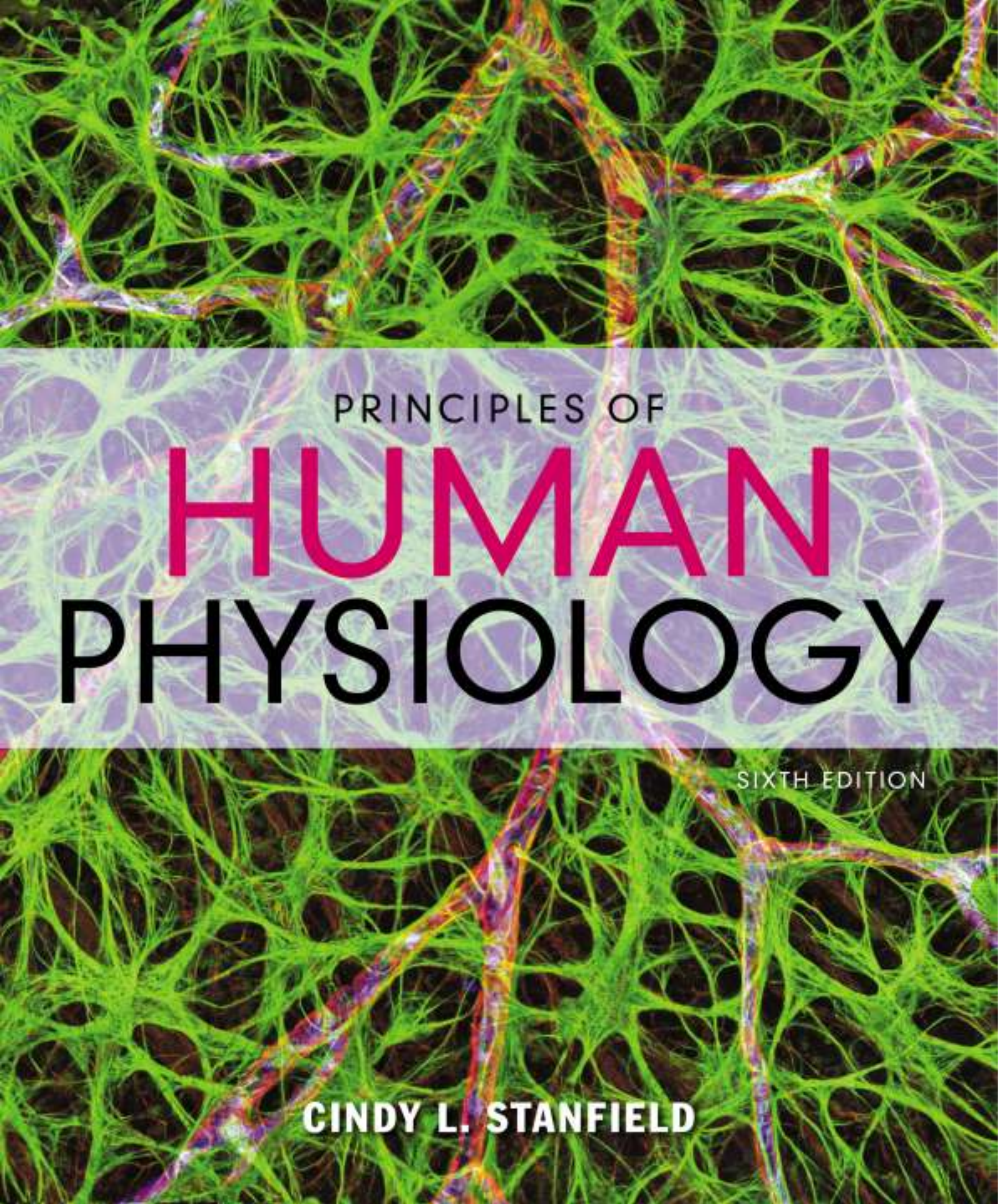


PowerPoint® Lecture Presentation

CHAPTER 19a

The Urinary System: Fluid and Electrolyte Balance

Chapter Outline

19.1 The Concept of Balance

19.2 Water Balance

19.3 Sodium Balance

19.4 Potassium Balance

19.5 Calcium Balance

19.6 Interactions Between Fluid and Electrolyte Regulation

19.7 Acid-Base Balance

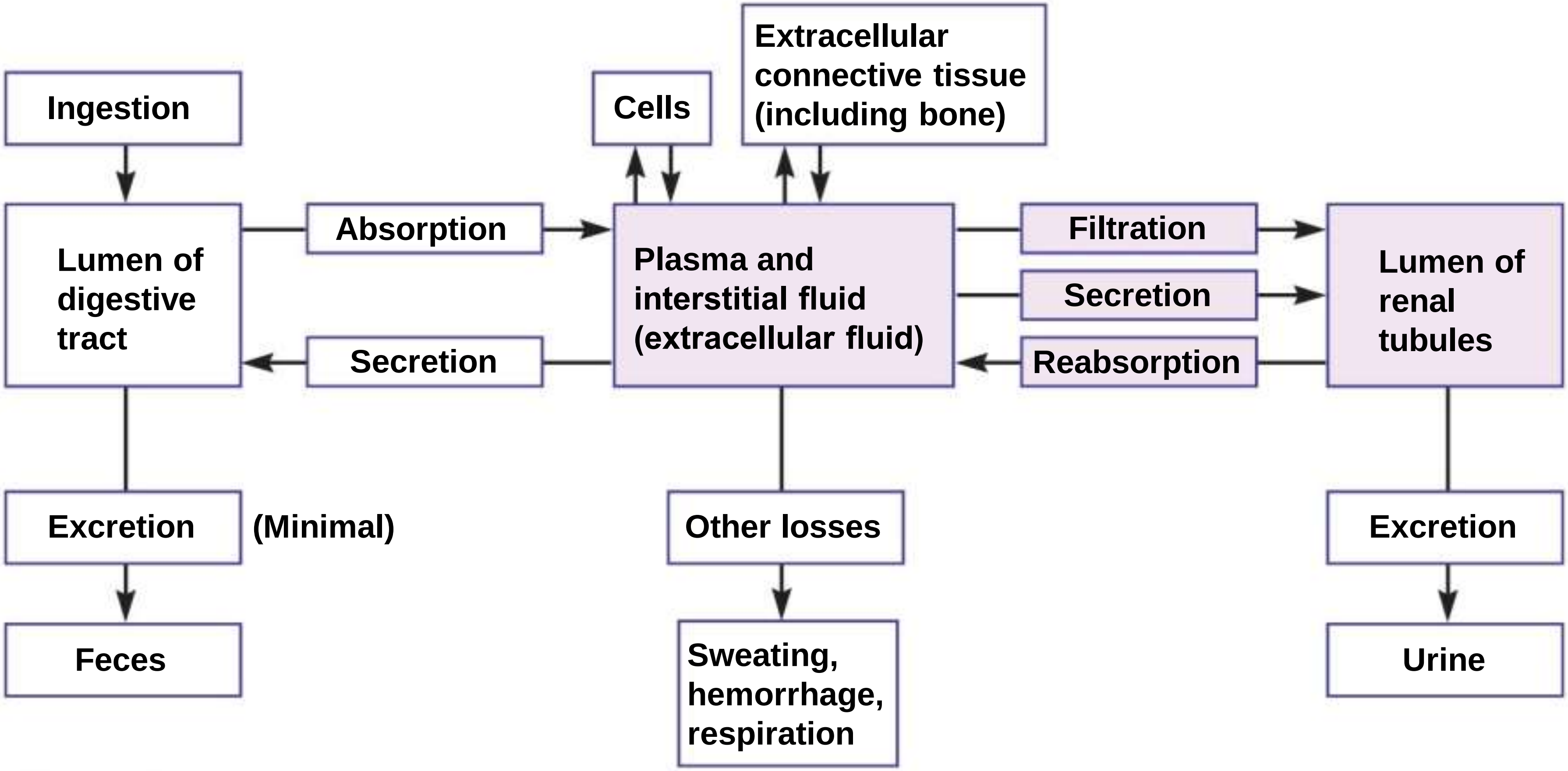
19.1 The Concept of Balance

- To maintain homeostasis, what comes in the body must eventually be used or excreted
- To be in balance
- Input + production = utilization + output

Factors Affecting the Plasma Composition

- Kidneys regulate solute and water content, which also determines volume
- Regulate acid-base balance
- Composition is also affected by exchange between different compartments of body
  - Cells
  - Connective tissue
  - Gastrointestinal tract
  - Sweating
  - Respiration

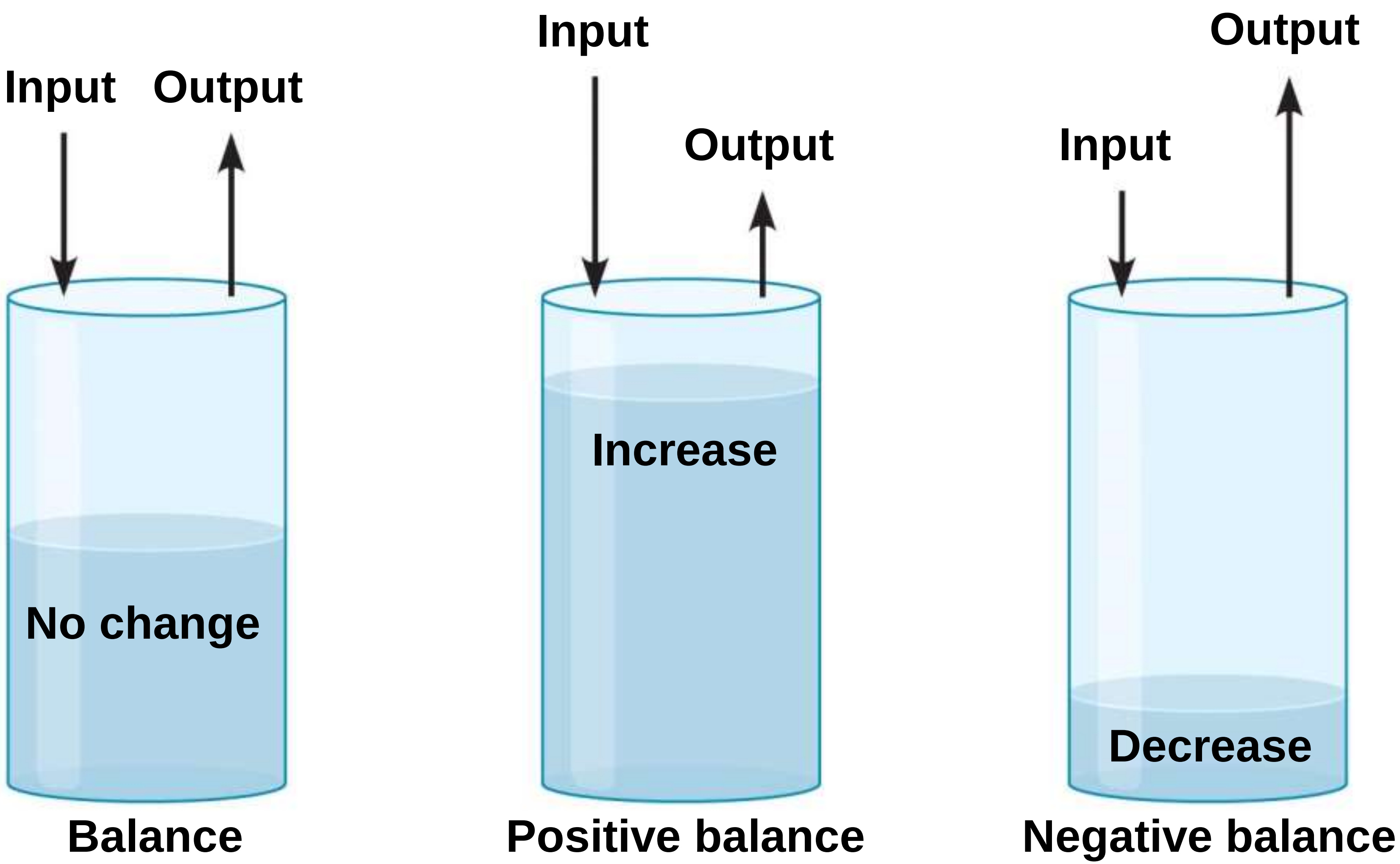
Figure 19.1 Material exchanges affecting plasma content.



Solute and Water Balance

- Balance
  - Solutes and water enter and exit plasma at the same rate
  - Quantity stays the same
- Positive balance
  - Solute or water enters plasma faster than it exits
  - Quantity increases
- Negative balance
  - Solute or water exits plasma faster than it enters
  - Quantity decreases

Figure 19.2 The concept of balance.



Solute and Water Balance

- Cells in late distal tubules and collecting ducts that regulate balance
  - Principal cells
    - Water
    - Electrolytes
  - Intercalated cells
    - Acid-base balance

19.2 Water Balance

- Osmolarity and the movement of water
- Water reabsorption in the proximal tubule
- Establishment of the medullary osmotic gradient
- Role of the medullary osmotic gradient in water reabsorption in the distal tubule and collecting duct

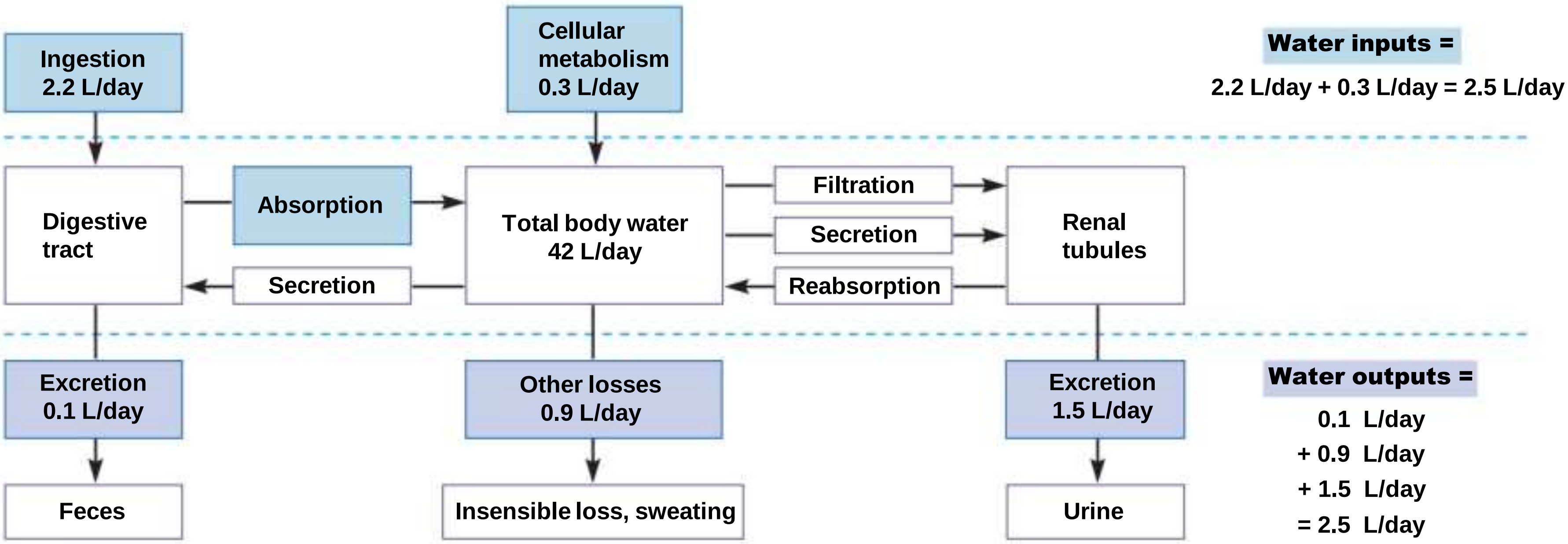
Water Balance

- Water intake + metabolically produced = water output + water used
- Intake
  - Gastrointestinal tract
  - Metabolism
- Output
  - Insensible loss
  - Sweating
  - Gastrointestinal tract
  - Kidneys

Water Balance

- Normovolemia = normal blood volume
- Hypervolemia = high blood volume due to positive water balance
- Hypovolemia = low blood volume due to negative water balance

Figure 19.3 Factors affecting water balance.



