



Energy, Work, and Power

Understanding the Body's Thermodynamics

The human body is a complex system that constantly transforms energy to power its functions.

The energy is defined as the capacity of the body to do a work. The more is the work done the more energy is used to do this work. The energy is a necessity of life.

Some of our organs are able to detect the presence of energy around us in various form such as;

earsdetect sound energy

eyesrespond to visible light

special nerves sensitive to temperature which indicate heat energy, and other nerves respond to electric energy as nerve signals.

Some other kinds of energies can be detected indirectly by our sense organs, for example we can sense the chemical, electrical, magnetic, gravitational, and nuclear energies. The forms of energy are mutually interchangeable, i.e. one form of energy can be changed to another form of energy

The body's basic energy (fuel) source is food. The food must be chemically changed by the body to make molecules that can combine with oxygen in the body's cells.

The body uses the food energy to:

1. Operate its various organs.
2. Maintain a constant body temperature.
3. Do external work.
4. Any energy that is left over is stored as body fat.

The First Law of Thermodynamics

Energy Change

The first law of thermodynamics states that energy can be transformed, but

it cannot be created or destroyed. In the body, this principle applies to the energy changes that occur during various metabolic processes.

All biological organisms require energy to survive. In a closed system, such as the universe, this energy is not consumed but transformed from one form to another. Cells, for example, perform a number of important processes. These processes require energy. In photosynthesis, the energy is supplied by the sun. Light energy is absorbed by cells in plant leaves and converted to chemical energy. The chemical energy is stored in the form of glucose, which is used to form complex carbohydrates necessary to build plant mass. The energy stored in glucose can also be released through cellular respiration. This process allows plant and animal organisms to access the energy stored in carbohydrates, lipids, and other macromolecules through the production of ATP. This energy is needed to perform cell functions such as DNA replication, mitosis, meiosis, cell movement, endocytosis, exocytosis, and apoptosis

Energy change in the body (Met, Basal metabolic rate (BMR))

The body's energy expenditure is measured by its metabolic rate (metabolism is a set of chemical reactions in the cells of an organism that maintain life). Metabolic rate includes the basal metabolic rate (BMR) and the energy required for physical activity and other processes. The units are joule or calorie

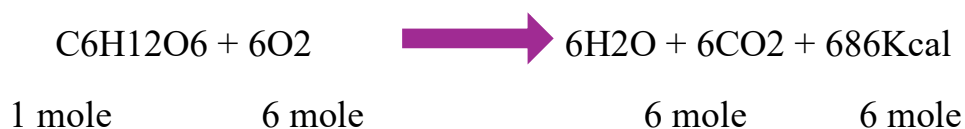
$$1 \text{ cal} = 4.184 \text{ J} \text{ or } 1 \text{ Kcal} = 4184 \text{ J}$$

Metabolism = anabolism (building up) + catabolism (breaking down)

The power is defined as energy or work per unit time = J/s = watt.

In the oxidation process within the body, heat is produced as energy of metabolism. The rate of oxidation is called metabolic rate.

For example the oxidation of one mole of glucose can be shown as:



180g

192g


108g

264g

Co₂ and O₂ are gases (1 mole of a gas at normal temp. and pressure has a volume 22.4 liters)

From the above equation we can calculate useful quantities for glucose metabolism:

- Kcal of energy released/g of fuel (glucose) =686/180=3.8
- Kcal of energy released/L of O₂ used=686/ (22.4×6) =5.1
- Liters of O₂ used/g of fuel glucose = (22.4×6)/180=0.75
- Liters of Co₂ produced /g of fuel glucose= (22.4×6)/180=0.75

So the ratio of moles of Co₂ produced to moles of O₂ used, called the (respiratory quotient) $R=1$  No. of moles of Co₂/No. of moles of O₂ =1

Similar calculation can be done for fats, proteins, and other Carbohydrates.

