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.

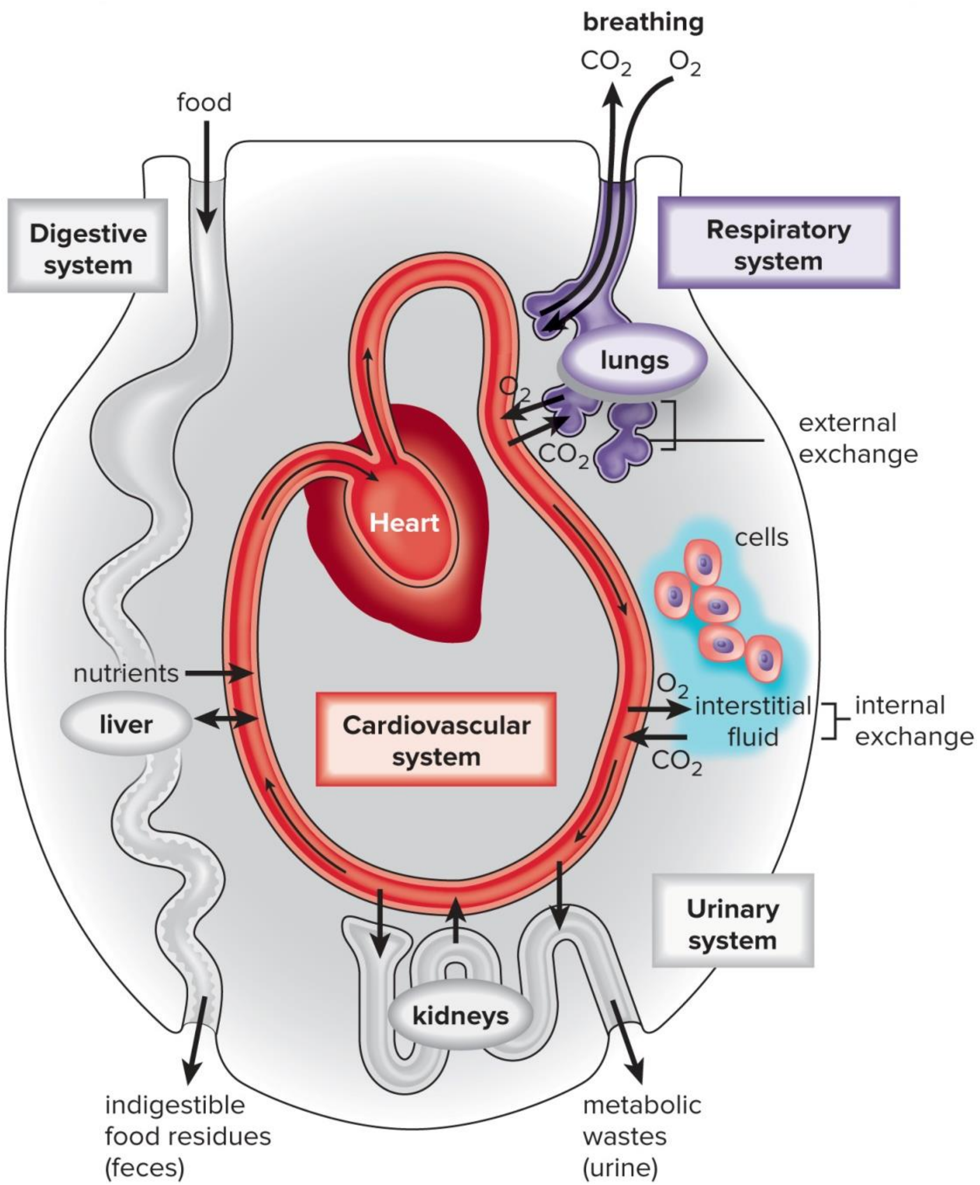
Steps in respiration in terrestrial vertebrates

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

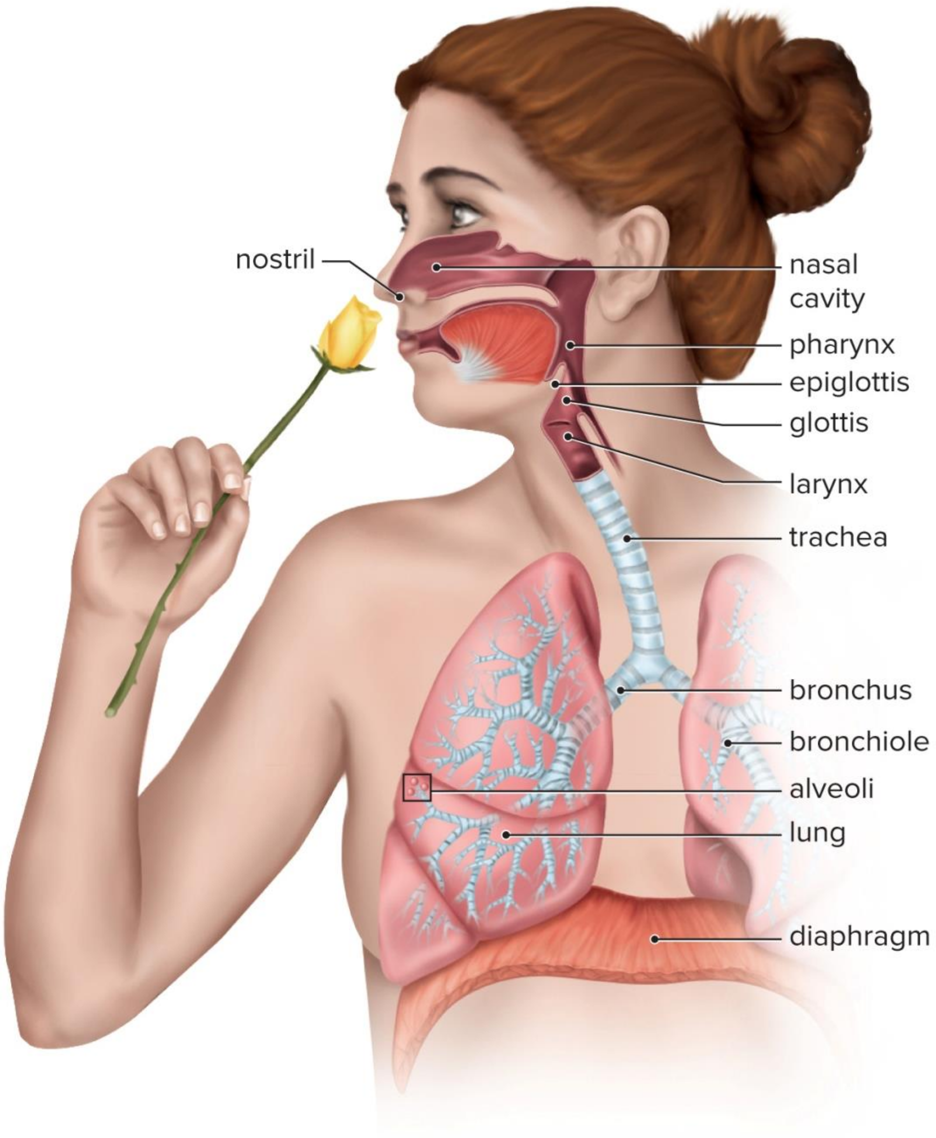
Oxygen required for cellular respiration to generate ATP

- Carbon dioxide is a waste product of this process.