Osmolarity and the Movement of Water

- Osmosis
  - Water diffuses down the concentration gradient
  - Water moves from area of low solute concentration to area of high solute concentration
  - Water reabsorption follows solute reabsorption

Osmolarity and the Movement of Water

- Osmolarity of body fluids = 300 mOsm (300 milliosmoles of solute per liter of plasma)
- No osmotic force for water to move between fluid compartments
- Kidneys compensate for changes in osmolarity of extracellular fluid by regulating water reabsorption
- Water reabsorption is a passive process
  - Based on osmotic gradient

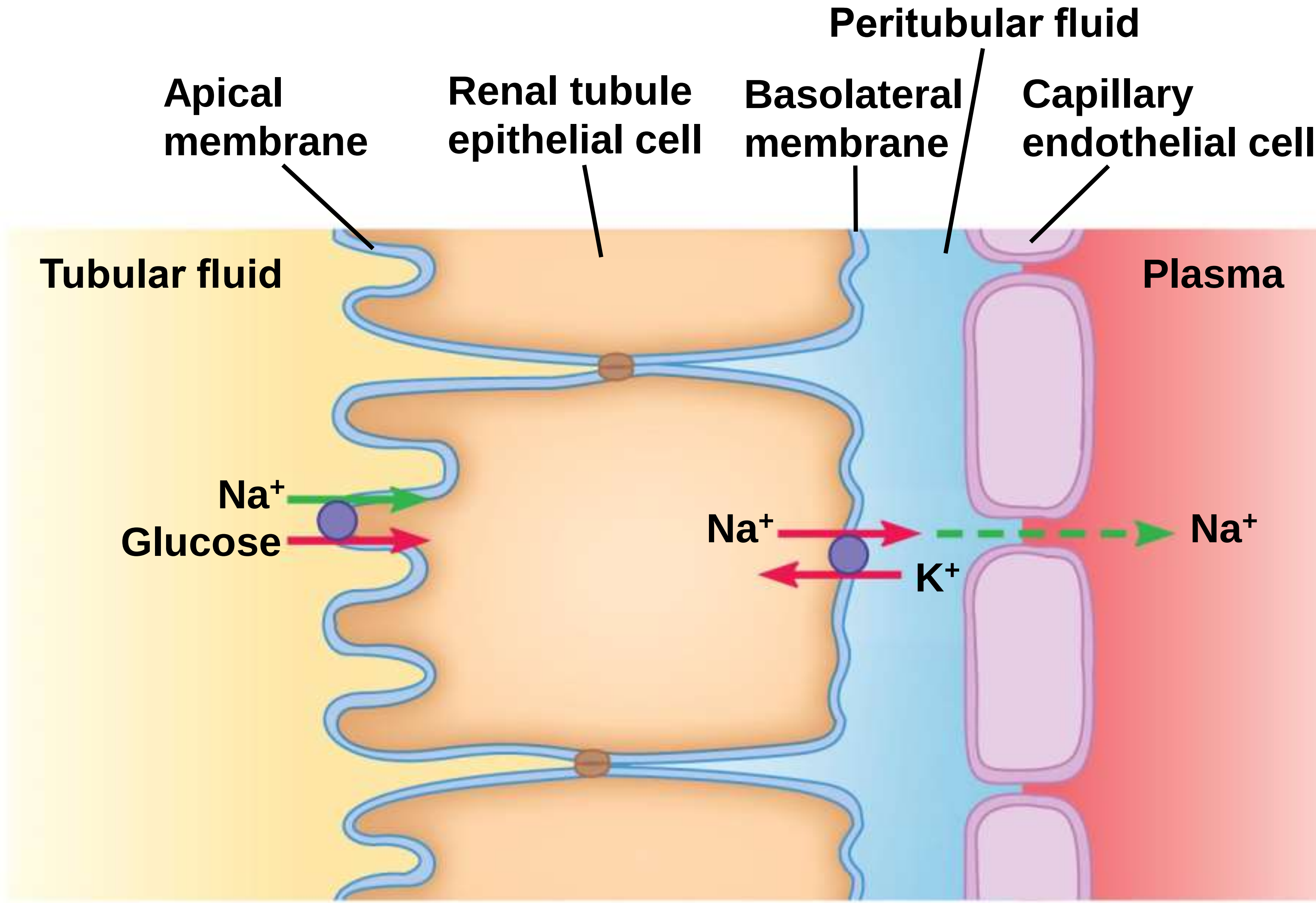
Osmolarity and the Movement of Water

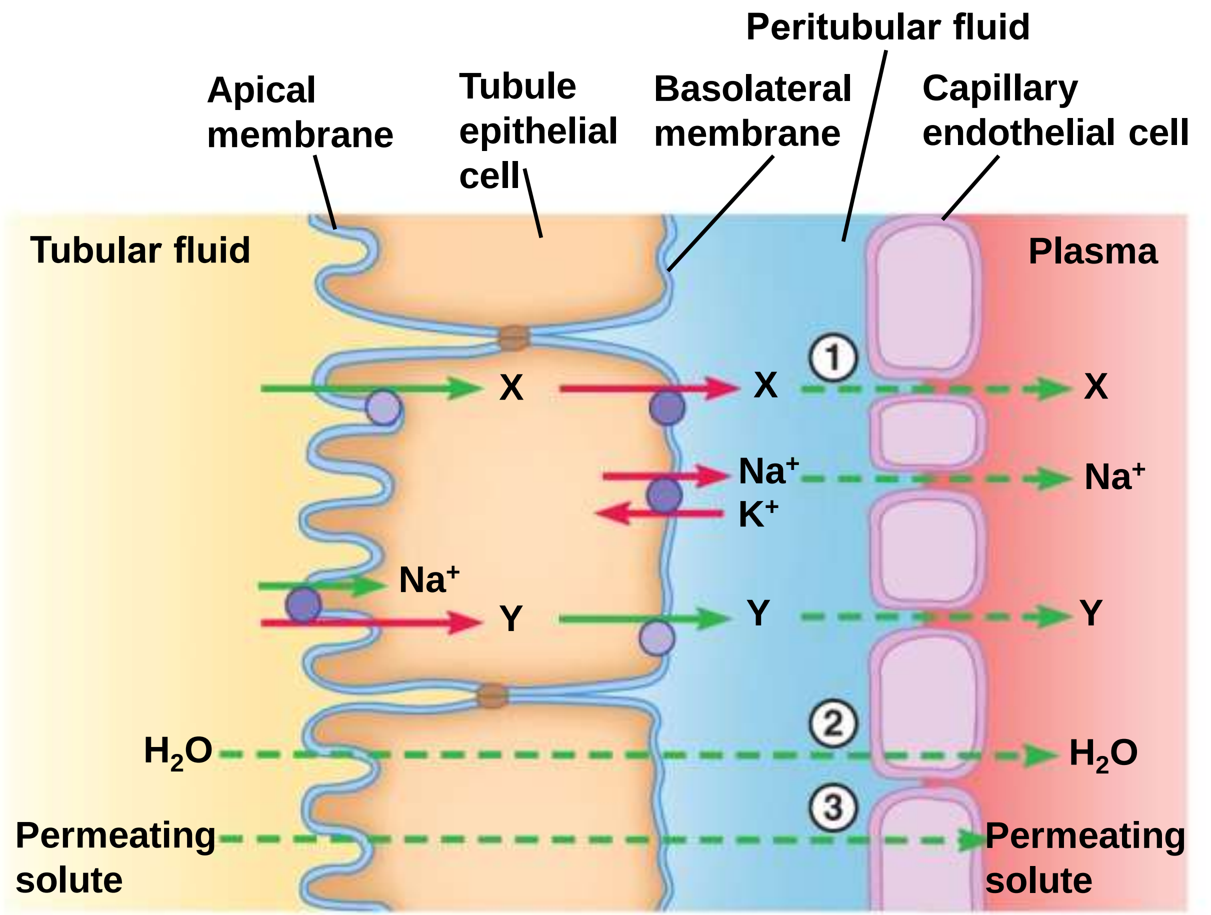
- Water reabsorption
  - Proximal tubules
    - 70% of filtered water is reabsorbed
    - Not regulated
  - Distal tubules and collecting ducts
    - Most remaining water is reabsorbed
    - Regulated by ADH (vasopressin)

Water Reabsorption in the Proximal Tubule

- Water reabsorption follows solute reabsorption
- Primary solute = sodium
- Na^+ is actively transported across the basolateral membrane; establishes an osmotic gradient for water reabsorption

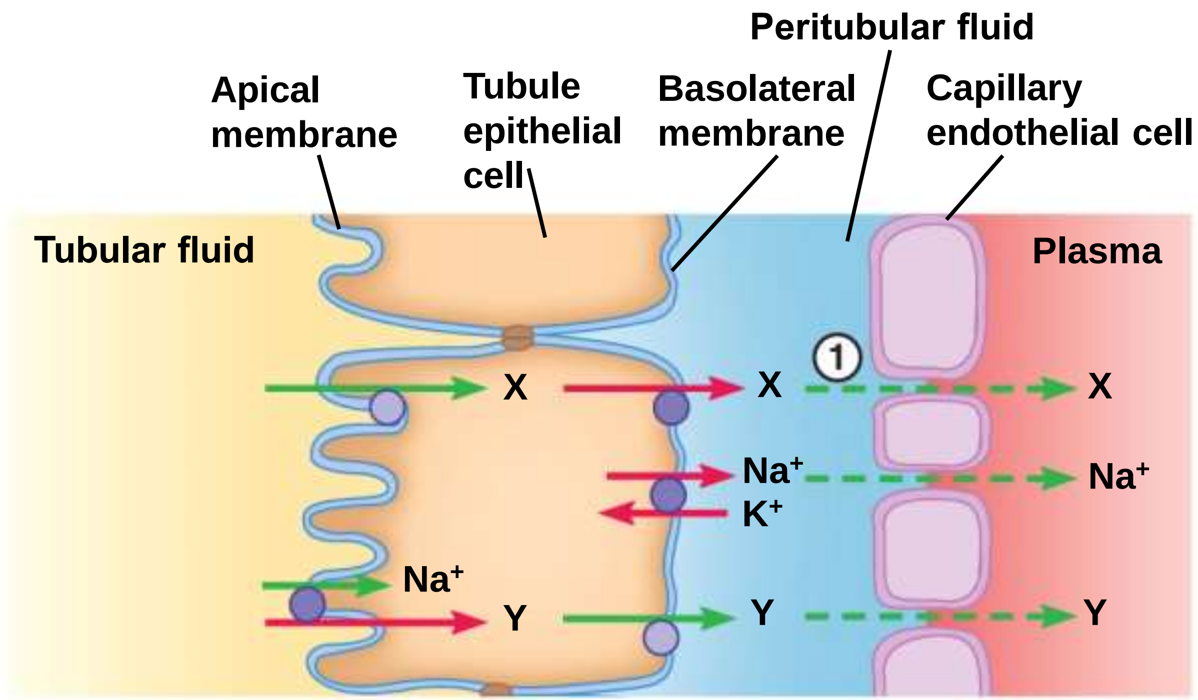
Figure 19.4 Mechanism of sodium reabsorption in the proximal tubule.





Steps for water and urea reabsorption:

1. Solutes (Na^+, X, Y) are actively reabsorbed, increasing the osmolarity of peritubular fluid and plasma.
2. Water is reabsorbed by osmosis.
3. Urea (permeating solute) is reabsorbed passively.



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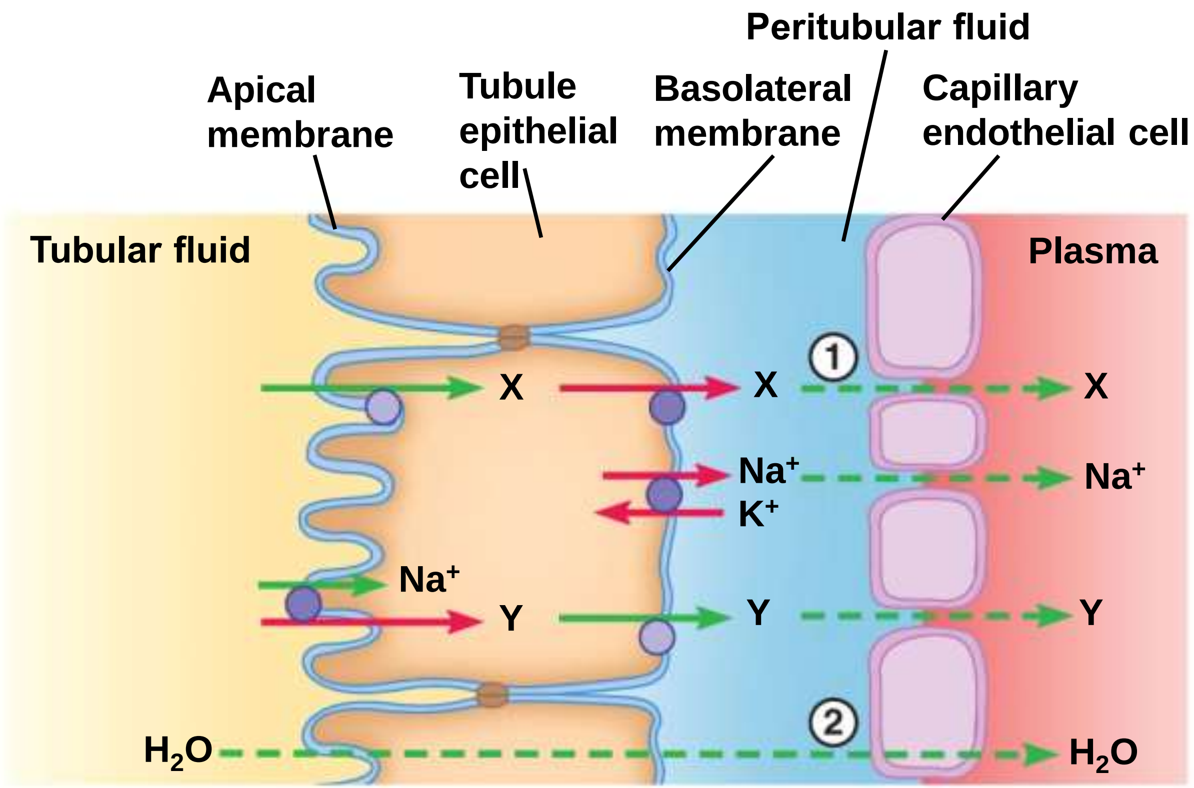

