Respiratory System

- Cells of your body are bathed in tissue fluid.
- They acquire oxygen and nutrients and get rid of carbon dioxide and wastes through exchanges with tissue fluid.
- In turn, tissue fluid exchanges with blood.
- Blood is refreshed because respiratory, urinary, and digestive systems make exchanges with the external environment.
Steps in Human Respiration

When blood enters the lungs, it gives up carbon dioxide and picks up oxygen.

Steps in respiration in terrestrial vertebrates

- Breathing—inspiration and expiration
- External exchange of gases between air and blood in lungs
- Internal exchange of gases between blood and tissue fluid

Oxygen required for cellular respiration to generate ATP

- Carbon dioxide is a waste product of this process.
Keeping the Internal Environment Steady
The Human Respiratory Tract

- nostril
- nasal cavity
- pharynx
- epiglottis
- glottis
- larynx
- trachea
- bronchus
- bronchiole
- alveoli
- lung
- diaphragm
The Process of Breathing

Breathing

• Inspiration—air moves in
  • Due to negative pressure
  • Caused by muscle contractions that lower diaphragm and raise ribs
  • Expands thoracic cavity
  • Lungs follow wall of cavity sucking air in
Inspiration Versus Expiration

a. Inspiration

Rib cage moves up and out.

Diaphragm contracts and moves down.

Pressure in lungs decreases, and air comes rushing in.
Path of Air Out of Lungs

Breathing, continued

• Expiration—air moves out
  • Due to increased pressure
  • Muscles of diaphragm and ribs relax
  • Thoracic cavity becomes smaller
  • Lungs become smaller, forcing air out
Neural Control of Breathing Rate

Should level of $\text{H}^+$ rise, breathing center in brain increases breathing rate
External Exchange of Gases

Lungs and external exchange of gases

- Alveolus (singular)
  - Alveoli increase the surface area for gas exchange in humans.
  - Surrounded by capillary bed
  - Diffusion alone accounts for gas exchange
    - Oxygen out of alveolus into blood
    - Carbon dioxide out of blood into alveolus
  - Diffusion requires large, thin, moist surface
    - Respiratory membrane—alveolar epithelium and capillary epithelium
Gas Exchange in the Lungs, 1

Blood supply of alveoli
Gas Exchange in the Lungs, 2

Capillary network of one alveolus
Internal Gas Exchange

Transport and internal exchange of gases

- Hemoglobin
  - Carries oxygen inside red blood cells
  - Each molecule made of four polypeptide chains
  - Each chain folded around an iron-containing heme group
    - Iron bonds with oxygen
  - 250 million hemoglobin molecules in each red blood cell
  - Hemoglobin gives up oxygen when:
    - Tissue fluid has a lower oxygen concentration—cells use oxygen in cellular respiration
    - Warmer temperature—cells give off heat
    - Lower pH—carbon dioxide waste product lowers pH
Hemoglobin

[Diagram showing the structure of hemoglobin with labels for heme group, polypeptides, iron (Fe^{++}), and oxygen (O_{2}).]
pH and Carbonic Acid

Carbon dioxide enters blood during internal exchange because tissue fluid has a higher concentration of carbon dioxide than blood.

Most carbon dioxide is transported as bicarbonate ion (HCO$_3^-$).

H$^+$ causes pH to lower but much of H$^+$ is absorbed by globin portion of hemoglobin.

• HCO$_3^-$ carried in plasma

As blood enters lungs, equation is reversed and carbon dioxide diffuses out of blood and into alveoli.
Urinary System and Excretion

Three kidney functions:

• Excretion of nitrogenous wastes, such as urea and uric acid
• Maintenance of the water-salt balance of the blood
• Maintenance of the acid-base balance of the blood
Keeping the Internal Environment Steady
The Human Urinary System
Overview of the Human Kidney

Human kidney

• Three major parts
  • Renal cortex—outer layer
  • Renal medulla—contains cone-shaped renal pyramids
  • Renal pelvis—innermost hollow region where urine collects before draining into ureter

• Microscopically, each kidney is composed of one million tiny nephrons that actually produce the urine.
Structure of the Kidney, 2

a. Kidney

- pyramid
- renal artery
- renal vein
- renal pelvis
- ureter

b. Two nephrons

- renal cortex
- renal medulla
- glomeruli capsule
- proximal convoluted tubule
- distal convoluted tubule
- peritubular capillary
- loop of the nephron
- collecting duct
Overview of Urine Formation

Urine formation

- Filtration
  - Blood pressure forces small molecules from blood capillary into capsule—creates filtrate
  - Water, nutrients, salts, and urea
  - Next steps prevent loss of nutrients and water

- Reabsorption of solutes
  - Substances move back into blood, out of filtrate
  - Selective process
  - Numerous mitochondria for active transport
  - Water follows as salt is reabsorbed

- Secretion
  - Moving substances into filtrate
  - Uric acid, hydrogen ions, ammonia, and penicillin
  - Helps get rid of harmful substances not filtered
Urine Formation

- **Filtration**: Water and solutes enter capsule.
- **Reabsorption**: Water and nutrients return to blood.
- **Secretion**: Certain substances are added to tubule.

- Water moves into the medulla and then the blood.
- Reabsorption of more water
- nephron loop
- collecting duct
- urine

**Proximal convoluted tubule**
**Glomerular capsule**
**Distal convoluted tubule**
**Peritubular capillary**
Nephrons and Water-Salt Balance

Regulation of water-salt balance and pH

- Typically, humans have some means of regulating the osmolarity of the internal environment so that water-salt balance stays within normal limits.