Keeping the Internal Environment Steady



The Human Respiratory Tract

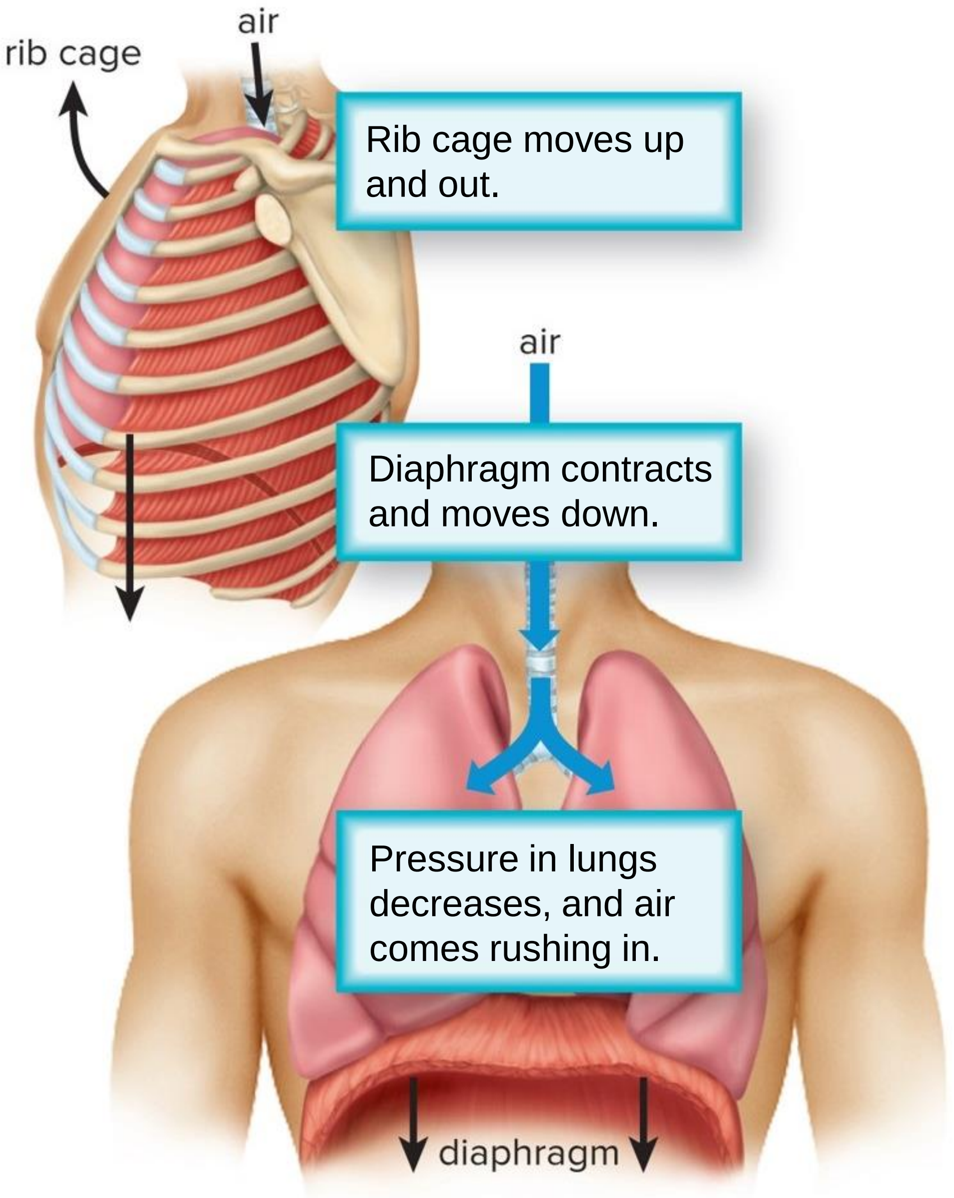


The Process of Breathing

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

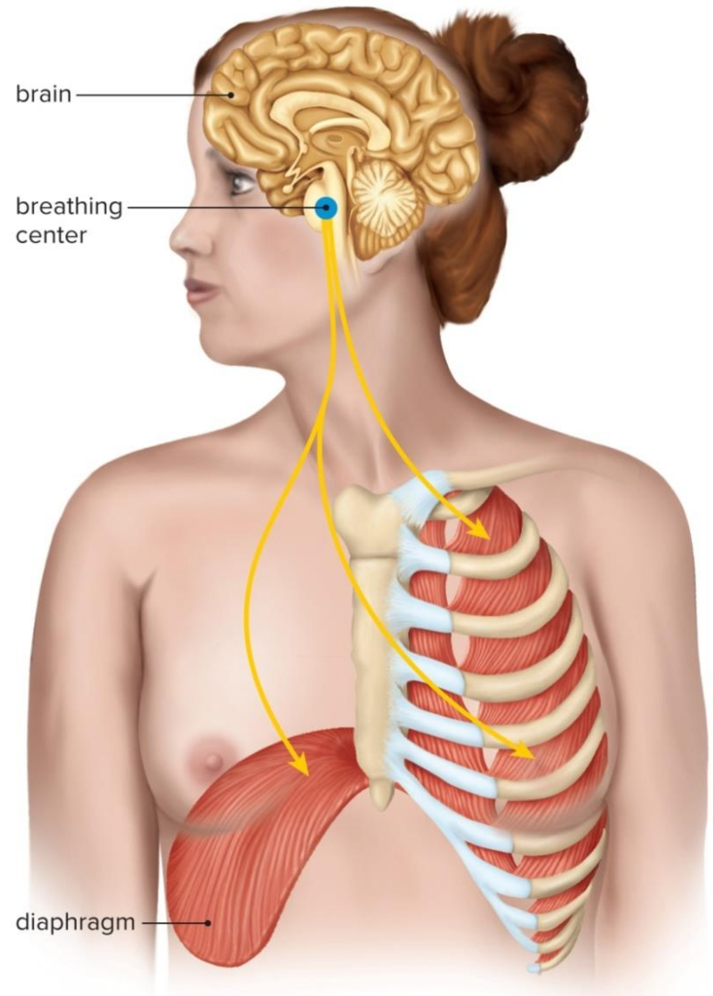
Path of Air Out of Lungs

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 H^+ rise, breathing center in brain increases breathing rate

