

Energetic Transference Occurring in the Biosphere Part I

Researched and Composed by Jacob Wilson, BSc. (Hons), MSc. CSCS. and Gabriel "Venom" Wilson, BSc. (Hons), CSCS.

Abstract

The anaerobic energy pathways govern in large part the capacity for peak performance during supramaximal exercise. Within this framework, capacity, power, and the time continuum will be discussed. Further, each step in the glycolytic pathway will be carefully analyzed, from reactants, to products. Additional attention will be partitioned to eleven specific enzymes responsible for the direction, and speed of glycolysis. Finally, techniques used to measure anaerobic energy systems will be reviewed.

Introduction

The purpose of this paper was to review the concepts of bioenergetics and the laws that govern energy transfers. Bioenergetics can be defined as the study of all energy transfers in biological systems.

In order to understand energy transfers within the biosphere (with a special interest in human beings), the reader must grasp several correlated concepts. The first three deal with systems, surroundings, and the universe. A system can be defined as a functional unit or a particular object or set of objects. This term can refer to a cell, organ, or the reader of this paper. Further, the system can be closed or open. When closed, the mass of the system is constant; when open, mass may enter or leave. The reader has no further to look for an example of an open system than the bodybuilder; namely in the off-season. The surroundings or environment constitute everything outside of the system. Finally, the universe is defined as the system combined with its environment.

First and Second Law of Thermodynamics

Thermodynamics deals with processes in which energy is transferred as heat or work. The first law of thermodynamics is the law of the conservation of energy. That is, in any energy transfer, energy is neither created nor destroyed but only changes in form. Energy is defined as the capacity to do work; therefore the body cannot create energy, but can instead transfer one form into another form. The potential energy (energy by position) held between the bonds of an ATP molecule can be transferred to kinetic energy or energy of motion. However, this leads into the second law of thermodynamics. The second law of thermodynamics states that no energy transfer is 100 percent efficient. Thus, when an athlete performs work (curling a barbell) the reaction which catalyzes $\text{ATP} \rightarrow \text{ADP} + \text{P}_i + \text{energy}$ will not be 100 percent efficient. That is, the energy can be fractionated into useable energy (kinetic) and non-useable energy (heat).

As a result of the second law, it can be stated that the entropy of the universe always increases in any energy transfer. Ludwig Boltzmann, in the 1800s, is said to have discovered entropy, which states that processes go toward a state of randomness. Entropy is denoted by the symbol 'S,' therefore training, which speeds energy transfer rates, tends to accelerate the randomness in the universe as heat is rapidly released into the environment.

A notable consequence of increased work production is therefore an increase in temperature. For a full review of thermoregulation, see King (2004, [Thermoregulation](#)). The reader should understand that temperature is positively correlated with enzymatic reactions in biological systems. Further, temperature is frequently measured in multiples of 10 (Almeida-Val, 1994, Bennett, 1984, Rall et al., 1990, Rome, 1990). The change found as temperature increases by 10 degrees Celsius is known as the Q_{10} effect. Enzymatic activity doubles with each multiple of 10 increase. Therefore, though an athlete cannot utilize heat directly, it can be used indirectly. Further, when dieting, the inefficiency of energy transfer is quite advantageous. To understand why, efficiency needs to be clearly reviewed. Efficiency is related to the concept of work. Work done on an object by a force is defined as the product of the magnitude of the displacement multiplied by the component of the force parallel to the displacement (Giancoli, 1989). In simple terms, work is equal to force multiplied by distance. Therefore, if an athlete were to ride on bicycle ergometer, the investigator would first need to measure the circumference of the wheel and then multiply this by the revolutions per minute for the number of minutes the exercise was performed. Finally, the resistance provided by the flywheel would need to be calculated. This is measured in kilograms (or kiloponds). As an example:

Circumference of wheel = 5 meters

Revolutions per minute = 60

Total Minutes of Exercise = 20 minutes.

Resistance = 3 kp

Work = 3 X (60 X 5 X 15) = 13,500 kilogram-meters.

Note: 1 kilogram-meter is the amount of work done when moving one kilogram a distance of 1 meter.

