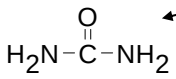
BIOLOGY 12 - EXCRETION: CHAPTER NOTES

Your cells are constantly carrying out chemical reactions to maintain homeostasis. Many of these chemical reactions produce wastes that must be removed from cells and from your body. Many of these wastes are small, water-soluble molecules that become dissolved in your blood along with other small molecules that are not wastes. How is your body able to separate and excrete waste products of Metabolism?

- **EXCRETION**: is the process that rids body of **METABOLIC WASTES**. (especially **Nitrogenous** wastes)
- Excretion is performed by:
- **KIDNEYS**: excrete **Nitrogenous Wastes** (Ammonia, Urea, Uric Acid, Creatinine), **LIVER**: excrete Bile Pigments, **LUNGS**: excrete CO_2, **SKIN**
- Excretion is ***not the same*** as **DEFECATION**, which is the process which rids the body of **UNDIGESTED**, **UNABSORBED food remains**, plus bacteria -- **NOT** metabolic end products.

Nitrogenous Wastes End Products: *what are nitrogenous wastes?*

- **AMMONIA** = NH_3: from deamination of amino groups. **VERY TOXIC** to tissues, so in land mammals NH_3 converted to **UREA** in liver.



Structure Of Urea

- Urea is **water-soluble** - excreted in **URINE**

- **CREATININE**: is another nitrogenous waste. Creatinine comes from **creatinine phosphate** in muscle metabolism (a *Phosphate-storage molecule*)

Other Excreted Substances (besides Nitrogenous wastes)

1. **BILE PIGMENTS**: from breakdown of **red blood cells**
2. **CO_2**: LUNGS major site of excretion
3. kidneys also excrete **HCO_3^-** (bicarbonate ion)
4. **IONS**: Salts K^+, Na^+, Ca^{++}, Mg^{++}, Fe^+
   - these ions are **not** metabolic products, but needed for various biochemical processes and must be maintained at specific concentrations. Are excreted to maintain proper balances of these ions
5. **WATER**: metabolic end product, maintains blood pressure, consumed with food

- **URINE** is composed mainly of **UREA** (~3%), **SALTS** ~(2%), **H_2O** (95%).

THESE ARE THE ORGANS of EXCRETION and their overall functions

1. **KIDNEYS**: Excrete urine, regulate blood **volume**, **pH**
2. **SKIN**: Glands excrete **perspiration** (which consists of H_2O, salt, and **small** amounts of **urea**
   - excretion from the skin is primary for **cooling**
3. **LIVER**: - excretes **bile**, which contains pigments that are breakdown products of RBC metabolism. Bile is sent to **small intestine**.
   - **UROCHROME** from breakdown of **heme**
   - urochrome gives urine its **yellow** colour
4. **LUNGS**: excrete CO_2, some H_2O
5. **INTESTINE**: excretes some **iron and Calcium salts**, which are secreted into intestine, then excreted into feces

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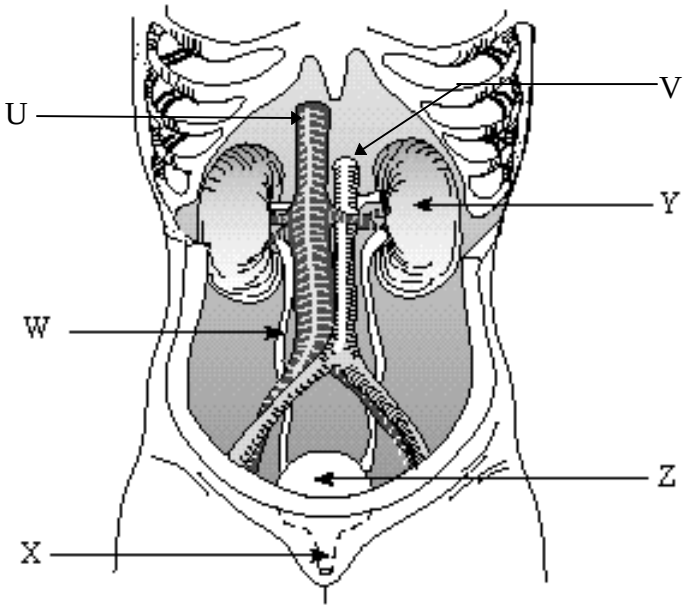
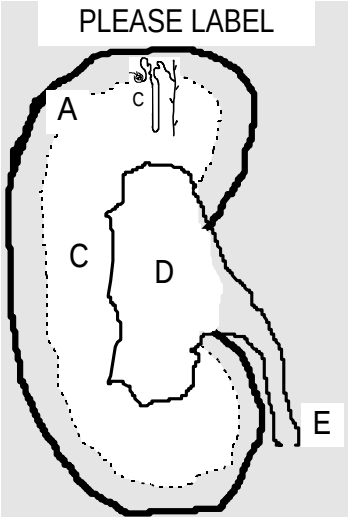