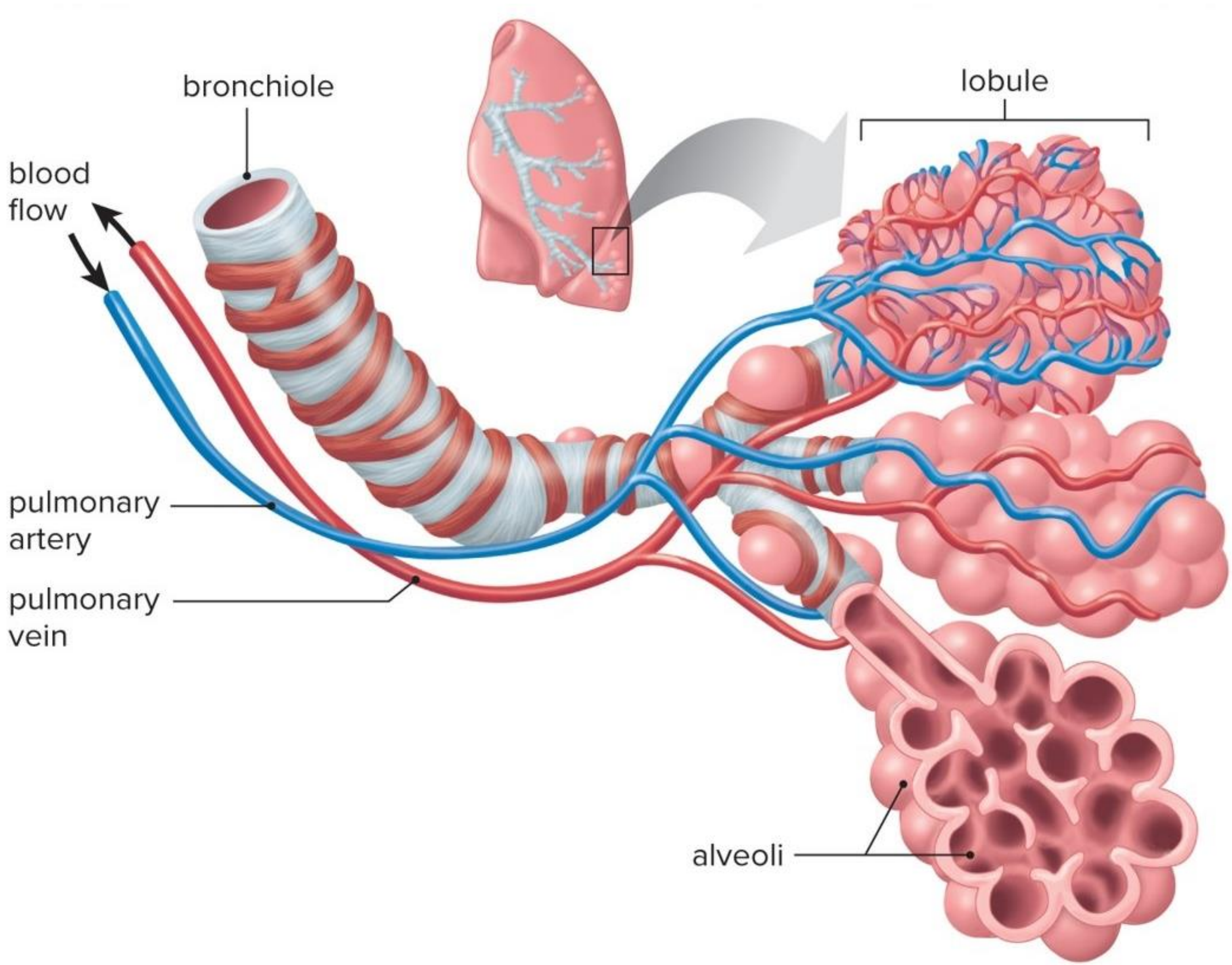


External Exchange of Gases

Lungs and external exchange of gases

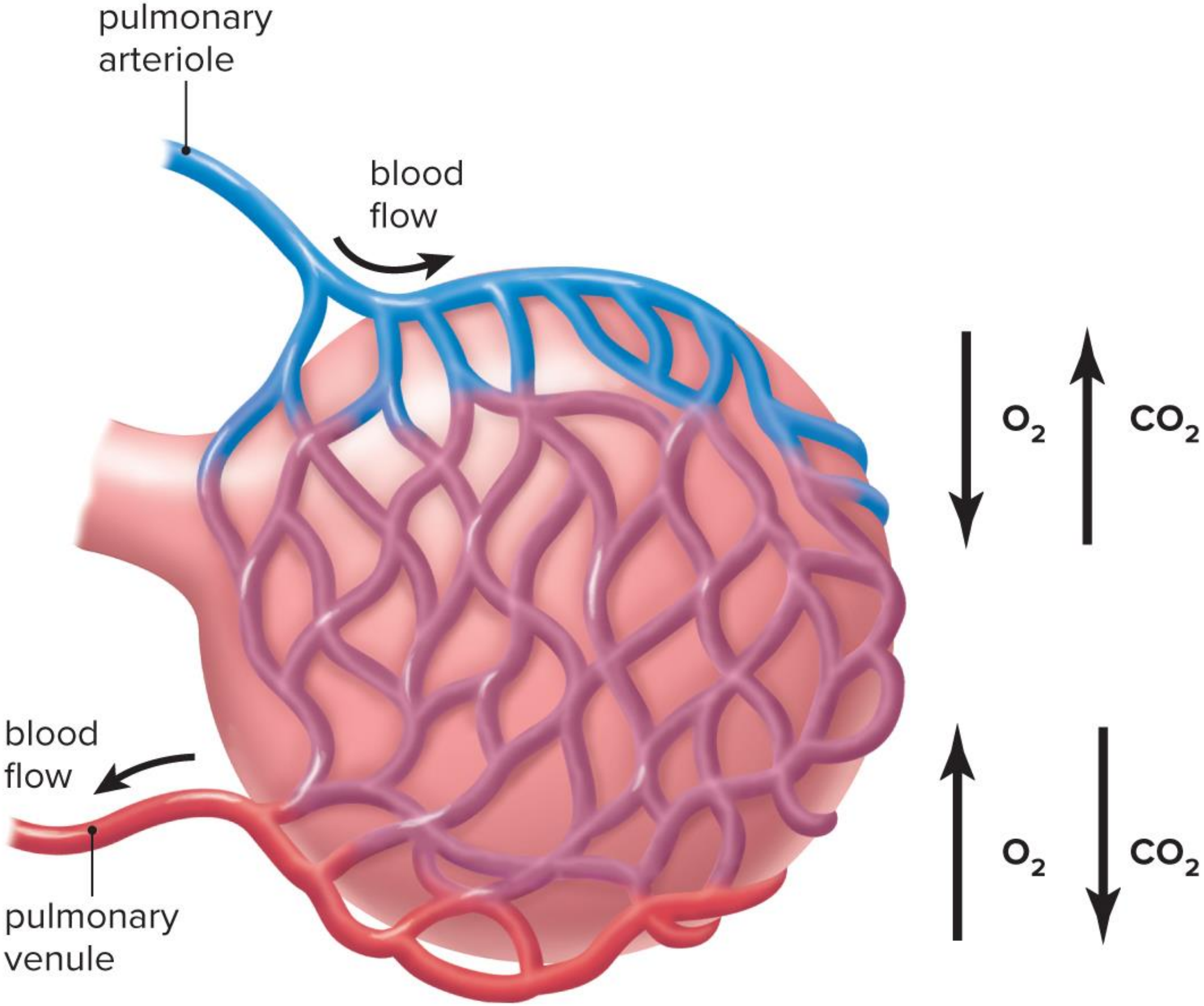
- Alveolus (singular)
  - Alveoli increase the surface area for gas exchange in humans.
  - Surrounded by capillary bed
  - Diffusion alone accounts for gas exchange
    - Oxygen out of alveolus into blood
    - Carbon dioxide out of blood into alveolus
  - Diffusion requires large, thin, moist surface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

