Biology 20 Chapter 12
Excretory System

Nelson pages 376 – 401
12.1 Waste Excretion and Internal Equilibrium (P378)

- Function of kidneys
  - Remove waste products
  - Balance blood pH
  - Maintain H$_2$O balance
REMVAL OF WASTE PRODUCTS

- Proteins
  - Contain an amino group – nitrogen and 2 hydrogen molecules

  - Deamination - removal of an amino group
    - Occurs in liver

  - Byproduct of deamination is $\text{NH}_3$
    - Water soluble and toxic
      - In the liver, 2 molecules of $\text{NH}_3$ combine with $\text{CO}_2$
        to form urea (waste product in urine)

- Nucleic acids
  - Breaks down into uric acid (waste product in urine)
MAINTENANCE OF WATER

- Humans cannot survive more than a few days without H$_2$O
- About 2 L of water lost / day through urination and perspiration
# Removal of Metabolic Waste

<table>
<thead>
<tr>
<th>Waste product</th>
<th>Origin</th>
<th>Organ of excretion</th>
</tr>
</thead>
<tbody>
<tr>
<td>ammonia</td>
<td>• Deamination of amino acids by liver</td>
<td>• Kidneys</td>
</tr>
<tr>
<td>urea</td>
<td>• Deamination of amino acids by liver</td>
<td>• Kidneys; skin (small amounts)</td>
</tr>
<tr>
<td></td>
<td>• Ammonia combined with carbon dioxide</td>
<td></td>
</tr>
<tr>
<td>uric acid</td>
<td>• Product of breakdown of nucleic acids, such as DNA</td>
<td>• Kidneys</td>
</tr>
<tr>
<td>carbon dioxide</td>
<td>• Waste product of cellular respiration</td>
<td>• Lungs</td>
</tr>
<tr>
<td>bile pigments</td>
<td>• Breakdown of red blood cell pigment hemoglobin</td>
<td>• Liver</td>
</tr>
<tr>
<td>lactic acid</td>
<td>• Product of anaerobic respiration</td>
<td>• Liver</td>
</tr>
</tbody>
</table>
Organs of Excretion

Skin excretes water and salts in perspiration.

Lungs excrete carbon dioxide as a gas.

Liver excretes bile pigments in bile.

Kidneys excrete nitrogenous wastes in urine.
I.) ANATOMY OF THE URINARY SYSTEM

- **Renal arteries** branch from aorta
  - Carry oxygenated blood to kidneys
- Wastes are filtered from blood by kidneys
  - Wastes are conducted from kidneys to urinary bladder by **ureters**
  - Sphincter muscle at base of **urinary bladder** acts as a valve
    - Permits storage of urine
renal artery
renal vein
aorta
inferior vena cava

kidneys (produce urine)
ureters (transport urine)
urinary bladder (stores urine)
urethra (excretes urine)
200 mL of urine collected
- Bladder stretches slightly
- Nerves send signal to brain

400 mL of urine
- More stretch receptors activated

600 mL of urine
- Voluntary control is lost
  - Sphincter relaxes
    - Urine enters urethra (tube that carries urine from bladder to exterior of body)
    - Urine is voided
URETHRA AND DIFFERENCES IN GENDER

- Female urethra
  - Lies within vulva
  - No connection to reproductive organs
  - Prone to urinary tract infections

- Male urethra
  - Found in penis
  - Common pathway for sperm and urine
    - Never at the same time
CROSS SECTION OF HUMAN KIDNEY

- 3 different structures:
  1. **Cortex** – outer layer of connective tissue
     - Encircles kidney
  2. **Medulla** – inner layer
     - Beneath cortex
  3. **Renal pelvis** – hollow chamber
     - Connects kidney with ureter
Figure 9.2 The view in (A) includes some blood vessels to reinforce the connection between the circulatory and excretory systems. The views in (B) and (C) do not include blood vessels, and identify the three regions of the kidney: renal cortex, renal medulla, and renal pelvis. The view in (C) introduces the functional unit of the kidney, the nephron, which you will examine in greater detail in Figure 9.3.
NEPHRONS

