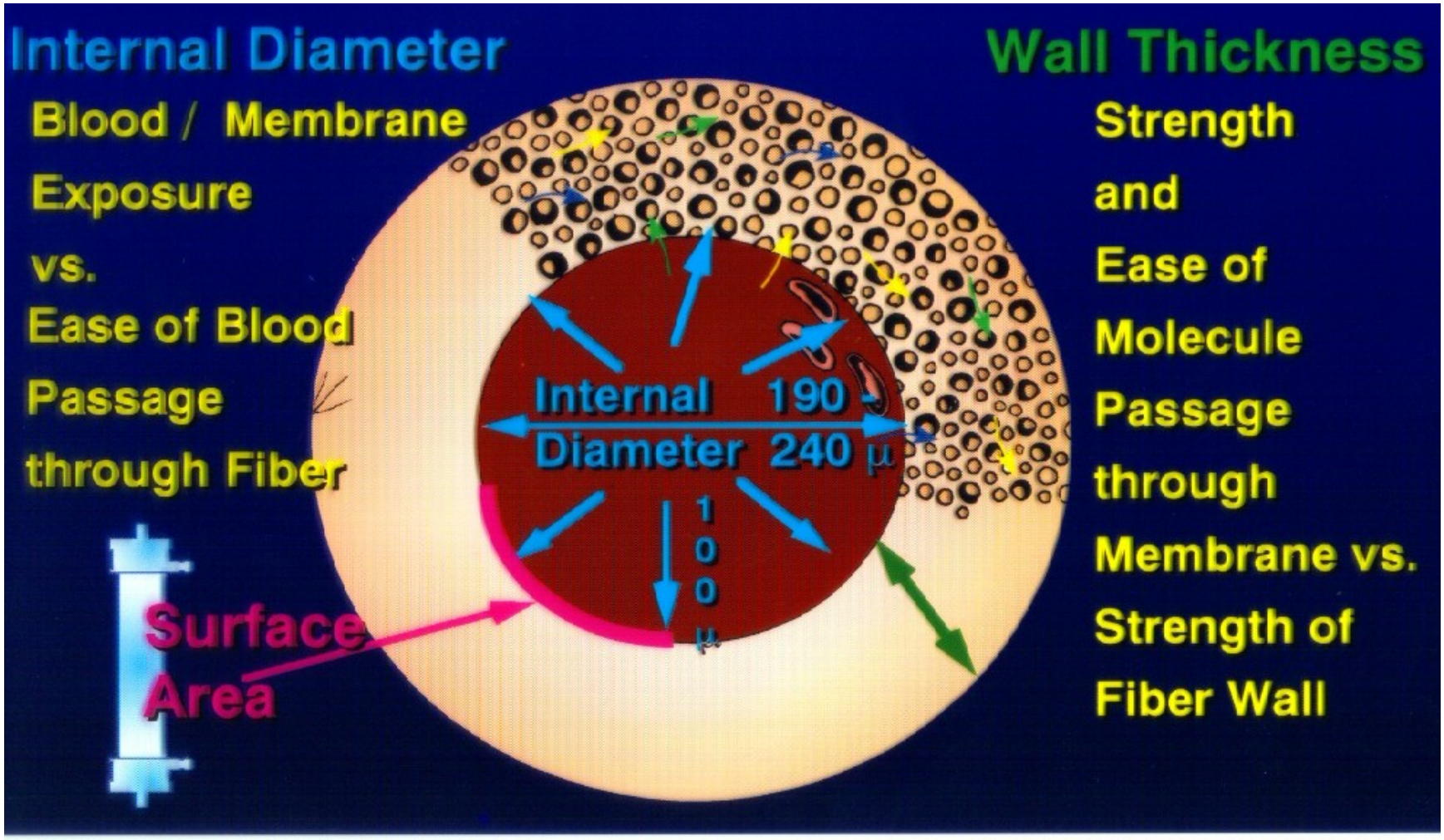
Dialysate Chemistry vs. Blood Chemistry
(milliEquivalents/Liter)