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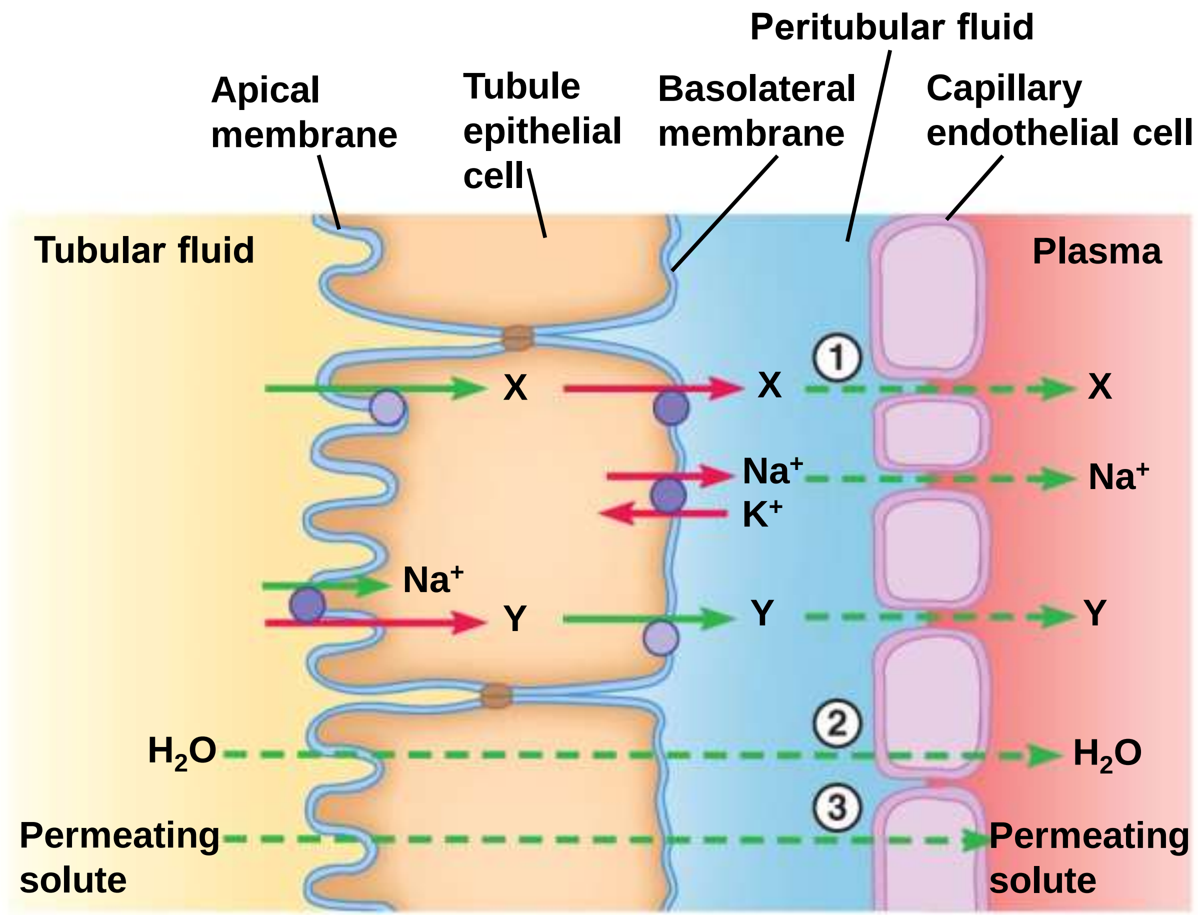

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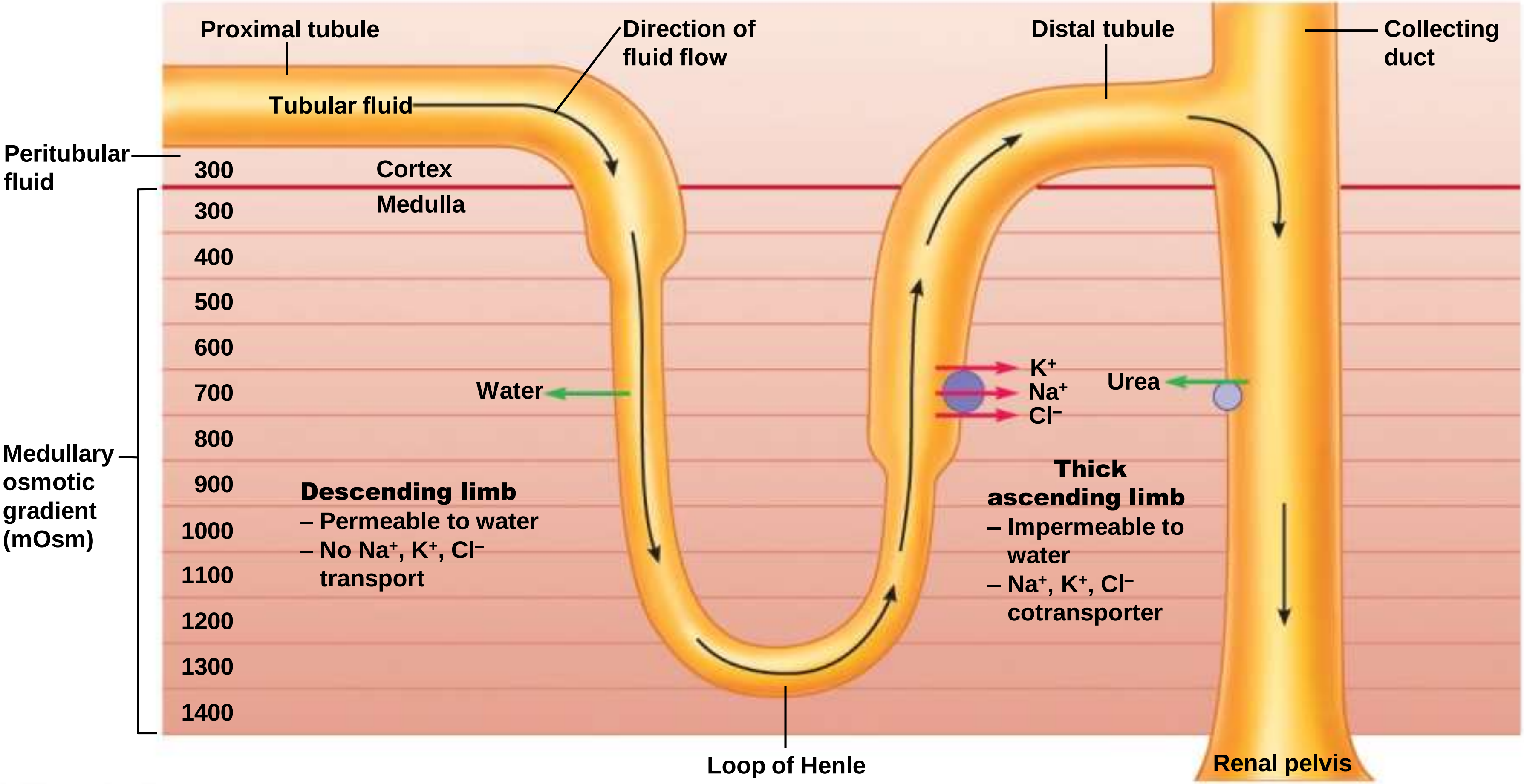
Establishment of the Medullary Osmotic Gradient

- Osmolarity of interstitial fluid of renal medulla varies with depth
  - Lower osmolarity near cortex
  - Greater osmolarity near renal pelvis
- Gradient is critical to water reabsorption

Figure 19.6 The medullary osmotic gradient.



Establishment of the Medullary Osmotic Gradient

- Osmotic gradient is established by the countercurrent multiplier
- Dependent on loop of Henle
- Ascending limb
  - Impermeable to water
  - Active transport of Na^+, Cl^-, and K^+
- Descending limb
  - Permeable to water
  - No transport of Na^+, Cl^-, or K^+

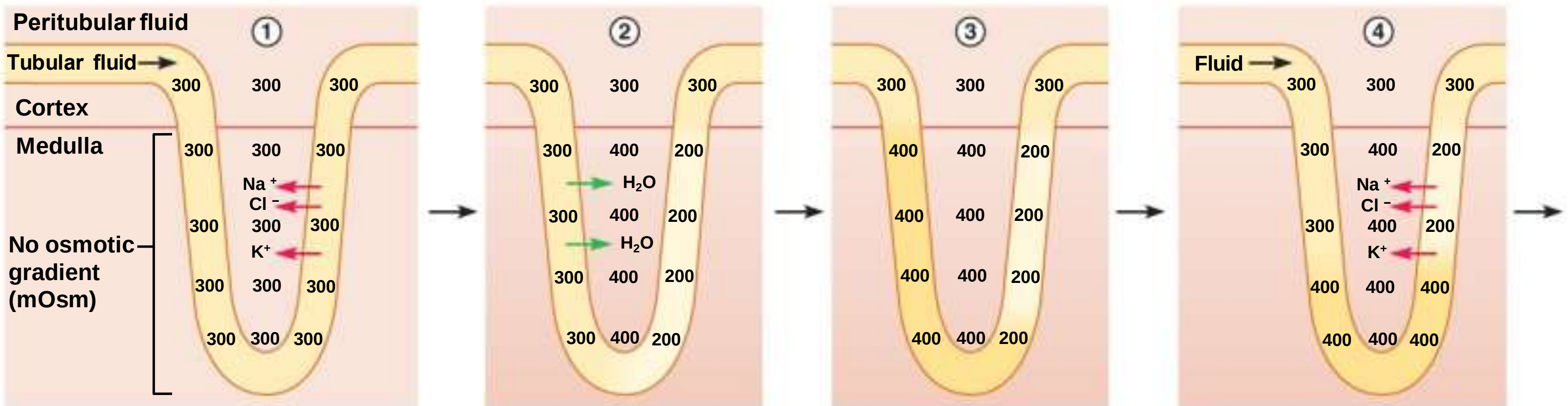
Establishment of the Medullary Osmotic Gradient

- Result of countercurrent multiplier
  - Fluid in proximal tubule = 300 mOsm
  - Fluid in descending limb: osmolarity increases as it descends
    - Osmolarity = interstitial fluid
    - Osmolarity > descending limb
  - Fluid in ascending limb: osmolarity decreases as it ascends
    - Osmolarity < interstitial fluid
    - Osmolarity < descending limb

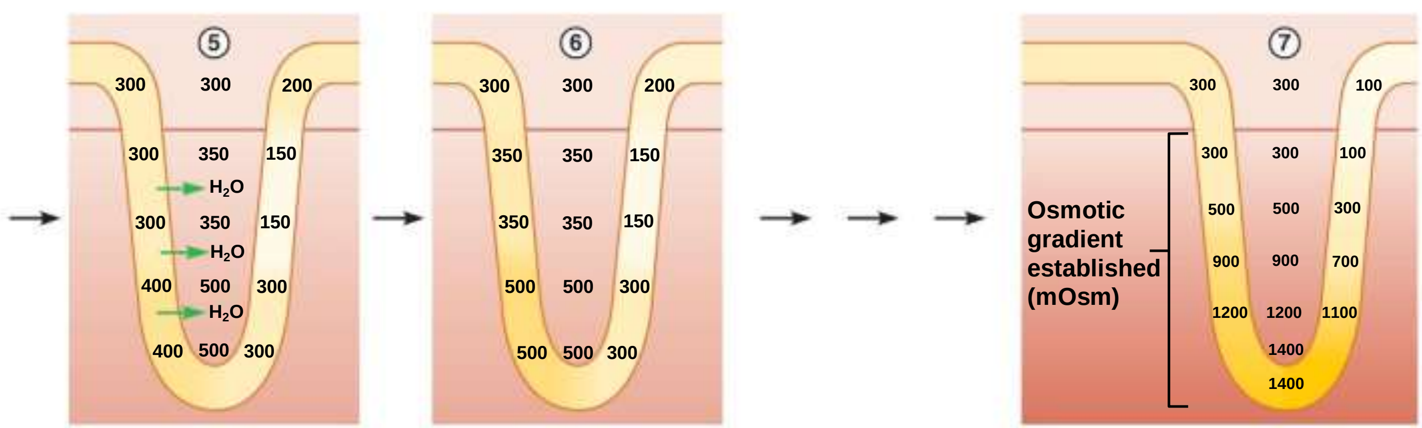
Establishment of the Medullary Osmotic Gradient

- Result of countercurrent multiplier
  - Fluid in distal tubule = 100 mOsm
  - Cortical interstitial fluid = 300 mOsm
  - Medullary interstitial fluid: increases from cortex to renal pelvis

Figure 19.7 How the countercurrent multiplier establishes the medullary osmotic gradient.

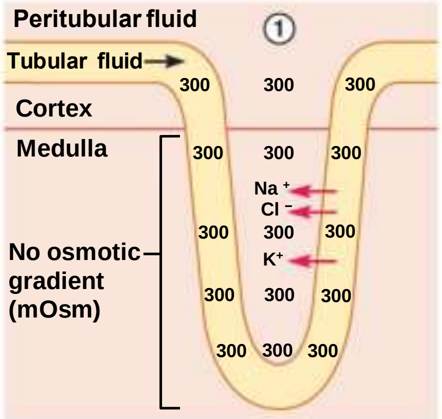


Fluid enters tubule → Active transport of Na⁺, Cl⁻, K⁺ ions into medullary interstitial fluid increases osmolarity → Water moves out of descending limb by osmosis → Iso-osmotic state in descending limb; osmotic difference between descending and ascending limbs → More fluid enters tubule, pushing fluid through by bulk flow → Active transport of Na⁺, Cl⁻, K⁺ ions into medullary interstitial fluid increases osmolarity



→ Water moves out of descending limb by osmosis → Iso-osmotic state in descending limb; osmotic difference between descending and ascending limbs → More water enters tubule and process continues → → → System is in steady state

Figure 19.7 How the countercurrent multiplier establishes the medullary osmotic gradient.



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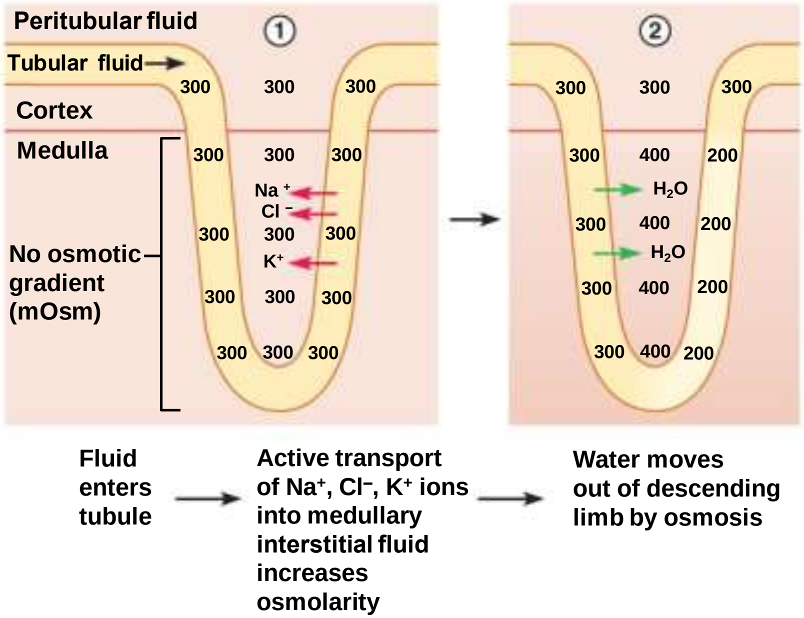

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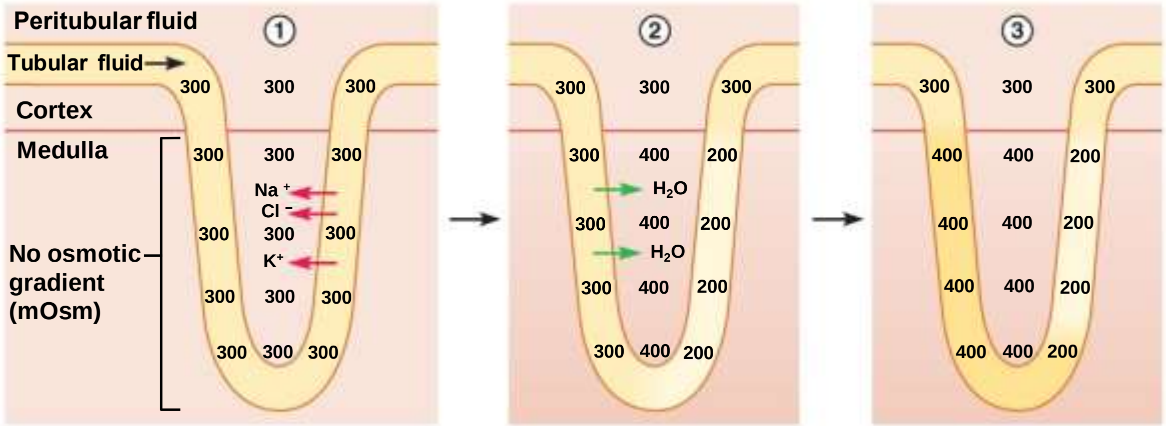

