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A Review Paper of the Laws of Thermodynamics to Apply the Human Bodies

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Abstract- The Second law governs changes that act in the direction in which entropy increases. We will now see through a detailed examination how the laws of thermodynamics relate to the energetic of the body. Metabolism involves the chemical processes in the body in which energy is transferred between various chemical compounds and in which thermal energy is generated. If the rate of metabolic reactions increases, then the rate of energy generation also increases. People require certain amounts of energy to achieve certain tasks. This has implications, for example, for athletic performance and survival. A sedentary man can produce energy of the order of 0.07 kJkg-1min-1 (which is about 80 W for a 70 kg-man).

Key word –Laws of the thermodynamics, Energy, Metabolism

Introduction

Metabolism is the total of all the chemical processes that occur in the cells of a body. It consists of anabolism in which molecules are built-up and catabolism in which enzymes break down the food consumed through hydrolysis, and at the cellular level involves the process of *phosphorolysis*. The *basal metabolic rate* (BMR) is the rate at which a fasting, sedentary body generates sufficient energy to achieve the vital functions of respiration, maintaining the body's temperature, the heart beat and production of tissue. BMR is approximately equal to the metabolic rate while sleeping, and while resting most of the energy is dissipated as thermal energy. BMR can be calculated using direct calorimetry or by use of a spirometer, which measures the oxygen consumption per unit time. In the calorimetric method, a person is placed in a chamber through which there are pipes carrying water. The amount of energy produced can be determined from the energy gained by the water passing through the pipes. In spirometer, the energy generated is related to the amount of oxygen taken in during respiration, and thus the metabolic rate measured.

Experiment

We assume that for a man, BMR is about 170 kJm-2h-1, and is 155 kJm-2h-1 for woman. Thus for a man of about 1.8 m2 surface area, this would make 7300 kJ per day or about 85 W. During the day, in addition to the basal requirements, energy will be required for mechanical work and physical exercise. Typical energy dissipations are: sleeping: 75 W, sitting: 80-100 W, walking: 150-450 W, running hard: 400-1500 W. The average person needs an additional 4200 kJ for a 'normal' working day; thus making a total requirements of about 12000 kJ per day. Since carbohydrates provide about 17 kJ/g, proteins 38 kJ/g and fats 17 kJ/g, by adjusting the various amounts this figure can be attained. Metabolism involves the chemical processes in the body in which energy is transferred between various chemical compounds and in which thermal energy is generated. If the rate of metabolic reactions increases, then the rate of energy generation also increases. People require certain amounts of energy to achieve certain tasks. This has implications, for example, for athletic performance and survival. A sedentary man can produce energy of the order of 0.07 kJkg-1min-1 (which is about 80 W for a 70 kg-man).

We have been examining the diet chart following age group: 5 to 15, 16 to 30, 30 to 45 and 45 to 60.

Thermodynamics and the human body

Humans breathe in oxygen and eat food, which is composed of carbohydrates, fats, oils and proteins. The carbohydrates are converted into glucose, the proteins into amino acids, and the fats into fatty acids. The blood then transports these, together with oxygen, to the cells, where enzymes, which are biological catalysts, convert the glucose into pyruvic acid, through the process of glycolysis. The fatty and most of the amino acids are converted into acetoacetic acid. These are changed into acetyl Co-A, and with further oxidation, produce adenosine triphosphate (ATP), carbon dioxide and water. This entire process is called the *Krebs Cycle*.ATP generates the energy that could be potentially used by the cells. The energy is stored in the phosphate bond when adenosine diphosphate (ADP) is transformed to adenosine triphosphate, and is dissipated when ATP is converted into ADP. When the energy is released it takes the form of heat, and this is transferred by the blood, around the body. Energy is also transferred from the cells to their surroundings by conduction because of the thermal gradient created between the cells and their environment. Thermal energy loss from the body is achieved through conduction, convection, radiation and evaporation from the skin, and through respiration. In humans energy is transferred to the surroundings at the skin's interface with the air outside. Since cooling results, this implies that a temperature gradient exists between the body's core and the skin's surface. This body temperature is stable as long as the production of energy equals the energy loss. Living organisms are also thermodynamics entities, in which thermal processes are characterized by energy flows and fluxes both within the body, and between the body and its environment. For people to survive, the core body temperature has to be maintained within a narrow temperature range of 35-400C. The normal body temperature is 370C. However, this is the core temperature. There is a temperature gradient as one move away from the core. Hence, not only is there a temperature drop between a person and their external environment, but also there is one within the body. What is the relevance of physics in a discussion on energy and metabolism? Physics underpins the biochemical processes that provide us with energy. Although this chapter is not concerned with biochemical processes, we will look at how physics, through the laws of thermodynamic, relates to metabolic processes.

First law of thermodynamics and the human body

For an energy balance, under steady-state conditions where the core body temperature and the ambient temperature remain constant, the quantity of energy produced will equal the quantity of energy dissipated. Hence, it is possible to invoke the First law of thermodynamics to the body. The total energy produced in the body is called the *metabolic rate* ($\mathrm{d}M$). It is related to the total metabolic energy production of the body ($\mathrm{d}H$), and the external work done by the body ($\mathrm{d}W$), by the expression:

$$\mathrm{d}M = \mathrm{d}H + \mathrm{d}M.$$

There is an obvious analogy if this is compared with the expression for the First Law. $\mathrm{d}H$ varies from one person to another, and depends on the activity engaged in, and on, the body's surface area. On average, the body's surface area is about 1.84 m2, the average male mass is 65-70 kg and the average female mass 55 kg. For a sedentary person the metabolic rate is about 100 W, and is 400 W for a person engaged in heavy physical work. Energy transfers in metabolic processes are governed by the First law of thermodynamics, and the Law can be applied to determine the quantity of energy that can be generated. If no mechanical work is done ($\mathrm{d}W = 0$), then the chemical energy input will be transferred as thermal energy, i.e. $\mathrm{d}H = \mathrm{d}U$ is the energy produced by the oxidation of the chemicals, and the total $\mathrm{d}H$ is the mass of the chemicals oxidized times $\mathrm{d}H$.