Constituent	Dialysate	Blood
Sodium	137 – 145	136 – 148
Potassium	0 – 4	3.5 – 5
Calcium	0.0 – 4.0	4.25 – 5.25
Magnesium	0.0 – 1.5	1.5 – 2.5
Chloride	101 - 108	95 - 103
Bicarbonate	25 - 40	22 - 26
Acetate	2.0 – 4.0	0.0
Dextrose	70 – 100 mg/dL	0.0 – 250 mg/dL
Carbon Dioxide	35 – 70 mmHg	40 mmHg

Concentration Gradient - Flow Geometry

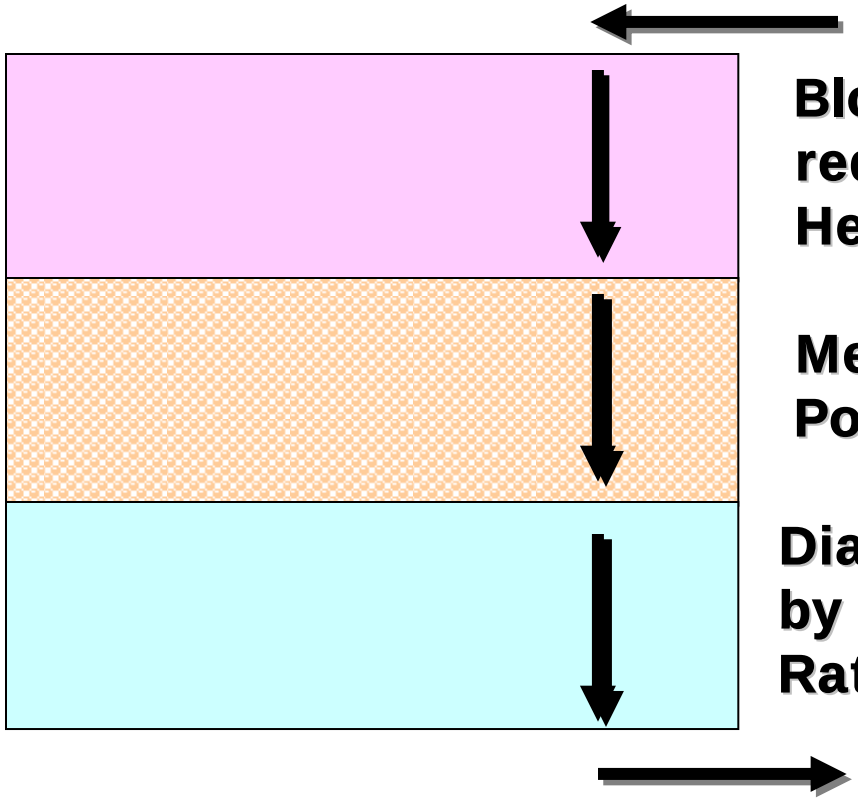


Membrane Surface Area and Wall Thickness



Resistance to Flow (KoA)

Diffusion Coefficient



Blood Film Layer…Resistance reduced by Thin Blood Channel Height and Rapid Blood Flow Rates