The work performed was therefore equivalent to 13, 500 kilogram-meters. Energy is required to perform work; in fact, energy is defined as the capacity to perform work and is measured in calories. One calorie is the amount of energy it takes to raise one gram of water 1 degree Celsius. Conversion factors allow the investigator to calculate the amount of calories needed to perform a specific quantity of work. It is known that 0.00234 Kilocalories are needed to perform one kilogram-meter of work. Therefore all that needs to be done is to multiply this conversion factor by the amount of work done like so:

$13, 500 \times 0.00234 = 31.59 \text{ kcals}$

Therefore in 20 minutes, if the body was 100 percent efficient, the participant would have metabolized approximately 32 kcals, and that is at a substantial work rate! If they continued for 3 hours they would only have burned 192 calories, which is

absolutely nothing! However, as stated, the athlete is not 100 percent efficient. In order to find efficiency, the oxygen consumed must be measured, as it is required for energy production. In the above example, a typical O₂ consumption may have been 1.90 liters of O₂ per minute. Using another conversion factor, liters of O₂ can be converted to calories metabolized. This measurement is known as indirect Spirometry. Direct Spirometry would be to measure the amount of heat dissipated (See Wilson, 2004: [Acute & Chronic Endocrine Responses to Exercise](#)). Once the amount of O₂ consumed is found, you multiply it by the conversion factor 5.047 Kcal. This is due to the fact that for every liter of O₂ consumed, 5.047 Kcals are used when carbohydrates are the source of fuel. To illustrate the point:

$(1.90 \text{ liters a min} \times 5.047) \times 20 \text{ minutes of exercise} = 192 \text{ calories}$

To find the efficiency of the activity, you simply divide the actual calories utilized into the calories needed to perform the work, like so:

$32 / 192 = 0.16$

Multiply this by 100 to get a percentage and you get 16 percent efficiency. Therefore this particular athlete would have actually burned 192 calories. The energy not used to perform work was dissipated as heat, which adheres to the second law of thermodynamics.

Further, the above calculation of efficiency is known as 'Gross Efficiency.' If resting energy is factored in, the efficiency of the task would be slightly higher, but the point is clear.

What is interesting to note is that various activities can be performed at optimal efficiency, and suboptimal efficiency. By manipulating this variable, the athlete can actually increase the amount of calories utilized to perform the task! As an illustration, performing a stationary bike at 109 % of leg length is the most efficient way to perform the task. Variance from this will lower the efficiency correspondingly.

Reactions

Energy transfers can be fractionated into exergonic and endergonic reactions. Exergonic reactions release energy into the environment and are also called spontaneous reactions. When this results in the release of heat, it is an exothermic reaction. An endergonic reaction is one in which energy is absorbed; this is also called a non-spontaneous reaction. Spontaneous refers to a process that will occur on its own without added energy. Non-spontaneous reactions require energy; that is, endergonic or energy-consuming reactions are coupled to exergonic or energy-releasing reactions. For example, the splitting of ATP to ADP + Pi + energy + heat is an exergonic (specifically exothermic) reaction which can be used to phosphorylate free creatine to creatine phosphate or CP. The energy state of the reactant creatine is lower than the energy state of the product creatine phosphate, and is therefore classified as being endergonic. The energy state of products ADP + Pi is lower than the energy state of the reactant ATP, and is therefore classified as an exothermic reaction. However, when ADP is phosphorylated, it absorbs energy and the reaction is exergonic.

The measure of the heat content of a substance is known as 'Enthalpy.' Enthalpy is denoted by the symbol 'H.' (note: Enthalpy can also be defined as the internal energy of a system + the product of V and Pressure.) This paper is concerned with a concept known as change in enthalpy. Change in enthalpy is denoted as ΔH , where Δ is the Greek letter delta, and stands for change. Of prime importance to biological reactions is the concept of free energy. Free energy is the amount of energy in a substance that can perform work. Free energy is denoted by the symbol G, named after Willard Gibbs, who is a father of bioenergetics as it is understood today. The greater the free energy, or available energy, the greater amount of work that can be done.

