NUTRITION AND METABOLISM

I. NUTRITION

- Food is metabolic fuel; that is, it is **OXIDIZED** (see later) and transformed into **ATP**.

  *energy value of food is measured in **KILOCALORIES** (kcal or “C”).

  NOTE: what most people refer to as a “calorie” is actually a kilocalorie (= one thousand calories)!

- **NUTRIENT**: any substance in food that is used to promote normal growth, maintenance & repair.

  *6 categories: carbohydrates, proteins, lipids, vitamins, minerals and water.

  - most foods are combinations of nutrients.

  - **ESSENTIAL NUTRIENTS**: 45-50 molecules **cannot** be manufactured by the body and must be taken in through the diet.

A) Carbohydrates

- recall: ring-shaped molecules stored in liver as glycogen.

1) Dietary Sources - almost all carbo’s are taken in from plant material. Exception is milk sugar.

2) Uses in the Body - major body fuel; all carbo’s are converted to glucose, which is the only carb. molecule delivered & used by the cells to make **ATP**.

B) LIPIDS

- recall: building blocks are fatty acids and glycerol.

1) Dietary Sources - most are in form of **NEUTRAL FATS**, although we also ingest some cholesterol and phospholipids. Liver can convert almost all fatty acids into each other. One exception (therefore, it is an **essential fatty acid**) is Linoleic acid.

2) Uses in the Body:
   (a) Concentrated energy source - long-term storage. Major energy source for muscle.
   (b) help body absorb **fat-soluble vitamins** (that is, those that do not dissolve in water - see later).
   (c) cholesterol & phospholipids are integral part of cell membranes.
   (d) fat deposits form cushions and insulate body organs.

C) PROTEINS

- recall: building blocks are amino acids.

1) Dietary Sources:

   (a) Animal products contain **COMPLETE PROTEINS**; that is, proteins that contain all the amino acids needed to make the proteins you need in protein synthesis.

   (b) Some plant materials are protein-rich; however, NONE contain complete proteins. Therefore, plant materials must be mixed to assure that all amino acids are ingested. Legumes (beans and peas) and rice are high in protein, and when mixed together provide all amino acids.
2) Uses in the Body - Major structural (fibrous proteins) and physiological (globular proteins) units in the body, including keratin, collagen, hormones, antibodies, enzymes, hemoglobin, etc., etc., etc.

However, proteins have some requirements for their metabolisms. These are:

(a) **All or None rule** - all amino acids found in the polymer must be present at the same time and in sufficient amounts. No substitutions, please!

(b) **Adequate caloric intake** - it takes ATP for protein synthesis, so sufficient carbo or fat calories must be present. No unleaded, please.

(c) **Nitrogen balance must be maintained** - a poisonous by-product of protein metabolism is Nitrogen, which quickly forms urea (NH4+); this must be removed from the body and that takes water!

(d) **Hormonal controls** - **ANABOLIC HORMONES (ANABOLIC STEROIDS)** regulate protein synthesis. We will see these next semester.

D) **VITAMINS**

- Organic compounds needed in minute amounts for growth and repair.

- NOT energy and NOT building blocks; rather, they are **COENZYMES** (= molecules needed by enzymes to do their job). Vitamins are **ESSENTIAL COENZYMES**; that is, they cannot be produced by the body.

- Two kinds of vitamins:

1. **Fat Soluble** - are hydrophobic; they can only be absorbed if accompanied by lipids. They are stored in the body, in adipose tissue, and can be toxic if their levels get too high (**HYPERVITAMINOSIS**). Example: vitamin A causes blindness and then death if consumed in large quantities.

2. **Water Soluble** - Absorbed with water in the gastrointestinal tract. Excess is excreted in the urine; therefore, they are not toxic in high doses.

- Some vitamins are **ANTIOXIDANTS** - “eat up free radicals” (free-floating electrons in the body) which may cause cancer (?). NOT WELL ESTABLISHED.

