Fluid, Electrolyte & Acid-Base Balance

“The best & safest thing is to keep a balance in your life, acknowledge the great powers around us & within us. If you can do that & live that way, you are really a wise man/woman.”

~Euripides
"Realize deeply that the present moment is all you ever have." ~Eckhart Tolle
Fluid, Electrolyte & Acid-Base Balance

• Most of the chemical reactions that occur in the body occur in a water environment
  – Inside the Cells
  – Outside the cells

• Many of the chemical reactions can only function within a **narrow range** of conditions
Fluid, Electrolyte & Acid-Base Balance

- Small changes in the total amount of water, the pH, or the concentration of electrolytes can alter these reactions
- Many homeostatic control mechanisms in the body are involved in regulating water volume, pH & electrolyte concentrations
Body Fluids

• Body Water Content
• Fluid Compartments
• Composition of Body Fluids
• Fluid Movement Among Compartments
Continuous Mixing of Body Fluids

Figure 26.3
Body Water Content

- Total Body Water approximation _____ L (~11 gallons) of water in an average adult male (154 lbs)
- Total Body Water is a function of age, body mass & fat
- In men it is about _____%
- In women it is about _____%
  - (women have relatively more body fat & less skeletal muscle than men)
- Body water declines throughout life, ultimately comprising about 45% of total body mass in old age
- In infants it is about 73% water
  - Due to their low body fat & bone mass
• Adipose tissue is the least hydrated tissue (20% water), with even less water than bone!
• Skeletal muscle is the most hydrated (65% water)
Fluid Compartments

There are 2 main fluid compartments of the body: ICF, ECF, Interstitium, Plasma

- Intracellular fluid volume = 25 L, 40% body weight
- Extracellular fluid volume = 15 L, 20% body weight
- Interstitial fluid volume = 12 L, 80% of ECF
- Plasma volume = 3 L, 20% of ECF

Total body water volume = 40 L, 60% body weight
Body Water Content

• **Extracellular Fluid** (ECF)
• ECF is found *within the body, but ________________*
• ECF is found *distributed among several sub-compartments in the body:*
  – Blood plasma
  – Interstitial fluid
  – Lymph
  – Cerebrospinal fluid
  – Synovial fluid
Intracellular Compartment

• Contains slightly less than $\frac{2}{3}$ (63%) of the Total Fluid Volume in the body

• **Intracellular fluid (ICF)**
  accounts for **25** of the **40** Liters of Total Body Water
Extracellular Compartment

• Includes all body water outside of the cells

• Extracellular Fluid (ECF) accounts for 37% (15 Liters) of the Total Body Water
Composition of Body Fluids

- Water serves as the solvent in the body, in which a variety of solutes are dissolved.
- 2 main solute classifications are:
  - __________________________
  - __________________________
Non-electrolytes

• Most are __________________________ such as glucose, lipids, creatinine & urea
• Their __________________________ keep them from dissociating into ions when placed in water
Electrolytes

• **Chemicals that dissociate into ions in water** including acids, bases, salts & some proteins
• Fluid balance depends primarily on electrolyte concentrations
• The fluids in the body are mostly **water**
  – **Water moves** from one compartment to another in the body **by**_______________
  – The determining factor for osmotic movement is colloid **osmotic pressure**, which is **determined by** _____________________________(K⁺ in the ICF, Na⁺ levels in the ECF) & proteins
Electrolytes

- ***Remember, water moves from a LESS concentrated area (less osmolality) to a MORE concentrated area (more osmolality) – water wants to DILUTE!
Electrolyte Composition of Body Fluids

Major components of ECF:
- Na⁺, HCO₃⁻, Cl⁻, some proteins

Major components in ICF:
- K⁺, Ca²⁺, HPO₄²⁻, HCO₃⁻, proteins

![Graph showing electrolyte concentrations in different fluids with key to symbols and legend.]
Fluid Movement Among Compartments

• Anything that changes solute concentration in any compartment leads to the movement of water

• Nearly protein-free plasma is forced out of the blood by Hydrostatic pressure & almost completely reabsorbed due to Colloid Osmotic pressure of plasma proteins
Fluid Movement Among Compartments

• Movement of water between the interstitial fluid & intracellular fluid involves substantial 2-way osmotic flow that is equal in both directions

• Ion fluxes between the interstitial & intracellular compartments are restricted & occurs by active transport
Fluid Movement Among Compartments