During a reaction, the change in enthalpy is equal to a change in entropy + the change in free energy. Or:

$$\Delta H = G + S$$

These concepts have extreme importance in understanding bioenergetics. First, recall that in any reaction, entropy, or randomness of a system, increases. Further, energy is neither created nor destroyed but only changes form. Therefore, when exercising, the change in enthalpy results in more and more unavailable energy and less and less free or available energy. This energy will need to be replaced at some point if activity is to continue. An additional concept that should be understood is that of equilibrium. A reaction has reached equilibrium when change in enthalpy is equal to zero available energy + entropy. That is, entropy in the reaction has peaked. Therefore, the greater the separation the reactants are from equilibrium, the greater the amount of free energy available to perform work will be. As an athlete trains, the amount of available energy continually decreases, and the amount of entropy increases. Of course the athlete should be sensitive to how that energy is stored, how quickly a particular form of potential energy is depleted, and how quickly it is replenished. An interesting term used to describe the form of energy used while training is known as Respiratory Exchange Ratio (RER). The Respiratory exchange ratio is defined as the amount of carbon dioxide produced divided by the quantity of oxygen consumed.

$$CO_{2\text{produced}} * O_{2\text{consumed}}^{-1}$$

The ratio gives the experimenter information in regards to fuel utilization during exercise.

The RER is a reflection of the chemical composition of the three varying substrates; that is carbohydrates, lipids (fats), and proteins. Reliance on 100 percent carbohydrate produces a ratio of 1.0. As an illustration:

Glucose ($C_6H_{12}O_6$) \rightarrow Utilizes 6 molecules of O_2 \rightarrow Resulting in production of 6 molecules of CO_2

$$6 CO_{2\text{produced}} / 6 O_{2\text{consumed}} = 1.0$$

The RER when fat is being used 100 percent of the time is approximately 0.7, while the ratio of protein at 100 percent is 0.8. From this the reader should understand that carbohydrates are the most efficient fuel during exercise, as they require less

oxygen to metabolize than fat or protein. However, fat has a greater store of potential energy.

Further, by obtaining the RER the investigator can know what percentage of fuels are used during specific exercise sessions and match their diet specifically to that ratio.

There are various forms of exercise, which can be fractionated into submaximal continuous, interval, supramaximal, isometric, and dynamic. Submaximal is in reference to the percentage of V_{O_2} max utilized. V_{O_2} max is defined as the highest amount of oxygen a participant can take in, transport, and utilize to produce ATP aerobically while breathing air during heavy exercise; therefore submaximal would be a fraction of the maximum. For example, biking lightly would be anything below 50 % V_{O_2} max. Intensity is the term to describe the level at which the participant trains relative to their maximum level of V_{O_2} . The higher the percentage of V_{O_2} max, the greater the intensity.

Supramaximal is work performed above 100 % V_{O_2} max. The higher the level is above maximal, the greater the reliance on anaerobic energy sources, and the shorter the activity can continue, as will be explained in the energy continuum aspect of this series. Isometric exercise refers to a stationary contraction of the musculature in which neither shortening or lengthening occurs, while dynamic is in reference to external resistance training with varying movements.

In general, the lower the athlete is in submaximal work loads, the closer the RER will be to 7.0, and the closer the individual is to maximal the closer they will be to a RER of 1.0. In fact, one of the criteria for a maximal V_{O_2} max testing is an RER of 1.0. As a second generality, a longer duration may lower the RER; that is, the session will progressively rely on fat stores as duration lengthens. External resistance training will yield an RER of approximately 1.0, for reasons seen when discussing glycolysis. The main carbohydrate source utilized during max exercise is glycogen. In fact, there is a high correlation between glycogen storage and duration and intensity while external resistance training (Wilson, 2004, Pre Contest Preparation). It is for this reason that carbohydrates should be a major food source for bodybuilders, or any athlete who relies on an RER of 1.0. Further, the fallacious protocol of fat and fiber post-workout, combined with fructose seems even more ludicrous in this light. This is due to the fact that the participant is utilizing a replacement cocktail which quite simply does not replace what was used! For a full review of the fallacy of post-workout suicidal strategies, see Knowlden (2004, [Scientific Investigation into Post Workout Meal](#)).

A further consequence of thermodynamic principles is the topic of mass gain. As stated, the bodybuilder is an open system. Since entropy is constantly increasing, it follows that for the many endergonic reactions which occur to build macromolecules such as contractile tissue, a number of exergonic reactions are also occurring in which the net effect is greater disorder of the universe for greater order of the system itself. Further, if the system expels more energy than is consumed, then the end result will be an overall lowered availability of stored energy in the body, with the intent of that stored energy being taken from subcutaneous tissue. However, the equation is not as simple as it may sound. To effectively diet, participants in the dieting program should understand at what moments energy will be consumed to its greatest extent. In the case of mankind, the answer is the basal metabolic rate, or the amount of calories utilized to maintain a resting state. In fact, the basal

metabolic rate accounts for 70 percent energy expenditure. It is prudent to therefore maintain or even increase this rate at all costs.