E) **MINERALS**

- Body needs 7 **inorganic ESSENTIAL MINERALS**. Also not used for fuel or building blocks. Instead, incorporated into tissues to give strength (calcium, phosphorus), to maintain electrolyte balances (sodium, magnesium, chloride, potassium) and to keep proteins together (sulphur).

- Also need several **TRACE MINERALS** - found in extremely low concentrations.
II. METABOLISM

A. Introduction

- Recall: metabolism is all chemical reactions involved in maintaining life; this requires the cycling of energy.
  *ANABOLISM: building large molecules from smaller ones.
  **often done through dehydration synthesis.
  *CATABOLISM: breaking down large molecules into smaller ones.
  **often done through hydrolysis.

- In the digestive tract, foods are hydrolyzed in the digestive tract into their component parts (nutrients).
  * Now, we have glucose available for CELLULAR RESPIRATION, where glucose is hydrolyzed within cells to release the energy in it's chemical bonds (another catabolic process!). This energy is "captured" in the bonds of ATP so the cell can use it when and where it wants to!

  Kind of like how you use electrical energy to charge a battery, so you can use it when and where you want to!
QUESTION: HOW CAN THE CELL HYDROLYZE GLUCOSE (THAT IS, BREAK IT’S CHEMICAL BONDS), AND THEN TRAP THE ENERGY RELEASED IN THE CHEMICAL BONDS OF ATP?

ANSWER: How about a little analogy:

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We can get the ball marked “A” to a higher energy level (“B”) by passing it up the stairs.
Each rise gives the ball a little more potential energy.
NOTE: each pass requires a small energy input.
In this analogy, our workers are enzymes.

 Bowling ball at low potential energy

 Bowling ball at higher potential energy.

As the ball is passed between workers up intermediate steps, it increases in potential energy.
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- How does this relate to ATP?

  * In our cells, electrons from glucose are “passed up the stairs” in three steps (see below).

  * The end result is PHOSPHORILATION (“forcing a phosphate group on to”) of ADP (Adenosine Diphosphate) into ATP (Adenosine Triphosphate).

- We phosphorylate ADP using a series of reactions called OXIDATION-REDUCTION reactions. In these reactions, one molecule is OXIDIZED (an oxygen is added) while another is REDUCED (an oxygen is taken away--it is “reduced in oxygen”). TO UNDERSTAND THE PROCESS, THE STUDENT MUST REMEMBER THIS: oxidized substances lose energy, while reduced substances gain energy.

  * So, how do we reduce one molecule (that is, give it more energy)? Simple: by oxidizing another molecule.

In other words - we switch oxygen from one molecule to another!
B. Overview:

- During cellular respiration, coenzyme molecules are reduced during 2 processes: **GLYCOLYSIS** and (if oxygen gas is present) **THE KREBS CYCLE**.

  **The energy to do this comes from glucose (mostly).** Other molecules, such as proteins and fats, can be used.

  The coenzymes are named "NAD" and "FAD". When reduced, they are called **NADH** and **FADH2**.

  Glycolysis happens in the cytoplasm, and occurs whether or not there is oxygen. Therefore, it is "**anaerobic**" (it does not require oxygen).

  During the "middle parts" of this process, a couple of ATP are formed.

- They (the coenzymes) pick up a little energy as they are reduced. Then, they transfer this "picked-up" energy to electrons in a process called **THE ELECTRON TRANSPORT CHAIN**.

- **THESE “ENERGIZED” ELECTRONS ARE THEN USED BY A PROTEIN CALLED ATPsynthase TO PHOSPHORILATE ADP INTO ATP!!!!!!!** 34 ATP are formed in the last part of the process from each glucose molecule.

- The three steps involved in "passing glucose electrons up the stairs" (that is, **CELLULAR RESPIRATION**) are: glycolysis, Krebs cycle, and the Electron Transport Chain.

  Glycolysis occurs in the cytoplasm, and doesn't require oxygen, so it is "**anaerobic**".

