Microbial Metabolism

A. Microbial Metabolism: Species' Distinction

One reason why the metabolism of microbes is an instrumental area of study is that it serves as a way of differentiating one species from another.

A second reason why metabolism (how, when, where, etc. an organism derives the energy and nutrients needed to live) is important is that it offers insight into a microbe's environmental niche, hence, basis for deciphering which industry it may possibly benefit.

Prokaryotes (explained in the previous lesson) can be organized into groups based upon their extremely diverse nutritional and metabolic needs.

Traditionally, these groups have been based upon the two central ideas:

- Nature of the energy source
- Nature of the carbon source used for building organic, biological macromolecules

B. Microbial Metabolism: Types & Processes

Metabolism

The sum total of all reactions which occur in a cell, metabolism, consists of two types of processes catabolism and anabolism.

Catabolism

How complex molecules are broken down into smaller, simpler, molecules with the release of energy and reducing power (electrons). This definition is simplistic - not all energy generating processes in bacteria involve the breaking down of larger molecules.

Anabolism

Synthesis of complex molecules from simpler ones to form cell structures, this requires energy and often a reduction of power. Generally speaking, all microbial metabolic functioning can be classified based upon the following three principles:

1. The manners via organisms derive carbon for the purpose of synthesizing cell mass:

- **Autotrophic** whereby carbon is obtained from carbon dioxide (CO_2)
- **Heterotrophic** whereby carbon is obtained from organic compounds
- **Mixotrophic** whereby carbon is obtained from both of the aforementioned methods: organic compounds and carbon dioxide

2. The methods by which organisms obtain reducing equivalents used during energy conservation or in biosynthetic reactions include:

- **Lithotrophic** whereby reducing equivalents are derived from inorganic compounds
- **Organotrophic** whereby reducing equivalents are derived from organic compounds

3. The method by which organisms derive energy so that it can both live and grow

- **Chemotrophic** whereby energy is obtained from external chemical compounds
- **Phototrophic** whereby energy is obtained from light

To further understand the metabolic process, we can take a look at the different types of energy inducing and releasing processes that exist.

While the overarching term 'metabolism' is defined as the sum of all chemical reactions occurring within a living organism, 'catabolic' reactions focus on reactions which are energy-releasing (exergonic). Hence, typically via hydrolysis, they break down more complex molecules into simpler components. The majority of organisms' chemical digestion processes tend to occur via this route.

In contrast with catabolic reactions, 'anabolic' reactions are energy-requiring (endergonic). Hence, via the process of condensation, out of smaller units, they tend to develop complex molecules.

Ironically, the energy need to produce an anabolic reaction is ALWAYS the by-product of a catabolic reaction. For this reason, anabolic and catabolic reactions are ALWAYS inescapably linked.

C. Adenosine Triphosphate (ATP)

As a result of any type of energy transfer, energy is ultimately stored in the form of Adenosine 5'-triphosphate (ATP) the energy -rich molecule. Known in the world of biochemistry as the 'molecular currency' of intracellular energy transfer, ATP's role is to transport chemical energy by and between cell structures.

An energy source that is generated during the processes of photosynthesis and cellular respiration. ATP can be produced by redox reactions using simple and complex sugars (carbohydrates) or lipids as an energy source.

However, so that ATP can be synthesized from complex fuels, it first needs to be broken down into its very basic forms: carbohydrates (hydrologized into simple sugars, i.e., glucose and fructose) and fats (triglycerides metabolized to yield fatty acids and glycerol).

Cellular respiration is defined as the overriding process by which glucose is oxidized glucose to form carbon dioxide. This process proves to be more than 40 percent efficient at transferring the chemical energy from glucose to the more useful form of ATP.

There are a range of different cellular processes through which ATP may be produced Within eukaryotic organisms, the three main pathways used to generate energy include: glycolysis (preparatory anaerobic process) followed by fermentation; the Kreb's cycle/oxidative phosphorylation (creation of energy transporters); and beta-oxidation (production of ATP either within aerobic or anaerobic conditions).

D. Energy Production Process

Before however we look further into the metabolic pathways used by bacteria to generate their energy requirements, we need to first review the major steps involved in the energy production (metabolic) process:

For starters, it helps to understand that three main tenets of Phosphorylation used by bacteria to produce ATP:

1. Conversion of ADP to ATP occurs when energy released via some metabolic reactions is trapped. Known as the process of 'phosphorylation', this chemical reaction is initially set off by the enzyme called ATP synthetase.
2. Substrate level phosphorylation occurs when ATP is formed directly by the addition of a phosphate to ADP. This activity occurs in both the processes of glycolysis and the Krebs cycle.
3. Oxidative phosphorylation occurs when energy (in the form of electrons) is released from oxidized organic compounds (e.g. glucose) and emitted to electron carriers.

Such electron carriers have the ability to enter a membrane-based electron transport system (ETS). With eukaryotes, the ETS and ATP synthetase occur on the inner mitochondrial membrane whereas with prokaryotes, it happened on the plasma membrane.

At this point, we now move on to discuss the nature of oxidation versus reduction. While both are types of reactions that commonly occur within biological systems, the distinction is that oxidation reactions release energy. Generally speaking, oxidation involves the loss of hydrogen atoms (in equal amounts to protons).

In contrast, reduction entails the entrapment of chemical energy. Reductions involve: the gaining of electrons and hydrogen atoms. Confusing are the terms for reduction tends to imply a loss of something.