Energy Production Pathways and Mechanisms of Phosphorylation

Biological work is fueled by three distinct energy pathways. That is, the exergonic energy yielding reactions afforded by the hydrolysis of ATP are provided by the phosphagen system (A Lactic Anaerobic), glycolysis (Lactic Anaerobic), and oxidative phosphorylation. The Phosphagen system and glycolysis are classified as anaerobic pathways, in that they are not reliant on oxygen, while oxidative, as the name implies, does depend on O₂.

ATP, or adenosine triphosphate, is a high-energy compound, in which potential energy is stored between chemical bonds. The process of adding a phosphate group to an adenosine diphosphate group is known as phosphorylation. Knowlden (2004) suggests that a more appropriate term is 'charging.' This charging effect is attributed to the very nature of the ATP molecule, which is classified as a nucleotide. It is classified as such as its constituents fit the definition. That is, the structure is composed of the nitrogenous base -adenine, the sugar ribose, and a tri set of phosphate groups.

The bonds between phosphate groups require energy to form, as the actual groups themselves repel each other through a negative charge mechanism. However, the nucleotide ADP and Pi are designed in such a way that electrons can be shared so as to reduce energy states when bonded. The reduced energy states formed are known as resonance hybrids, a process which reverses when the phosphate group is removed. The effect is similar to the loading of a dart gun. Energy is required to load the dart into a gun and overcome the repelling forces provided by the spring mechanism. Energy is then released as the trigger is pulled.

Anaerobic pathways work through a process known as substrate level phosphorylation. This refers to a process where one molecule directly donates a phosphate group to a second molecule. However, aerobic metabolic pathways operate through oxidative phosphorylation. This process utilizes a complex structure known as the electron transport chain, which is able to harnesses energy via a process known as chemiosmotic coupling (discussed in detail in future issues; however, for a review see Knowlden, 2003, [Eight Weeks To A Freakier Tibialis](#)) to provide the energy capable of phosphorylating ADP.

Control of the Rate of Energy Pathways

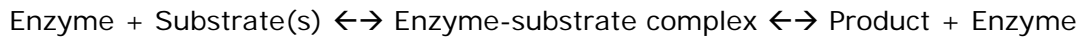
The rate of pathway operation is dependent on enzymatic catalytic activity. The human body is designed to react quickly to various energy demands, and therefore enzymes are highly adaptable to both acute and chronic demands placed on the physiological parameters. An enzyme is a complex that speeds or catalyzes a reaction without actually being affected by the reaction itself.

As was mentioned, spontaneous reactions will occur in a downhill manner, or without added input. However, the processes that promote these exergonic reactions are too slow to keep up with the maintenance of homeostatic function in the biological organism. Though these reactions occur spontaneously, they also require the input

of energy. At first this seems contradictory, but it is quite the opposite. Molecules are always in a state of random thermal motion. As they randomly move, collisions occur, which affords the energy required for the reaction to take place.

The energy barrier, which must be overcome, is known as 'Activation Energy.' Enzymes are able to lower the Activation Energy drastically, thereby increasing the rate of reaction.

A diagrammatical format of how enzymes react with substrates is as follows:



Note that in the above diagram the reactions are reversible. This is an important concept, in that it signifies the fact that if the enzyme does not have a high enough affinity for the substrates, it will not be able to interact with it long enough to provide the mechanisms responsible for the release of a product. Affinity refers to the binding capability that an enzyme has for the substrate. Chronic adaptations in enzymes actually increase the affinity of the complex to the substrate, thus enhancing the direction of a reaction. It also shows that enzymes have the capability of binding reversibly to a product, and re forming the original substrate. For example, the enzyme Lactate Dehydrogenase can bind pyruvate, and two hydrogens to form Lactic Acid. However, it can also reversibly bind Lactic acid to release the products of pyruvate and 2H^+ .

Pathways such as glycolysis are regulated by a number of enzymes responsible for each step in the process. Interestingly enough, enthalpy is measured collectively over each of these steps. According to Hess's Law, if a process can be written as the sum of several steps (i.e. glycolysis), the enthalpy change of the process equals the sum of the enthalpy changes of the individual steps.