When the body is completely at rest, it will have the lowest rate of energy consumption this is called the basal metabolic rate (BMR), which is the amount of energy needed to perform minimal body functions (such as breathing and pumping the blood through the arteries) under resting conditions, and for typical person 92 Kcal/hr \approx 107w or about 1 met (met is 50 Kcal/m²hr).

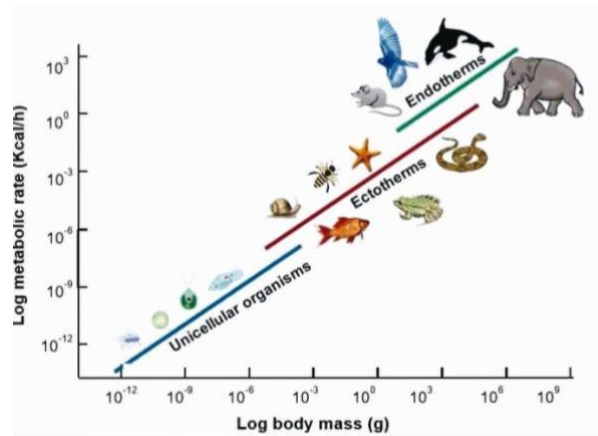
m²: body surface area

BMR depends on

- sex, age, height, and weight
- it depends primarily on thyroid function, overactive thyroid gives higher BMR.
- the surface area or to the mass of the body.

Since the energy used for basal metabolism becomes heat which is mainly dissipated from the skin, so the basal rate is related to the surface area or to the mass of the body. In Figure below represents the change

between BMR (kcal/day) and the mass of different animals, the slope of the graph indicates that the BMR is proportional to mass.



- The BMR depends to large extent on the body temp. for an increase of 1°C it will change by 10% in the metabolic rate, so for 3°C the change will be 30% greater than normal. Similarly, if the body temp. drops 3°C below normal metabolic rate decreases by about 30%. For this reason hibernating animals at low body temp. will reduce the metabolic rate very much.

Work and Power

The body's ability to perform work and generate power is directly related to its energy expenditure. Understanding the relationship between energy, work, and power is crucial for optimizing physical performance and efficiency. Work and power

Chemical energy stored in the body is converted into external mechanical work as well as into life preserving functions. The Internal work: is the force (F) moved through a distance Δx .

$$\Delta W = F\Delta x \quad (4)$$

Where the force and the motion Δx must be in the same direction.

Power: is the rate of work done

$$P = \Delta W / \Delta t = F \Delta x / \Delta t = Fv \quad (3)$$

When the force is perpendicular to the displacement work appears to be zero, such as walking man, his weight is perpendicular to distance of movement but practically it will not be zero because he uses energy against friction and other movement of his body, his muscles are doing internal work which appears as heat in the muscle and causes a rise in its temperature this additional heat in the muscle is removed by blood flowing through the muscle, by conduction to the skin, and by sweating.

But in the case of climbing person for distance (h) the weight is on the same line of displacement then the work = mgh.

The efficiency (ϵ) of human body can be obtained from the usual definition of the efficiency E,

$$E = \text{work done} / \text{energy consumed}$$

Efficiency is usually lowest at low power but can increase to 20% for trained individuals in activities such as cycling.

Anaerobic and Aerobic Phases

Anaerobic Phase

During high-intensity or short- duration physical activity, the body relies on anaerobic metabolism, which does not require oxygen.

This phase produces a rapid but limited energy output, leading to the buildup of lactic acid and fatigue.

Aerobic Phase

As exercise continues, the body transitions to aerobic metabolism, which utilizes oxygen to produce energy more efficiently and sustainably. This phase is characterized by a slower but more prolonged energy output, allowing for longer-duration physical activity.

Efficiency and Heat Losses

The body's energy conversion processes are not 100% efficient, and a significant portion of the energy is lost as heat.

Understanding the mechanisms of heat loss, such as radiation, convection, evaporation, and respiration, is crucial for maintaining thermal homeostasis.