Gas Exchange in the Lungs, 1



Blood supply of alveoli

Gas Exchange in the Lungs, 2



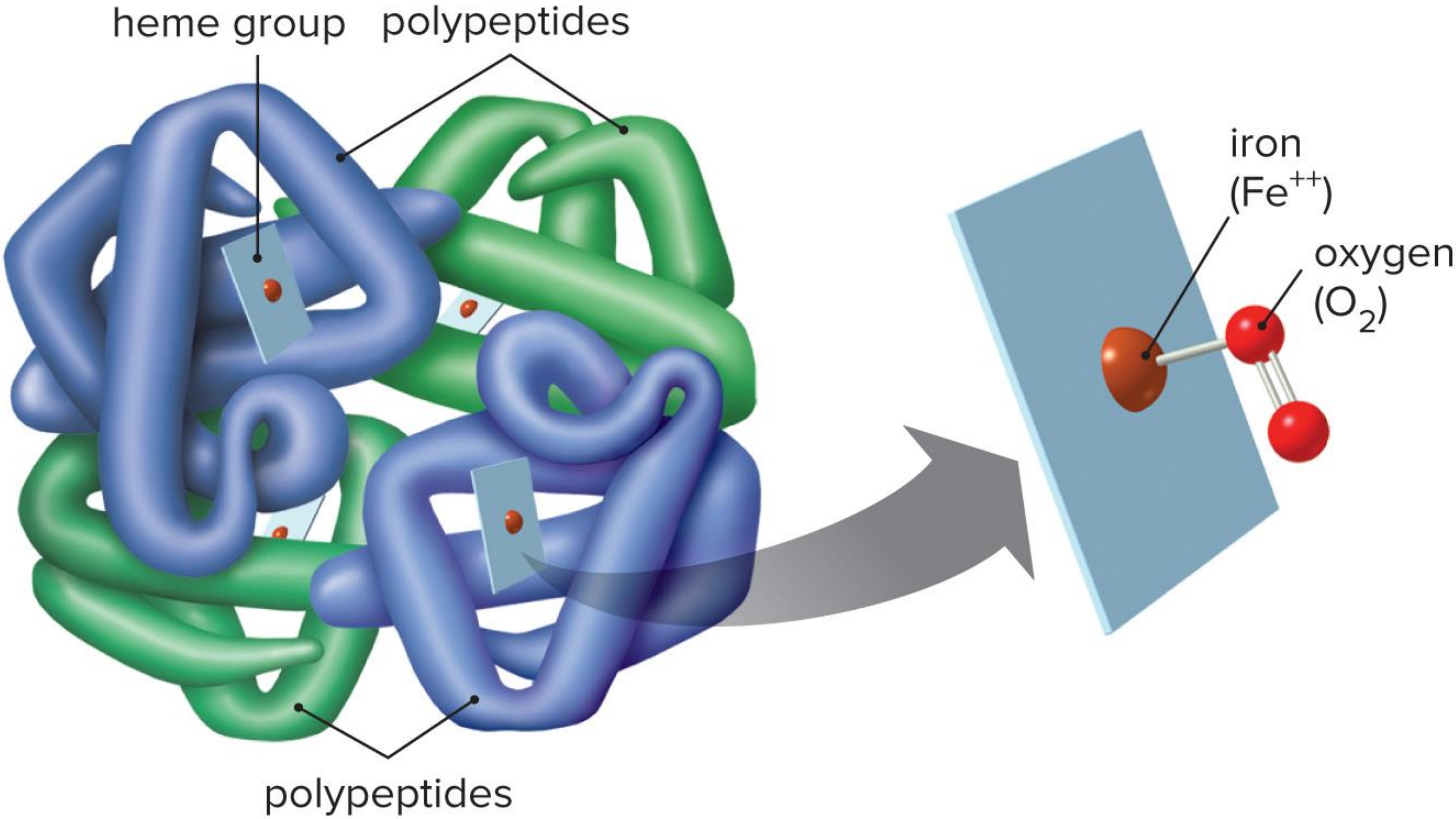
Capillary network of one alveolus

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



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^-).

CO_2	+	H_2O	$\longrightarrow$	H_2CO_3	$\longrightarrow$	H^+	+	HCO_3^-
carbon dioxide		water		carbonic acid		hydrogen ion		bicarbonate ion

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

- HCO_3^- carried in plasma

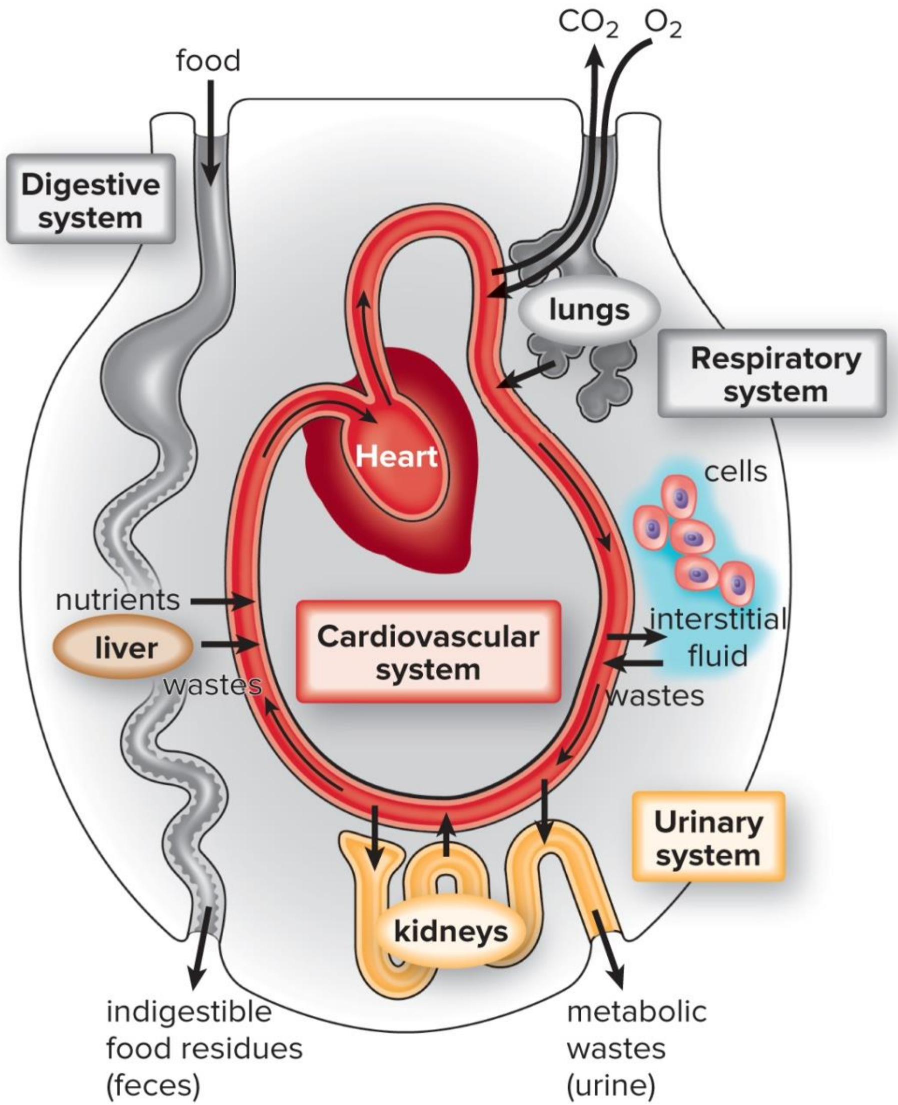
As blood enters lungs, equation is reversed and carbon dioxide diffuses out of blood and into alveoli.