- Are functional units of kidneys
- About 1 million slender tubules / kidney
- **Afferent arteriole**
  - Small branches from renal artery
  - Supply nephrons with oxygenated blood
  - Located in cortex of kidney
**Glomerulus**
- Capillary bed, branching from afferent arteriole
- Unlike other capillaries
  - Does NOT transfer blood to a venule
- Site of filtration

**Efferent arteriole**
- Located in cortex of kidney
- Area where blood leaves glomerulus
- Carries blood to a capillary net called peritubular capillaries
  - Net wraps around kidney tubule
- **Bowman’s capsule**
  - Cup like structure
  - Located in cortex
  - Surrounds glomerulus
  - Receives filtered fluids from glomerulus

- **Proximal Tubule**
  - Filtrate enters from Bowman’s capsule
  - Filtrate is carried to the **Loop of Henle**
    - Loop descends into medulla of kidney
Distal tubule
- Conducts urine from Loop of Henle to collecting duct

Collecting Duct
- Receives urine from a number of nephrons
- Carries urine to the renal pelvis of kidney
Figure 9.3 The structures of the nephron are labelled here to help outline the processes by which blood becomes urine in the nephron. The word “proximal” (in proximal tubule) means nearby and refers to the fact that this part of the tubule is located near the Bowman’s capsule. The word “distal” (in distal tubule) means distantly and refers to the fact that this part of the tubule is located more distantly from the Bowman’s capsule.
Take the Nephron Anatomy Test:
Part 1:  
http://www.mhhe.com/biosci/genbio/maderbiology7/graphics/mader07b/mader_labeling/mader_labeling_source/mi16-04a.dcr
Part 2:  
http://www.mhhe.com/biosci/genbio/maderbiology7/graphics/mader07b/mader_labeling/mader_labeling_source/mi16-04b.dcr
Tasks to be Completed:

- Read Section 12.1 in your textbook. Pages 378-386. For anatomy of urinary system, kidneys, and the nephron, read pages 378-380.
- Label the diagrams in your workbook
- Coloring activity in your workbook
- Section 12.1 Questions: page 386 #1-4
II.) FORMATION OF URINE

- 3 steps
  1. Filtration
  2. Reabsorption
  3. Secretion
Figure 9.4 This simplified depiction of the nephron outlines the four main steps in the process of forming urine. The tubule has been depicted in a straight line to help you focus on the processes, rather than on the parts.

1. **Glomerular filtration:** creates a plasma-like filtrate of the blood.

2. **Tubular reabsorption:** removes useful substances from the filtrate and returns them to the blood for reuse.

3. **Tubular secretion:** adds wastes from the blood to the filtrate.

4. **Water reabsorption:** removes water from the filtrate and returns it to the blood for reuse.
1. **Filtration**

- Movement of fluids from [glomerulus](https://example.com) to **Bowman’s capsule**
- Blood moves from afferent arteriole into glomerulus
- Glomerulus is under high pressure
- Solute moves from high to low pressure
  - Small molecules
    - H₂O, NaCl, C₆H₁₂O₆, amino acids, H⁺ ions
  - Plasma proteins, blood cells, and platelets are too large
    - Do NOT move from glomerulus to Bowman’s capsule
Comparison of solutes

<table>
<thead>
<tr>
<th>Solute</th>
<th>Glomerulus</th>
<th>Bowman’s Capsule</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>sodium chloride</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>glucose</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>amino acids</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>hydrogen ions</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>urea</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>plasma proteins</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>erythrocytes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>platelets</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
2. **Reabsorption**

- 600 mL of fluid flows through kidneys per minute
  - 20 % or 120 mL is filtered from nephrons
- **Selective** transfer of essential solutes and \( \text{H}_2\text{O} \) back to blood
- 1 mL of urine formed for every 120 mL of fluid filtered from nephron
  - Remaining 119 mL of fluid and solutes is reabsorbed back into body
- Occurs in proximal tubule
Active transport

- Carrier molecules packed with mitochondria
  - Move Na\(^+\) across cell membranes that line nephron, back to blood
  - Cl\(^-\), HCO\(^3-\) follow
    - Threshold, or maximum amount, for reabsorption of molecule
ACTIVE TRANSPORT CONT’D

- Glucose and amino acids attach to specific carriers
  - Shuttled out of nephron and back to blood
    - Amount reabsorbed is limited
      - Individuals with high blood glucose levels will excrete some excess glucose through urine
Passive transport

- Two osmotic forces are created:
  a.) Molecules transported by active transport create an osmotic gradient
    - $H_2O$ flows from nephron back to blood via osmosis
  b.) Proteins that remain in bloodstream
    - Draw $H_2O$ from interstitial fluid into blood
    - Solutes become concentrated as urine is formed
Summary of Reabsorption

- Nutrients (e.g., glucose, amino acids, Na\(^+\), K\(^+\)) are actively reabsorbed.
- Negatively charged ions (e.g., Cl\(^-\)) are passively reabsorbed by electrical attraction.
- Water is reabsorbed by osmosis.