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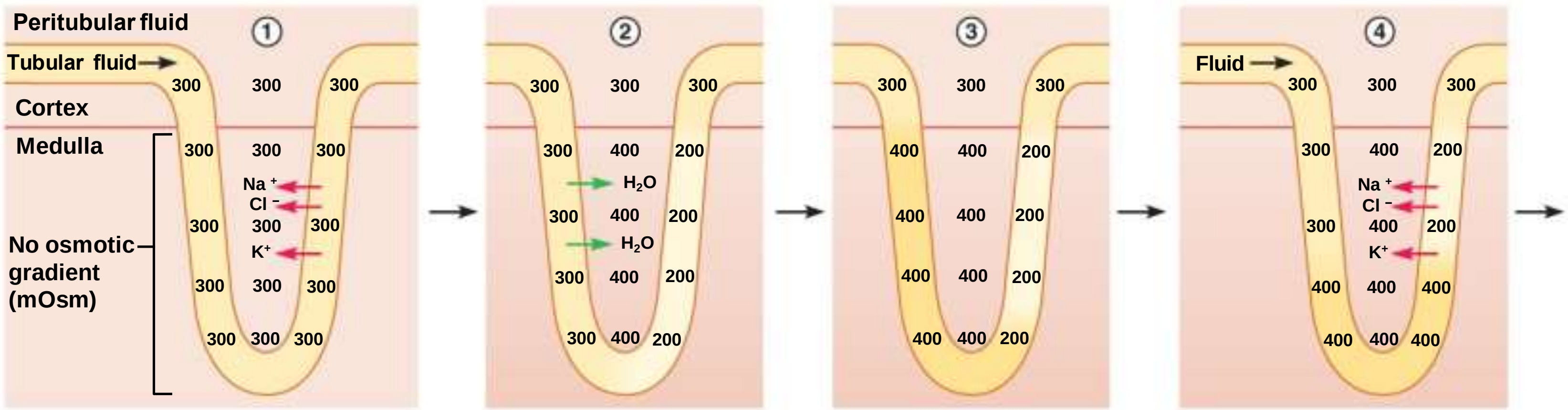

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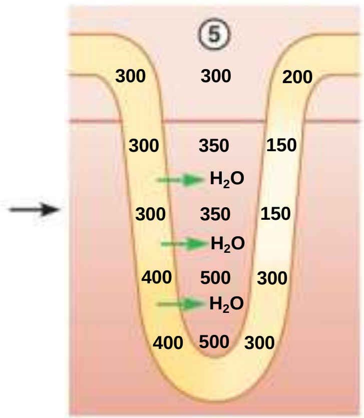

Water moves out of descending limb by osmosis

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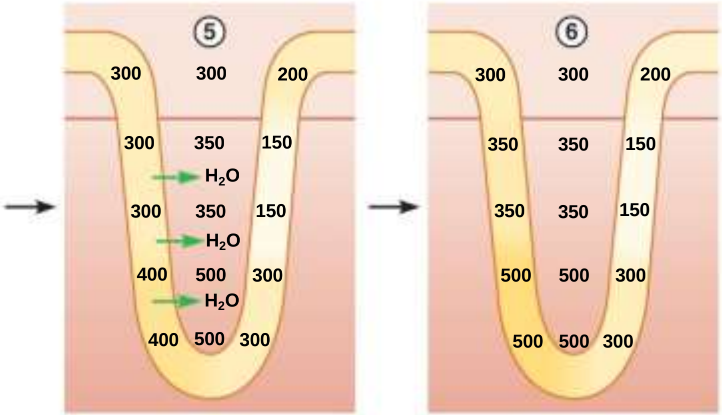

Water moves out of descending limb by osmosis

Iso-osmotic state in descending limb; osmotic difference between descending and ascending limbs

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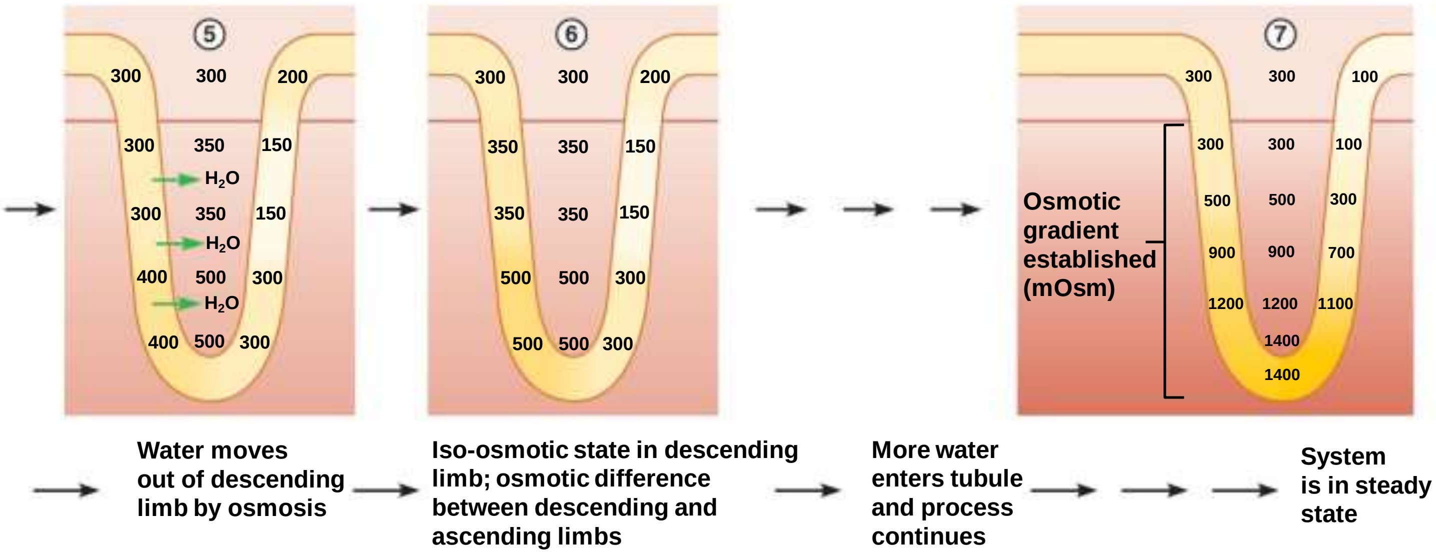

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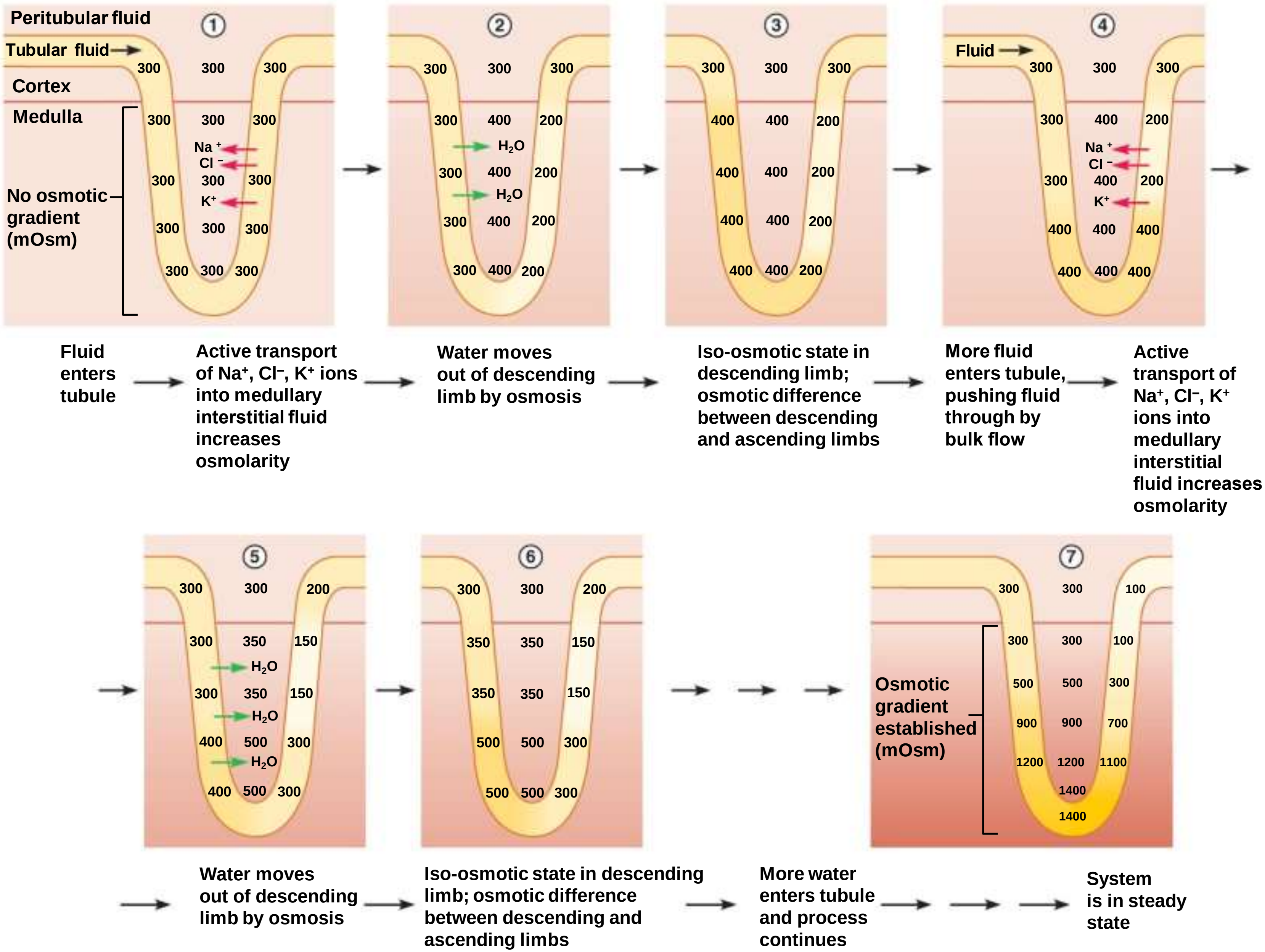
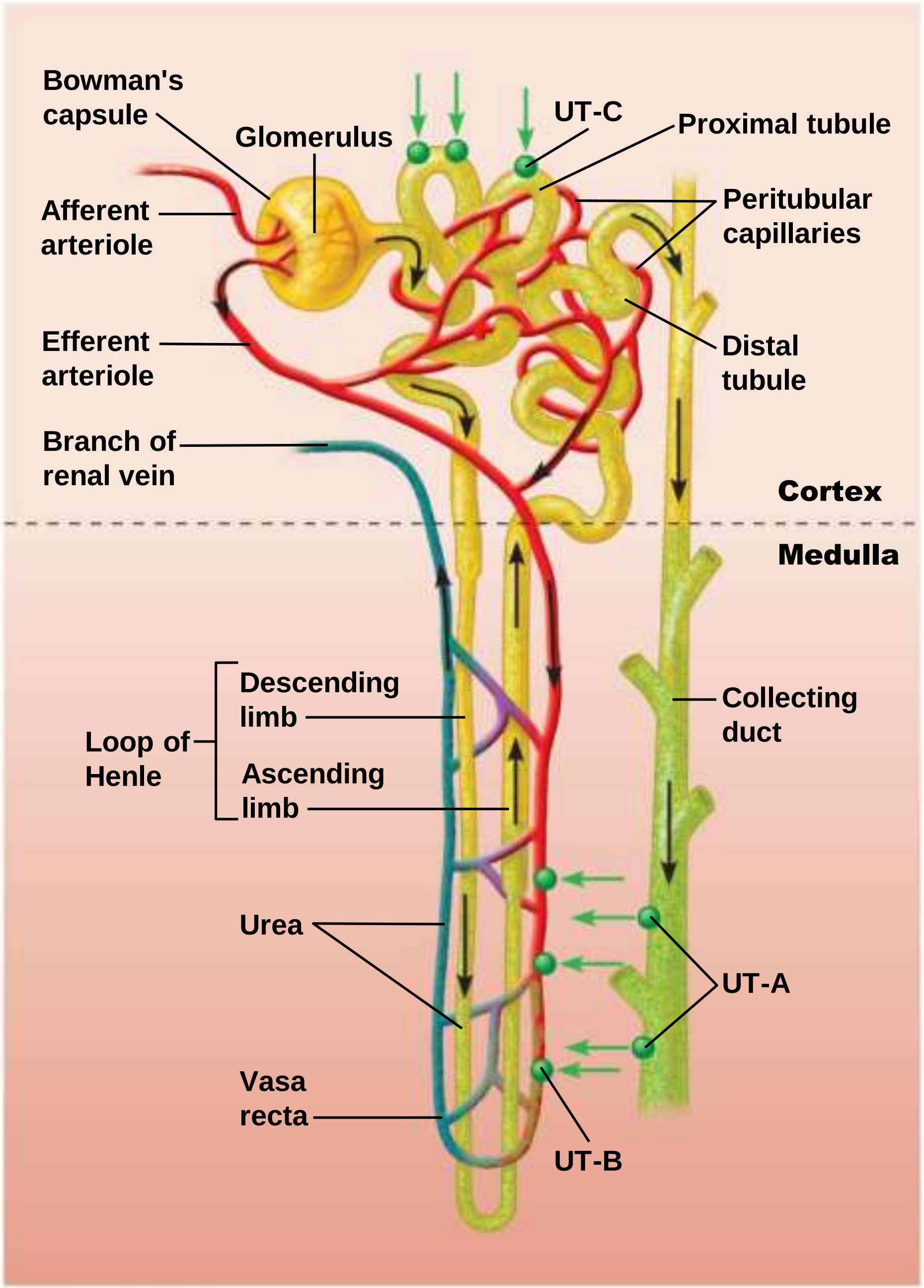


Establishment of the Medullary Osmotic Gradient

- Role of urea in the medullary osmotic gradient
  - Urea
    - Generated by liver
    - Nitrogen elimination
    - Extremely water soluble
    - Requires urea transporters: UTA, UTB, and UTC
  - Transport of urea through UTA from filtrate to peritubular fluid contributes approximately 40% of the osmolarity of the gradient

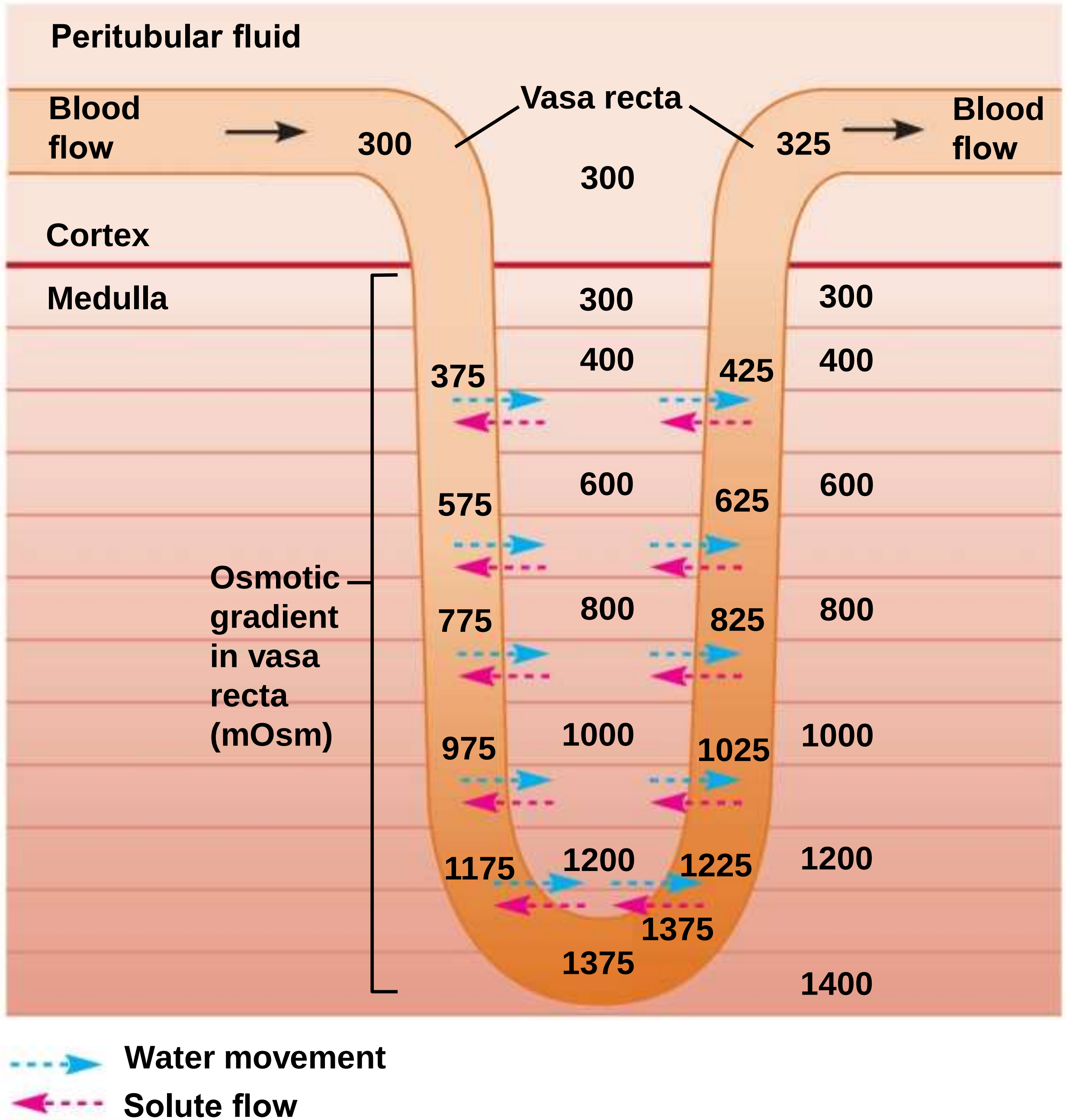
Figure 19.8 Contribution of urea to the medullary osmotic gradient.