- Movement of nutrients, respiratory gases & wastes typically occur in one direction
- For example, glucose & $O_2$ move into cells while $CO_2$ & other metabolic wastes move out
- **Water** moves freely between compartments & changes in ICF or ECF concentrations can change the direction of water movement
  - An increase in the ECF solute content (**mainly NaCl**) causes water to move from **OUT OF** cells
  - A decrease in the ECF solute content causes water to move **INTO** the cells
Water Balance & ECF Osmolality

• Proper Hydration
• Regulation of Water Intake
• Regulation of Water Output
• Influence of ADH (Antidiuretic Hormone)
• Disorders of Water Balance
Proper Hydration

• Water intake must equal Water output
Water Input

• Most water enters the body through ingested liquids & food, but is also produced by _________________

• Around ______ mL of water is ingested per day in adults
  – Beverages = 1500 ml
  – Foods = 750 ml
  – __________________ = 250 ml
Water Output

- Due to evaporative loss from lungs & skin (insensible water loss), sweating, defecation & urination
- This should equal the ______ mL that is ingested

- __________ = 1500 ml
- Skin & lungs = 700 ml (insensible H2O loss)
- Sweat = 200 ml
- Feces = 100 ml
Water Intake & Output

Metabolism 10%
Foods 30%
Beverages 60%

Average intake per day:
- Metabolism: 250 ml
- Foods: 750 ml
- Beverages: 1500 ml

Total intake: 2500 ml

Average output per day:
- Feces: 100 ml
- Sweat: 200 ml
- Insensible losses via skin and lungs: 700 ml
- Urine: 1500 ml

Total output: 2500 ml
Regulation of Water Intake

- _________ is the driving force for water intake

- The thirst mechanism is triggered by an increase in plasma osmolality (plasma get more concentrated), which excites osmoreceptors in the ______________________ Thirst Center
Other Stimulators of Thirst

• **Dry mouth**
  resulting from a lack of saliva output as the body conserves water

• **Angiotensin II**
  stimulates the thirst center in the hypothalamus
  – RECALL that angiotensin II is formed as a result of renin release from JG cells in the kidneys in response to a decrease in blood pressure

• Thirst is quenched as the mucosa of the mouth is moistened & continues with distention of the stomach & intestines, resulting in inhibition of the hypothalamic thirst center
Regulation of Water Intake: Thirst Mechanism

Key:
- Increases, stimulates
- Reduces, inhibits
- Initial stimulus
- Physiological response
- Result

Diagram showing the process:
1. Plasma osmolality increases
2. Osmoreceptors in hypothalamus
3. Dry mouth
4. Sensation of thirst; person takes a drink
5. Water moistens mouth, throat; stretches stomach, intestine
6. Water absorbed from GI tract
7. Plasma osmolality decreases

Other steps:
- ▼ Plasma volume
- ▼ Blood pressure
- JG cells in kidney
- Renin-angiotensin mechanism
- ▼ Angiotensin II
Dehydration:
So how much is too little?

- **The effects are based on amount of water lost:**
  - Dehydration Weight loss (\% of initial weight)
  - **Symptoms:**
    - **1-** Thirst
    - **2-3** Strong thirst, loss of appetite, increasing blood concentration
    - **4-5** Lagging pace, flushed skin, impatience, nausea, apathy
    - **6-8** Tingling in arms, hands & feet; headache; increased body temp., pulse rate, and respiratory rate
    - **8-9** Labored breathing, dizziness, cyanosis, slurred speech, mental confusion
    - **10-14** Spastic muscles, loss of balance with eyes closed, swollen tongue, circulatory insufficiency, delirium, failing kidneys
    - **15-18** Shriveled skin, inability to swallow, sunken eyes, deafness, no urine formation
    - **20** Bare survival limit ☠
Clinical Note

- while the sense of thirst is important in prodding us to drink, it may not be completely reliable as an indicator of how MUCH we need to drink.

- As the water moistens the mucosa in the mouth & stretches the stomach, inhibitory signals are sent to the thirst center, even if an inadequate amount of water has been ingested.

