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Thermal Balance of the Body and Methods of Heat Exchange

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Annotation: It is shown that heat exchange occurs on the body's surface and involves four main modes: conduction, convection, radiation, and evaporation. It is also shown that heat transfer occurs only through the evaporation of fluid from the body's surface, as a person evaporates 0.3-0.4 liters of fluid from the mucous membranes of the respiratory tract per day. Entropy is a physical quantity characterizing the value of a given system per unit temperature. States characterized by high order have a relatively low probability. Low-order states have a high probability of existence. Conversely, the degree of order in a system is characterized by its entropy.

Keywords: heat exchange, surface, bodies, thermal conductivity, convection, radiation, evaporation, respiratory tract, shell, entropy, system, orderliness.

Along with performing work, the body transforms nutrients; ultimately, all the energy received by the body from food, except for the part that goes into mechanical work, is converted into heat, and is given off by the body to the environment in the form of heat.

It is customary to distinguish several stages in this heat generation, which are divided into two types:

1. First of all, heat loss is inherent in the biological oxidation of nutrients, which synthesizes ATP. The thermal energy released during this process is called primary heat.

2. All other forms of heat are called secondary heat. These include: heat generated during the synthesis of macromolecules (except ATP); during the maintenance of gradients due to active transport; during muscle contraction; during the friction of muscles, blood vessels, joints, etc.; during the breakdown of proteins and other macromolecules; and during the passive transport of substances.

The figure shows a diagram of the transformation of solar energy in the human body.

All thermal energy generated in the human body is lost. Heat exchange occurs on the body's surface, and there are four main modes of heat exchange:

1. Thermal conductivity -

2. Convection -

3. Radiation -

4. Evaporation -

Thermal conductivity plays a major role in the transfer of heat through clothing.

1. The thermal energy transferred by conduction can be calculated using the following formula:

$$Q_T = K \cdot S \cdot \frac{T_i \cdot T_E}{l} \cdot t$$

- ✓ thermal conductivity coefficient;
- ✓ heat exchange area;
- ✓ body surface temperature;
- ✓ ambient temperature;
- ✓ thickness of the layer (clothing);
- ✓ the time during which the heat exchange process takes place.

2. Convection is the transfer of heat through a medium, that is, a moving gas or liquid. A distinction is made between natural and forced convection. In natural convection, the movement of the medium is caused by the temperature difference between its different parts. For example, cold air, being denser and heavier, sinks and displaces the lighter, warmer air. In forced convection (wind, fan), there is an external force, and forced convection transfers heat much more efficiently than natural convection. Heat transfer during convection is described by the

same formula as for thermal conductivity, but it is not a constant value, but depends on the specific conditions of the body.

3. Radiative heat transfer occurs through the emission of infrared rays. According to Wien's law, the maximum radiation emitted by the human body at a surface temperature of 36.7°C occurs at a wavelength of 10 microns. The amount of energy emitted by the body can be approximately calculated using the formula derived from the Stefan-Boltzmann law:

- ✓ since, for this infrared (IR) region of the spectrum, a person is an absolutely black body.

4. The heat removed from the body by evaporation is calculated using the formula:

- ✓ latent heat (specific) of evaporation
- ✓ the mass of liquid evaporated from the surface of the body.

Heat loss occurs only through the evaporation of fluid from the body's surface. If a person sweats heavily but there are no conditions for its evaporation, heat loss is ineffective. For example, at 100% relative humidity (steam bath), evaporation ceases completely. Not only water but also intercellular fluid evaporates from the skin. Approximately 0.3-0.4 liters of fluid evaporates from the skin's surface per day. Fluid evaporates not only from the skin but also from the mucous membranes. For example, a person evaporates 0.3-0.4 liters of fluid from the mucous membranes of the respiratory tract per day.

Evaporation is the most efficient means of heat exchange in the body at high temperatures and low humidity. All other heat transfer methods function only when the ambient temperature is lower than human skin temperature; otherwise, they act as a means of additional heating.

Heat exchange processes are vital for the body's survival. Maintaining a constant body temperature (thermal homeostasis) is essential for human life.

In this regard, all processes reflected in the heat balance equation are reliably regulated. The mechanisms of chemical and physical thermoregulation are different.

Chemical thermoregulation refers to the potential increases or decreases in heat production (H) due to changes in the intensity of oxidative processes. Chemical thermoregulation is mediated by influencing metabolism. Metabolism itself is very important for the body, and altering it while maintaining a specific temperature is highly inappropriate. The body resorts to chemical thermoregulation only in special circumstances.

Under normal conditions, the main method of maintaining temperature is physical thermoregulation, that is, temperature regulation through the following heat transfer mechanisms:

Heat exchange between the body and the environment occurs at the body's surface. The thermal conductivity of living tissues is low, so its role in transferring thermal energy from internal organs to the skin surface and mucous membranes is minor.

The main role in this process, that is, in ensuring thermoregulation of internal organs, belongs to blood circulation.

The heat capacity of blood is quite large (like water), and normal blood flow is sufficient to effectively transfer heat from internal organs to the body surface.

Regulation of such heat transfer is carried out mainly by increasing or decreasing blood flow.

In other words, through vascular reactions. When a greater amount of heat needs to be released, the blood vessels of the skin and mucous membranes dilate, leading to a significant increase in the volume of circulating blood, which is at the temperature of the internal organs, and thus increases heat loss. To reduce heat loss, the blood vessels constrict.

Humans experience significant heat loss through their hands and feet. When moving from cold to warm, blood flow in the hand increases 30-fold, and in the fingers, approximately 600-fold.

Evaporation is the most efficient means of heat exchange in the body at high temperatures. Physical thermoregulation is a multifactorial system that effectively maintains a constant body temperature. This multifactorial nature allows body temperature to be regulated under various conditions; when some mechanisms are disabled, others are activated.