URINARY SYSTEM CONSISTS OF THESE PARTS!

- **RENAL VEIN** : carries **blood** from kidneys back to hearty
- **RENAL ARTERY** : carries blood **to** kidneys
- **KIDNEYS** : reddish-brown organs about **4 inches long**, **2 inches wide**, **1 inch thick**, anchored against the dorsal body wall by connective tissue.
- **URETER** : muscular tubes, move urine from kidneys to bladder via **peristalsis**

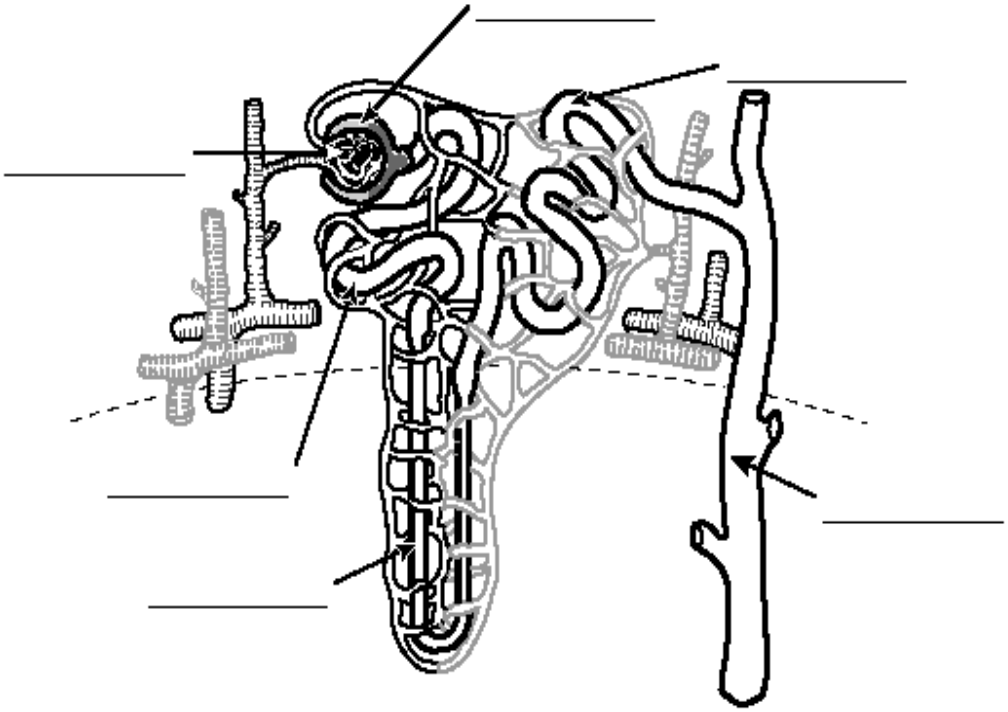
- **<u>BLADDER</u>**: holds up to 600 ml to 1000 ml urine, can expand/contract. Has stretch receptors that indicate when it is full, notifies the brain.
- **<u>URETHRA</u>**: tube connecting bladder to outside.
  - the urethra of a man is about 6 inches long (extends through penis). In the man, the urethra also transports **semen** (but never at the same time as urine). For women, the urethra is only ~1 inch (which is why get more **infections** here -- bacteria can invade more easily).