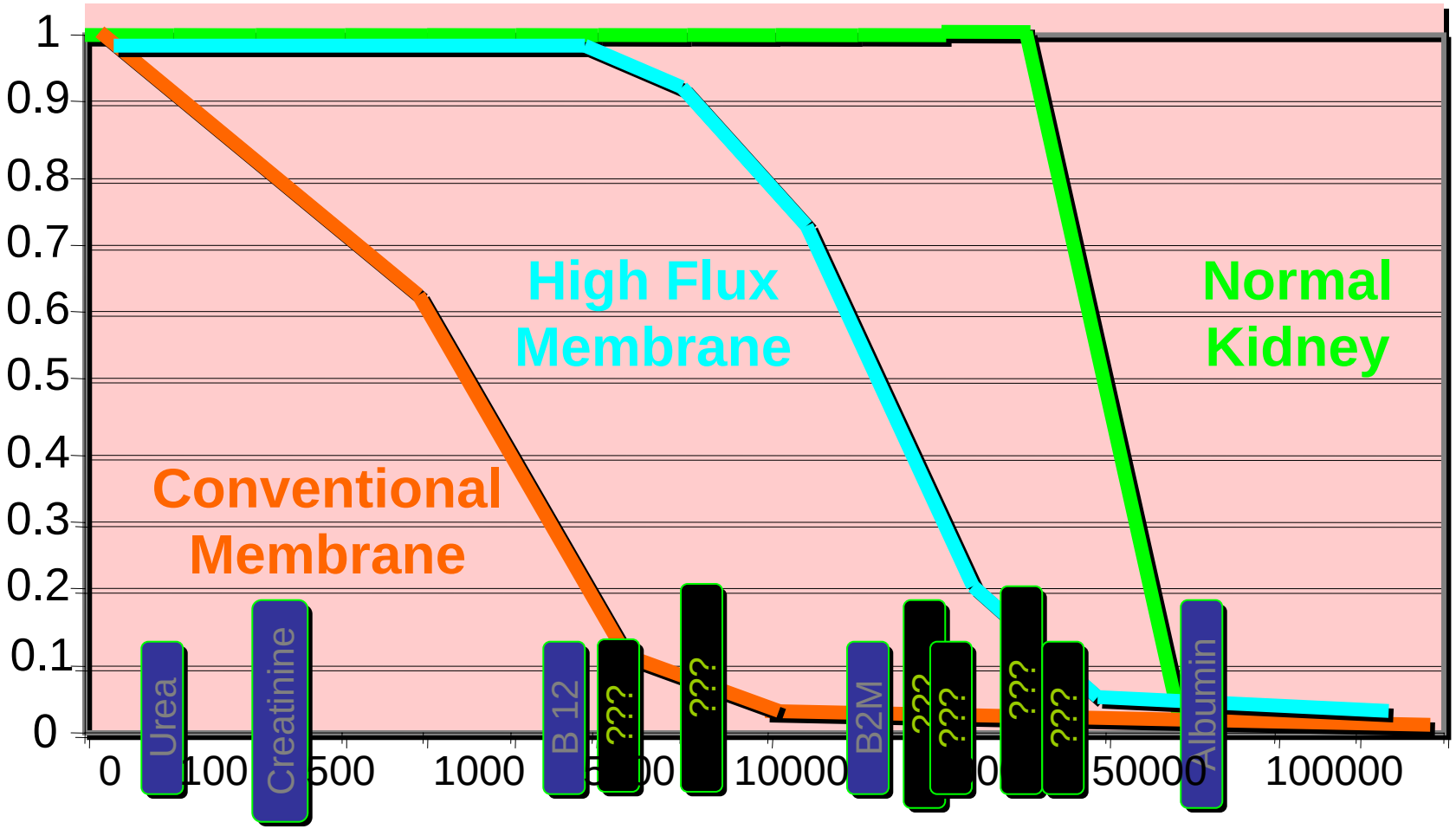
Membrane Thickness and Porosity is Fixed

Dialysate Film Layer…Reduced by More Rapid Dialysate Flow Rates

Clearance for a dialyzer can be calculated once the blood flowrate, dialysate flowrate, and K_0A are known. KoA range = 250 – 1,400

