ANAEROBIC AND AEROBIC RESPIRATION

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Summary

Metabolism can be divided into two sections, namely catabolism, in which energy is harvested as chemical compounds are broken down, and anabolism, in which chemical compounds are synthesized. Cellular respiration is the process cells use to convert the energy in the chemical bonds of nutrients to ATP energy. Depending on the organism, cellular respiration can be aerobic, anaerobic, or both.

Fermentation is an anaerobic breakdown of carbohydrates in which an organic molecule is the final electron acceptor. Some fermentation end products produced by

micro-organisms are very beneficial to humans and are the basis of a number of industries (brewing, dairy, etc.). Anaerobic digestion for waste treatment involves the breakdown of organic waste by a mixture of bacteria. It is commonly used as a treatment process for household waste, waste from industries such as dairy and other food processing and sewage solids. It also produces a methane-rich biogas, which can be used to generate heat and/or electricity. The future of anaerobic digestion for the treatment of wastes is likely to be expanded.

Fermentation has always been an important part of our lives: foods can be spoiled by microbial fermentations, foods can be made by microbial fermentations, and muscle cells use fermentation to provide us with quick responses. Fermentation gives us the basic food, bread, alcoholic beverages and dairy products. Alcohol fermentation is carried out by many bacteria and yeasts. Fermentation has become widely used in several fields of commercial biotechnology, such as production of enzymes, food processing, waste management and antibiotics.

1. Introduction

Metabolism can be divided into two sections, namely catabolism and anabolism. Catabolism (reactions in which energy is harvested as chemical compounds are broken down.) refers to the exergonic process by which energy released by the breakdown of organic compounds such as glucose can be used to synthesize adenosine triphosphate (ATP), the form of energy required to do cellular work. Anabolism (energy-requiring reactions in which chemical compounds are synthesized) is the endergonic process that uses the energy stored in ATP to synthesize the building blocks of the macromolecules that make up the cell.

As can be seen, these two metabolic processes are closely linked. Another factor that links catabolic and anabolic pathways is the generation of precursor metabolites. Precursor metabolites (intermediate molecules in catabolic and anabolic pathways that can be oxidized to generate ATP or synthesize subunits of macromolecules) are intermediate molecules in catabolic and anabolic pathways that either can be oxidized to generate ATP or can be used to synthesize macromolecular subunits such as ammo acids, lipids and nucleotides.

Cellular respiration is the process cells use to convert the energy in the chemical bonds of nutrients to ATP energy. Depending on the organism, cellular respiration can be aerobic, anaerobic, or both. Aerobic respiration is an exergonic pathway that requires molecular oxygen (O_2). Anaerobic exergonic pathways do not require oxygen and include anaerobic respiration and fermentation.

The elucidation of metabolic pathways is a slow and tortuous process, usually involving many workers over a number of decades. The performance of a single, seminal experiment in which a number of jigsaw pieces are fitted together is a rare occurrence, but a biochemist named Hans Krebs achieved it when he described the tricarboxylic acid cycle, or citric acid cycle. Krebs, a German-born biochemist working in Britain, first postulated the mechanism in 1937, under the name *citric acid cycle*.

The work had already begun with a series of experiments in the early 1900s, in which Thunberg, Batelli and Stem worked on anaerobic suspensions of minced animal tissues.

They demonstrated that the tissues contained enzymes which could transfer hydrogen atoms from low molecular weight acids to other reduced compounds, such as the dye methylene blue. Methylene blue was used because the color change from blue to colorless that occurs when the dye is reduced is very easy to observe. Just a small number of organic acids were found to be active, namely citrate, fumarate, malate and succinate. Later on, it was further demonstrated that these acids could be oxidized in air to carbon dioxide and water.

Albert von Szent-Gyorgyi, a Hungarian (who later moved to the USA in 1947), extended these studies by describing a sequence of reactions for succinate oxidation, specifically from succinate to fumarate to malate to oxaloacetate. Von Szent-Gyorgyi further discovered that adding a small amount of malate or oxaloacetate stimulated the reduction of far more oxygen than was needed to completely oxidize the substance added.