Heat Loss from the Body

Birds and mammals are referred to as “Homoeothermic” (warm blooded) they are constant body temperature, while other animals such as frog and snake are considered “Poikilothermic” (cold blooded) are variable body temperature will have a higher body temp. on a hot day than mammals, birds and mammals both have mechanisms to keep their body temp. constant despite fluctuations in the environmental temp. Constant body temp. permit metabolic processes to produce at constant rates and these animals to remain active even in cold climates.

The normal human temp. is 37°C which is obtained from taking the temp. of large number of healthy people. For a single individual the body temp. may vary about $\approx 0.5^{\circ}\text{C}$. The rectal temp. is about 0.5°C higher than the oral temp.

The temperature of the body depends on the:

1. Time of the day (lower in the morning).
2. Environment temp.
3. The amount of clothing.
4. Health of the person.
5. On his recent physical activity.

The body losses heat mainly by radiation, convection, and evaporation, all these processes can take place in the skin. The evaporation of perspiration from the skin can cool down the skin by absorbing the latent heat of evaporation from it.

Evaporation takes place also in breathing causing cooling effect. If the air is cold it will also cool down the body. Eating and drinking cold or hot food can also decrease or increase the body temp.

The body temp. is kept constant for this reason the hypothalamus gland in the brain can control the body temp. (thermostat like).

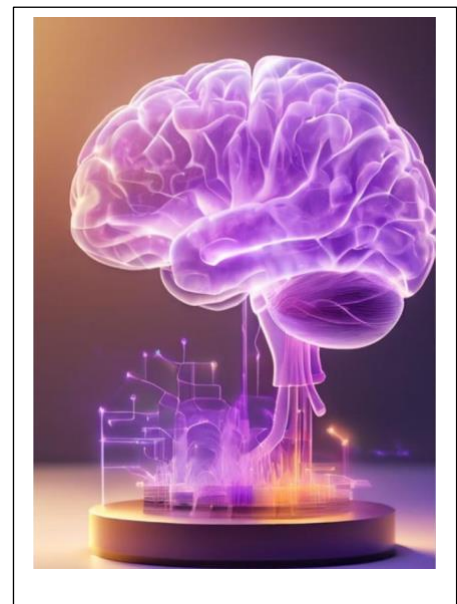
- Hypothalamus (body thermostat)
The hypothalamus is a small but crucial region of the brain that acts as the body's thermostat, regulating body temperature and maintaining thermal homeostasis.
- Thermoregulation Mechanisms

The body employs various mechanisms to regulate temperature, including blood vessel dilation, sweating, and shivering. These processes help the body adapt to changes in environmental conditions and maintain a stable internal temperature.

- Importance of Thermal Balance

Maintaining thermal balance is essential for the body's optimal function and overall health. Disruptions in thermoregulation can lead to a range of physiological and medical issues, underscoring the importance of understanding the body's thermodynamic processes.

After heavy exercise the body is heated the hypothalamus initiate the sweating and vasodilation, heat will be lost by first evaporation and the second increasing the blood supply to the skin.



On the other hand if the environment temp. drops the thermoreceptors on the skin signals to the hypothalamus which in turn induce shivering to increase the body temp.

The heat losses depends on many factors:

1. The temp. of the surroundings
2. Humidity
3. Motion of the air
4. The physical activity of the body
5. The amount of the body exposed
6. The amount of the insulation of the body (like clothes and fat)

Heat exchange mechanisms

1. Radiation

Heat is lost from the body through the emission of infrared radiation, a which occurs when the body's surface temperature is higher than the surrounding environment.

2. Convection

Heat is transferred from the body to the surrounding air through the movement of air currents, which can be influenced by factors such as wind and air temperature.

3. Evaporation

The evaporation of sweat from the skin's surface is a highly effective mechanism for cooling the body, as it removes large amounts of heat energy.

4. Respiration

The exchange of gases during breathing, including the release of warm, moist air, also contributes to the body's heat loss through convection and evaporation.

