AN OVERVIEW OF METABOLISM[1]

On the earth, the ultimate source of energy for the maintenance, growth and reproduction of living things is the sun. Only photosynthetic plants and bacteria, however, are able to tap the sun's energy and turn it into chemical energy to power metabolic reactions. Plants and bacteria convert the sun's energy into carbohydrates and perhaps lipids in the process of photosynthesis and in so doing use solar energy, water and carbon dioxide. They release oxygen as a by-product of breaking down water and so are responsible for most if not all of the oxygen found in the atmosphere. By contrast, **respiration** is the process whereby both plant and animal cells break down carbohydrates or other compounds (usually lipids) to transfer the energy originally fixed in photosynthesis and convert it into compounds where it is more immediately useful.

Life requires significant energy expenditure. In order for decidedly non-spontaneous processes such as growth, synthesis and movement to occur, these processes must be **coupled** to and driven by processes that produce very large changes in entropy. Thus, the second law of thermodynamics remains true and the amount of disorder or improbability that is produced must be more than paid for by creating disorder elsewhere. The most common way to drive unfavorable processes is by using energy.

In most cases, the immediate source of energy to drive synthesis and movement (the so-called **"DEMAND" REACTIONS**) is the transfer of the outer-most “high-energy” phosphate of ATP (or some other NTP) to another molecule. Such a transfer will cause the recipient molecule to undergo an **allosteric change** and perhaps also make the recipient molecule unstable and more reactive. We commonly think of this process as the hydrolysis of ATP:

1. $ATP + H_2O$ -------> ADP + Pi - energy

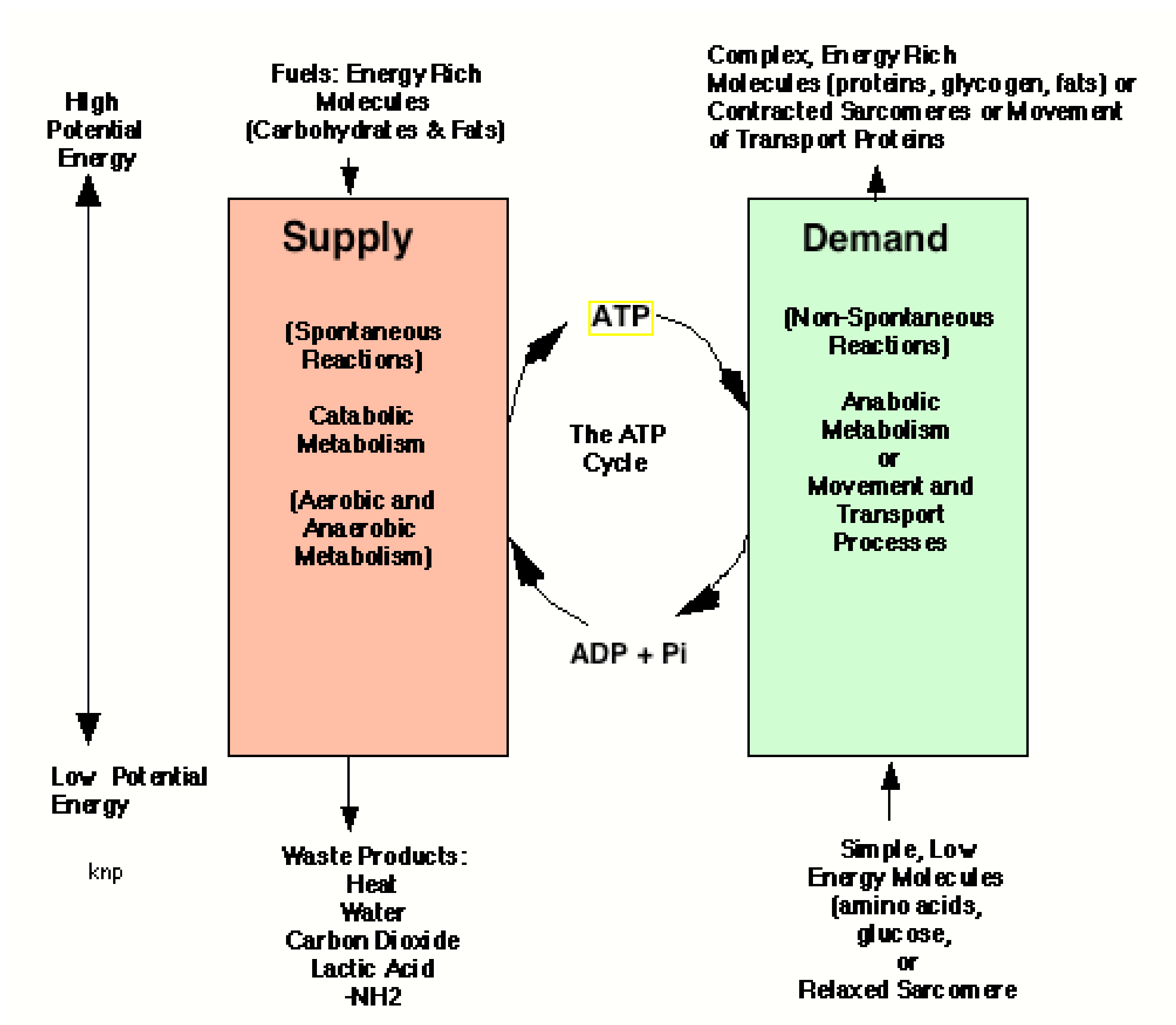
Please note that eq. 1 can mislead you into thinking that ATP is used to drive reactions by releasing energy near some target molecule. Nothing is further from the truth. More about this later.