- As a result, some of our troops stationed in desert areas such as Iraq or Afghanistan are trained to drink certain amounts at regular intervals, regardless of whether or not they “feel” thirsty.
Regulation of Water Output

• The primary way your body regulates fluid volume is by adjusting ________________

• Drinking is necessary since there is obligatory water loss due to the insensible water losses (through skin, exhaled breath, feces)

• Beyond obligatory water losses, solute concentration & volume of urine depend on fluid intake, diet & water losses via other avenues
  – Example – perspiring profusely on a hot day means less urine needs to be excreted by the kidneys in order to maintain water balance

• __________ is the powerful “magnet” that pulls water into the urine or back into the bloodstream
Influence of ADH

• (Antidiuretic Hormone/Vasopressin)
• The amount of water ____________________ in the renal collecting ducts is proportional to ADH release
  – When ADH levels are low, most water in the collecting ducts is not reabsorbed, resulting in large quantities of dilute urine
  – When ADH levels are high, filtered water is reabsorbed, resulting in a lower volume of concentrated urine
• ADH secretion is promoted or inhibited by the Hypothalamus in response to changes in solute concentration of extracellular fluid, large changes in blood volume or pressure, or vascular baroreceptors
Mechanisms & Consequences of ADH Release

Figure 26.6
Disorders of Water Balance

- Dehydration
- Hypotonic Hydration
- Edema
Dehydration

- Occurs when water output exceeds water intake, & may lead to weight loss, fever, mental confusion or hypovolemic shock.
- Can occur due to: sweating, hemorrhaging, severe burns, vomiting, diarrhea, water deprivation, abuse of diuretics.
- As water is lost from the ECF, the ECF gets more concentrated... This causes water to move from the ICF & into the ECF... As a result, the body cells shrink (crenate).
Disorders of Water Balance: Dehydration

1. Excessive loss of $\text{H}_2\text{O}$ from ECF
2. ECF osmotic pressure rises
3. Cells lose $\text{H}_2\text{O}$ to ECF by osmosis; cells shrink

Mechanism of Dehydration

Figure 26.7a
Hypotonic Hydration

• Is a result of renal insufficiency or intake of an excessive amount of water very quickly or infusion of the wrong type of IV fluid

• As the ECF becomes more diluted, water begins to move from the ECF into the ICF & the body cells swell & may even burst (lysis)

• Metabolic disturbances can lead to nausea, vomiting, cramping, cerebral edema (which can result in disorientation, convulsions, coma & Death ☠️
Disorders of Water Balance: Hypotonic Hydration

Mechanism of Hypotonic Hydration

1. Excessive $H_2O$ enters the ECF
2. ECF osmotic pressure falls
3. $H_2O$ moves into cells by osmosis; cells swell

Figure 26.7b
Edema

- an accumulation of fluid in the interstitial space, resulting in tissue swelling

Factors that cause edema:
- Increased hydrostatic pressure in blood capillaries, results in more fluid loss from the plasma (due to local vessel blockage, incompetent venous valves, high blood volume)
- Increased capillary permeability (due to inflammation)
- Low levels of plasma protein (hypoproteinemia)
- Blockage of lymphatic vessels
Electrolyte Balance

- Recall that electrolytes are acids, bases & salts
- When placed in water, they dissociate into ions such as Na\(^+\), K\(^+\), Cl\(^-\), etc
- While they have many important functions in the body, one of the important functions they serve is maintenance of the proper concentration of fluids in the body
• Remember that water moves by osmosis from areas of low solute concentration to areas of high solute concentration

• Changes in the amount of electrolytes in the body can have profound effects on the movement of water from one fluid compartment to another

• This could result in too much water moving into or out of cells, resulting in either swelling or cell dehydration & edema of the tissues

• So, one of the ways the body regulates fluid balance is by regulating the levels of electrolytes
Central Role of Na\(^+\) in Fluid & Electrolyte Balance

- __________ is the most important cation to regulation of fluid & electrolyte balance in the body due to its abundance & osmotic pressure.

- Since all body fluids are in chemical equilibrium, **any change in sodium levels causes a compensatory shift in __________**, affecting **plasma volume, blood pressure & intracellular & interstitial fluid volumes**.
Regulation of Na\(^+\) Balance

- Aldosterone
- Cardiovascular baroreceptors
- Atrial Natriuretic Peptide (ANP)
- Estrogens
Aldosterone

- **primary regulator of** \( \text{Na}^+ \) concentrations in the ECF
- When **aldosterone** secretion from the adrenal cortex is high, nearly all the filtered \( \text{Na}^+ \) is reabsorbed in the distal convoluted tubule & the collecting duct in the kidneys
- Water follows by osmosis, especially if tubule permeability to water has been increased by ADH
- When aldosterone secretion is low, almost NO \( \text{Na}^+ \) is reabsorbed, so it stays in the filtrate & goes out with the urine, along with more water
- The most important trigger for the release of aldosterone is the **Renin-Angiotensin mechanism**, initiated in response to sympathetic stimulation, decrease in filtrate osmolality, or decreased blood pressure
- The **angiotensin II** that is formed stimulates the adrenal cortex to release aldosterone
Regulation of Sodium Balance: Aldosterone
Cardiovascular Baroreceptors