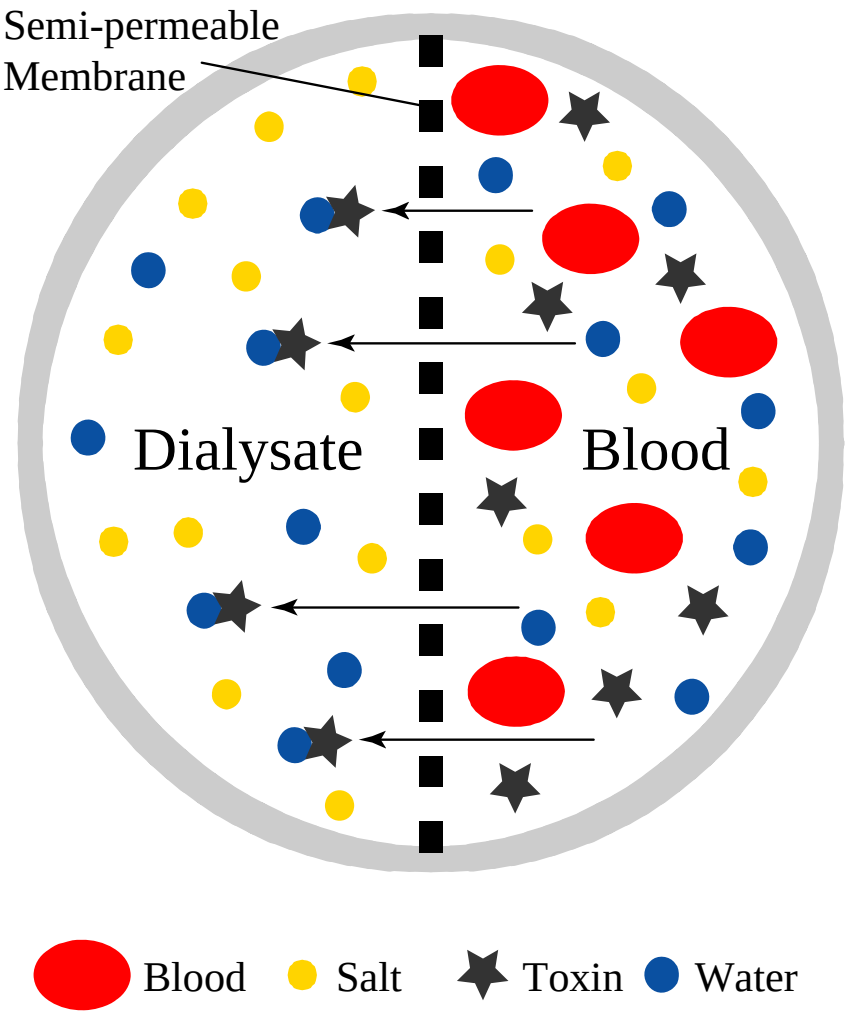
Diffusion vs. Molecular Weight Chart

Sieving Coefficient = The ratio of the average concentrations of a substance across the a membrane



Solute Molecular Weight

Toxin Removal - Convection



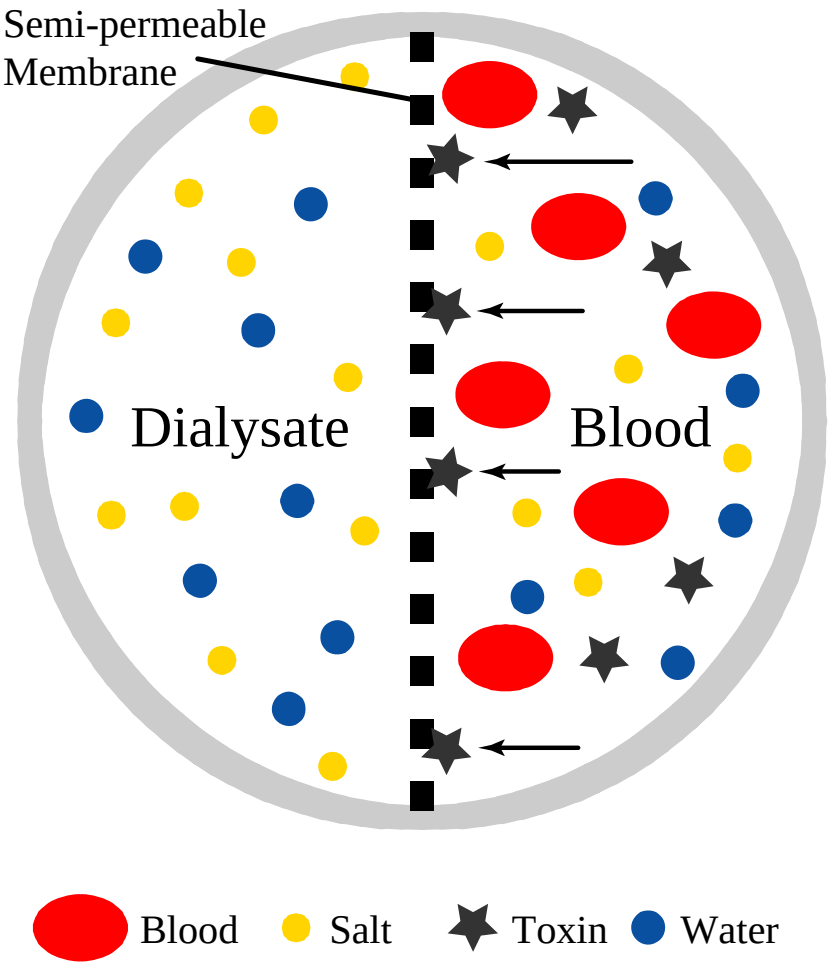
The movement of solute in the same concentration as it exists in water, when water moves across a membrane