Establishment of the Medullary Osmotic Gradient

- Role of the vasa recta
  - Anatomical arrangement of vasa recta capillaries prevents the diffusion of water and solutes from dissipating the medullary osmotic gradient
  - Descending limb of vasa recta (300 mOsm)
    - As it descends, water leaves capillaries by osmosis and solutes enter by diffusion
  - Ascending limb of vasa recta (325 mOsm)
    - Water moves into plasma and solutes move into interstitial fluid
    - Osmolarity is higher due to the lack of urea transporters

Figure 19.9 How the vasa recta prevents the dissipation of the medullary osmotic gradient.



Role of the Medullary Osmotic Gradient in Water Reabsorption in the Distal Tubule and Collecting Duct

- 70% water reabsorbed in proximal tubule
  - Not regulated
- 20% reabsorbed in distal tubule
  - Regulated by ADH
- 10% reabsorbed in collecting ducts
  - Regulated by ADH

Role of the Medullary Osmotic Gradient in Water Reabsorption in the Distal Tubule and Collecting Duct

- Dependent on osmotic gradient established by countercurrent multiplier
- Dependent on epithelium permeability to water
- Water permeability dependent on water channels
  - Aquaporin-3: present in basolateral membrane always
  - Aquaporin-2: present in apical membrane only when ADH present in blood

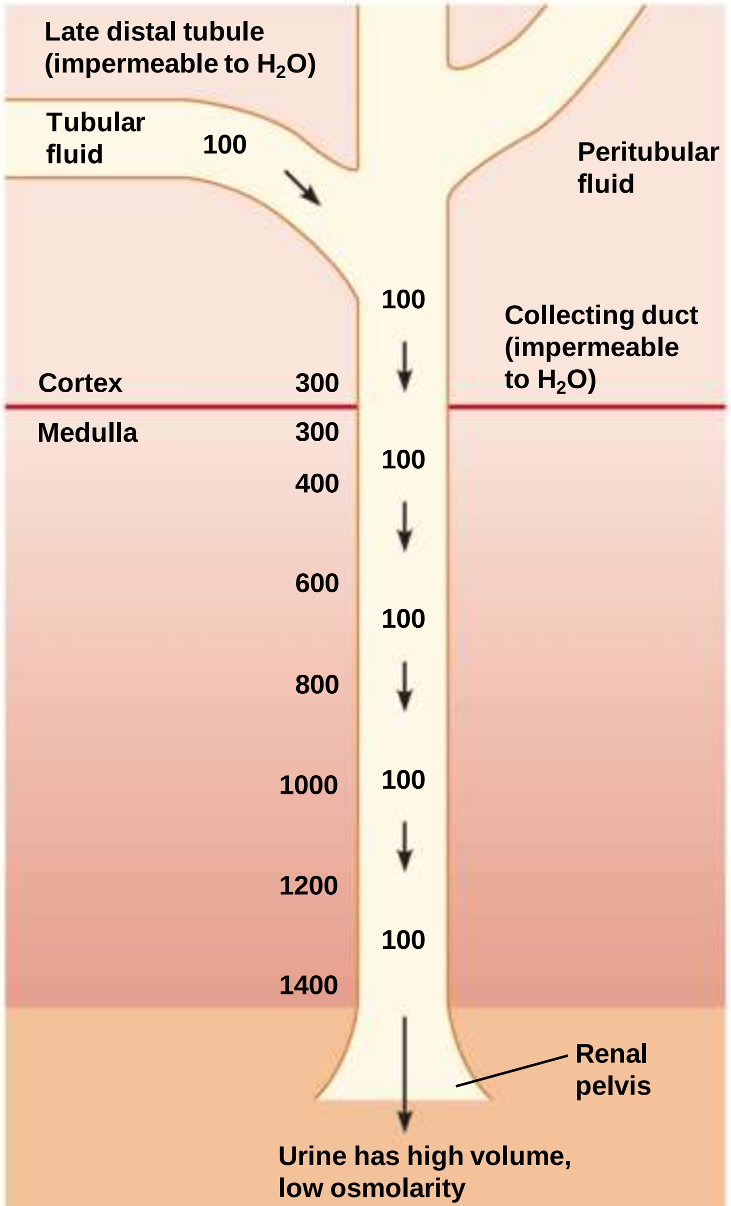
Role of the Medullary Osmotic Gradient in Water Reabsorption in the Distal Tubule and Collecting Duct

- When membrane of late distal tubule and collecting duct is impermeable to water
  - Water cannot leave the tubules
  - No water reabsorption
  - More water is excreted in urine

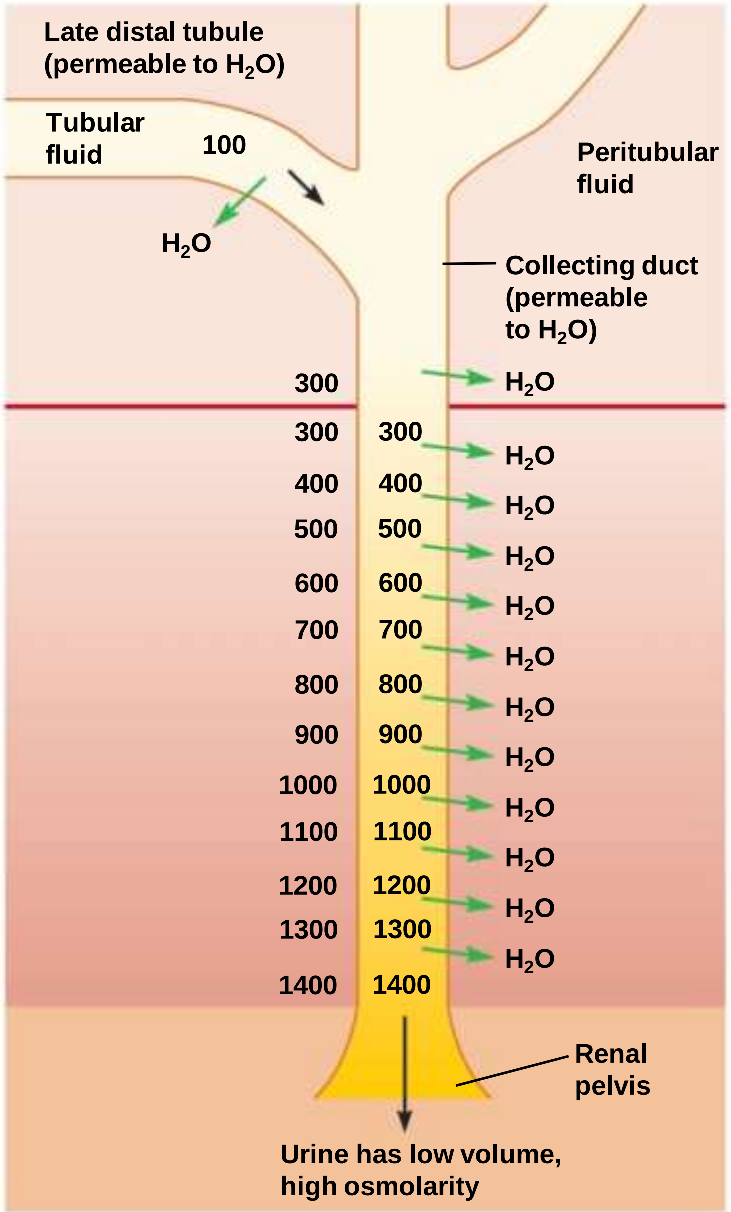
Role of the Medullary Osmotic Gradient in Water Reabsorption in the Distal Tubule and Collecting Duct

- ADH stimulates the insertion of water channels (aquaporin-2) into apical membrane
  - Water is reabsorbed by osmosis
  - Maximum urine concentration is 1400 mOsm
- Maximum amount of water reabsorbed depends on length of loop of Henle

Figure 19.10 Water reabsorption across the late distal tubule and collecting duct.



(a) Late distal tubule and collecting duct impermeable to water



(b) Late distal tubule and collecting duct permeable to water

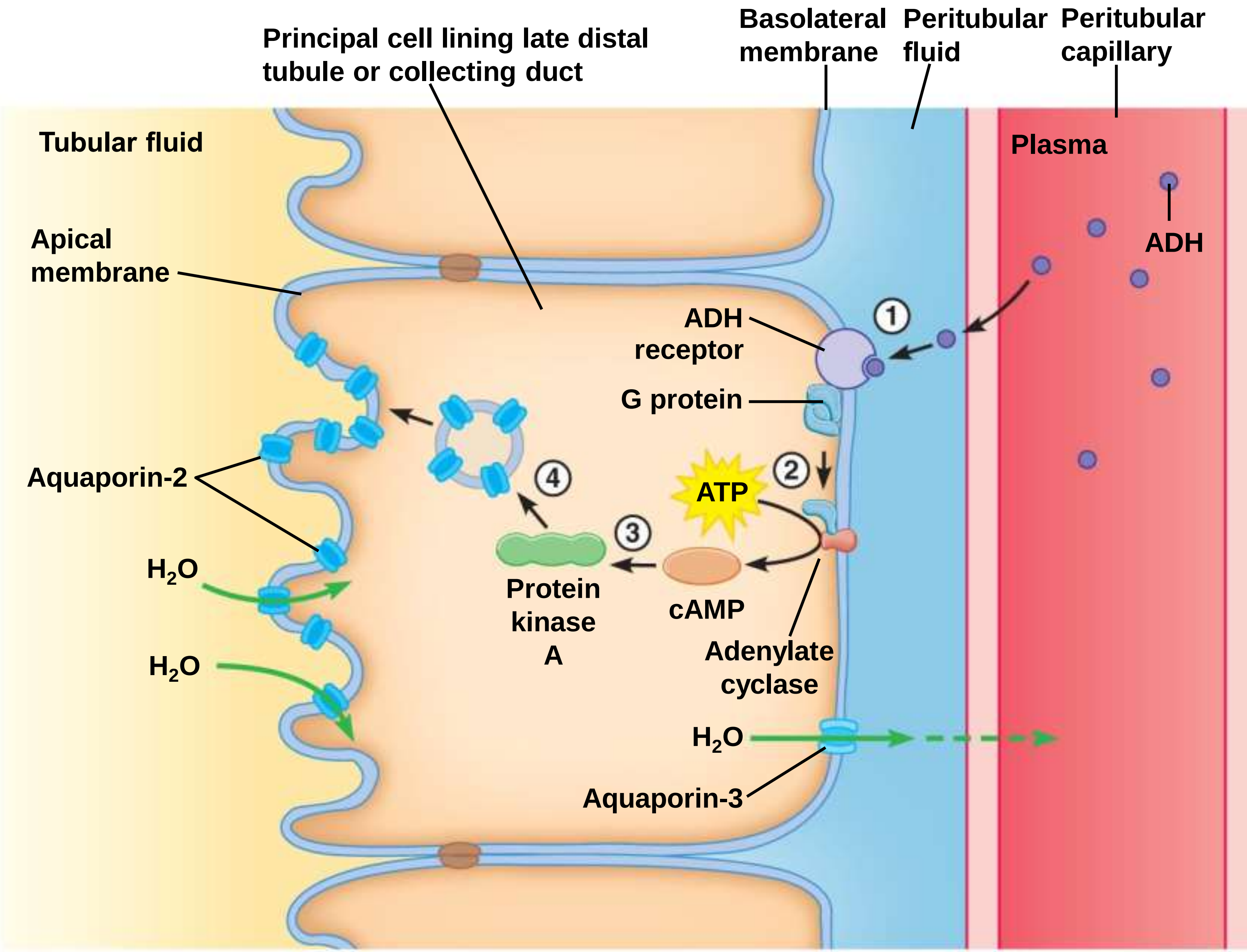
Role of the Medullary Osmotic Gradient in Water Reabsorption in the Distal Tubule and Collecting Duct

- Obligatory water loss
  - Minimum volume of water that must be excreted in the urine per day
  - Maximum osmolarity urine = 1400 mOsm
  - Some solute must be excreted
  - Minimum water loss = 440 mL
    - Necessary to eliminate nonreabsorbed solutes

Role of the Medullary Osmotic Gradient in Water Reabsorption in the Distal Tubule and Collecting Duct

- Effects of ADH on water reabsorption
  - ADH regulates permeability of late distal tubules and collecting ducts
  - Urine osmolarity range: 100–1400 mOsm
  - Aquaporin-2 varied by ADH
  - Antidiuretic

Figure 19.11 Effects of ADH on principal cells lining the late distal tubules and collecting ducts.