Long nephrons can create a hypertonic urine.

- Ascending limb pumps out salt and urea into renal medulla
- Water follows by osmosis out of collecting duct
- Three hormones regulate water-salt reabsorption in kidneys
  - ADH (inc. H₂O reabsorption)
  - Aldosterone (inc. Na⁺ reabsorption)
  - Natriuretic peptides (inc. Na⁺ secretion)
Figure 26.10
Regulation of Blood pH

Most humans can also regulate pH of blood

- Bicarbonate ($\text{HCO}_3^-$) buffer system and regulation of breathing rate rid the body of $\text{CO}_2$
- Only the kidneys can secrete a wide variety of acidic and basic substances.
- Kidneys are slower acting but more powerful than buffer/breathing mechanism.
- To simplify, kidneys reabsorb bicarbonate ions and excrete hydrogen ions as needed.
  - If the blood is acidic, hydrogen ions are excreted and bicarbonate ions are reabsorbed.
  - If the blood is basic, hydrogen ions are not excreted and bicarbonate ions are not reabsorbed.
Acid-Base Balance

- pH affects all functional proteins and biochemical reactions in the body
  - Regulation prevents changes in body’s internal environment
- Alkalosis or alkalemia: arterial blood pH > 7.45
- Acidosis or acidemia: arterial pH < 7.35
Acid-Base Balance

- Concentration of hydrogen ions is regulated by
  1. Chemical buffer systems
     - Rapid, first line of defense
  2. Brainstem respiratory centers
     - Acts within 1–3 minutes
  3. Renal mechanisms
     - Most potent
     - Requires hours to days to affect pH changes
Acid-Base Balance

- Lungs
  - Regulate carbonic acid levels by $\text{CO}_2$ manipulation

- Kidneys
  - Selectively secrete and reabsorb to maintain pH
Respiratory Regulation of pH

1. Carbon dioxide reacts with $H_2O$ to form $H_2CO_3$. An enzyme, carbonic anhydrase, found in red blood cells and on the surface of blood vessel epithelium, catalyzed the reaction. Carbonic acid dissociates to form $H^+$ and $HCO_3^-$. An equilibrium is quickly established.

2. Decreased pH in the extracellular fluid stimulates the respiratory center and causes an increased rate and depth of breathing.

3. Increased rate and depth of breathing causes $CO_2$ to be expelled from the lungs, thus reducing the extracellular $CO_2$ levels. As $CO_2$ levels decrease, the extracellular concentration of $H^+$ decreases, and the extracellular fluid pH increases.
Acid-Base Balance

- Most important renal mechanisms:
  - Conserving (reabsorbing) $\text{HCO}_3^-$
  - Excreting $\text{HCO}_3^-$
  - Secretion of $\text{H}^+$
    - $\text{H}^+$ secretion occurs in the PCT and in collecting tubules
Renal Regulation of Acid-Base Balance

1. When the filtrate or blood pH decreases, H\(^+\) combine with HCO\(_3\)\(^-\) to form carbonic acid that is converted into CO\(_2\) and H\(_2\)O. The CO\(_2\) diffuses into tubule cells.

2. In the tubule cells, CO\(_2\) combines with H\(_2\)O to form H\(_2\)CO\(_3\) that dissociates to form H\(^+\) and HCO\(_3\)\(^-\).

3. An antiport mechanism secretes H\(^+\) into the filtrate in exchange for Na\(^+\) from the filtrate. As a result, filtrate pH decreases.

4. Bicarbonate ions are symported with Na\(^+\) into the interstitial fluid. They then diffuse into capillaries.

5. In capillaries, HCO\(_3\)\(^-\) combine with H\(^+\). This decreases the H\(^+\) concentration and increases blood pH.
Acid-Base Balance

- **Examples**
  - **Respiratory Acidosis**
    - Kidneys
  - **Respiratory Alkalosis**
    - Kidneys
More on Compensation...

- **Uncompensated**
  - pH *abnormal* and either CO$_2$ or HCO$_3^-$ is off
  - The other system has not started to compensate at all

- **Partially compensated**
  - pH is *abnormal* and both CO$_2$ and HCO$_3^-$ are off
  - The other system is trying to compensate

- **Fully compensated**
  - pH is *normal* and both CO$_2$ and HCO$_3^-$ are off
  - The other system has corrected the pH but there is still an acid base imbalance since CO$_2$ and HCO$_3^-$ are abnormal
IN SUMMARY: TRANSPORT OF CARBON DIOXIDE IN THE BLOOD

Carbon dioxide can be transported through the blood via three methods. It is dissolved directly in the blood, bound to plasma proteins or hemoglobin, or converted into bicarbonate.

The majority of carbon dioxide is transported as part of the bicarbonate system. Carbon dioxide diffuses into red blood cells. Inside, carbonic anhydrase converts carbon dioxide into carbonic acid (H$_2$CO$_3$), which is subsequently hydrolyzed into bicarbonate (HCO$_3^-$) and H$^+$. The H$^+$ ion binds to hemoglobin in red blood cells, and bicarbonate is transported out of the red blood cells in exchange for a chloride ion. This is called the chloride shift.

Bicarbonate leaves the red blood cells and enters the blood plasma. In the lungs, bicarbonate is transported back into the red blood cells in exchange for chloride. The H$^+$ dissociates from hemoglobin and combines with bicarbonate to form carbonic acid with the help of carbonic anhydrase, which further catalyzes the reaction to convert carbonic acid back into carbon dioxide and water. The carbon dioxide is then expelled from the lungs.