Also called ‘solute drag’

Small molecules: Diffusion

Large molecules: Convection

Toxin Removal - Adsorption



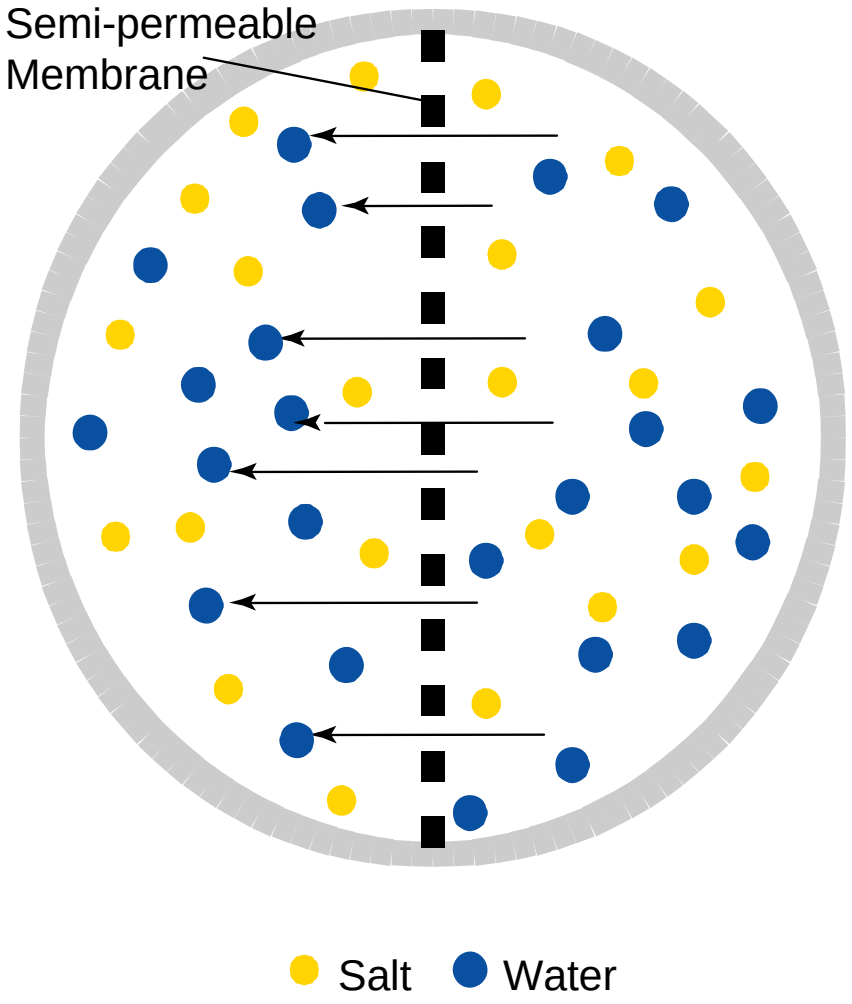
<u>Ad</u>sorption is not the same as <u>Ab</u>sorption