- monitor blood volume so that blood pressure remains stable
- A decrease in blood pressure causes less stimulation of the baroreceptors
- As a result, there is less inhibition of sympathetic signals to smooth muscle in arterioles & vasoconstriction (& increased blood pressure) occurs
- An increase in blood pressure increases stimulation of the baroreceptors, resulting in more inhibition of sympathetic signals from the vasomotor center & vasodilation (& decreased blood pressure) occurs
Atrial Natriuretic Peptide (ANP)

• from cells in the right atrium reduces blood pressure & blood volume by inhibiting release of ADH, renin & aldosterone & directly causing vasodilation

• So, more Na⁺ & water are lost in the urine & urine volume increases
Mechanisms & Consequences of ANP Release

Figure 26.10
Estrogens

• are chemically similar to aldosterone & enhance reabsorption of salt by the renal tubules

• Because water follows the Na\(^+\), many women retain fluid as estrogen levels rise during the menstrual cycle
• **Hypernatremia** – an excess of Na+
  – Caused by dehydration, excessive salt intake, infusion of concentrated saline; vomiting & diarrhea (because water loss exceeds loss of solutes)
  – Results in thirst, agitation, hypertension, seizures, tachycardia, flushed skin, dyspnea, respiratory arrest & death if severe

• **Hyponatremia** – a deficiency of Na+
  – Caused by excessive solute loss, water retention, or both; excess ADH release; insufficient aldosterone release; renal disease
  – Headache, muscle twitching, hypotension, nausea, tachycardia, vasomotor collapse if severe
Regulation of Potassium Balance

• Potassium is critical to the maintenance of the membrane potential of neurons & muscle cells
  – Recall that a nerve impulse or “_______________________________” involves movement of Na+ & K+ in opposite directions across the cell membrane of a neuron
• The heart is particularly sensitive to changing levels of K+ & excesses or deficiencies can disrupt normal heart rhythm (more about this later)
• K+ is also a buffer that compensates for shifts of hydrogen ions in or out of the cell
• Shifts of H+ into or out of cells cause shifts of K+ in the opposite direction:
• Potassium balance is chiefly regulated by renal mechanisms, which control the amount of potassium secreted into the filtrate
Regulation of Potassium Balance

- The cortical collecting ducts secrete K+ when ECF levels are excessive
- When ECF levels of K+ are low, the collecting duct cells secrete less K+
- **Blood plasma levels of potassium are the most important factor regulating potassium secretion**
  - A high-potassium diet increases K+ in the ECF & more K+ is secreted by the collecting duct cells
  - A low-potassium diet depresses the secretion of K+ into the urine
- **Aldosterone** influences potassium secretion, since potassium secretion is simultaneously enhanced when sodium reabsorption increases
- Na+ & K+ apparently don’t like each other very much & refuse to occupy the same areas in the body!
Regulation of Potassium Balance

Clinical Note

- the renal mechanism regulates K+ concentrations by adjusting how much is secreted
- And there is always some level of K+ being secreted, even when the kidneys are trying hard NOT to
- This is in contrast to Na+, which is never secreted, only reabsorbed
- And the kidneys are much better able to adjust the rate at which Na+ is being reabsorbed
- As a result, it is easier to suffer from a deficiency of K+ if it is lacking in the diet
Homeostatic Potassium Imbalances

• **Hyperkalemia** – excessive K+
  – Results from inability of kidney to excrete excessive K+ (renal dysfunction); ↓ urine output; burns; dehydration
  – Symptoms include tachycardia followed by bradycardia; nausea; muscle weakness, flaccid paralysis

• **Hypokalemia** – deficiency of K+
  – Results from excessive losses through GI tract (vomiting, diarrhea, laxative abuse); trauma in which damaged cells lose potassium, which enters ECF & is excreted in urine; certain drugs (diuretics, steroids)
  – Symptoms include dizziness, hypotension, arrhythmias, muscle weakness, mental depression, respiratory paralysis
Acid-Base Balance

• Because of the abundance of hydrogen bonds in the body’s functional proteins, they are strongly influenced by $H^+$ concentration.
• When arterial blood pH rises above 7.45, the body is in alkalosis
• When arterial blood pH falls below 7.35, the body is in acidosis
• **Optimal pH varies slightly among body fluids:**
  • Arterial blood = 7.4
  • Venous blood = 7.35
  • Interstitial fluid = 7.35
  • ICF = 7.0
Acid sources

