

Fermentation

Slide 2 We have previously discussed oxidative, or aerobic, respiration, which produces ATP by the complete oxidation of glucose, and by using a proton gradient produced by electron transport. Oxidative respiration is dependent on oxygen as a final electron acceptor in its electron transport chain. There are many environments or instances, however, where oxygen is not available to cells or organisms. Consider, for example, the muddy bottom of a bog, or even your muscles when they are rapidly overworked. In both of these instances, oxygen supply is very limited in the immediate environment of living cells. In these and other similar situations, many types of cells are still capable of producing energy by a process called fermentation.

Slide 3 Fermentation is relatively common, and is found in virtually all types of organisms to some degree. Some organisms, such as certain types of bacteria, live in anaerobic environments and so produce energy only with fermentation. Other organisms, such as plants, animals, and fungi, are able to utilize either fermentation or oxidative respiration to some degree, depending on how much oxygen is present. Finally, there are even some organisms that inhabit aerobic environments, but are still only capable of fermentation, rather than oxidative respiration.

Slide 4 The actual pathway of fermentation consists of a short set of reactions immediately following glycolysis. Recall that glycolysis produces ATP, reduced NADH, and pyruvate. During fermentation, reduced NADH from glycolysis is used to reduce pyruvate. Pyruvate is reduced into ethanol or lactate. But why is it important to reduce pyruvate, especially when it could be further oxidized to produce more ATP, as happens in aerobic respiration?

When organisms are exposed to anaerobic conditions, oxygen is not available as a terminal electron acceptor. Without oxygen to accept electrons, the electron transport chain does not function, and NADH has nowhere to donate its electrons. Because of this, the pool of available NAD^+ is quickly converted to reduced NADH. Without NAD^+ as a substrate, glycolysis, the Krebs cycle, and ATP production will all come to a stop.

The NAD^+ produced by the oxidation of pyruvate during fermentation rapidly cycles back to participate again in glycolysis. In this way, cells can still perform glycolysis, and gain the ATP it produces, even in the absence of oxygen.

Slide 5 It should not be surprising that oxidative respiration and fermentation result in very different energy yields for a cell. A glucose molecule metabolized by oxidative respiration is completely oxidized to carbon dioxide through glycolysis and the Krebs cycle, and its energy is further transferred into a proton gradient used for ATP production. During fermentation, on the other hand, glucose is only partly oxidized to pyruvate through glycolysis, and then is reduced again by NADH. As you can imagine, the amount of ATP gained per molecule of glucose from oxidative respiration is much greater than that of fermentation. In fact, oxidative respiration generally results in around 18 times as much ATP per molecule of glucose as fermentation.

Slide 6 The reduction of pyruvate that occurs during fermentation may result in a number of different products, depending on what type of organism is being considered. In many organisms, fermentation produces either an acid or an alcohol. Two of the most common and well studied fermentative pathways, for example, produce lactate, or lactic acid, and ethanol and carbon dioxide. Fermentation resulting in lactate is common in bacteria, protists, fungi, and many types of animal cells. We notice this process when our muscles are worked too hard and too fast, and we feel the 'burn' associated with lactic acid buildup.

Fermentation resulting in production of ethanol and carbon dioxide is common in yeast and plant cells. The alcohol resulting from fermentation in yeast has been used for centuries to produce alcoholic beverages such as beer and wine. The carbon dioxide produced, on the other hand, is commonly used in baking to cause dough to rise.

Slide 7 So what happens to the ethanol or lactic acid produced by fermentation in an organism? Remember that these molecules started out as high energy glucose, and were only partly oxidized through glycolysis. In addition, they were reduced by NADH. This means that they still contain a fair amount of energy, which could be utilized by an organism. In fact, in many cases, the end products of fermentation are further metabolized to produce usable energy, either by the organism that produced them, or by another organism.