Second law of thermodynamics and the human body

If a metabolic process occurs in a particular direction, does it also occur in the reverse manner? The Second law helps to explain both the direction and attainment of equilibrium in metabolic processes, and now it can be seen that the entropy change can assist in the understanding of the direction that a metabolic process will take. It also tells us whether that particular process will occur. In the oxidation of glucose amount of energy is 'wasted'2. Thus, the process is not 100 % efficient. The 'waste' is the production of energy as heat – a prerequisite for maintaining the core body temperature. This 'wasted' energy is the driving force for the direction in which a metabolic process should go. The idea of potential energy is a useful direction it will occur. If one drops a body, its potential energy is transformed into kinetic energy and then into heat, sound and, possible, light. As a result, the entropy of the surroundings (i.e. Universe) will increase. The change in entropy is a function of the energy transferred from the body. If the entropy tells us the direction of a spontaneous change, it would be useful to develop the criteria, from energetic considerations, for the propensity of a system to provide 'free energy' to do useful work. The criterion is provided by the idea of the, Gibbs *free energy*, *G*. Since the First law o thermodynamics can be represented as $\mathrm{d}Q = \mathrm{d}U + p\cdot \mathrm{d}V$,

where p and $\mathrm{d}V$ is the pressure and the change in volume, and the Second law by

$$\mathrm{d}S = \mathrm{d}Q/T, \text{ then}$$

$$T\cdot \mathrm{d}S = \mathrm{d}U + p\cdot \mathrm{d}V,$$

Where $\mathrm{d}S$ is the change in entropy related to a change in energy, $\mathrm{d}Q$. Therefore, the change in internal energy is

$$\mathrm{d}U = T\cdot \mathrm{d}S - p\cdot \mathrm{d}V.$$

This is the Gibbs equation. It incorporates the idea of temperature, it embraces the Zeroth, the First and Second laws of thermodynamics. The temperature is a central Characteristic of a thermodynamic system. It can be applied to any physical systems (and to the biophysical system that is the human body).

Using the definition of enthaly, $H = U + pV$, we have

$$\mathrm{d}H = \mathrm{d}U + p\cdot \mathrm{d}V + V\cdot \mathrm{d}p = T\cdot \mathrm{d}S + V\cdot \mathrm{d}p.$$

Now, we define the Gibbs free energy, *G*, as

$$G = U - TS + pV.$$

Thus, it is easy to see that the change in the Gibbs free energy is

$$\mathrm{d}G = \mathrm{d}H - T\cdot \mathrm{d}S.$$

The above equation gives the maximum possibility of a process achieving work. *G* is not free energy in the sense that it comes from nothing. It implies that it is the energy available for work. d*G* influences the possible direction of a metabolic process. If it is negative, then free energy is released and the process will occur. If it is positive, it will not.

Energy transfers

To feel warm, whether one is in the house or walking outside, is a question of energy conservation, but the underlying principle is that of an energy balance, and for this to be achieved energy exchange is necessary. Energy can be transferred from one point to another by the following mechanisms: conduction, convection, radiation, and evaporation.

Conduction

Thermal conduction is the process by which energy can be transferred between two points in a material at different temperatures. In solids this is achieved in two ways :(i) through molecular vibrations transferring energy through the crystal lattice, and (ii) through the mobility of free conduction electrons throughout lattice. In semiconductors both components contribute to energy transfer because there are less free electrons, but in insulators the above (i)-way predominates. These lattice vibrations, which are called *phonons*, generate elastic acoustic standing waves which pass through the material at the speed of sound for that material. J. Fourier had discovered that the *rate of flow of thermal energy*, $\mathrm{d}Q/\mathrm{d}t$, through a material depends on the cross-sectional area, A, the length or thickness of the material, L, and the difference in temperature between the two sides, $\Delta T = T1 - T2$. This can be expressed as $\mathrm{d}Q/\mathrm{d}t = -kA\cdot\Delta T/L$, where k is the thermal conductivity of a material. The effectiveness of a material as an insulator can be determined by measuring its thermal conductivity. Good thermal conductors like copper have a high thermal conductivity, e.g. 380 Wm-1K-1, while poor conductors like water have a low thermal conductivity, i.e. 0.59 Wm-1K-1. The ratio of the temperature difference divided by the length is called the *temperature gradient*. The minus sign in the above equation is significant. It shows that the flow of energy is from the region at the higher temperature to that at the lower temperature, i.e. it flows along the temperature gradient. It implies that energy flow is unidirectional. The equation is true for steady-state conditions, i.e. when the two temperatures are stable and that the thermal energy input equals the thermal out, or for the short time interval.

Conclusion

All the equation is true for steady-state conditions, i.e. when the two temperatures are stable and that the thermal energy input equals the thermal out (for the short time interval). If the entropy tells us the direction of a spontaneous change, it would be useful to develop the criteria, from energetic considerations, for the propensity of a system to provide 'free energy' to do useful work.

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