• produced by chemical reactions in the body, usually when large molecules are being broken down into smaller ones
• Also, some food contain acidic substances
  – **Carbonic acid** – formed during the aerobic breakdown of glucose (cellular respiration: \( \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} \))
    
    \( \text{CO}_2 \) diffuses out of the cells & reacts with \( \text{H}_2\text{O} \) in the extracellular fluids & in RBCs to form carbonic acid: \( \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \)

  – **Lactic acid** – formed when glucose is broken down under anaerobic conditions. Recall: Glucose \( \rightarrow \) Pyruvic acid \( \rightarrow \) Lactic acid

  – **Sulfuric acid** – formed when amino acids containing sulfur are broken down

  – **Phosphoric acid** – formed when proteins containing phosphorus are broken down

  – **Ketone bodies** – resulting from the metabolism of fats
Chemical Buffer Systems

- A chemical buffer is a system of one or two molecules that acts to resist changes in pH by binding H+ when the pH drops, or releasing H+ when the pH rises
- This system **reacts very quickly to changes in pH**
- The **bicarbonate buffer system** is the **main buffer** of the extracellular fluid, & consists of carbonic acid & its salt, sodium bicarbonate
  - When a strong acid is added to the solution, carbonic acid is mostly unchanged, but bicarbonate ions of the salt bind excess H+, forming more carbonic acid

\[
\text{HCl} + \text{NaHCO}_3 \rightarrow \text{H}_2\text{CO}_3 + \text{NaCl}
\]
  - When a strong base is added to solution, the sodium bicarbonate remains relatively unaffected, but carbonic acid dissociates further, donating more H+ to bind the excess hydroxide

\[
\text{NaOH} + \text{H}_2\text{CO}_3 \rightarrow \text{NaHCO}_3 + \text{H}_2\text{O}
\]
- **The phosphate buffer system** operates in the urine & intracellular fluid similar to the bicarbonate buffer system
- **The protein buffer system** consists of organic acids containing carboxyl groups that dissociate to release H+ when the pH begins to rise, or bind excess H+ when the pH declines
Respiratory Regulation of H+

- Respiratory regulation of pH is a physiological buffer, which acts more slowly than a chemical buffer system, but has much greater buffering power.
- CO$_2$ from cellular metabolism enters erythrocytes & is converted to bicarbonate ions for transport in the plasma.

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}^+ 
\]

- When hypercapnia (excess CO$_2$) occurs, blood pH drops, activating medullary respiratory centers, resulting in increased rate & depth of breathing & increased unloading of CO$_2$ in the lungs.
- **So, the above reaction is pulled to the left & the free H+ are pulled out of solution.
- When blood pH rises, the respiratory center is depressed, allowing CO$_2$ to accumulate in the blood, lowering pH.
- **The above reaction proceeds to the right.
Renal Mechanisms of Acid-Base Balance

• Only the kidneys can rid the body of acids generated by cellular metabolism, while also regulating blood levels of alkaline substances & renewing chemical buffer components.

• This system has longer-lasting effects than the chemical buffers or the respiratory mechanism, but it takes longer to have an initial effect on pH.

• It may take the kidneys 1 or 2 days to start affecting the pH levels in your blood following the onset of acidosis or alkalosis.

• The most important renal mechanisms for regulating acid-base balance of the blood involve:
  – Conserving (reabsorbing) or generating new HCO3-
  – Excreting (secrating) H+

• These 2 mechanisms are related, because in order to reabsorb bicarbonate, H+ has to be secreted & when excess bicarbonate is excreted, more H+ is retained.
Abnormalities of Acid–Base Balance

- Acidosis
- Alkalosis
Metabolic Acid-Base Imbalances

- Metabolic disturbances primarily involve a deficiency or excess of sodium bicarbonate.
- The cause is always some abnormality that does NOT involve the respiratory system.
- **Metabolic acidosis**
- **Metabolic alkalosis**
Metabolic Acidosis