Urinary System and Excretion

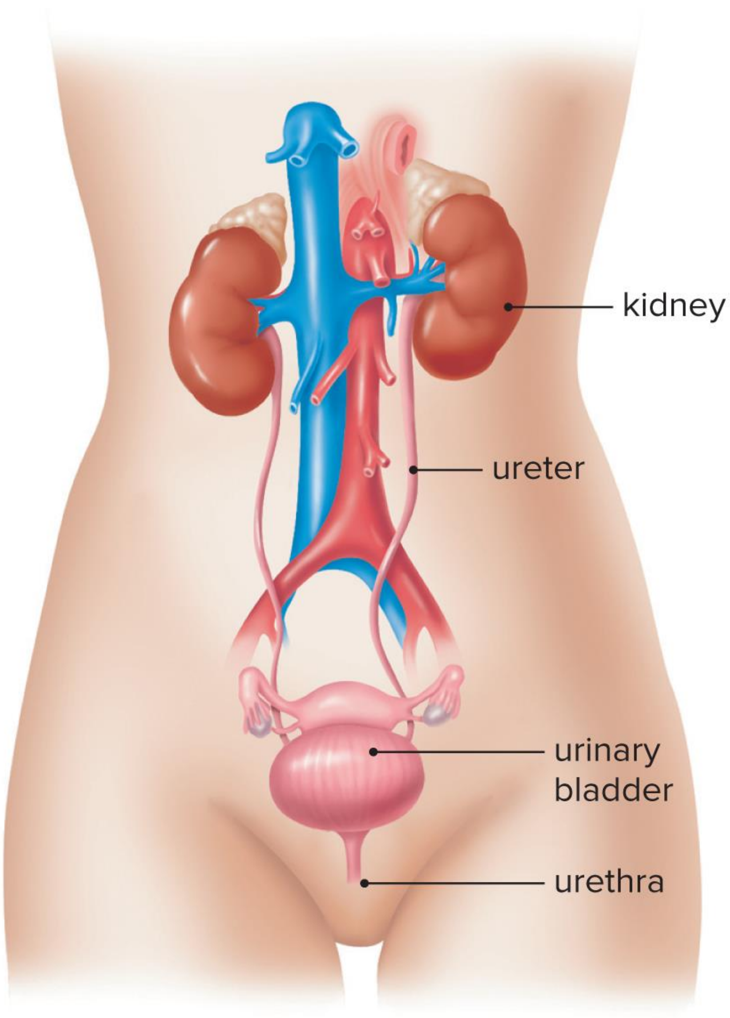
Three kidney functions:

- 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

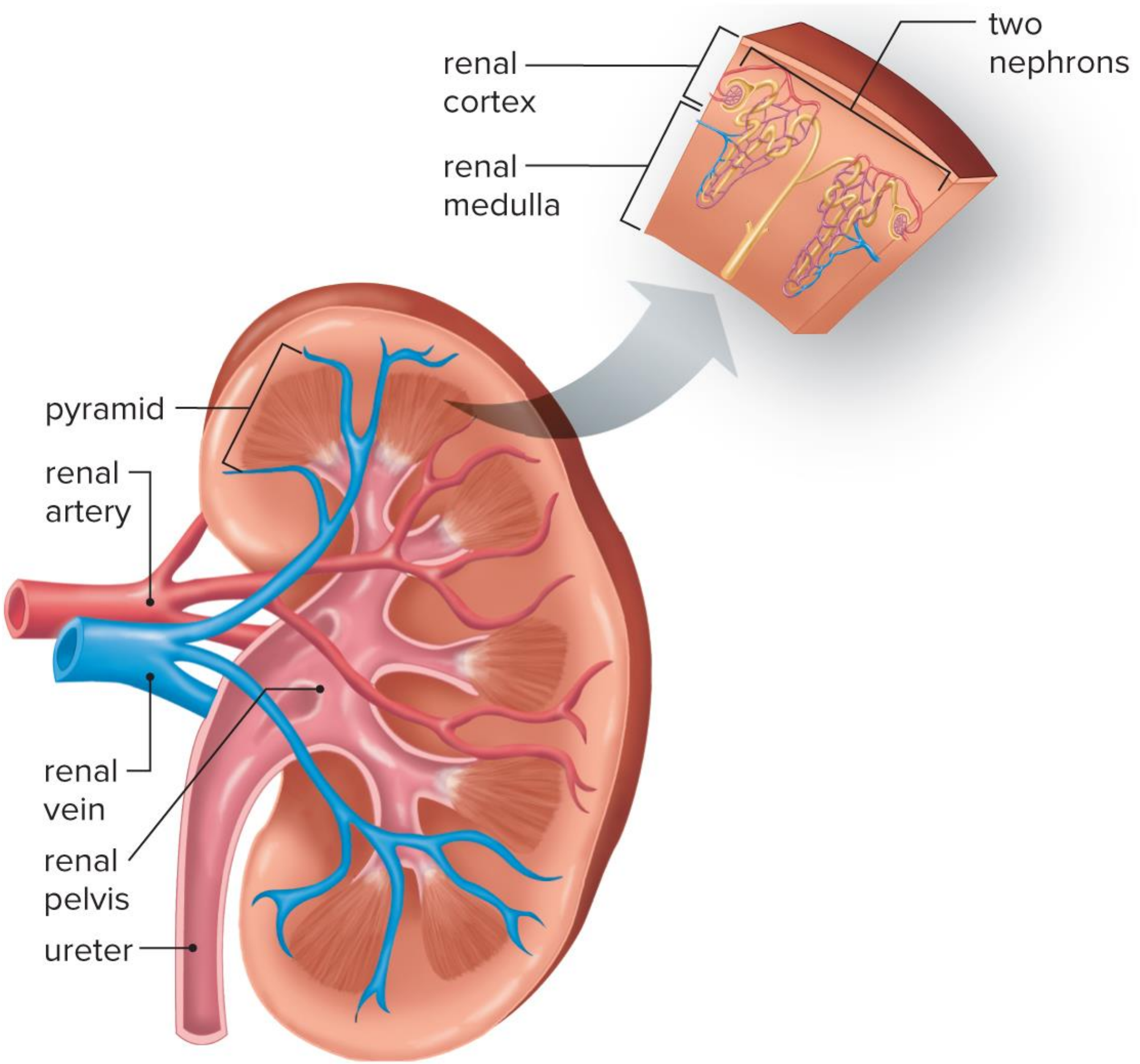


Overview of the Human Kidney

Human kidney

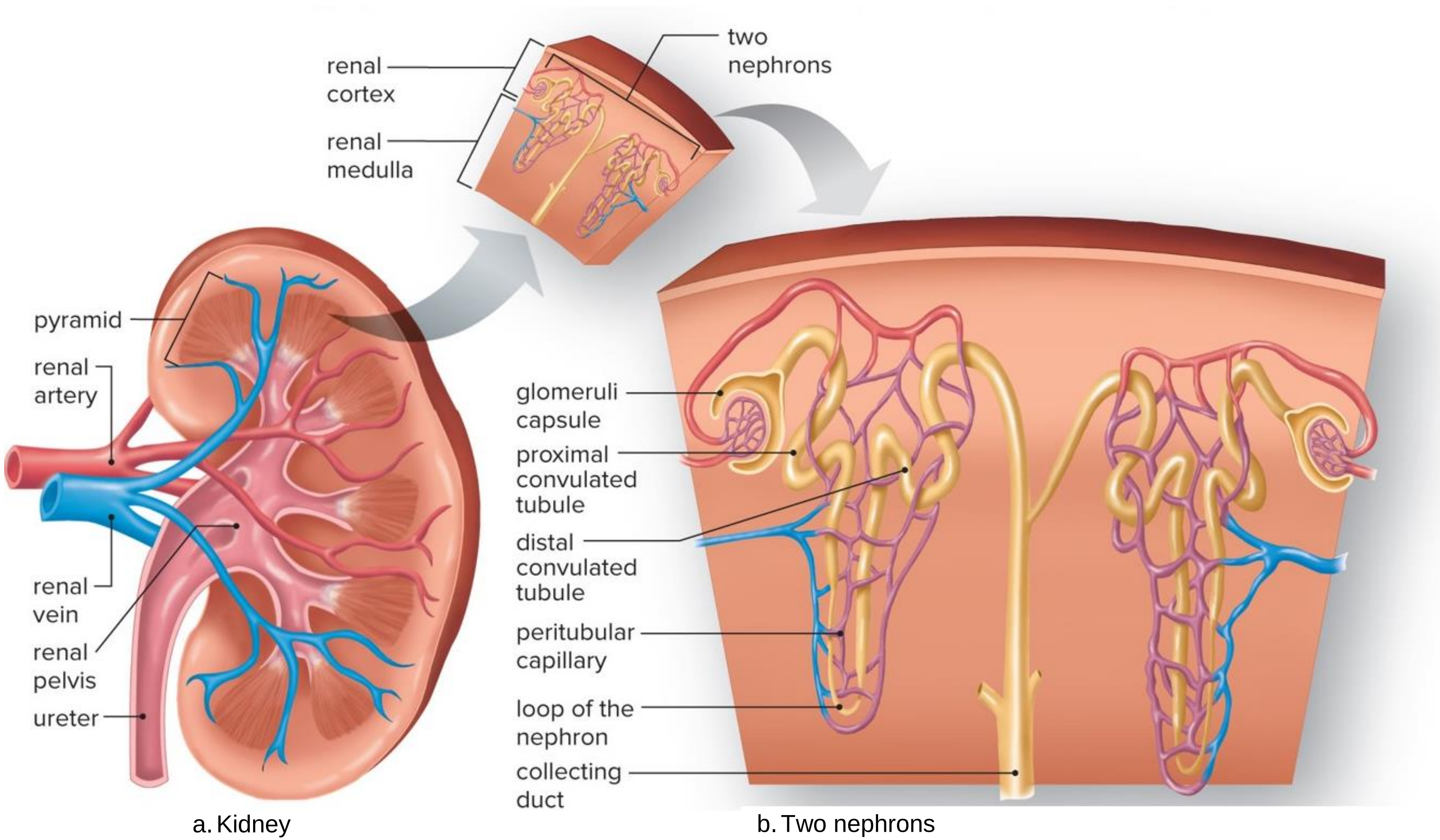
- Three major parts
  - Renal cortex—outer layer
  - Renal medulla—contains cone-shaped renal pyramids
  - Renal pelvis—innermost hollow region where urine collects before draining into ureter
- Microscopically, each kidney is composed of one million tiny nephrons that actually produce the urine.