- **<u>Ab</u>sorption – think sponge**
- **<u>Ad</u>sorption – think clothing dye**
  - **Molecules bind permanently.**

Membranes all adsorb to varying degrees

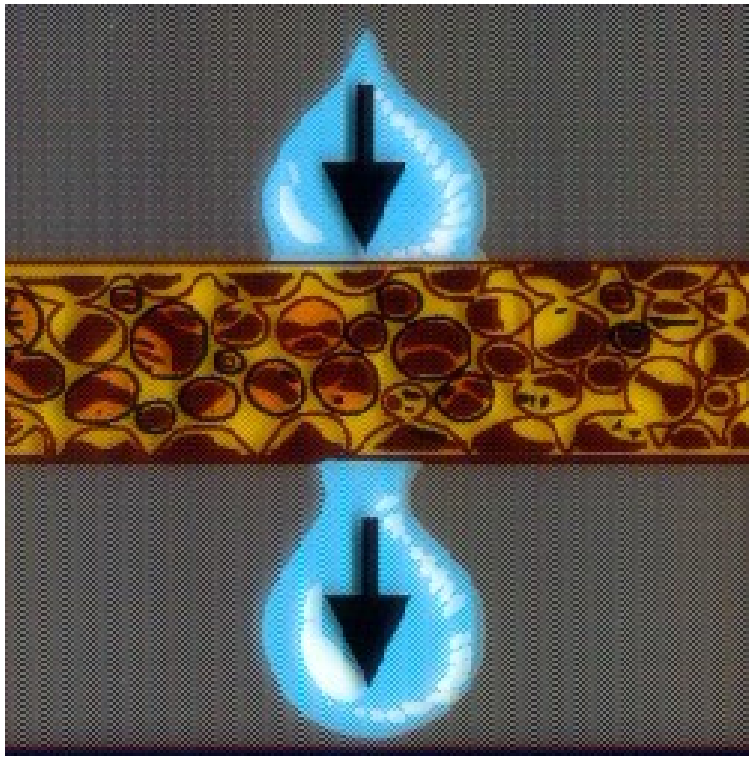
- **Function of membrane material**
- **Only molecules that have a charge can be adsorbed (bound to the membrane)**
- **Dialysis membranes (currently) are not designed to bind specific molecules**

Water Removal - Osmosis



The movement of a solvent (water) from an area of greater solvent concentration to an area of lesser solvent concentration, or from an area of lesser solute concentration to an area of greater solute concentration across a Semi-Permeable Membrane until the concentration is equal.

Water Removal - Ultrafiltration



- The movement of a solvent from an area of greater hydraulic pressure to an area of lesser hydraulic pressure across a semi-permeable membrane

Water Removal – Ultrafiltration (continued)

In dialysis, the movement of fluid through the membrane (dialyzer) is due to pressure being exerted by the dialysis machine

- Typically, ultrafiltration is from blood side to dialysate side
- Can go the opposite direction – backfiltration

Suggested Reading and Reference Material

Dialysis Technology – A Manual for Dialysis Technicians, 3rd Edition, Editors: Jim Curtis CHT and Philip Varughese BS, CHT; NANT

Core Curriculum for Nephrology Nursing, 4th Edition; Larry E. Lancaster, Editor; American Nephrology Nurses' Association. 2001.

Core Curriculum for the Dialysis Technician, 2nd Edition, Edith Oberly, Project Director; Amgen Inc by Medical Media Associates, Inc., 1998.

Daugirdas, John T and Ing, Todd S.; *Handbook of Dialysis*, 2nd Edition, Little, Brown & Co. 1994.

Gutch, Stoner, and Corea; *Review of Hemodialysis for Nurses and Dialysis Personnel*, 5th Edition, Mosby. 1993.

Nephrology 101 Course Materials; *Anatomy and Physiology* by Eknoyan, Rubenstein, and Mujais, CNNT Division of the National Kidney Foundation, Spring Clinical Meetings. 2002, 2003, 2004,2005.