Energy, Work, and Power of the Body

All activities of the body including thinking, involve energy changes. The conversion of the energy into work such as lifting a weight occurs continuously in the body. Under resting (Basal) conditions about 25% of the body's energy is being used by the skeletal muscles and the heart using, 19% is being used by the brain, 10% is being used by the kidneys, and 27% is being used by the liver and the spleen. A small percent of about 5% of food energy being excreted in feces and urine.

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 energy used to operate the organs eventually appears as body heat. Some of this heat is useful in maintaining the body at its normal temperature, but the rest must be disposed of.

Conservation of energy in the body

Our own bodies, like all living organisms, are energy conversion machines. The fraction going into each form depends both on how much we eat and on our level of physical activity. If we eat more than is needed to do work and stay warm, the remainder goes into body fat. There are continuous energy changes in the body both, when it is doing work and when it is not.

The conservation of energy in the body is expressed by the first law of thermodynamics:

- change in stored energy in the body = heat lost or gained – work done by
  (i.e. food energy, body fat and body heat) of the body body

$$\Delta \mathbf{U} = \Delta \mathbf{Q} - \Delta \mathbf{W} \qquad \textbf{(1)}$$

Considering the three terms above in a short time interval Δt, we obtain relation for the time rates of change of the energy, heat, and work

- Rate of change of stored energy = rate of heat loss or gain - rate of work done

$$\Delta \mathbf{U}/\Delta \mathbf{t} = \Delta \mathbf{Q}/\Delta \mathbf{t} - \Delta \mathbf{W}/\Delta \mathbf{t} \qquad \textbf{(2)}$$

The time rate of doing work (Δ W/Δt) is called “power”

$$P = \Delta \mathbf{W}/\Delta \mathbf{t} = \mathbf{F}\Delta \mathbf{x}/\Delta \mathbf{t} = \mathbf{F}\mathbf{v} \qquad \textbf{(3)}$$

Energy Changes in the Body

- **Units of energy and power**

- 1 kcal (kilocalories) = 1 C or Cal (Calorie) = 4184 J = 4184 N-m
- 1 J = 10^7ergs = 0.737 ft-lb
- 1 kcal/min = 69.7 W = 69.7 J/s = 0.094 hp
- 100 W = 1.43 kcal/min
- 1 hp = 642 kcal/hr = 746 W = 550 ft-lb/sec
- 1 met = 50 kcal/m^2hr = 58 W/m^2
- 1 kcal/hr = 1.162 W

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

- Oxidation process
- Heat is released as energy
- Metabolic rate: rate of oxidation

Energy consumption is directly proportional to oxygen consumption because the digestive process is basically one of oxidizing food. Oxidation occurs in the cells of the body. In the oxidation process within the body heat is released as energy of metabolism. The rate of oxidation is called the "metabolic rate".

Let us consider the oxidation of glucose, a common form of sugar used for intravenous feeding. The oxidation equation for 1 mole of glucose is:

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

1 mole	6 mole	6 mole	6 mole	released heat energy
1 (180 g)	6 (32g)	6 (18 g)	6 (44 g)	192g

1 mole of a gas at normal temperature and pressure has a volume of 22.4 liter.

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 O_2 used=686/(22.4×6) =5.1
- Liters of O_2 used/g of fuel glucose =(22.4×6)/180=0.75
- Liters of CO_2 produced/g of fuel glucose=(22.4×6)/180=0.75

So the ratio of moles of CO_2 produced to moles of O_2 used, called the "respiratory quotient" (R) =1. Similar calculations can be done for fats, proteins, and other carbohydrates. Typical caloric values of these food types and common fuels are given in table (1).

Table 1. Typical energy relationships for some foods

Food	Energy Released per Liter of O_2 used (kcal/liter)	Caloric Value (kcal/g)
Carbohydrates	5.3	4.1
Proteins	4.3	4.1
Fats	4.7	9.3
Typical diet	4.8-5.0	-
Gasoline	-	11.4
Coal	-	8.0
Wood (pine)	-	4.5

The rate at which the body uses energy when it is completely at rest is called "basal metabolic rate (BMR)" $Kjh^{-1}m^{-2}$, it 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 ≈107w or about 1 met (met is 50 $Kcal/m^2hr$). (m^2 is the body surface area). Children have high values of BMR because of the energy required for growing while men have slightly higher values than women, because men have less body fat and therefore use more energy in maintaining body temperature.

BMR depends on:

1. Sex, age, height, and weight.
2. It depends primarily on thyroid function, over active thyroid gives higher BMR.
3. BMR is proportional to $(mass)^{3/4}$ see fig. (1)

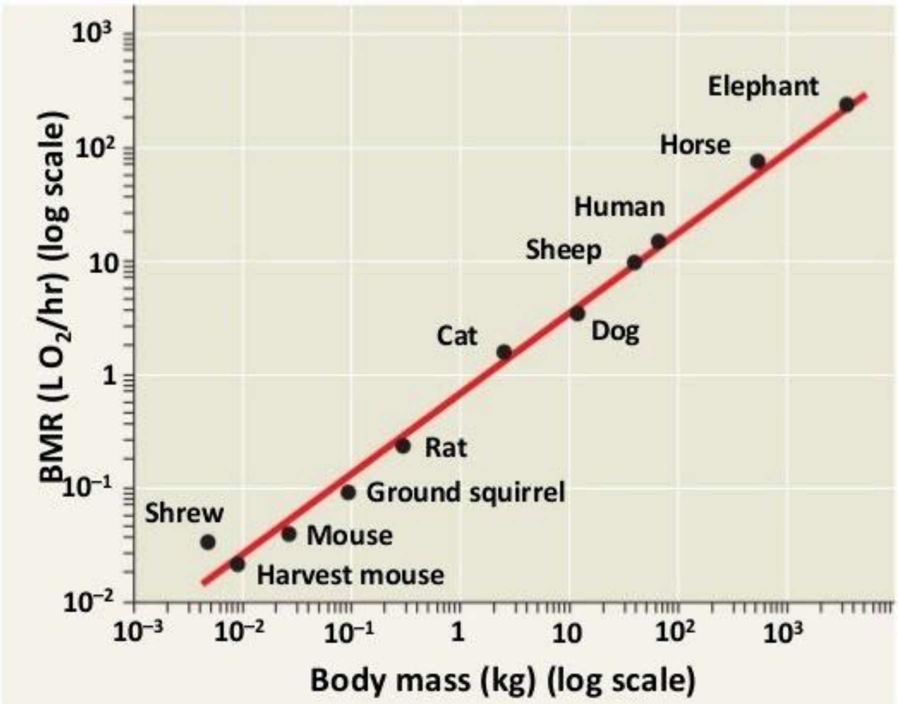

Fig.(1) relationship between basal metabolic rate and body mass for several different animals

4. 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, the

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

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.

$$\mathbf{\Delta W = F\Delta x} \qquad \textbf{(4)}$$

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

Power: is the rate of work done

$$P = \mathbf{\Delta W/\Delta t = F\Delta x/\Delta t = Fv} \qquad \textbf{(3)}$$

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 the 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=work done/ energy consumed

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

The maximum work capacity of the body is variable, for short period of time the body can perform at very high power levels, like running very fast but it is more limited for longer periods. It is found that long term power is proportional to the maximum rate of oxygen consumption in the working muscles. The body supplies instantaneous energy for short - term power needs by splitting energy - rich phosphates and glycogen , leaving an oxygen deficit in the body .This process can only last about a minute and is called the anaerobic (without oxygen) phase of work ;long –term activity requires oxygen (aerobic work).

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 ≈0.5°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). 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 loses 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)