Structure of the Kidney, 1



a. Kidney

Structure of the Kidney, 2

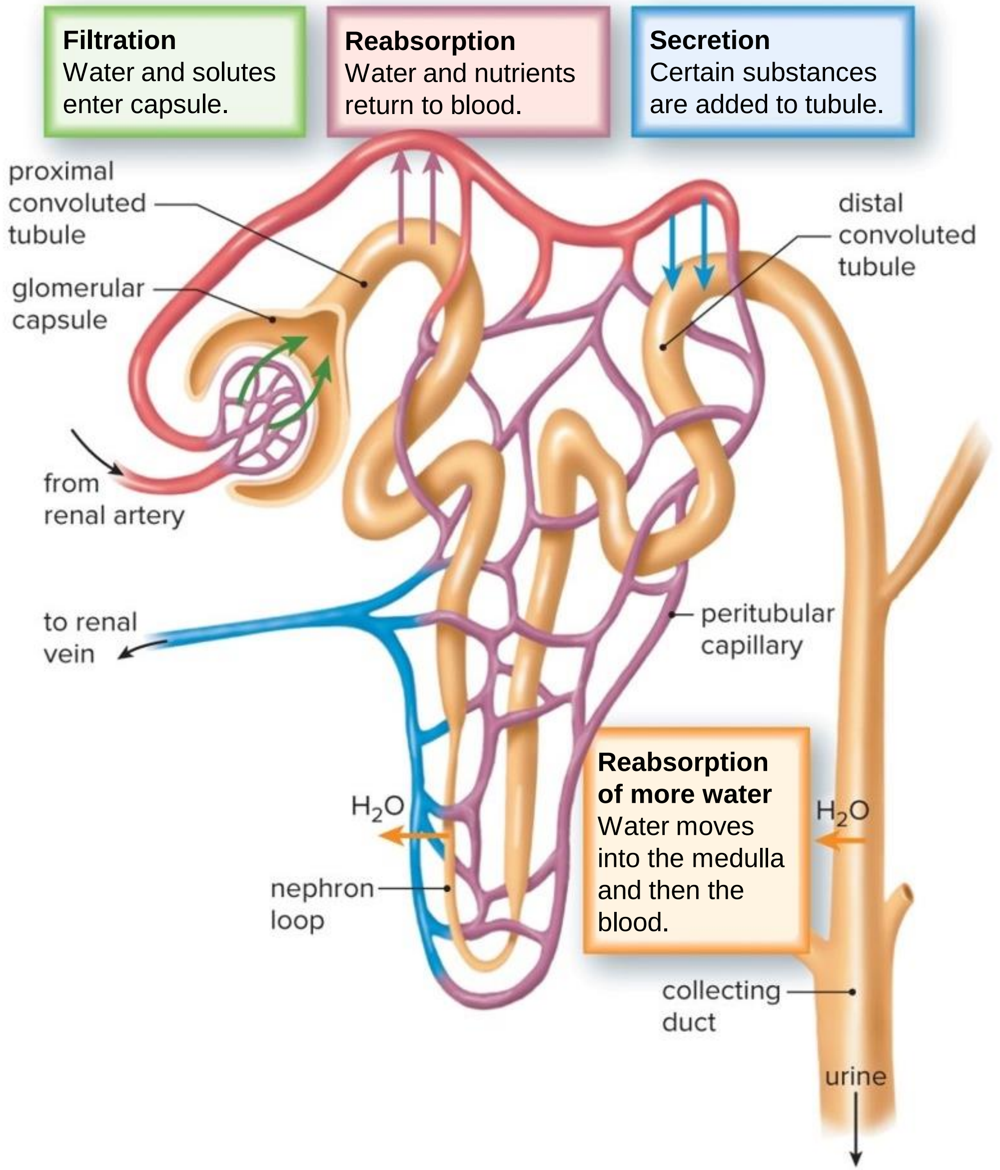


Overview of Urine Formation

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



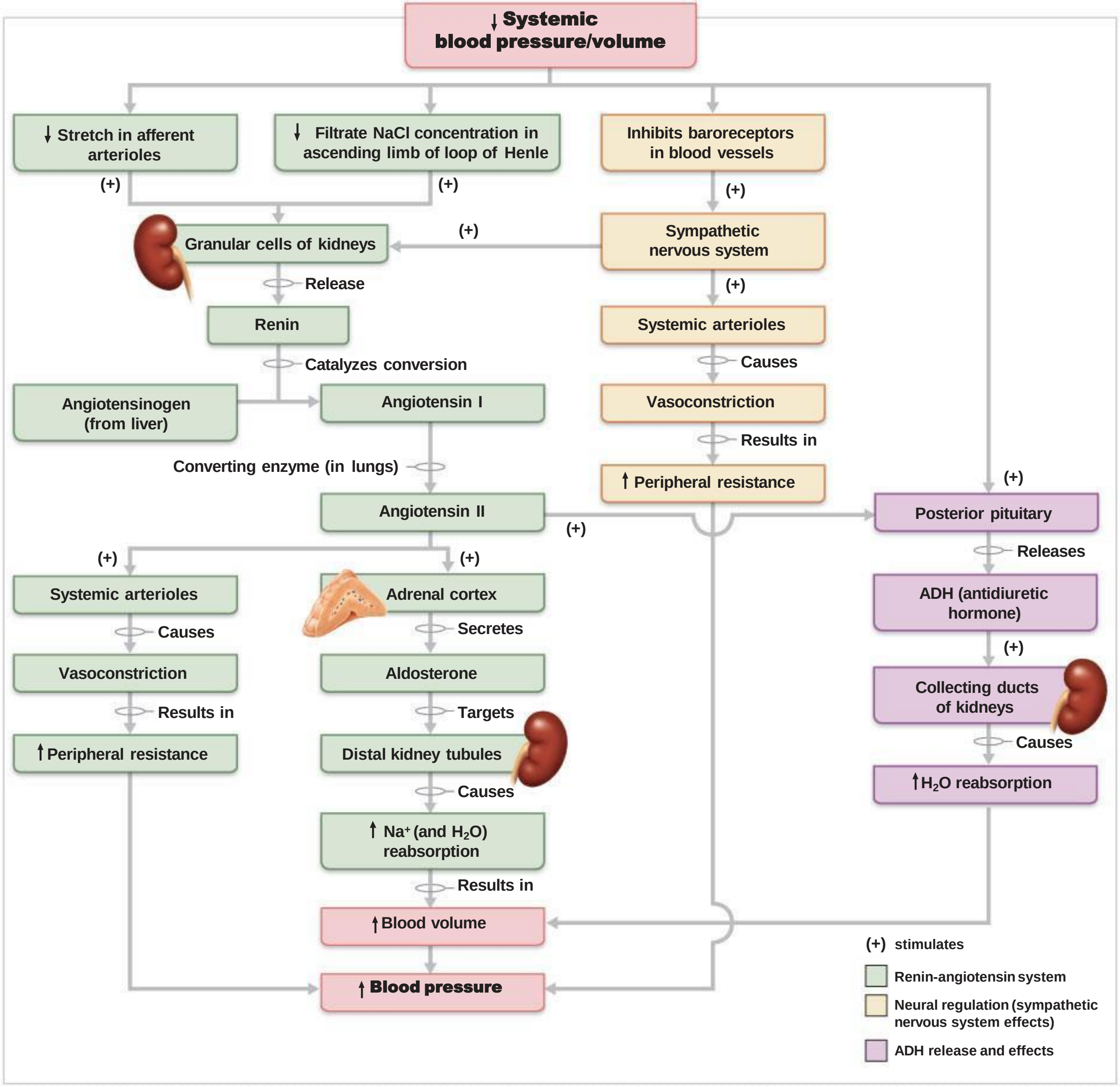
Nephrons and Water-Salt Balance

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. H_2O reabsorption)
  - Aldosterone (inc. Na^+ reabsorption)
  - Natriuretic peptides (inc. Na^+ secretion)



↓ Systemic blood pressure/volume
↓ Stretch in afferent arterioles
↓ Filtrate NaCl concentration in ascending limb of loop of Henle
Inhibits baroreceptors in blood vessels
(+)
Granular cells of kidneys
Sympathetic nervous system
Release
Renin
Systemic arterioles
Catalyzes conversion
Causes
Angiotensinogen (from liver)
Angiotensin I
Vasoconstriction
Results in
Converting enzyme (in lungs)
↑ Peripheral resistance
Angiotensin II
Posterior pituitary
Releases
Systemic arterioles
Adrenal cortex
ADH (antidiuretic hormone)
Causes
Secretes
Vasoconstriction
Aldosterone
Collecting ducts of kidneys
Results in
Targets
Causes
↑ Peripheral resistance
Distal kidney tubules
↑ H_2O reabsorption
Causes
↑ Na^+ (and H_2O) reabsorption
Results in
↑ Blood volume
↑ Blood pressure
(+) stimulates
Renin-angiotensin system
Neural regulation (sympathetic nervous system effects)
ADH release and effects

Figure 26.10

Regulation of Blood pH

Most humans can also regulate pH of blood

- Bicarbonate (HCO_3^-)buffer system and regulation of breathing rate rid the body of 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 proteinsand 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