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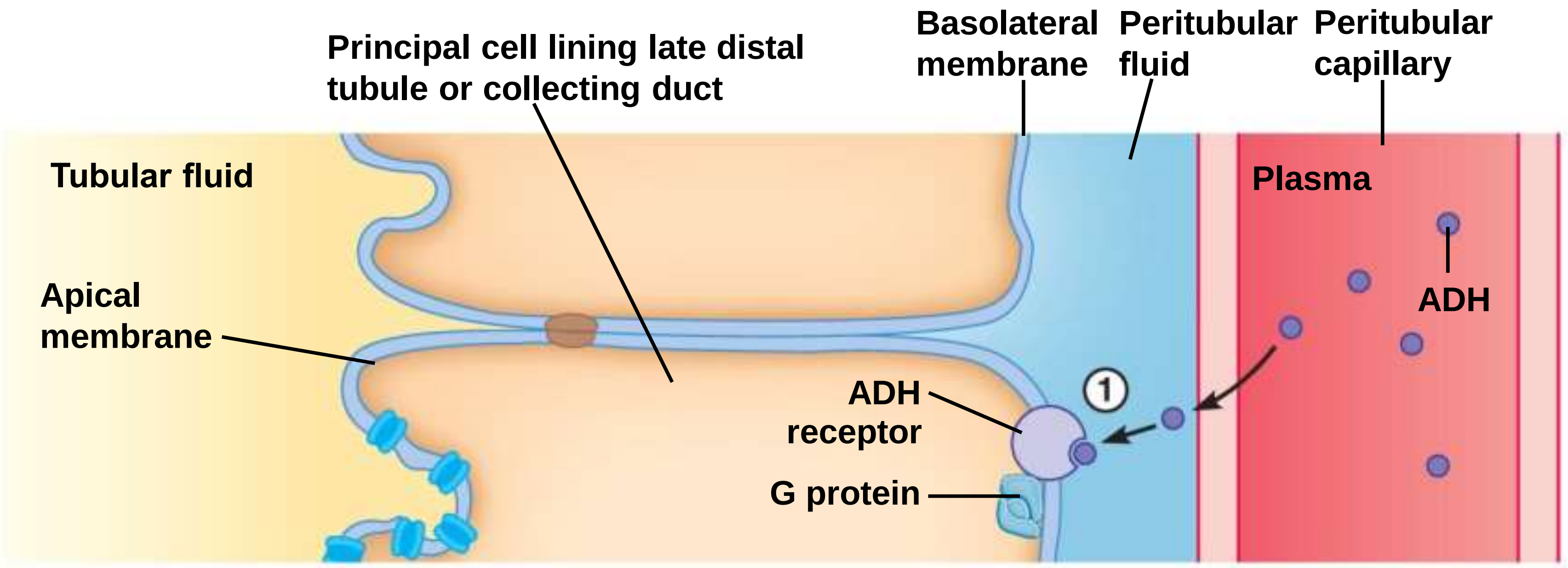

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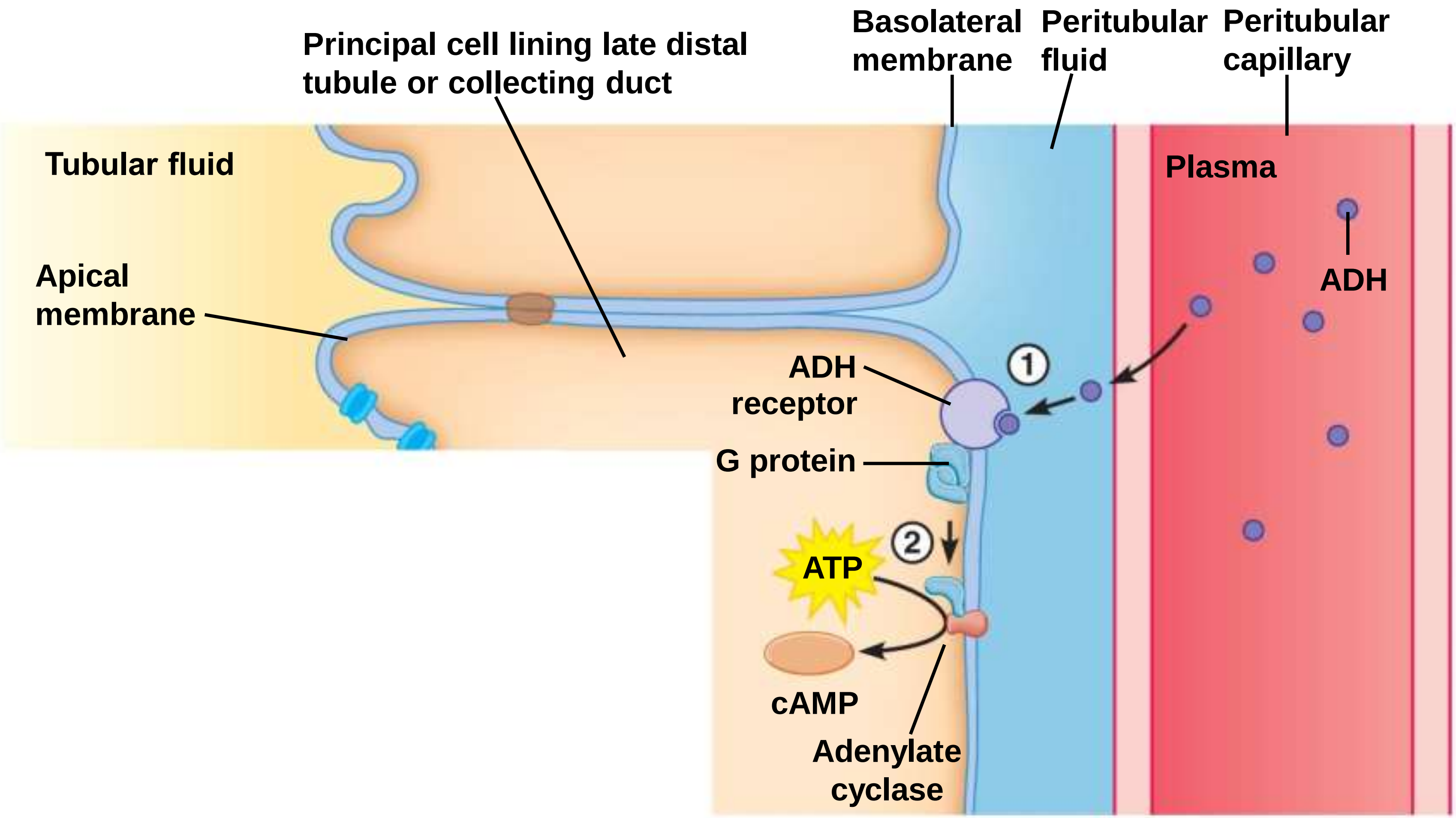

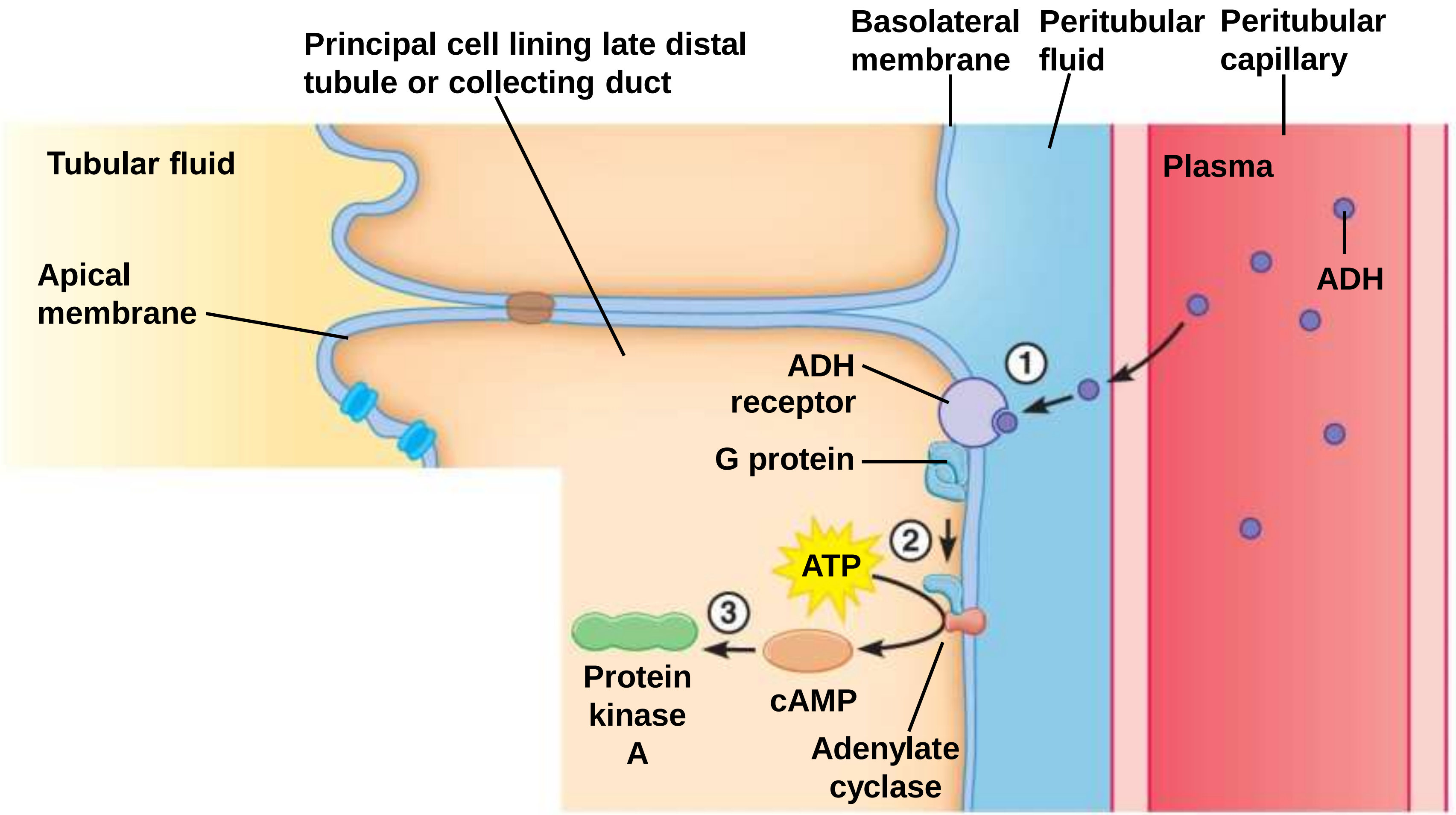
Principal cell lining late distal tubule or collecting duct
Basolateral membrane
Peritubular fluid
Peritubular capillary
Tubular fluid
Plasma
Apical membrane
ADH
1
ADH receptor
G protein
2
ATP
3
Protein kinase A
cAMP
Adenylate cyclase

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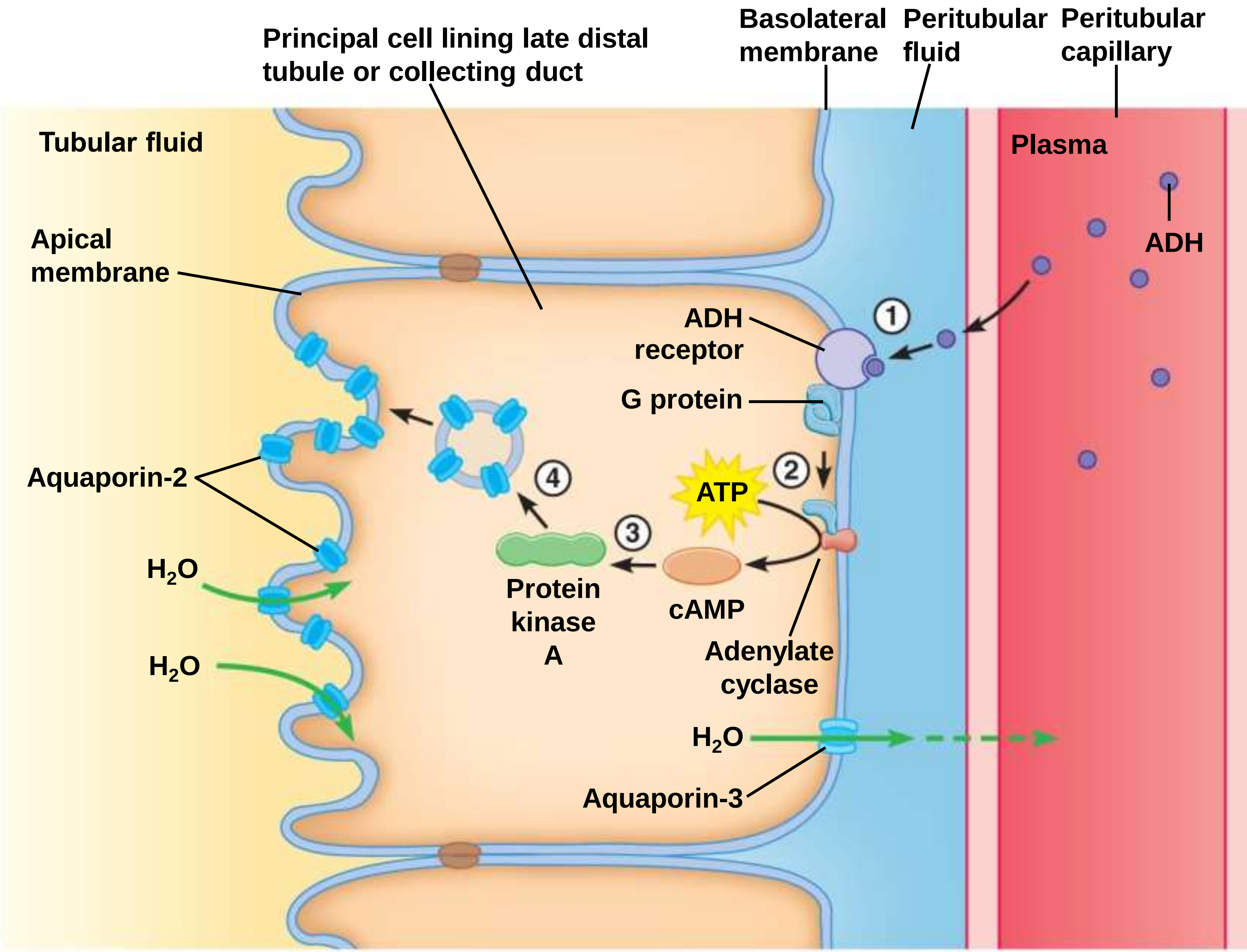
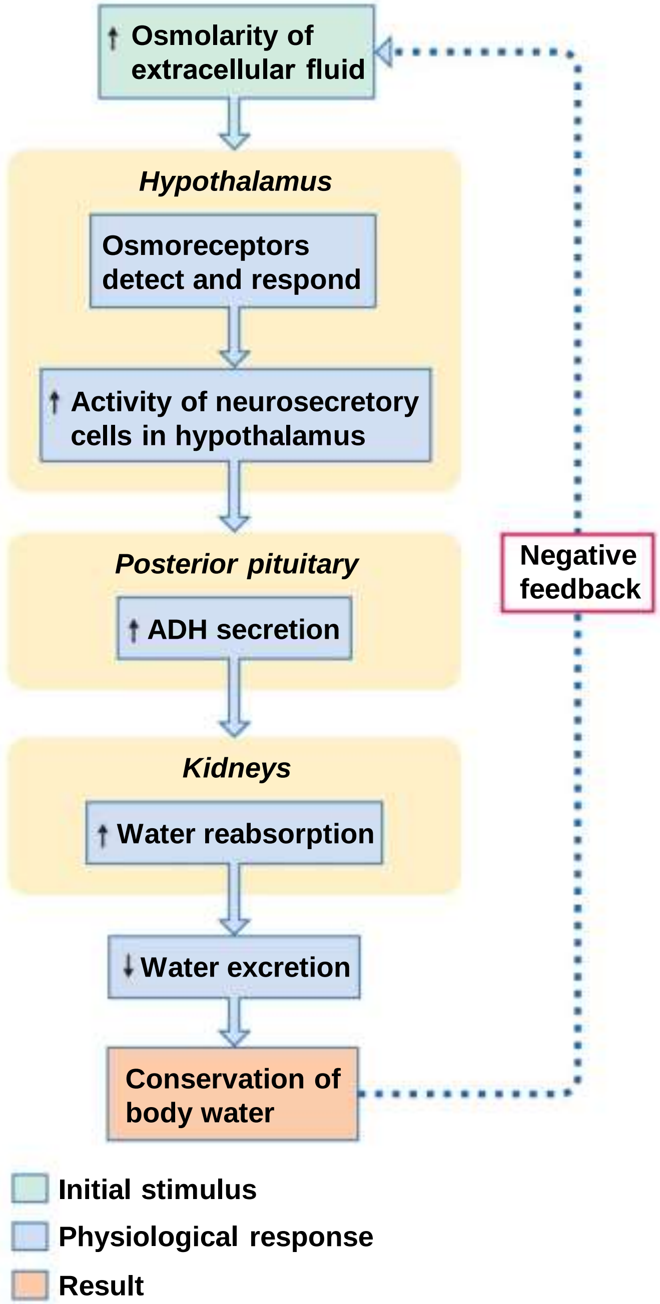


Role of the Medullary Osmotic Gradient in Water Reabsorption in the Distal Tubule and Collecting Duct

- Regulation of ADH secretion
  - Released from terminals in the posterior pituitary from cell bodies originating in the hypothalamus
  - Osmoreceptors in the organum vasculosum of laminae terminalis (OVLT) sense osmolarity
  - OVLT is not surrounded by the blood-brain barrier
  - ADH is also affected by baroreceptors detecting blood volume and pressure
  - ↓ baroreceptor activity = ↑ ADH secretion

Figure 19.12 Pathway for extracellular fluid osmolarity and ADH secretion to interact.