  Krebs cycle and ETC occur in the mitochondria. They rely on oxygen, so this part of the process is called "**aerobic**", and the chemical processes of putting a phosphate onto ADP are (all together) called "**oxidative phosphorylation**".

  There are a couple of waste products from these chemical steps: **CO2** (which is an acid in water, and must be dealt with) and **H2O** (which our cells like!)
C. Processes involved in Cellular Respiration

1) CARBOHYDRATE DIGESTION & METABOLISM - The breaking down of polysaccharides into monosaccharides, and then converting all monosaccharides into the hexose called GLUCOSE. More on this during the Digestion section.

Then, glucose is picked up in the bloodstream by INSULIN and stored as glycogen in the liver.

When it is needed, glycogen is hydrolyzed (broken down), the individual glucose molecules enter the bloodstream, and diffuse into the cells using FACILITATED DIFFUSION (you saw this in the cell chapter, under the Passive Transport section).

Interesting side note:

Insulin increases the conversion of glycogen into glucose, making glucose available to the cells.

BUT: it decreases the conversion of fatty acids into glucose (a process called gluconeogenesis ... see later).

Therefore, high insulin levels make it hard to burn fat.
Once the glucose molecule is in the cell, we are ready for the second step:

2) GLYCOLYSIS - Glycolysis is “anaerobic respiration” ....we don’t use oxygen for this. It is not very efficient—we won’t get many ATPs per glucose molecule. But, we will reduce several NAD molecules into NADH—these will later be used to “charge” electrons during the third step. Glycolysis takes place in the cytoplasm of the cell.

- Detail steps:

1. **ACTIVATION**: a glucose molecule is “activated” (think of “charged”), which uses up 2 ATP!

2. **CLEAVAGE**: The molecule is then split in two, forming 2 short molecules. These 2 molecules are highly reactive, and love to bind to oxygen (become oxidized).

3. **OXIDATION AND FORMATION OF ATP**: These 2 molecules “steal” oxygen from NAD, thereby reducing NAD!!! In the process, the molecules are converted into PYRUVIC ACID.

- NOTE: THERE IS A NET GAIN OF 2 ATPs THROUGH DIRECT PHOSPHORYLIZATION!

- What becomes of Pyruvic Acid? That depends. If there is no oxygen present, it is converted into LACTIC ACID, which is stored in the liver until it can be broken down into a harmless substance later.

    *If there is oxygen present, however, we go on to the next step:*
3) OXIDATIVE PHOSPHORILATION: THE KREBS CYCLE AND THE ELECTRON TRANSPORT CHAIN

- There are 2 processes that make up oxidative phosphorylation. Both occur in the mitochondria:

(i) KREBS CYCLE

- Fueled by the pyruvic acid produced in glycolysis - IT IS THE NEXT STEP AFTER GLYCOLOGY, IF OXYGEN IS AVAILABLE.

- STEPS:

1. Convert pyruvic acid into acetyl coenzyme A (acetyl CoA), catalyzed by an enzyme. CO2 is a waste product of this step.

2. Hook up acetyl CoA to “pickup molecule”, which has 4 carbons—we now have citrate — CITRIC ACID (the Krebs Cycle is also known as the “citric acid cycle”).

3. Go through a series of chemical steps where CO2 is removed from the molecule (therefore, it is oxidized!). Each time, we reduce NAD or FAD. By the time the process is over, we have reduced them 4 times, and have directly phosphorylated ADP into ATP once (NOT SHOWN).

4. At the end of the cycle, we end up with the “pickup molecule”, which is then ready to attach to the next Acetyl CoA that is made available -- the cycle is continuous as long as:

(i) pyruvic acid is being produced by glycolysis!
(ii) oxygen is present, so the reduced coenzymes don't "back upo" (see next section on Electron Transport Chain).