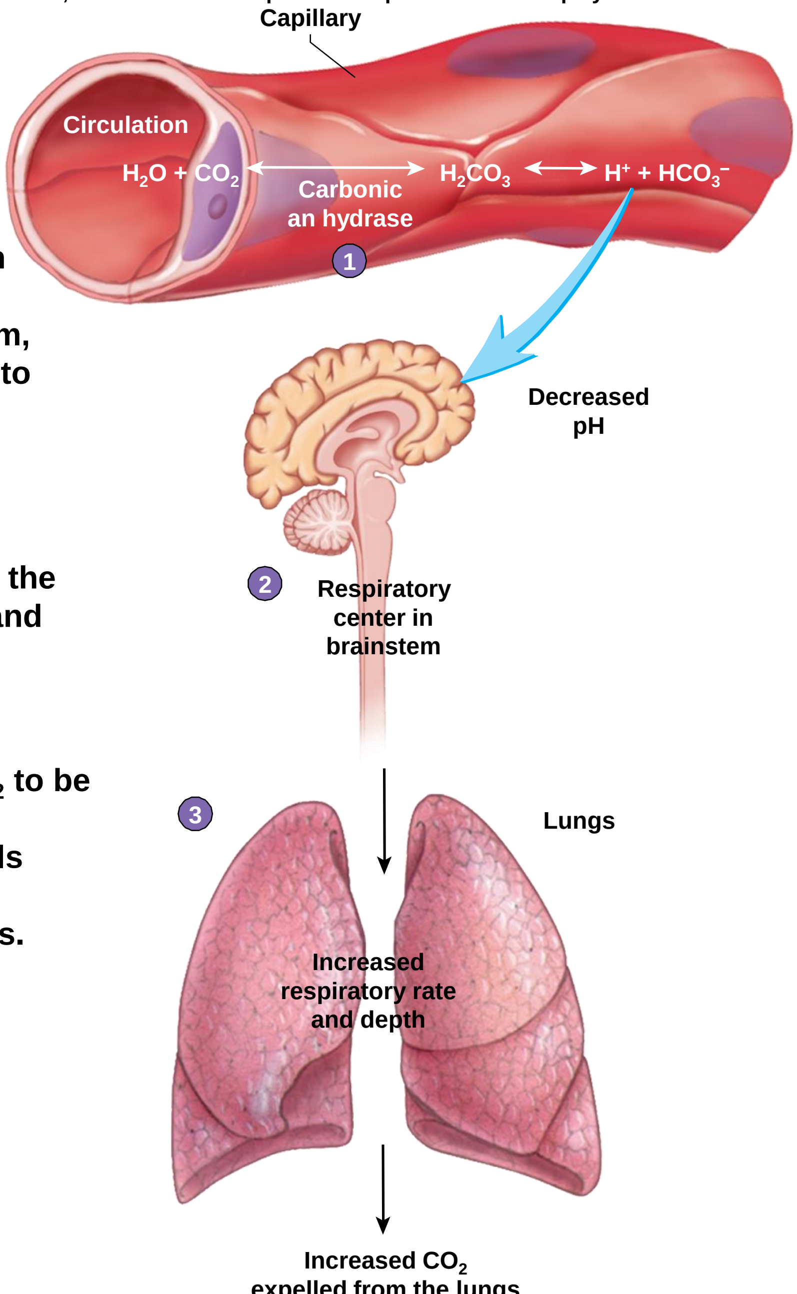
- **Lungs**
  - **Regulate carbonic acid levels by CO_2 manipulation**
- **Kidneys**
  - **Selectively secrete and reabsorb to maintain pH**

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) HCO_3^-**
  - **Excreting HCO_3^-**
  - **Secretion of H^+**
    - **H^+ secretion occurs in the PCT and in collecting tubules**

Renal Regulation of Acid-Base Balance

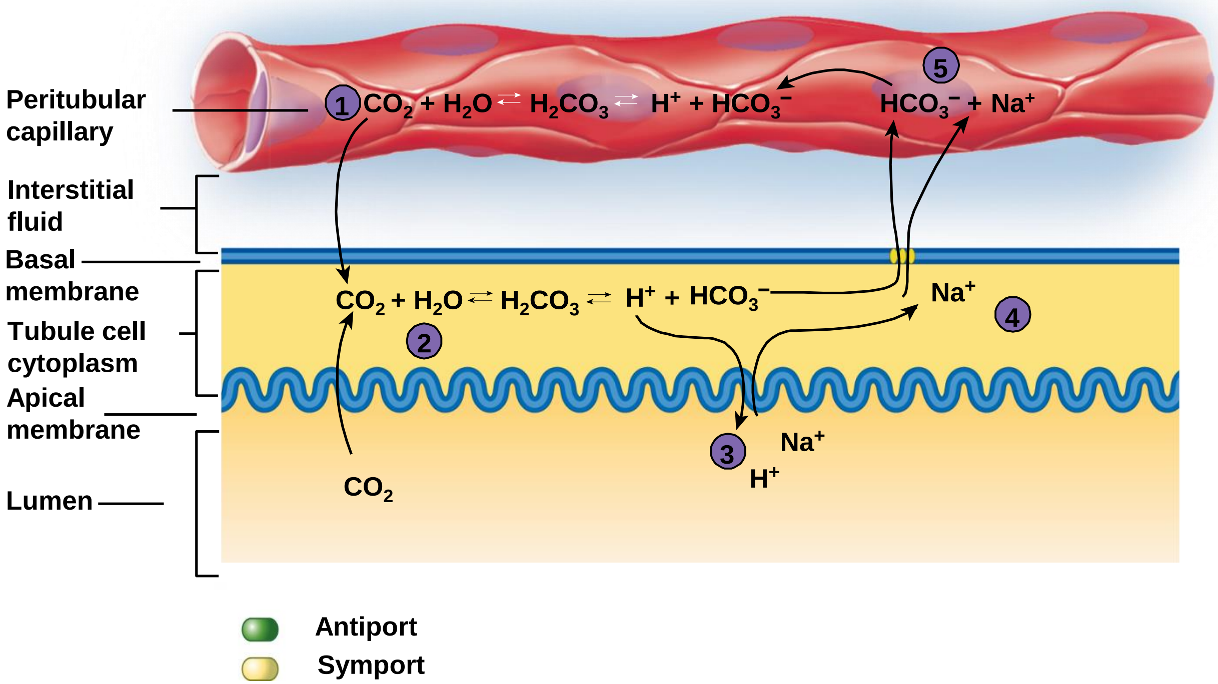
1 When the filtrate or blood pH decreases, H^+ combine with HCO_3^- to form carbonic acid that is converted into CO_2 and H_2O. The CO_2 diffuses into tubule cells.

2 In the tubule cells, CO_2 combines with H_2O to form H_2CO_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 <u>either</u> CO_2 or HCO_3^- isoff**
  - **The other system has not started to compensate at all**
- **Partially compensated**
  - **pH is *abnormal* and <u>both</u> CO_2 and HCO_3^- are off**
  - **The other system is trying to compensate**
- **Fully compensated**
  - **pH is *normal* and <u>both</u> CO_2 and HCO_3^- are off**
  - **The other system has corrected the pH but there is still and acid base imbalance since CO_2 and HCO_3^- areabnormal**

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_2CO_3), which is subsequently hydrolyzed into bicarbonate $\left(HCO_3^-\right)$ 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.