KIDNEYS - the main organ of excretion

- Structurally, kidneys have 3 major divisions: **CORTEX** (outer layer), **MEDULLA** (middle, striated), **PELVIS** (inner cavity).
- **KIDNEY STONES** can sometimes form in **pelvis**. **DRAW SOME KIDNEY STONES ON THIS DIAGRAM.**
  - kidney stones consist of **Calcium salts** and **uric acid**. They can pass naturally (ouch!) or be treated with surgery, or destroyed with sound waves or laser light. Primary Cause: ***too much protein in diet!***
- **<u>NEPHRONS</u>** - are the **<u>functional</u>** **<u>units</u>** of the kidney. They **filter wastes** from the blood, and **retain water** and **other needed materials**. There are about **1 million nephrons per kidney**. Urine formation occurs in the nephron.

<u>Structure of Nephron: PLEASE LABEL THE DIAGRAM BELOW</u>



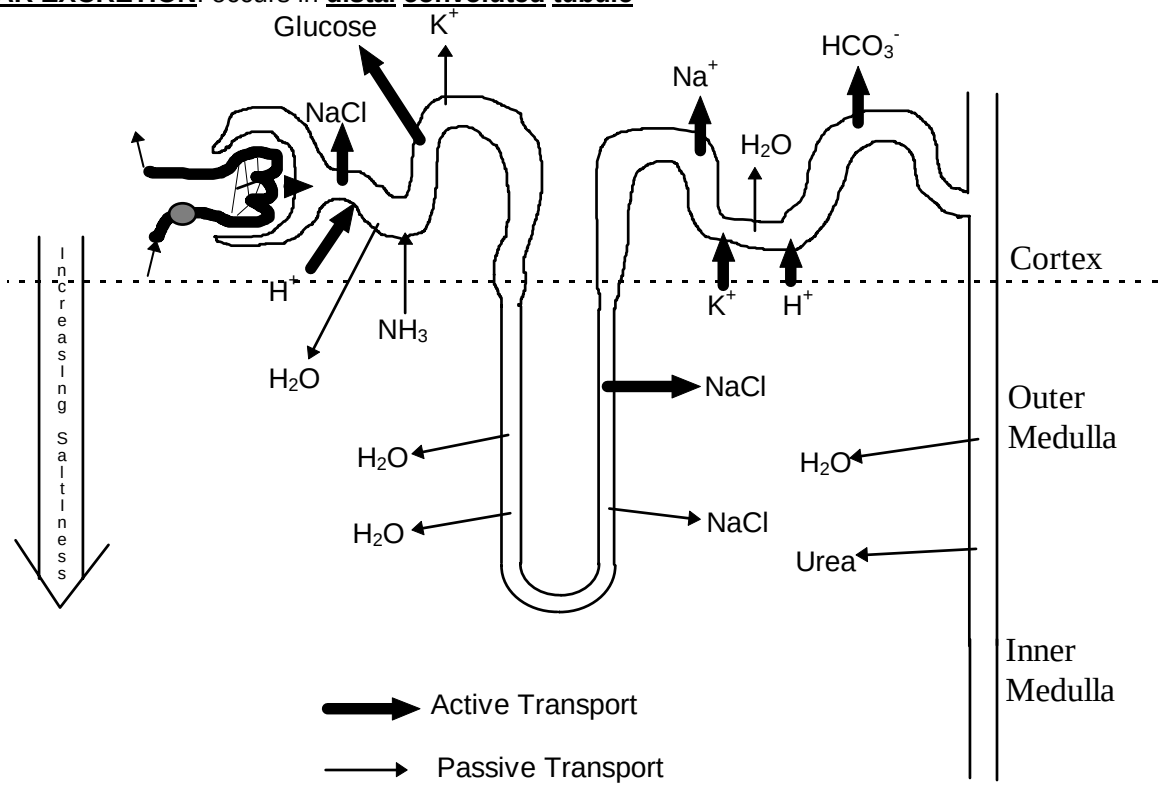
- **<u>BOWMAN'S CAPSULE</u>** - **Cup-like** end of nephron where **wastes are forced out of the blood** and into the nephron. The blood enters a **capillary tuft** called the **<u>GLOMERULUS</u>**.
- **<u>AFFERENT ARTERIOLE</u>** - carries blood to glomerulus
- **<u>EFFERENT ARTERIOLE</u>** - carries blood from glomerulus
- From capsule, nephron narrows into **<u>PROXIMAL CONVOLUTED TUBULE</u>**, which makes a turn to **<u>FORM LOOP OF HENLE</u>**, which is surrounded by the **<u>PERITUBULAR CAPILLARY NETWORK</u>**. Loop leads to the **<u>DISTAL CONVOLUTED TUBULE</u>**, which finally enters a **<u>COLLECTING DUCT</u>**.