Transport mechanism:
- active transport
- passive transport
- osmosis
Figure 9.6 Reabsorption in the loop of Henle.

A Water diffuses from the filtrate into surrounding capillaries. Solutes, to a much lesser extent, diffuse in the opposite direction.

B The ascending limb of the loop of Henle is not permeable to water. Solutes diffuse from the filtrate into the surrounding capillaries.

C Active transport of sodium and passive transport of other ions occurs in the thick segment of the ascending limb of the loop of Henle. There is no reabsorption of water in this part of the nephron.
Figure 9.7 Reabsorption in the distal tubule and collecting duct.
3. **SECRETION**

- Movement of wastes from blood into nephron
  - Nitrogen – containing wastes
  - Histamine
  - Excess $H^+$
  - Excess minerals, such as $K^+$
  - Products of drugs
- Cells that line the distal tubule are packed with mitochondria
  - Active transport
Summary of urine formation

- Copy table 3 of Nelson page 383!
- Review Urine formation: http://bc.swhfreem.an.com/thelifewire/content/chp51/51020.html
Filtrate:
- H₂O
- Salts (NaCl, etc.)
- HCO₃⁻
- H⁺
- Urea
- Glucose
- Amino acids
- Some drugs

Reabsorption:
- Active transport
- Passive transport
- Secretion (active transport)

Diagram of the kidney showing the processes of filtration, reabsorption, and secretion in the proximal tubule and distal tubule.
# Steps in Urine Formation

<table>
<thead>
<tr>
<th>Name</th>
<th>Process</th>
<th>Examples of Molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glomerular filtration</td>
<td>Blood pressure forces small molecules from the glomerulus into the glomerular capsule.</td>
<td>Water, glucose, amino acids, salts, urea, uric acid, creatinine</td>
</tr>
<tr>
<td>Tubular reabsorption</td>
<td>Diffusion and active transport return molecules to blood at the proximal convoluted tubule.</td>
<td>Water, glucose, amino acids, salts</td>
</tr>
<tr>
<td>Tubular secretion</td>
<td>Active transport moves molecules from blood into the distal convoluted tubule.</td>
<td>Uric acid, creatinine, hydrogen ions, ammonia, penicillin</td>
</tr>
<tr>
<td>Reabsorption of water</td>
<td>Along the length of the nephron and notably at loop of the nephron and collecting duct, water returns by osmosis following active reabsorption of salt.</td>
<td>Salt, water</td>
</tr>
<tr>
<td>Excretion</td>
<td>Urine formation rids body of metabolic wastes.</td>
<td>Ammonium, salts, water, uric acid, urea, creatinine</td>
</tr>
</tbody>
</table>
III.) pH Balance

- pH of body remains relatively constant
  - 7.3 – 7.5

- Factors affect pH levels in blood
  - Food
  - Cellular respiration
    - carbonic acid formed as waste product
Acid – base balance is maintained by buffer systems

- Absorb excess H\(^+\) ions or ions that act as bases
- Excess H\(^+\) ions are buffered by bicarbonate ions
- \(\text{HCO}_3^-\) prevent a change in pH
- Carbonic acid is produced
  - Breaks down to form CO\(_2\) and H\(_2\)O
  - CO\(_2\) transported to lungs where it is exhaled
\[ \text{HCO}_3^- + \text{H}^+ \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}_2\text{O} + \text{CO}_2 \]

- Kidneys help restore buffer system by reversing reaction
- \(\text{CO}_2\) is actively transported from peritubular capillaries into cells that lines nephron
- Bicarbonate ions diffuse back into blood
- \(\text{H}^+\) ions recombine with either phosphate ions or ammonia
  - Excreted with filtrate from nephron
Water Balance and Kidney’s

- ADH (Antidiuretic Hormone)
- ADH increases water reabsorption in nephrons = decrease conc of urine
- therefore, increase conservation of water in body
Body’s Response to low H2O levels:

H₂O levels (Exercise, decreased water intake, sick, etc.)