He therefore postulated that the addition must trigger oxidization of some endogenous substance in the tissues, perhaps glycogen. This was later demonstrated, and von Szent-Gyorgyi and was awarded the Nobel Prize for Physiology in 1937 for his work on biological oxidation. Martius and Knoop later discovered another part of the sequence, from citrate to alpha-ketoglutarate to succinate.

In a succinct and conclusive series of experiments, Krebs then worked out the cyclic nature of the reactions using pigeon flight muscle. Like von Szent-Gyorgyi, he noted that only certain organic acids were readily oxidized by muscle, and found that the oxidation of endogenous carbohydrate or pyruvate could be stimulated by a number of specific acids, all of which proved to be substrates of the tricarboxylic acid cycle enzymes.

Krebs observed that malonate, which competitively inhibits succinate dehydrogenase, completely stopped the oxidation of pyruvate by the addition of organic acids, and so he concluded that the succinate to fumarate reaction must be a critical link in a chain of reactions involving all of the known catalytically active acids that can stimulate the oxidation of pyruvate.

Krebs also discovered the formation of citrate from oxaloacetate and pyruvate, the 'missing link' that allowed the known reactions to form a cyclic sequence. Adding malonate to muscle suspensions caused an accumulation of succinate in the presence of citrate, isocitrate, cis-aconitate or alpha-ketoglutarate. In the presence of fumarate, malate, or oxaloacetate, succinate also accumulated, clearly establishing a cyclic sequence leading to succinate.

Malonate poisoning also limited the ability of oxaloacetate to stimulate the oxidation of pyruvate; where one molecule of oxaloacetate could stimulate the oxidation of many molecules of pyruvate in the uninhibited system, only one molecule of pyruvate was oxidized per molecule of oxaloacetate in the malonate-poisoned system. Thus, pyruvate clearly entered a cyclic system of oxidation of substrates.

Proper names for the cyclic oxidation of substrates in the mitochondria matrix are ‘tricarboxylic acid cycle’ or ‘citric acid cycle’. It was not established until later that citric acid was indeed the first substrate formed from the reaction of pyruvate and oxaloacetate, so the cycle was called simply the tricarboxylic acid cycle for many years.

Now, both names are accepted, as well as the term '*Krebs cycle*.' Many people refer to the process as the Krebs cycle in recognition of the contribution of Hans Krebs to the discovery. Krebs was awarded a Nobel Prize in 1953 for his work on cell metabolism.

2. Cellular Anaerobic Respiration

Some prokaryotes are able to carry out anaerobic respiration, respiration in which an inorganic molecule other than oxygen (O_2) is the final electron acceptor. For example, some bacteria called soleplate reducers can transfer electrons to soleplate (SO_4^{2-}) reducing it to H_2S. Other bacteria, called nitrate reducers, can transfer electrons to nitrate (NO_3^-) reducing it to nitrite (NO_2^-). Other nitrate reducers can reduce nitrate even further to nitrous oxide (NO) or nitrogen gas (N_2).

Like aerobic respiration, anaerobic respiration involves glycolysis, a transition reaction, the citric acid cycle and an electron transport chain. The total energy yield per glucose oxidized is less than with aerobic respiration with a theoretical maximum yield of 36 ATP or less.

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Biographical Sketches

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Jo joined Rhodes University in 2002 after spending several years at Cranfield University in the UK, where

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Brett Pletschke obtained his PhD (Biochemistry) in 1996 at the University of Port Elizabeth, South Africa. He was subsequently appointed as a Postdoctoral Fellow/Chief Scientific Officer in the Departments of Chemical Pathology and Biochemistry at the University of Cape Town from June 1997 to Dec 1999. In January 2000, he accepted the post of Lecturer at the Department of Biochemistry, Microbiology and Biotechnology at Rhodes University. His research interests are in the field of environmental enzymology, and he is actively involved in conducting research on enzymes involved in the accelerated digestion of sludge under biosulfidogenic conditions and in the enzymatic monitoring of pollution in water.