However, if you are gaining electrons and hydrogen atoms, what exactly is being lost? Yet, if you look at it from the perspective that reducing agent needs to be a source of electrons then you can see why it is called a reducing agent-for it aides in oxidizing (reducing) other substrates.

Most microbes are heterotrophic whereby they use organic compounds as both carbon and energy sources. Heterotrophic microbes live off of nutrients that they scavenge from living hosts (as parasites) or find in dead organic matter of all kind (saprophages).

Posthumously, microbial metabolism is the main contributor to the bodily decay of all organisms.

Many eukaryotic microorganisms are heterotrophic because they act as predators (predation) or parasites (parasitism).

Examples of such organisms include: Bdellovibrio (an intracellular parasite of other bacteria, lethal it has the power to cause death to its victims) and Mycobacterium.

Note: Mycococcus -- which are predators of other bacteria that re killed and /or surrounded by swarms of large amounts of single cells of Mycobacteria).

The majority of pathogenic bacteria are classified as being heterotrophic parasites of humans or of other eukaryotic species on which they may affect.

Biochemically speaking, even though many prokaryotes share a common basic metabolic model with eukaryotes, the metabolism of prokaryotic heterotrophic organisms proves to be much more versatile than that of eukaryotic organisms/.

E. Glycolysis --The term Glycolysis is literally defined as 'sugar splitting.' Because it is the most common pathway for the breakdown or oxidation of glucose, it is typically the first stage in carbohydrate catabolism.

Glycolysis involves several distinct chemical reactions, each catalyzed by a different enzyme. Glycolysis (Embden-Meyerhof Pathway) is used by eukaryotic cells, as well as, many anaerobic and anaerobic bacteria.

The primary series of events that occur within gycolysis include:

- During the preparatory stage, the addition of two phosphate groups energizes the glucose. This step also alters the continued formation of glucose, for it forcibly retains it within the cell. The two molecules of ATP used to energize glucose, in turn, experience a subsequent split into two, three-carbon compounds.
- Glycolysis as an energy-yielding pathway is often the optimal method for it allows for a balanced distribution of nutrients throughout the organism.

F. The Krebs Cycle

The central function of the Krebs cycle is to capture beneficial energy in the form of electrons as it is carried by the two reduced coenzymes: NADH and FADH2.

G. Electron Transport Chain

The carriers of the electron transport system occur on the plasma membrane of bacteria.

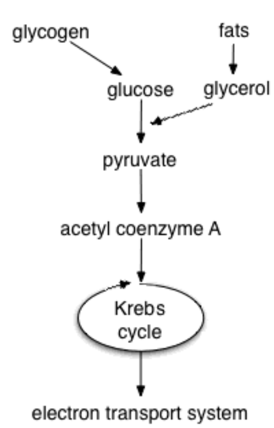
Energy carrying molecules of NADH and FADH2 donate their electrons to a series of coenzymes. The electrons are ultimately donated to a terminal electron acceptor, which in the case of aerobic respiration, is oxygen. The electrons are then are reunited with protons to form water.

Each carrier is reduced as it picks up electrons and oxidized as it passes them on (gives up energy)

Most ATP generated by aerobic respiration is by oxidative phosphorylation.

In prokaryotes, a total of 38 ATP is produced by aerobic respiration.

Cellular Respiration Flow Chart:



H. Chemiosmosis

Essentially, chemiosmosis focuses on the ways in which energy captures forms of ATP.

British biochemist Peter Mitchell is responsible for formulating the Chemiosmosis theory which proposes the mechanism by which electrons are siphoned off from the Krebs cycle and used as energy to produce ATP by oxidative phosphorylation.

A rule of thumb is that for each molecule of NADH entering this system, three molecules of ATP are produced.

I. Fermentation

The definition of Fermentation can take on many forms from simple concepts to more complex, scientific meanings. However, in 1988, Tortora in *Microbiology*, 6th Ed, 1998 defined fermentation as the following:

- *Any spoilage of food by microbes is viewed to be fermentation. For example, the spoilage of wine to vinegar is a very general usage of fermentation.*
- *Any process that produces alcoholic beverages or acidic dairy products (again general use)*
- *Any large scale microbial process occurring with or without air (industrial use)*
- *Any energy-releasing process that occurs only under anaerobic conditions (more scientific)*

Any metabolic process that releases energy from a sugar or other organic molecule, does not need oxygen or an electron transport system, and uses an organic molecule as the final electron acceptor. It is this last definition that we will use.

With regard to microbial metabolism, some other key points that to keep in mind include:

A complete fermentation pathway begins with a substrate (a substance upon which an enzyme acts or ferments) includes glycolysis and results in various end-products. The different fermentation pathways typically are named for the end products that are formed.

As far as an energy is concerned, though fermentation does not generate ATP directly it does recycle it a limited amount of NAD+ which in turn reverts back into glycolysis and serves to continue the glycolysis process. Note: All fermentation pathways are anaerobic.

Cells that are capable of both respiration and fermentation will typically use respiration when possible. Respiration yields more energy from a lot less substrate.

Lesson 5 – Assignment 1: Metabolism for Molecules

Name the two different types of microbial metabolism and define each.

Lesson 5 – Assignment 2: Energy Generator

Describe the function of the Krebs Cycle.