Osmoreceptors Detect ↑ in osmotic pressure in blood (hypothalamus cells shrink, water leaves into bloodstream)

Nerve message sent pituitary gland (in brain) to release ADH hormone

ADH travels through blood stream to Kidney
ADH causes ↑ permeability to water of nephron cells

Water is reabsorbed at distal tubule and collecting ducts (remaining 15%)

Water levels ↑
Figure 9.8 The release of ADH controls the amount of water reabsorbed or excreted in urine.

Osmoreceptors in hypothalamus sense increased osmotic pressure, and send signals to the pituitary gland to release ADH into bloodstream.

Body fluids too dilute (osmotic pressure too low).

Body fluids too concentrated (osmotic pressure too high).

Osmotic pressure of body fluids.

Osmoreceptors in hypothalamus send signal to decrease release of ADH.

Osmotic pressure of body fluids increases.

Decreased reabsorption of water in kidney tubules and collecting ducts; increased water in urine.

Increased reabsorption of water in kidney tubules and collecting ducts; decreased water in urine.
Tasks to be completed:

- Read all of section 12.1 – pages 378-386 of your textbook
- Complete 12.1 Questions 1-9 on page 386
12.2 Kidney Dysfunction

- Proper functioning of kidneys is essential for body to maintain equilibrium.
- Many kidney disorders may be detected by urinanalysis.
I.) **Diabetes Mellitus**

- Caused by inadequate secretion of **insulin** from islet cells in pancreas
- Blood sugar levels tend to rise
  - Excess sugar remains in the nephron
- Excess sugar provides osmotic pressure that opposes osmotic pressure created by other solutes that have been actively transported out of nephron
  - Water remains in nephron and is lost with urine
  - Void large volumes of sweet urine
  - Always thirsty
DIABETES INSIPIDUS

- Caused by:
  - Destruction of **ADH (anti-diuretic hormone)** producing cells of hypothalamus
    - **ADH** regulates water reabsorption in nephron
  - Destruction of nerve tracts leading from hypothalamus to pituitary gland
- Urine output increases dramatically
- 20 L of urine produce each day, creating a strong thirst response
II.) Nephritis

- A broad description of many diseases characterized by inflammation of nephrons
- One type of nephritis affects tiny blood vessels of glomerulus
  - Toxins produced by invading microbes destroy tiny blood vessels, altering permeability
- Proteins and other large molecules are able to pass into nephron
- Proteins remain in nephron and create osmotic pressure that draws water into the nephron
  - Increases output of urine
  - May lead to irreversible kidney damage and failure
III.) **Kidney Stones**

- Caused by precipitation of mineral solutes from the blood
- Two groups:
  - Alkaline or acid stones
    - Sharp – sided stones may become lodged in renal pelvis or move into narrow ureter
    - Delicate tissues are torn as stone moves toward bladder
    - Stone may move farther down excretory passage and lodge in urethra
  - Excruciating pain as it moves
Blasting Kidney Stones

- Traditional treatment
  - Surgical removal

- New treatment
  - Extracorporeal shock – wave lithotripsy (ESWL)
    - Uses high – E shock waves to break kidney stones that are less than 2 cm in size
      - Waves pass through soft tissue and strike stone
      - Tiny granules from stone can be voided by excretory system

- Advantages of ESWL
  - Can be performed as an outpatient basis
  - Recovery time reduced

- Considerations of ESWL
  - Size of stone, location in urinary tract, and composition of stone
IV.) Dialysis Technology

- Dialysis machine
  - For people whose kidneys cannot effectively process bodily wastes

- Dialysis
  - Exchange of substances across a semipermeable membrane

- Dialysis machine
  - Performs on basis of diffusion and blood pressure, like a kidney
  - Cannot perform active transport, unlike a kidney
2 types of Dialysis