URINE FORMATION: YOU MAKE ABOUT 1 mL OF URINE PER MINUTE!

- occurs in **nephron** as molecules are **exchanged** between **blood vessels** (i.e. the glomerulus and peritubular capillary network) and **nephrons**.

Urine formation consists of 3 STEPS

1. **PRESSURE FILTRATION**: occurs inside **Bowman's capsule** as molecules are forced through the **glomerulus**.
2. **SELECTIVE REABSORPTION**: occurs in the **proximal convoluted tubule** (Na^+,Cl^-, H_2O)
3. **TUBULAR EXCRETION**: occurs in **distal convoluted tubule**



1. **PRESSURE FILTRATION**

   high blood pressure in **GLOMERULUS** (~60mm Hg) forces **SMALL MOLECULES** [*H_2O, nitrogenous wastes, *nutrients, *ions (salts)] into **BOWMAN'S CAPSULE**.

   note: we don't want to lose these substances constantly- we would quickly die of dehydration and starvation. Therefore, these substances must be absorbed back into the blood.

- **large** molecules are **unable to pass** (i.e. **blood cells, platelets, proteins**). ***These remain in the blood*** **and leave the glomerulus via EFFERENT ARTERIOLE**
- the small, filterable molecules that are forced into Bowman's capsule form **FILTRATE**.
- **high blood pressure is necessary** for filtration This is accomplished through the functioning of the **juxtaglomerular apparatus** (a special region of afferent arteriole) and will, if necessary, release **RENIN** to increase blood pressure. People with **kidney disease** often have high blood pressure because their juxtaglomerular apparatus is constantly releasing renin.

2. **SELECTIVE REABSORPTION**

- If the kidneys only did pressure filtration, we would quickly die from water and nutrient loss. Once the original filtrate is made, the next task is to ***reabsorb molecules in filtrate*** that are needed by the body (e.g. water, nutrients, some salts).
- the molecules that are reabsorbed move from the **proximal convoluted tubule to the peritubular capillary network** (i.e. back into the blood). This is very efficient. Every minute about **1300 mL of blood enters the kidneys** and **1299 mL of blood leaves**. Only about 1 mL becomes urine.
- **WHAT GETS REABSORBED**?: most H_2O, nutrients, some salts (Na+, Cl-)
- **WHAT DOESN'T GET REABSORBED**: some H_2O, wastes, excess salts
  - non-reabsorbed material continues through **Loop of Henle**

  Reabsorption is both **ACTIVE and PASSIVE**
  - **ACTIVE**: requires ATP and carrier molecule (e.g. glucose, Na+)

- **PASSIVE**:e.g. Cl-, water

- Tubular fluid now enters the **LOOP OF HENLE**
- primary role of Loop of Henle is **REABSORPTION OF WATER**. Over **99%** of the water in original filtrate is reabsorbed by the nephron during urine formation.
- salt (Na+Cl-) is also passively and actively reabsorbed
- this **CONCENTRATES THE URINE**, allowing it to be **HYPERTONIC to plasma**

3. TUBULAR EXCRETION (=TUBULAR SECRETION)

- This is an **ACTIVE PROCESS** by which **other non-filterable wastes** can be added to the tubular fluid so that these wastes will also be excreted in the urine.
- Occurs in the **DISTAL CONVOLUTED TUBULE**: secreted substances include some chemicals (e.g. **penicillin, histamine**) **H^+ ions, NH_3**
- fluid now enters **COLLECTING DUCT**
  - in **cortex**, fluid in duct is **ISOTONIC** to the surrounding cells (therefore, there is no net movement of water)
  - in the **medulla**, fluid is **HYPOTONIC** to cells of medulla **THEREFORE H_2O PASSIVELY DIFFUSES OUT OF COLLECTING DUCT**.
- The tubular fluid, which we can now call **URINE** passes from duct into **pelvis** of kidney, and enters **ureter** for transport to **bladder**.