In biophysics, physiology, and medicine, heat production is commonly referred to as the body's energy expenditure. Energy expenditure varies greatly depending on the body's environment and the nature of its activities, as all of these factors influence metabolism.

To assess the functional state of the body, it is necessary to create standard conditions when measuring its energy expenditure, that is, when measuring the amount of thermal energy released by the body into the environment.

Standard conditions are those under which the body's energy expenditure is minimal. To achieve this, factors that increase energy metabolism must be eliminated, including muscle activity, food intake, emotional stress, temperature and humidity fluctuations outside the comfort zone, etc.

It's best to measure basal metabolic rate (energy expenditure) while awake (not asleep), but the patient should lie quietly in bed. The procedure is recommended to be performed early in the morning (5-6 a.m.), when, according to the circadian rhythm, metabolic rate is lowest. Animal protein should be excluded from the patient's diet for two days prior to the measurement.

The measurement is taken on an empty stomach, that is, 12-14 hours after the last meal, while the room temperature should be within 20- C, and the relative humidity should be 50-60%.

The amount of heat production is measured several times to obtain a statistically reliable result.

Thus, for a healthy middle-aged man (40-50 years old), with an average weight of 70 kg, the basal metabolic rate is 7800 kJ or 1800 kcal per day, or h, which corresponds to a power of 90 W.

The exchange rate per unit surface area of the human body is approximately h, or 100 h.

Women have a 7-10% lower basal metabolic rate. It varies greatly with age. In a newborn, it is 300 hours, but by age 70-80, it drops to 120 hours.

To determine energy expenditure, it is necessary to measure the amount of heat released by the body into the environment over a given period of time. Two methods are used for this: direct and indirect calorimetry.

The direct calorimetry method uses special physiological calorimeters designed in such a way that animals or humans can be placed in them for the required time.

However, direct calorimetry is not always feasible, particularly when studying energy expenditure during work. Indirect calorimetry is most commonly used. This method is based on studying the body's gas exchange. It has been established that there is a linear relationship between the volume of energy consumed by the body and energy expenditure under fixed conditions.

The coefficient is the so-called calorimetric equivalent, equal to the amount of heat generated in the body when 1 liter is used to oxidize nutrients.

The calorimetric equivalent is not the same for the oxidation of iron, beta, and carbon, and which substances are predominantly oxidized in each specific case can be determined by the respiratory quotient, which is defined as the volume of carbon dioxide released to the volume of oxygen absorbed over the same period of time.

$$Д_к = \frac{V_{CO_2}}{V_{O_2}}$$

Thus, with predominantly carbohydrate oxidation, the respiratory quotient (RQ) approaches 1, while with fat oxidation, it has the lowest values, approximately 0.7. Special tables and monograms exist that can be used to determine the oxygen equivalent value based on the determined RQ value.

Thus, gas analysis measures the volumes of oxygen absorbed and carbon dioxide released over the same time. The oxygen equivalent is calculated by taking the ratio of oxygen to carbon dioxide. The oxygen equivalent is then calculated from the oxygen equivalent. Multiplying this by the volume of oxygen absorbed determines the energy expenditure during the experiment.

Thermal energy generated in an organism represents a specific form of bound energy in a biological system. Under living conditions, it cannot be converted into any of the forms of work performed by the organism. It depends on the degree of disordered molecular or atomic motion, and its quantitative measure is temperature. The relationship between and temperature is proportional. However, the magnitude of is not always the same in different systems at the same temperature. Consequently, the degree of disordered molecular motion depends not only on temperature but also on other properties of the system. Clausius expressed these properties in 1865 as a coefficient, which he designated S and called "entropy." Then:

$$s = \frac{W_{св}}{T} \quad s = [\frac{Дж}{K}]$$

Entropy is a physical quantity that characterizes the value of a given system per unit temperature.

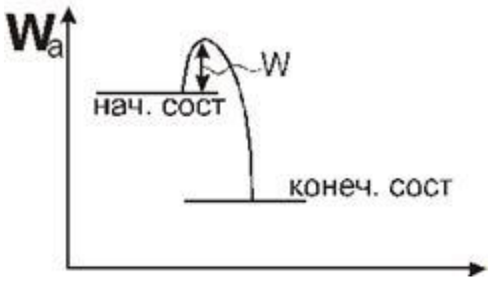
In thermodynamics, these are called microscopic parameters. If two identical molecules in a given system are interchanged, the macroscopic parameters of the system as a whole will remain unchanged. The probability of a system's state is determined by its degree of order. States characterized by high order have a relatively low probability. States with low order have a high probability of existence. Conversely, the degree of order in a system is characterized by its entropy.

Therefore, there is a relationship between the entropy of a state and its probability, which Boltzmann expressed by the formula:

- Boltzmann constant

- thermodynamic probability, that is, the number of possible microscopic states that can realize a given macroscopic state.

Many real processes in biological systems proceed by overcoming a potential barrier. This means that the initial and final states of the system are separated by some intermediate state with high energy.



For a process to occur, the system must initially receive additional energy to overcome the potential barrier. The magnitude of this energy is called the height of the potential barrier or the activation energy of the process.

Chemical and biochemical reactions serve as examples of processes that involve overcoming a potential barrier (PB). Almost all of them undergo an intermediate state with increased energy. In chemistry, this state is called an activated complex.

In real bodies, different particles (molecules, ions, etc.) have different energies. Therefore, in each specific case, some particles are capable of overcoming the static pressure limit, while others are not. Therefore, the rate of processes involving the molecules of a given substance will be determined solely by the number of molecules capable of overcoming the static pressure limit.

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