1. Hemodialysis
   - Machine is connected to patient’s circulatory system by a vein
   - Blood is pumped through a series of dialysis tubes
     - Submerged in a bath of various solutes
   - Glucose and a mixture of salts set up a concentration gradient
Hemodialysis

- Bicarbonate ions will move from the bath to the blood, if it is too acidic
- Urea always moves from blood into dialysis fluid
- Process continually removes urea and other waste solutes
- Body also receives hormones the kidney are unable to produce
In hemodialysis, blood is pumped from an artery to a dialysis machine and returned to the body by way of a vein. (The artery and vein are surgically joined, forming what is called a fistula, to enable easier long-term access to the person’s blood.) Each hemodialysis treatment takes three to five hours and is performed three or four times a week. A person must remain seated or lying down during the procedure.

In peritoneal dialysis, a catheter (flexible tube) is surgically inserted into the abdominal cavity and dialysate may be delivered, removed, and replaced. Because dialysate is always present, the blood is continuously filtered. The full name for this type of dialysis is continual peritoneal dialysis, or CPD. There are several types of CPD. In continuous ambulatory peritoneal dialysis (CAPD), the procedure can be done at home, work, or school—any place that is clean and convenient. Usually, three to five exchanges of fresh dialysate for used dialysate are needed each day. In automated peritoneal dialysis (APD), a machine performs the exchange, which often is done at night for a period of up to 12 hours.

Figure 9.10
Hemodialysis (A) and peritoneal dialysis (B)
2. **Peritoneal Dialysis**

- A.k.a continuous ambulatory *peritoneal dialysis* (CAPD)
- 2 L of dialysis fluid is pumped into abdominal cavity
- Membranes of cavity selectively filter wastes from blood
- Urea and wastes diffuse from plasma into peritoneum and dialysis fluid
- Wastes accumulate in dialysis fluid
  - Can be drained off and replaced several times a day
- As dialysis occurs, patient may continue with non–strenuous activities
  - Allows for greater independence
    - Procedure may be performed at home
DISADVANTAGES OF DIALYSIS TECHNOLOGY

- Cannot produce hormones
  - Erythropoietin
    - Required for RBC production
  - Renin
    - Helps adjust low blood pressure back to normal
- Cannot activate vitamin D
NEW TECHNOLOGY

- Transplant of kidney cells from a pig into a dialysis machine
  - Living cells:
    - Produce hormones
    - Regulate electrolyte and pH better than machine
V.) KIDNEY TRANSPLANTS

- Are 85% successful
- Advantages:
  - Produce hormones
  - Responds to homeostatic adjustments of other body systems
- Disadvantage:
  - Immune response of recipient
  - Donor kidney is often identified as a foreign invader
    - Recipient’s immune system attempts to destroy kidney
**Kidney Transplant Process**

- Involves placing a new kidney and ureter in lower abdomen near groin
  - Surgically attached to blood vessels and urinary bladder
- Operation takes 2 – 4 hours
- Old kidneys are not removed unless they are very large or chronically infected
- After surgery, a catheter is inserted into bladder for several days
  - Drains urine produced by new kidney
  - Sometimes, dialysis is required until new kidney can fully function
  - Immunosuppressive drugs are given to help prevent rejection of new organ
Tasks to be completed:

- Read Section 12.2 – Pages 387-391
- Complete Section 12.2 Questions – Page 392 #1-3, 5, 8
- Urinalysis lab
- Rat Dissection
- Prepare for Unit Exam!
  - Define Key words on page 395
  - Complete #’s 1-11, 20-21 on pages 396-397
  - Read your notes and study the diagrams!!!
Using the nephrons of the kidneys, the excretory system removes metabolic wastes from the body, maintains water and pH balance through filtration and secretion, and returns required solutes by reabsorption.

1. Filtration (blue arrow) results in the movement of fluid from glomerulus into the nephron.

2. Solutes are reabsorbed (purple arrow) across the wall of the nephron into the interstitial fluid by active transport and diffusion. Solutes are transported back to the body for reuse.

3. Solutes are secreted (orange arrow) across the wall of the nephron into the filtrate for removal by excretion.

Excretory system utilizes these processes to help maintain homeostasis by regulating water-salt concentrations and pH of blood.

Healthful lifestyle practices support the excretory system. Disorders of the system may be addressed through technologies such as renal dialysis and kidney transplant operations.