- **Bicarbonate Deficit**
- if there are not enough bicarbonate ions in the body fluids, or too many H+, acidosis can result
- **Causes:**
- Elimination of large amounts of bicarbonate such as through diarrhea or vomiting of lower intestinal contents (Alkaline Fluids)
- Ingestion of large amounts of acidic drugs such as aspirin, which would severely deplete bicarbonate ions & result in decreased blood pH
- Production of large amounts of fatty acids & breakdown products such as ketone bodies, which result when the body switches from glucose to fat-use **Ketoacidosis**
- Inadequate oxygen delivery to tissue, resulting in anaerobic respiration & lactic acid build-up can result from exercise, heart failure or shock **Lactic acidosis**
Metabolic Alkalosis

- **Bicarbonate Excess**
  - if there are too many bicarbonate ions, too many H+ get taken out of solution, or if too many H+ get eliminated from the body, the pH could increase too much
- **Causes:**
  - Elimination of H+, either through prolonged or severe vomiting or formation of acidic urine in response to over-secretion of Aldosterone
  - Prolonged use of Diuretics
  - Ingestion of large amounts of alkaline substances (Antacids)
Respiratory Acid-Base Imbalances

- Respiratory disturbances in the body primarily involve a deficiency or excess of carbonic acid.
- The cause is always an abnormality of the respiratory system as mentioned in the Respiratory Unit.
- There are 2 types of Acid-Base Imbalances due to the Respiratory System.

- Respiratory acidosis
- Respiratory alkalosis
Respiratory Alkalosis

- **Carbonic Acid Deficit**
- this usually results from hyperventilation of the lungs, leading to excessive loss of \( \text{CO}_2 \)

**Causes:**
- Hyperventilation triggered by strong emotions (Anxiety)
- Decreased atmospheric pressure & a reduced amount of \( \text{O}_2 \) entering the bloodstream from the lung alveoli would stimulate an increase in respiratory rate
Respiratory Acidosis

• **Carbonic Acid Excess**

  this usually results from inadequate ventilation of the lungs (hypoventilation), which means you are not getting rid of CO₂ quickly enough (Excess CO₂)

**Causes:**

  – Pulmonary Pathologies, Congestive Heart Failure & Drugs (Barbiturates)
  – Hypoventilation due to trauma, shock
Maintenance of Blood Pressure Homeostasis

- Declining systemic blood pressure/volume
  - Reduces stretch in afferent arterioles
  - Reduces filtrate volume or osmolality in distal tubules
    - JG cells of kidneys
      - Release Renin
        - Catalyzes conversion to Angiotensin I
          - Converting enzymes (in lungs)
            - Angiotensin II
              - Systemic arterioles
                - Causes vasoconstriction
                  - Results in ↑Peripheral resistance
              - Causes ↓Peripheral resistance
                - Potentiate ADH release
                  - Posterior pituitary releases ADH (antidiuretic hormone)
                    - Collecting ducts of kidneys
                      - Causes ↑H₂O reabsorption

Key:
(+)=stimulates
- Renin-angiotensin system
- Neural regulation (sympathetic nervous system effects)
- Effects of ADH release

Figure 26.9
Reabsorption of Bicarbonate

- Carbonic acid formed in filtrate dissociates to release CO$_2$ & water
- CO$_2$ then diffuses into tubule cells, where it acts to trigger further H$^+$ secretion
Hydrogen Ion Excretion

- In response to acidosis:
  - Kidneys generate bicarbonate ions & add them to the blood
  - An equal amount of hydrogen ions are added to the urine
Ammonium Ion Excretion

Key:
- Red arrow = Primary active transport
- Blue arrow = Passive transport (simple diffusion)
- Pink circle = Protein carrier
- Red and blue double arrow = Secondary active transport

Figure 26.14
Fluid Objectives

• Describe and compare the composition of plasma, interstitial fluid and intracellular fluid
• Describe the normal values of various electrolytes
• Describe typical intake and output of water
• Discuss the homeostasis of fluids and electrolytes with special reference to the action of ADH and aldosterone
• Discuss the factors determining the movement of fluid between various fluid compartments
• Describe edema and how it is produced in heart failure, renal failure and in malnutrition (hypoprotenemia)
• Define dehydration, shock and physiology of anaphylactic shock
Fluid Objectives

• Describe various causes of the metabolic acidosis and alkalosis and describe the mechanisms of their correction in body
• Describe disturbances of serum potassium, how they are related to the renal physiology and result in cardiac arrhythmia
• Define pH and its deviations in relation to acids and bases
• Define buffers and describe how they act in controlling the pH
• Define the Henderson-Hasselbalch equation
• Describe how respiratory acidosis and alkalosis are produced and describe the mechanism of their correction by the body
• Discuss the urinary control of pH by tubular excretion of H+ ion and ammonia