Energy and Work of the Body

Objective:

- **The importance of energy to body.**
- **Why does the temperature of the body remain constant?**
- **What is the basal metabolic rate?**

Energy is a basic concept of physics. All activities of the body, including thinking, involve energy changes. The conversion of energy into work represents only a small fraction of the total energy conversions of the body.

25% is being used by the skeletal muscles and the heart.

19% is being used by the brain.

10% is being used by the kidneys.

27% is being used by the liver and spleen.

The body's basic energy source is food.

The uses the food energy to:-

1) Operate its various organs,
2) Maintain a constant body temperature,
3) Do external work.

A small percentage (~5%) of the food energy is excreted in the feces and urine.

Conservation of energy in the body:-

We can write the first law of thermodynamics as

$$\Delta U = \Delta Q - \Delta W \qquad (1)$$

ΔU is the change in stored energy

ΔQ is the heat lost or gained

ΔW is the work done by the body in some interval of time

this equation assumes that no food or drink is taken in and no feces or urine is excreted during the interval of time. A body doing no work (ΔW=0) and at a constant temperature continues to lose heat to its surroundings, ΔQ is negative. Therefore, ΔU is also negative, indicating a decrease in stored energy. It is useful to consider the change of ΔU, ΔQ, and ΔW in a short interval of time Δt. Equation(1) then becomes

$$\frac{\Delta U}{\Delta t} = \frac{\Delta Q}{\Delta t} - \frac{\Delta W}{\Delta t} \qquad (2)$$

$\Delta U / \Delta t$ is the rate of change of stored energy

$\Delta Q / \Delta t$ is the rate of heat loss or gain

$\Delta W / \Delta t$ is the rate of doing work (chemical power)

Eq.(2) is merely another form of the first law of thermodynamics. It tell us that energy is conserved in all processes, but it does not tell us whether or not a process can occur.

Energy change in the body:-

Physiologist usually use kilocalories (kcal) for food energy and kilocalories per minute for the rate of heat production. In physics the unit for energy is the newton – meter or joule (N . m =J) ; power is given in joule per second or watts(W). The unit in the cgs system is the erg, and that in the English system is the foot – pound(ft –lb).

A convenient unit for expressing the rate of energy consumption of the body is the (met).

1met=50 kcal/m^2 of body surface area per hour.

A typical man has about 1.85m^2 of surface area and a woman has about 1.4m^2 and thus for a typical man 1met=92 kcal/hour=107W.

Oxidation occurs in the cells of the body. In oxidation by combustion heat is released. In the oxidation process within the body heat is released as energy of metabolism. The rate of oxidation is called the metabolic rate. The oxidation equation for 1mole of glucose($C_6H_{12}O_6$) is

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + 686\ kcal$$

This is, 1 mole of glucose(180g) combines with 6 mole of O_2 (192g) to produce 6 mole of each of H_2O(108g) and CO_2(264g), releasing 686 kcal of heat energy in the reaction. Similar calculation can be done for fats, protein, and other carbohydrates. Typical caloric values of these food types and of common fuel are given in Table(1). This table also lists for the various types of food the energy released per liter of oxygen consumed; thus by measuring the oxygen consumed by the body, we can get a good estimate of the energy released.

Table(1)

Food or Fue	**Energy Released per Liter O_2 Used (kcal/liter)**	**Caloric Value(kcal/g)**
Carbohydrate	5.3	4.1
Proteins	4.3	4.1
Fat	4.7	9.3
Typical diet	4.8 – 5.0	–

Not all of this energy is available to the body because part is lost in incomplete combustion. The unburned products are released in feces, urine, and flatus (intestinal gas). What remains is metabolizable energy. The body is usually quite efficient at extracting energy from food. For example, the energy remaining in normal feces is only about 5% of the total energy contained in the consumed food. When the body is at constant temperature the energy that is extracted from food plus the body fat make up the available stored energy.

When completely at rest, the typical person consumes energy at a rate of about 92 kcal/hr, or 107W, or about 1 met. This lowest rate of energy consumption, called the basal metabolic rate ***(BMR),*** is the amount of energy needed to perform minimal body functions (such as breathing and pumping the blood through the arteries) under resting conditions. The BMR depends primarily upon thyroid function. A person with an overactive thyroid has a higher BMR than a person with normal thyroid function.

Since the energy used for basal metabolism becomes heat which is primarily dissipated from the skin, one might guess that the basal that the basal rate is related to the surface area or to the mass of the body and is proportional to $mass^{3/4}$.

The metabolic rate depends to a large extent on the temperature of the body. Chemical processes are very temperature dependent, and a small change in the temperature can produce a large change in the rate of chemical reactions. If the body temperature changes by 1^0C, there is a change of about 10% in the metabolic rate. For example, if a patient has a temperature of 40^0C, or 3^0C above normal, the metabolic rate is about 30% greater than normal. Similarly, if the body temperature drops 3^0C below normal, the metabolic rate(and oxygen consumption) decreases by about 30%. You can see why hibernating at a low body temperature is advantageous to an animal and why a patient's temperature is sometimes lowered during heart surgery.

Obviously, in order to keep a constant weight an individual must consume just enough food to provide for basal metabolism plus physical activities. Eating too little results in weight loss; continued too long it results in starvation. However, a diet in excess of body needs will cause an increase in weight. Weight loss through dieting and physical exercise as in the following example:-

Example(1) suppose you wish to lose 4.54 kg either through physical activity or by dieting.

a – How long would you have to work at an activity of 15 kcal/min to lose 4.54 kg of fat?(of course, you could not maintain this activity rate very long)

From table, you can expect a maximum of 9.3 kcal/g. If you worked for T minutes, then

$$(T\ min)\left(\frac{15\ kcal}{min}\right) = (4.54 * 10^3 g)\left(\frac{9.3\ kcal}{g}\right) = 4.2 * 10^4\ kcal$$

T =2810 min ~47 hr

Not that a great deal of exercise is needed to lose a few pounds.

b – It is usually much easier to lose weight by reducing your diet intake. If you normally use 2500 kcal/day, how long must you diet at 2000 kcal/day to lose 4.54 kg of fat?

$$T = \frac{energy\ of\ 4.54\ kg}{energy\ deficit\ per\ day} = \frac{4.2*10^4 kcal}{5*10^2 kcal/day} \cong 84\ days$$

The BMR is sometimes determined from the oxygen consumption when resting. We can also estimate the food energy used in various physical activities by measuring the oxygen consumption. Oxygen consumption for various organs has been measured, some of the organs use rather large amounts of energy and that the kidney uses more energy per kilogram than the heart.

Reference: Medical Physics by Cameron ch.5