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 CO₂, **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** = NH₃: from deamination of amino groups. VERY TOXIC to tissues, so in land mammals NH₃ converted to **UREA** in liver.

  ![Structure Of Urea](image)

  - 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. **CO₂**: LUNGS major site of excretion
3. kidneys also excrete **HCO₃⁻** (bicarbonate ion)
4. **IONS**: Salts K⁺, Na⁺, Ca²⁺, Mg²⁺, Fe²⁺
   - 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%), **H₂O** (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 H₂O, 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 CO₂, some H₂O
5. **INTESTINE**: excretes some **iron** and Calcium salts, which are secreted into intestine, then excreted into feces

**URINARY SYSTEM CONSISTS OF THESE PARTS!**

- **RENAL VEIN**: carries blood from kidneys back to heart
- **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
• **BLADDER**: holds up to 600 ml to 1000 ml urine, can expand/contract. Has stretch receptors that indicate when it is full, notifies the brain.

• **URETHRA**: 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 we 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 the **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!**

• **NEPHRONS** - are the **functional units** 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.

**Structure of Nephron: PLEASE LABEL THE DIAGRAM BELOW**

• **BOWMAN’S CAPSULE** - 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 **GLomerulus**.

• **AFFERENT ARTERIOLE** - carries blood to glomerulus

• **EFFERENT ARTERIOLE** - carries blood from glomerulus

• From capsule, nephron narrows into **PROXIMAL CONVOLUTED TUBULE**, which makes a turn to **FORM LOOP OF HENLE**, which is surrounded by the **PERITUBULAR CAPILLARY NETWORK**. Loop leads to the **DISTAL CONVOLUTED TUBULE**, which finally enters a **COLLECTING DUCT**.

**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\(_2\)O)

3. **TUBULAR EXCRETION**: occurs in **distal convoluted tubule**

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### Pressure Filtration
- **High blood pressure** in **glomerulus** (~60mm Hg) forces **small molecules** [*H\(_2\)O, 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 **effluent arteriole**.

- The small, filterable molecules that are forced into Bowman's capsule form **filtrate**.

### 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.

### Tubular Excretion
- **WHAT GETS REABSORBED?**: most H\(_2\)O, nutrients, some salts (Na\(^+\), Cl\(^-\))
- **WHAT DOESN'T GET REABSORBED**: some H\(_2\)O, 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**

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Raycroft
Here is how ADH does its job:

1. **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 (ANTI DIURETIC 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 its job: 
        1. cells in hypothalamus detect low H$_2$O content of blood 
        2. ADH released into blood, acts on DISTAL CONVOLUTED TUBULE and COLLECTING DUCT 
        3. more H$_2$O 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). 
    - **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 

2. **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$_2$O 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!

<table>
<thead>
<tr>
<th>URINE</th>
<th>PLASMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER: 95%</td>
<td>WATER: 90-92%</td>
</tr>
<tr>
<td>UREA: ~2.5-3%</td>
<td>PROTEINS: 7-8%</td>
</tr>
<tr>
<td>CREATININE: .2%</td>
<td>SALTS: &lt;1%</td>
</tr>
<tr>
<td>AMMONIA: ~.2%</td>
<td></td>
</tr>
<tr>
<td>URIC ACID: ~.1%</td>
<td></td>
</tr>
<tr>
<td>IONS: ~2%</td>
<td>URINE IS HYPERTONIC</td>
</tr>
<tr>
<td>Na+, Cl-, K+,SO$_4$$^{2-}$</td>
<td>TO PLASMA</td>
</tr>
<tr>
<td>Mg$^{+2}$, PO$_4$$^{2-}$, Ca$^+$</td>
<td></td>
</tr>
</tbody>
</table>

| Notes - Excretion - Student.doc — Page 4 |
• [Na+] in blood important to kidneys ability to reabsorb H₂O
  • if [Na+] in blood too low, too little H₂O 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 H⁺ and NH₃ that they excrete and the amount of HCO₃⁻ and 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⁺HCO₃⁻ + HOH ----> H₂CO₃ + NaOH (strong base)
  • if blood alkaline - less H⁺ excreted, less Na⁺ and HCO₃⁻ 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