The rate at which enzymes function is dependent upon the catalytic rate, affinity, enzyme concentration, and substrate concentration. The former have briefly been discussed. Enzyme concentration is another example of a chronic adaptation to exercise stress. That is, specific enzymes increase in concentration specifically to the demands placed on the system. This will be discussed in metabolic adaptations further in the series. Substrate availability can be regulated acutely by the athlete. For example, after training, the greater the supply of glucose provided to the musculature, the higher the synthetic rate of glycogen via the enzyme glycogen synthase. Further, during exercise, the greater the concentration of glucose in the cell, the faster the rate of glycolysis will be. And the faster the rate, the greater the athlete's performance in weight training activities will be. This supply of glucose is increased through diet and through endogenous hormone secretion during training. For example epinephrine will stimulate the breakdown of glycogen, which increases glucose concentration.

Enzymatic Regulation through Allosteric Reactive Mechanisms

When enzymes contain binding sites for molecules, which are not substrates, they are known as covalent enzymes. When they contain more than one binding site, they are referred to as multivalent enzymes. The molecules that bind are known as modulators, and can either be inhibitory or excitatory (increase catalytic rate). Enzymes are able to bind certain substrates because of their specific shape. When

bound to a modulator, the enzyme undergoes a shape change known as a conformational change, or allosteric reaction. Like substrates, modulator regulation is directly correlated to the concentration of the modulator itself. Further, the binding is again reversible and therefore subject to the law of mass action, which states that as reactants increase relative to products, the reaction will further increase the proportion of products. In this case, however, the time that the modulator molecule is bound will increase.

Rate Limiting Enzymes

A rate-limiting enzyme can be defined as an enzyme whose activity is directly proportional to the rate of an entire series of enzymatic reactions contained within an energy pathway. One such enzyme is Phosphofructokinase (PFK), which is an allosteric enzyme. As its rate increases, the rate of glycolysis itself increases. When muscular contraction increases, by necessity the byproducts of that contraction increase. ADP and Pi increase from the hydrolysis of ATP, and AMP increases through the use of the phosphagen anaerobic system. These byproducts bind to PFK and act as excitatory modulators. However, when ATP and CP stores increase, they act to inhibit PFK. This makes sense, as the need for energy production via glycolysis is lowered.

The implication is that rapid breakdown of ATP via muscular contraction leads to rapid increases in glycolysis through such mechanisms, as well as the Q-10 effect, enzyme concentration, and substrate concentration.

Final Thoughts

Interestingly enough, the Bible discussed the second law of thermodynamics millenniums ago. The Apostle Paul states:

Hebrews 1:10-12

10 And, Thou, Lord, in the beginning hast laid the foundation of the earth; and the heavens are the works of thine hands: **11** They shall perish; but thou remainest; **and they all shall wax old as doth a garment; 12** And as a vesture shalt thou fold them up, and they shall be changed: but thou art the same, and thy years shall not fail.

The Universe is decaying (entropy is increasing to a maximum) on a daily basis. Indecently, this fact demolishes the religion of evolutionism.

The law of cause and effect states that every effect must have had a cause, and the definition for cause here is the chief agent causing something to be made. So if one were to punch a dent into a wall, the cause would be the participant's fist and the effect was the dent in the wall. To state that a dent came about without a cause would be to go against all logic. Professor W.T. Stace (1934), in his *A Critical History of Greek Philosophy* states:

Every student of logic knows that this is the ultimate canon of the sciences, the foundation of them all. If we did not believe the truth of causation, namely, everything which has a beginning has a cause, and that in the same

circumstances the same things invariably happen, all the sciences would at once crumble to dust. In every scientific investigation this truth is assumed (1934, p. 6).

Therefore, if it can be shown that the universe had a beginning it must have had a cause (creator). And the evidence clearly points to this. As discussed previously, the first two laws of thermodynamics state:

- 1st Law: The total amount of mass-energy in the universe is constant.
- 2nd Law: The amount of energy available for work is running out, or entropy is increasing to a maximum.

If the total amount of mass-energy is limited, and the amount of usable energy is decreasing, then the universe cannot have existed forever, otherwise it would already have exhausted all usable energy. Therefore, the universe had to have had a beginning.

- Everything which has a beginning has a cause.
- The universe has a beginning.
- Therefore the universe has a cause

Further, Einstein's general relativity shows that time is linked to matter and space. Therefore time itself would have begun along with matter and space. The Bible discusses the cause of the universe, and the origin of time, space, and matter:

Genesis 1:1-2

1 In the beginning (**time**) God created the heavens (**space**) and the earth (**matter**).

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