THE 4 REDUCED COENZYME (NADH2 & FADH2) MOLECULES DRIFT OFF TO THE MITOCHONDRIA, WHERE THEY WILL ENTER THE “ELECTRON TRANSPORT CHAIN” IF OXYGEN IS AVAILABLE!
(ii) THE ELECTRON TRANSPORT CHAIN - OXIDATIVE PHOSPHORILIZATION

- Series of chemical reactions that use special proteins embedded into the cristae of the mitochondria:

**See Image Next Page**

1. The mitochondria have an outer membrane, an inner folded membrane called the cristae, and a matrix.

2. Inside the matrix, the Krebs Cycle is occurring, reducing coenzymes. Here, we'll only talk about NADH.

3. The cristae are encrusted with enzymes that will perform the Electron Transfer Chain.

4. First, we oxidize the reduced coenzyme:

5. The hydrogens that are released are “pulled” across the cristae using special proteins embedded in the membrane.

   * This builds up highly energized hydrogen ions, as the hydrogens have been "pushed" against their electromagnetic gradient.

6. The hydrogens then rush back into the mitochondria through a special protein channel, called ATP synthase. This releases their energy, which ATP synthase uses to phosphorylate ADP into ATP.

   It literally grabs one ADP and one Pi and sticks them together!

7. Oxygen is needed because we now have 2 free-floating hydrogens in the mitochondrial matrix; they must be dealt with or we would change pH. They are attached to oxygen to form water:

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   2 \text{H}^+ + \text{O}_2 \rightarrow \text{H}_2\text{O}
   \]

- In total, 34 ATP are produced from the original glucose molecule.

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**WHAT THE STUDENT SHOULD KNOW:**

1. ATP production occurs across the mitochondria cristae, and in the mitochondria matrix.
2. Oxygen is needed, and we use it to make water.
3. Special enzymes embedded in the cristae, including ATP synthase, are needed.
4. Reduced coenzymes are oxidized to release their energy, forcing Hydrogen ions across the cristae.
5. The potential energy in the free hydrogen ions are used by ATP synthase to phosphorylate 34 ADPs into 34 ATPs.

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D) SUMMARY of cellular respiration!!!!!!!

1. A glucose molecule enters glycolysis in the cytoplasm. It takes 2 ATPs to “activate” it, but we get 4 ATPs out through direct PHOSPHORILIZATION = net gain of 2 ATPs. More importantly, we reduce 2 coenzymes (NAD), which will later go into the electron transport chain (if O2 is present), and be used to form 3 more ATPs each! Pyruvic acid is the end product of glycolysis.

2. The pyruvic acid has 2 choices:
   
   a. If no O2 is present, it goes to the liver and is stored as lactic acid. But we will have to “deactivate” it later, and that takes oxygen = the “Oxygen Debt”.

   b. If O2 is present, the pyruvic acid enters the Krebs Cycle. Here, it is oxidized several times; each time it is oxidized, it produces CO2 (waste) AND reduces a coenzyme (NAD and FAD), which will later enter the electron transport chain to make ATP. To start this process, pyruvic acid is converted into acetyl CoA, which is then attached to a “pick-up” molecule.

3. The coenzymes made during glycolysis and the Krebs’s Cycle enter the mitochondria. Here,
enzymes rip off the hydrogens (= oxidize the coenzymes) and are shunted across the cristae, where they gradually pick up energy. The H+ then rushes back across the membrane through an enzyme called ATP synthase, which used the energy to phosphorylate ADP. We get a lot of ATPs out of this process. Total yield is about 38 ATPs.

4) GLYCOGENESIS AND GLUCONEOGENESIS - processes involved in making glucose available if the body is not immediately getting it from digestion:

1. **Glycogenesis** = process of forming glycogen from individual glucose molecules using dehydration synthesis.

2. **Glycogenolysis** = process of hydrolyzing glycogen into individual glucose molecules.

3. **Glyconeogenesis** (“making new glucose”) - series of chemical process that convert lipid (fatty acids) and proteins (amino acids) into glucose.

   * Therefore, ATP synthesis can continue even in the event of HYPOGLYCEMIA (low blood sugar).