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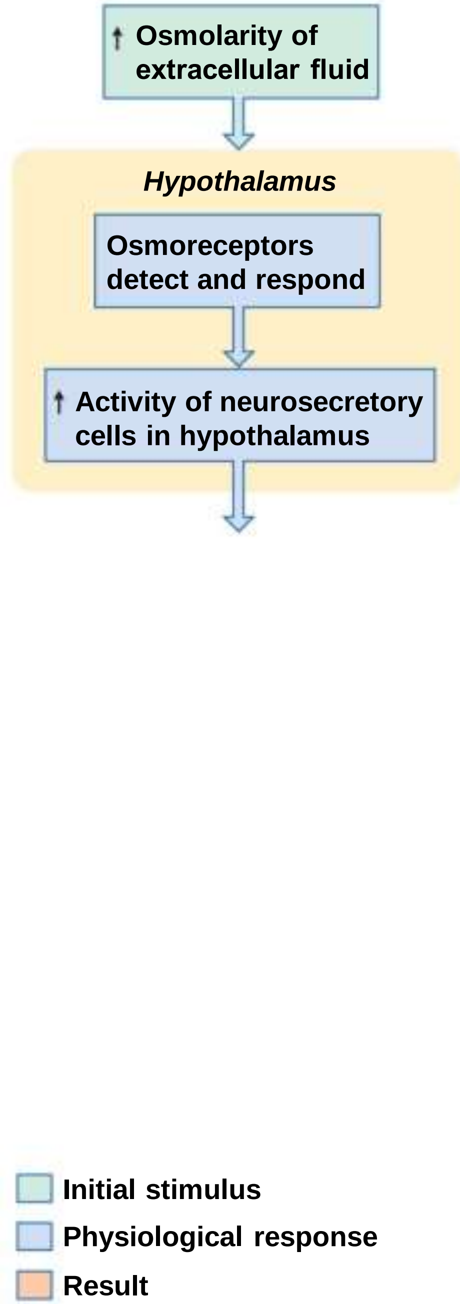

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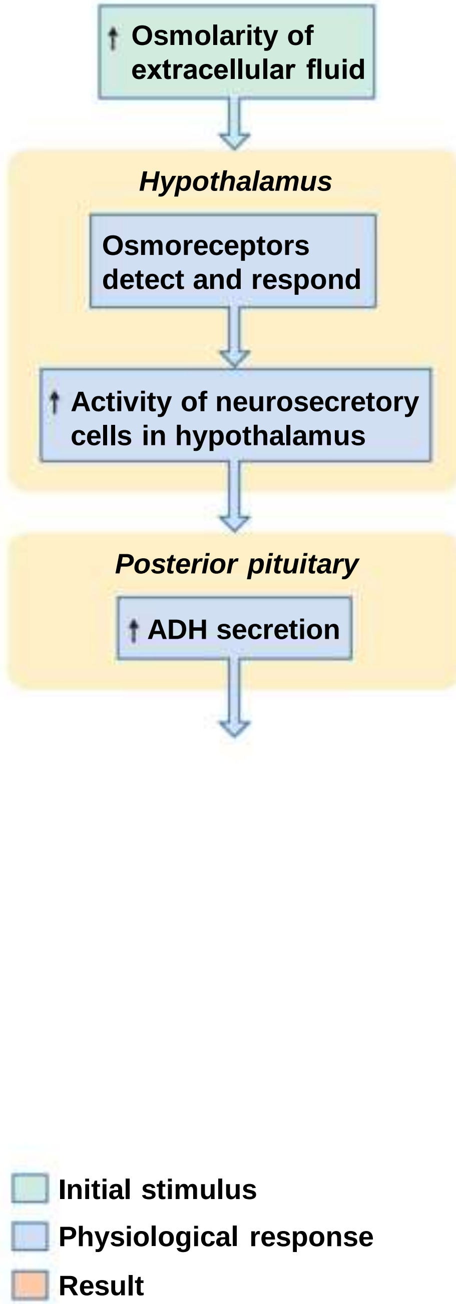

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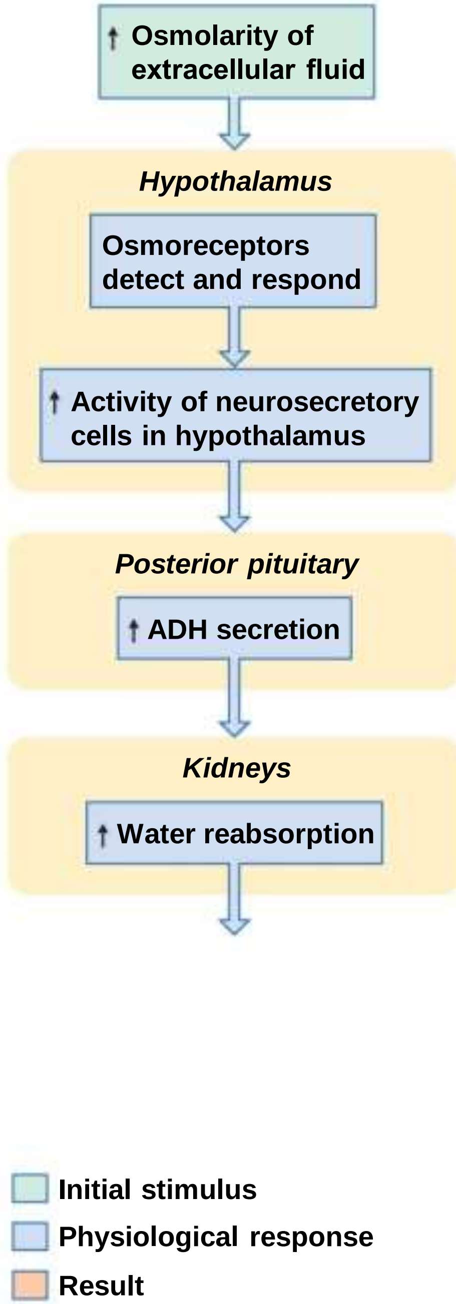

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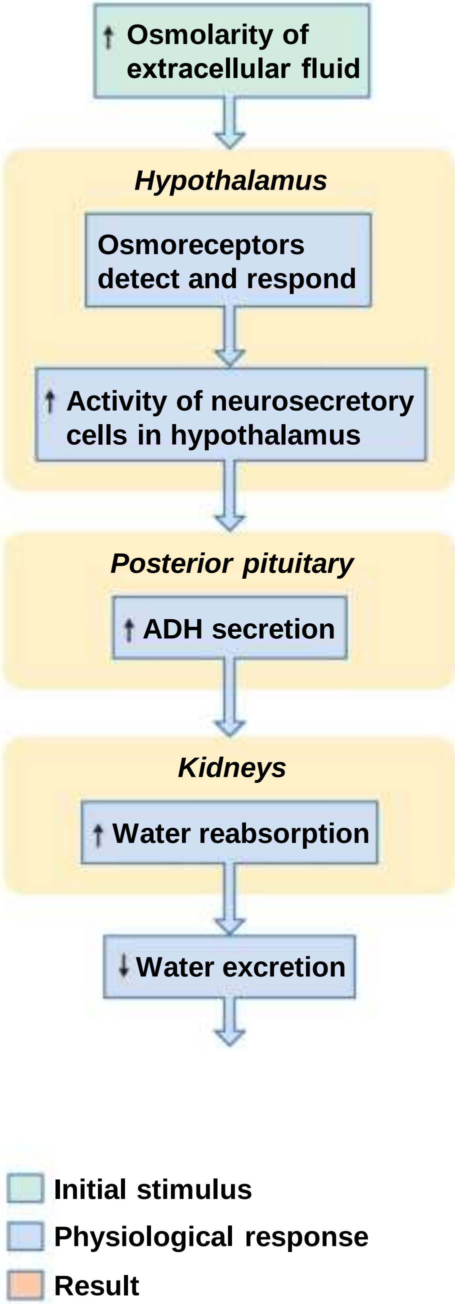

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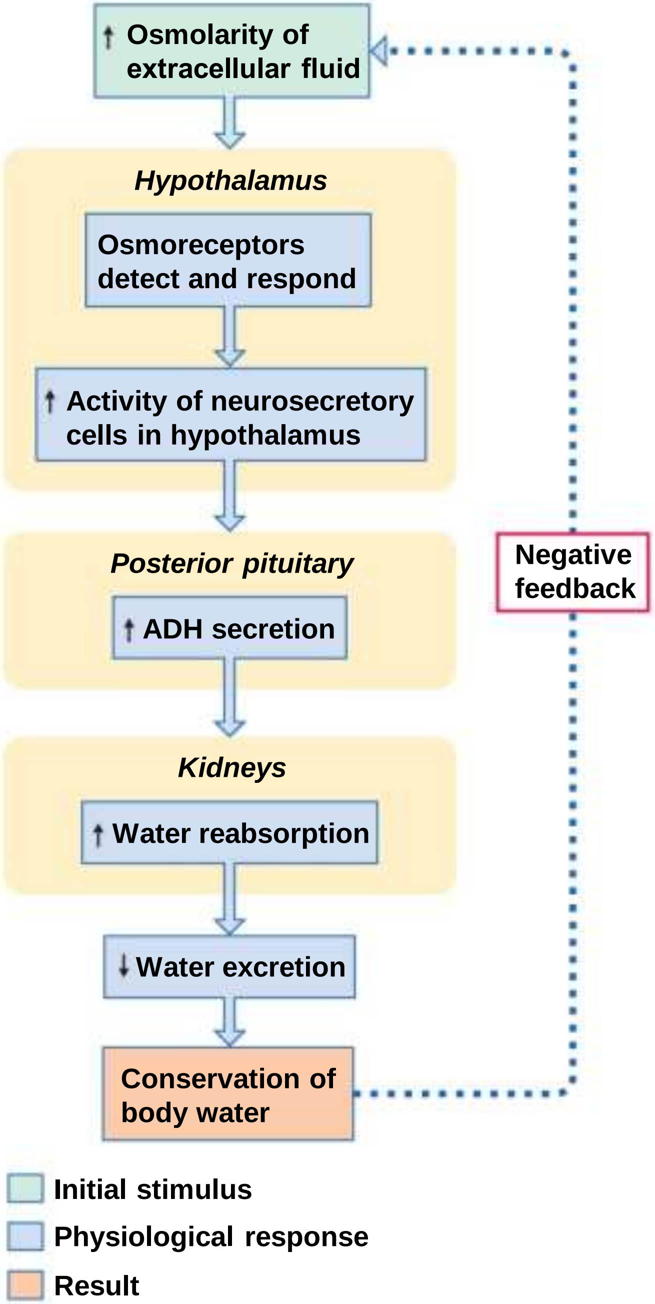
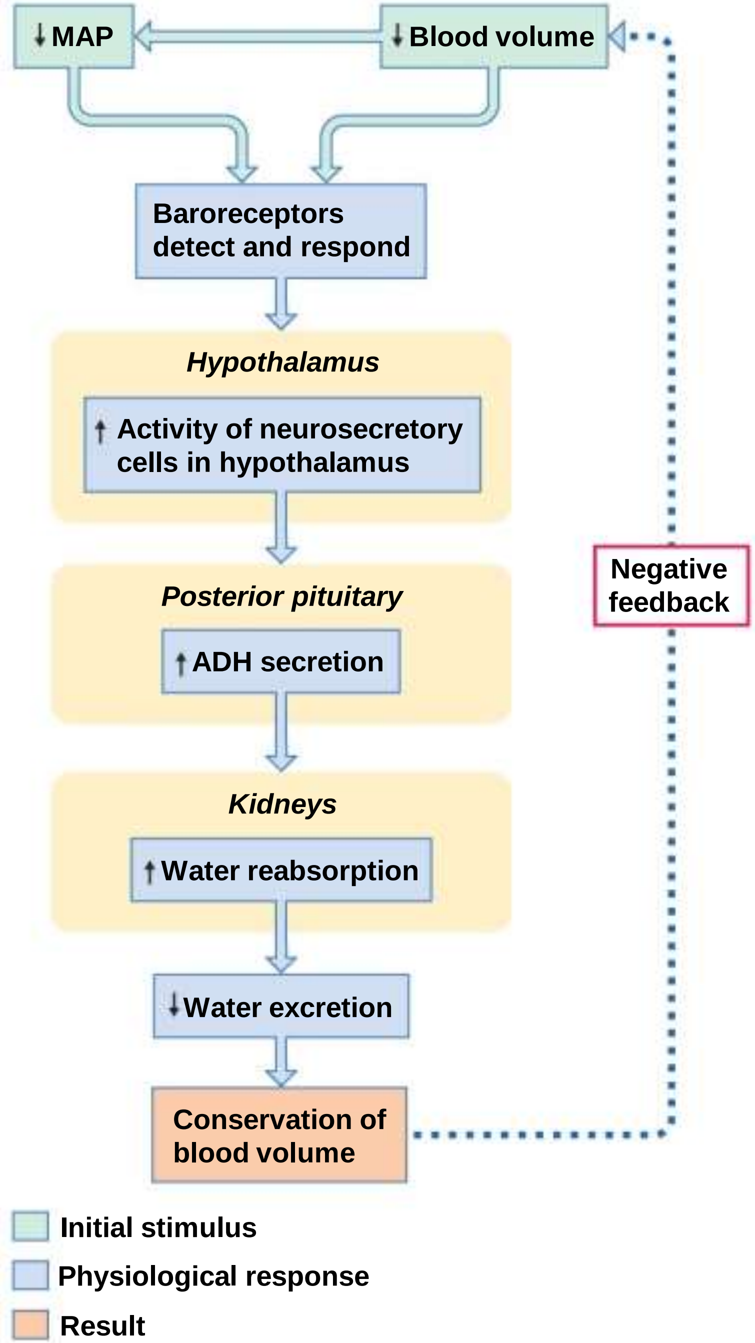


Figure 19.13 Effects of arterial and cardiac baroreceptors on ADH.