In any case, ATP is used in a great many reactions. However, the total amount of ATP found in any given cell is very small. For example, the amount in muscle cells could sustain perhaps one second of maximal contraction at best. So, ATP (and other NTPs) must constantly resynthesized by what we can refer to as the **"SUPPLY" REACTIONS**:

2. ADP + Pi + energy ---------> $ATP + H_2O$

where the energy required for the synthesis is supplied by the supply reactions (also known as catabolic processes).

The **ATP CYCLE** links the two great processes of metabolism. We will see that the demand side is controlled entirely by necessity -- the need of the organism to synthesize compounds, the need to move, or to transport ions. So, it will be the **role of the supply reactions to speed up or slow down so that the *ratio of ATP to ADP remains within acceptable limits***. In short, **the supply reactions regulate ATP concentration so that demand reactions can always occur when needed at whatever rate that is needed (within limits, of course**). Here is the overview:



To keep things reasonably simple, the following discussion will only deal with the breakdown of glucose or glycogen (recall that glycogen is a branched polymer of glucose) to yield energy. In the case of biologically important molecules, maximum amounts of energy are released by process that somehow involves combining fuel molecules with O_2 to yield CO_2 and H_2O as waste products. For any hexose such as glucose:

3. $C_6H_{12}O_6 + 6\ O_2$ ------------> $6\ CO_2 + 6\ H_2O$ - 686 Kcal (= 2872 kJ)

Thus, **if a cell totally oxidizes 1 mol of hexose, then up to 686 Kcal of energy are available for it to use in "demand-type" reactions**. Now, in organisms the way this really works is that up to 686 Kcal are available to be used to make ATP from ADP and Pi (see eq. 2). The ATP will then be used in the demand reactions.

In non-living systems, reaction #3 would most likely occur as violent combustion. In such a reaction, the hexose is broken down more or less at random. In such an uncontrolled process there are many possible ways that the glucose molecule can be broken down and react with oxygen. Put another way, there is no well-defined pathway for the reaction -- many paths are followed in the breakdown, each of which occurs at some frequency. **By contrast, in a living cell the breakdown is a highly ordered affair**. There is **an exact sequence in which reactions occur involving about 29 separate steps** some of which are used only once per molecule broken down and others are used many times. Thus, small parts of the molecule and small amounts of energy are involved in each step. **The biological process is like a DISASSEMBLY LINE whereas combustion is essentially an explosion**.

The reason that cellular respiration is so ordered is that each step of the breakdown process is controlled by a specific type of enzyme. The product of the reaction catalyzed by one enzyme becomes the substrate for another. Thus, an interlocking series of reactions results that always disassembles a molecule exactly the same way -- via the same path we say. This leads to the name "**BIOCHEMICAL PATHWAY**". A biochemical pathway describes a series of inter-linking reactions, whether catabolic or anabolic, with some function to the organism. **Each particular step of the pathway is controlled by single type of enzyme** analogous to a single, specialized worker on a factory assembly line.

Typically the demand (catabolic) reactions are considered to be either **anaerobic** (in which case they do not require oxygen) or **aerobic** (O_2 requiring). The operation of these two and their roles in different organisms will be out next topics.