A comparison of urine and plasma!	
URINE	**PLASMA**
WATER: 95%	WATER: 90-92%
UREA: ~2.5-3%	PROTEINS: 7-8%
CREATININE: .2%	SALTS: <1%
AMMONIA: ~.2%	
URIC ACID: ~.1%	
IONS: ~2%	**URINE IS HYPERTONIC TO PLASMA**
Na+, Cl-, K+,SO_4^{-2} Mg^{+2}, PO_4^{-2}, Ca^+	

REGULATORY FUNCTION OF KIDNEYS: the kidneys do much more than just filter the blood!

1. REGULATE VOLUME OF BLOOD (i.e. water volume). This is done by **two HORMONES**: ADH and ALDOSTERONE.

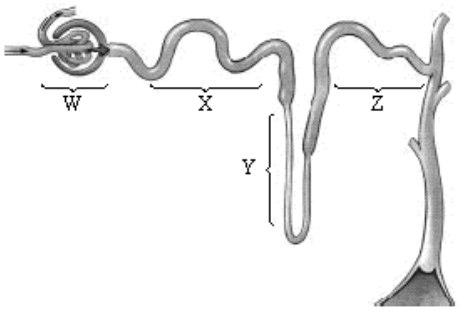
ADH (**ANTIDIURETIC HORMONE**) (old name = *vasopressin*)
anti-"**increased urine output**", **anti-"pee-more"** hormone released by pituitary gland
promotes reabsorption of water from collecting duct and distal convoluted tubule

Here is how ADH does it's job:

1. cells in **hypothalamus detect low H_2O content** of blood
2. **ADH released** into blood, **acts on DISTAL CONVOLUTED TUBULE and COLLECTING DUCT**
3. more H_2O reabsorbed, volume of **urine decreases**
4. therefore, **blood volume increases**
5. as blood becomes more **dilute**, this is detected by the hypothalamus, ADH secretion **stops** (a ***negative feedback*** loop!)

- **DIURETIC DRUGS**, prescribed for high blood pressure, **inhibits ADH secretion** - lower blood volume and thus b.p. (cause increased urination).

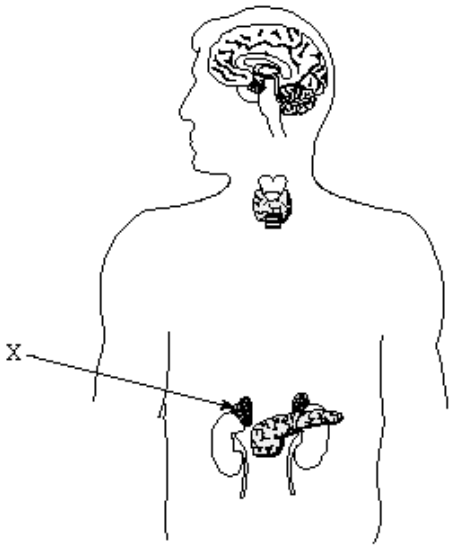
Label this diagram and indicate on the diagram where ADH acts.



ALCOHOL also **inhibits ADH secretion**

- drinking alcohol therefore causes increased urination ---> dehydration ---> **HANGOVER**
- **beer and alcohol cannot quench your thirst!** (you will urinate more liquid than you take in)

- **inability** to produce **ADH** causes **DIABETES INSIPIDUS** (= watery urine)
  - sufferers urinate too much
  - thus, they lose too much salts from urine and **blood ion levels drop**
  - treatment is **injections of ADH**



ALDOSTERONE

- this is a hormone released by **ADRENAL CORTEX** (adrenal glands sit on top of kidneys). Aldosterone acts on kidney to **RETAIN Na+ and EXCRETE K+. Label the adrenal gland on the picture of the kidney!**
- concentration of **sodium** in blood, in turn, regulates secretion of aldosterone (another *negative feedback* loop)
- [Na+] in blood important to kidneys ability to reabsorb H_2O
- if [Na+] in blood too low, too little H_2O is reabsorbed, results in **HYPOTENSION**.
- if [Na+] in blood too high, results in **HYPERTENSION**