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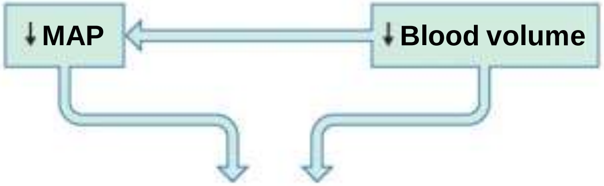

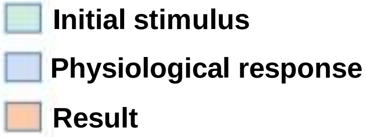

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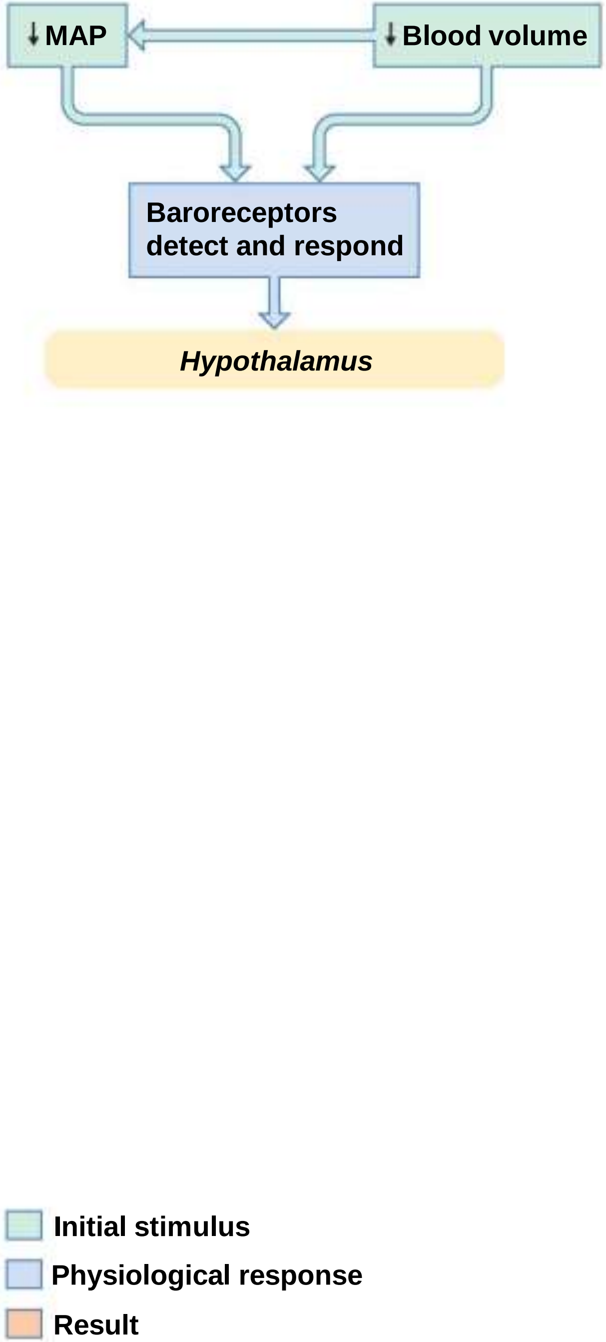

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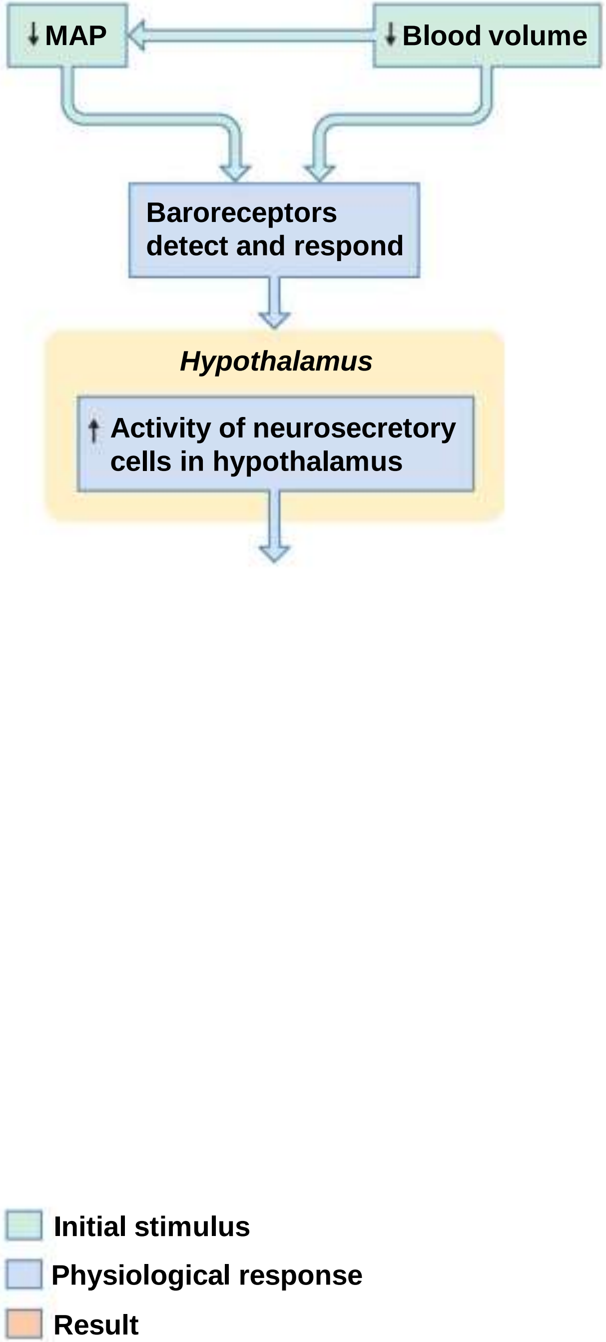

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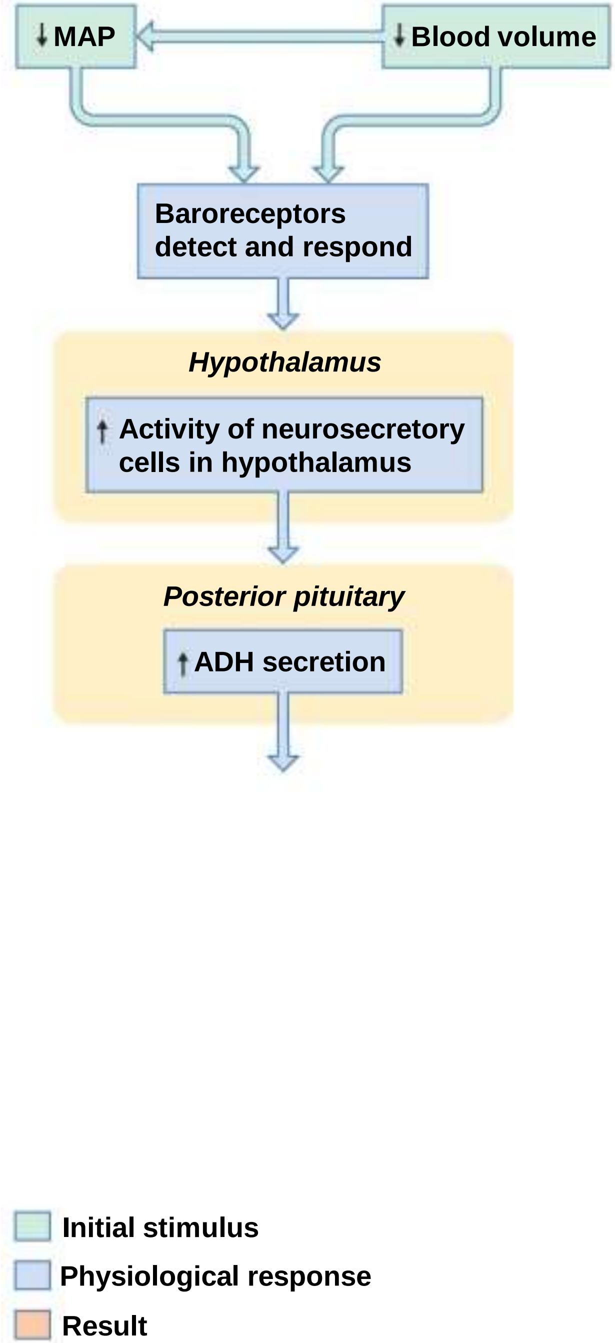

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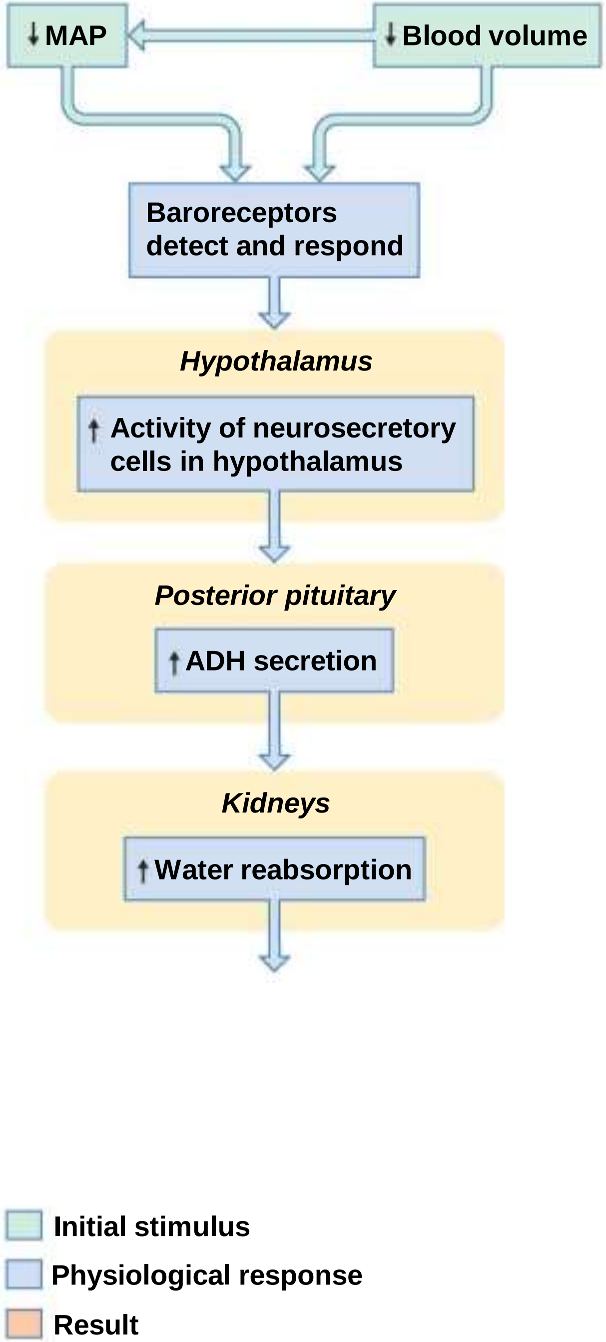

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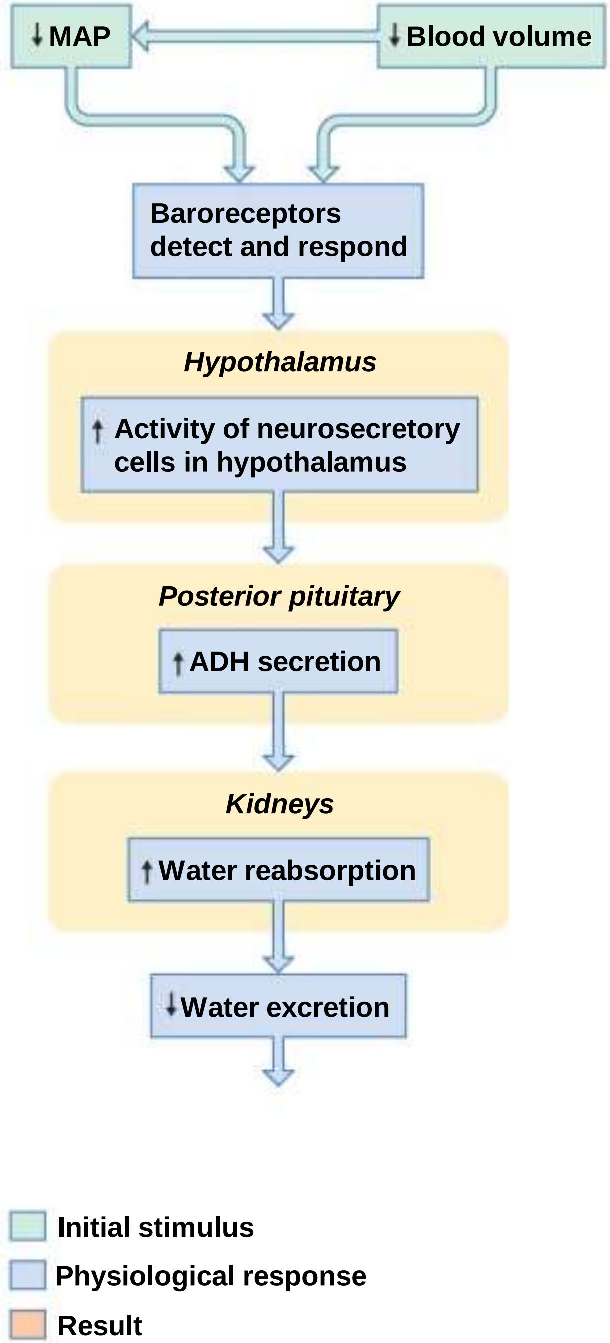

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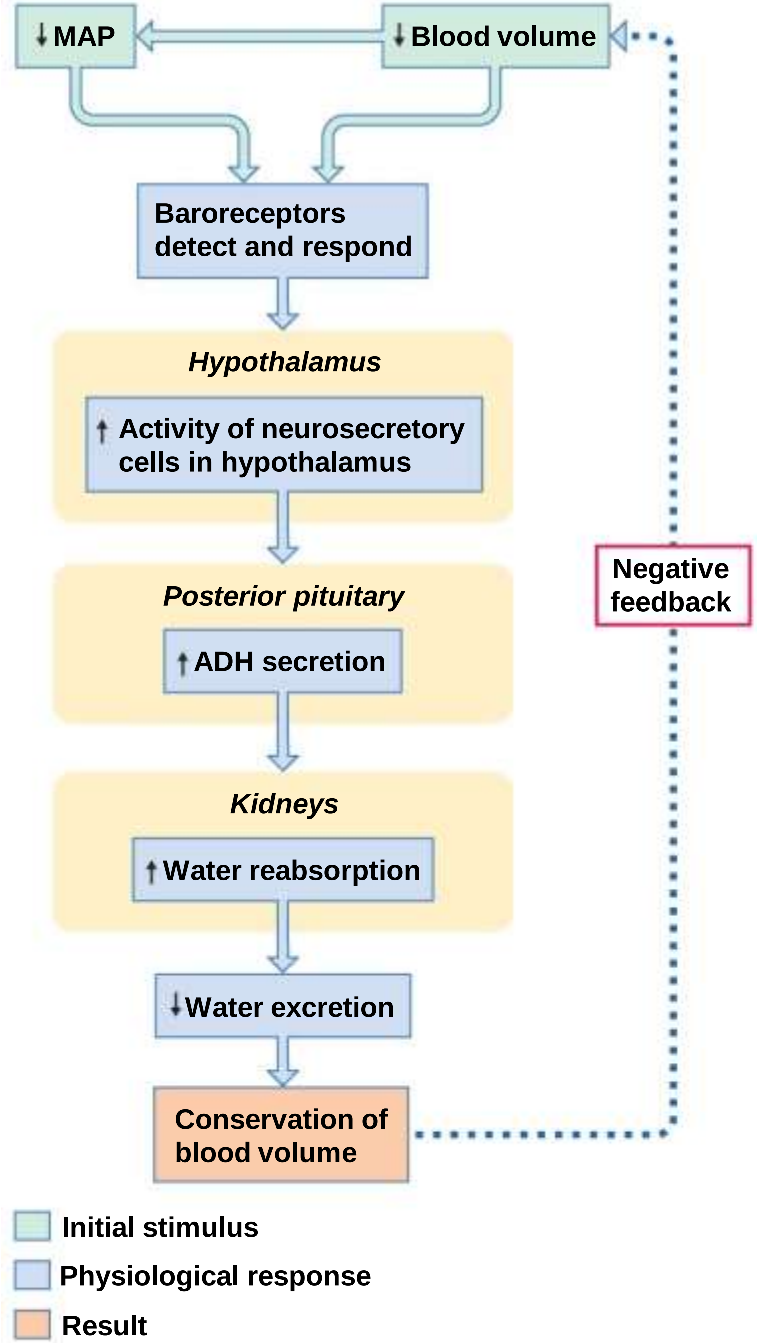

Role of the Medullary Osmotic Gradient in Water Reabsorption in the Distal Tubule and Collecting Duct

- Regulating water excretion by changing GFR
  - GFR is normally autoregulated
  - If blood pressure drops to less than 80 mm Hg
    - Decrease in GFR
    - Decrease in water filtered
    - Decrease in water excretion
  - If blood pressure increases to more than 180 mm Hg
    - Increase in GFR
    - Increase in water filtered
    - Increase in water excretion
    - Occurs only in pathological circumstances