2. KIDNEYS AND BLOOD pH

- **kidneys help maintain blood pH**
- nephrons vary the amount of $\mathbf{H^+}$ and $\mathbf{NH_3}$ that they excrete and the amount of $\mathbf{HCO_3^-}$ and $\mathbf{Na^+}$ they reabsorb. - ***keeps pH within normal limits***.
- if blood **acidic**, ***more H^+ and ammonia excreted***, and more ***sodium bicarbonate is reabsorbed***.
- Sodium bicarbonate neutralizes acid.

$$Na{+}HCO_3^- + HOH \text{ -----> } H_2CO_3 + NaOH \text{ (strong base)}$$

- if blood **alkaline** - ***less H+ excreted, less Na+ and HCO_3- reabsorbed***
- Reabsorption and excretion of ions (e.g. K^+, Mg^{++}) by kidneys also **maintains proper ELECTROLYTE BALANCE** of blood.

KIDNEY PROBLEMS

- kidney functions are **vital** to homeostasis; ***problems can be life-threatening***
- **CYSTITIS: infection of bladder** after bacteria get into urethra.
- If it *spreads to kidneys* it is called **NEPHRITIS** - affects glomeruli (either by making them blocked or more permeable)
  - infections can be detected with **URINALYSIS** - look for blood cells and proteins in urine. **NORMAL URINE NEVER HAS BLOOD PROTEIN OR BLOOD CELLS IN IT. IT SHOULD ALSO NOT CONTAIN MORE THAN TRACE AMOUNTS OF GLUCOSE.**
- if glomeruli damage extensive (2/3 or greater are wrecked), wastes accumulate in blood (=**UREMIA**)
- if water and salts retained, causes fluid accumulation in body tissues, plus **ionic imbalances** (- leads to problems in including loss of consciousness and heart failure). This condition is called **EDEMA**

KIDNEY REPLACEMENTS

- must be used in case of renal failure
- **options**: 1) transplant 2) artificial kidney (=**dialysis**)

1) **KIDNEY TRANSPLANT** - one kidney is adequate for normal functioning, so it is possible to donate one kidney and live.
   - requires living or recently deceased donor (there is a big shortage of donors)
   - organ rejection a problem: - ~10% for non-relative donors, only ~3% rejection rate for relatives. The advent of anti-rejection drugs, monoclonal antibodies (work against body's cytotoxic T cells) has helped lower rejection rates.
2) **DIALYSIS** - there are two basic forms a) **kidney machine** b) **continuous ambulatory peritoneal** (= abdominal) dialysis **CAPD**

- both utilise **semi-permeable membrane** that allows molecules to diffuse across it according to **concentration gradients** - are manipulated so that **wastes can be removed**, **nutrients/ions added, pH adjusted**.

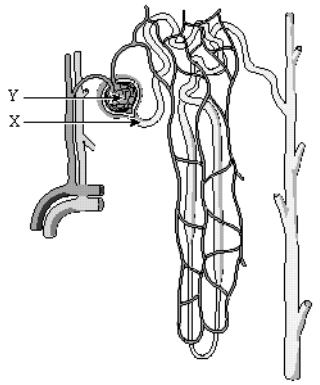
a) **<u>KIDNEY MACHINE</u>** - when no available donors, a machine is used to filter the patients blood.

1) Blood passes across semi-permeable membrane which has balanced salt (dialysis) solution
2) Wastes exit blood into solution because of pre-established concentration gradient
3) Can extract substances from blood, or add substances
4) Works **faster** than real kidneys - therefore only needs to be done twice a week (6 hour session)

b) **<u>CAPD (Continuous Ambulatory Peritoneal Dialysis)</u>**: allows dialysis away from hospitals.

1) Patient has tube permanently implanted into abdominal cavity
2) Dialysate fluid introduced into abdominal cavity through plastic bag, which is rolled up after so student can move around.
3) Wastes and water pass into fluid (4-8) hours.
4) Bag lowered, fluid drains out.
5) Process repeated with fresh fluid.

In the diagram below, which of the following should be found in structure **Y**, but **not** in **X** ?



A. Urea.
B. Water.
C. Glucose.
D. Formed elements.