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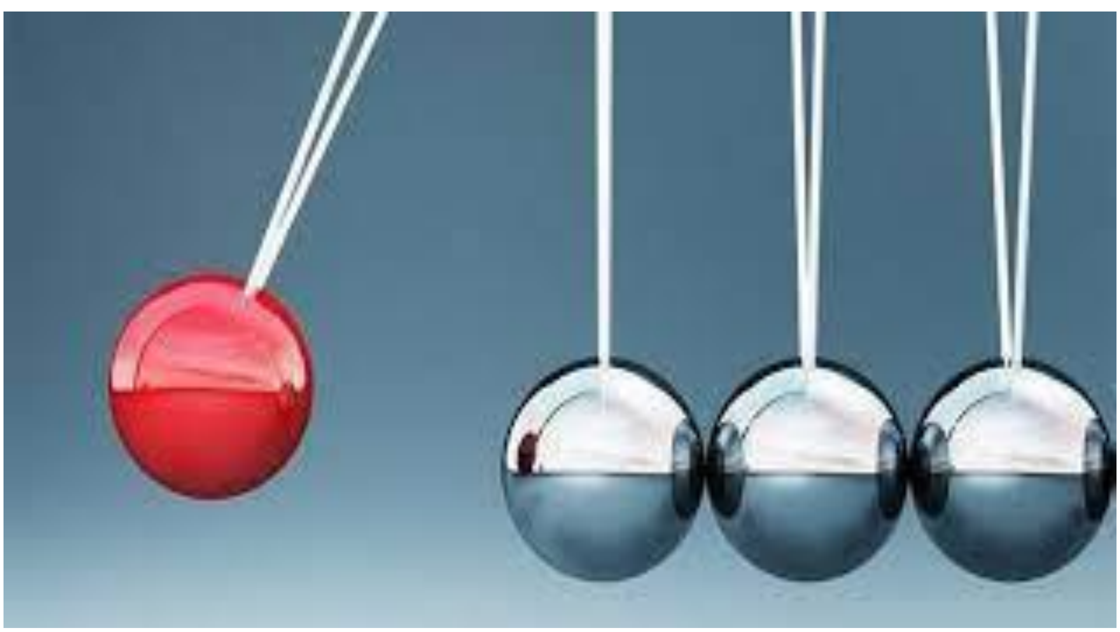
Energy, Work and power of the body



Energy, Work, and power of the body

All activities of the body including thinking, involve energy changes. The conversion of the energy into work occurs continuously in the body. Under resting conditions the body energy is being used as follows.

1. **27% by the liver and spleen.**
2. **25% by the skeletal muscles.**
3. **9% by the brain.**
4. **10% by the kidney.**

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

The body uses the food energy to:-

1. **Operate its various organs.**
2. **Maintain a constant body temperature.**
3. **Do external work e.g. lifting.**

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

***Any energy that is left over is stored as body fat.**

***The energy used to operate the organs appears as body heat.**

<u>Conservation of energy in the body:-</u>

There are continuous energy changes in the body both, when it is doing work and when it is not. We can write the first law of thermodynamics as:

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

Where:

ΔU: is the change in stored energy.

ΔQ: is the heat lost or gained.

ΔW: is the work done by the body.

If a body no work ($\Delta W=0$) and at constant temperature continues to lose heat to its surrounding , and ΔQ is negative.

Therefore, ΔU is also is negative, indication a decrease in stored energy. The rate of change of energy is given by:

$\Delta U/\Delta t = \Delta Q/\Delta t - \Delta W/\Delta t$…………..….(2)

Where:

$\Delta U/\Delta t$: Rate of change of stored energy.

$\Delta Q/\Delta t$: Rate of heat loss or gain.

$\Delta W/\Delta t$: Rate of doing work.

Equation (2) tells us that energy is conserved in all processes, but it does not tell us whether or not a process can occur.

Energy changes in the body:-

The energy value of food referred to by nutritionists as a Calorie C is actually a kilocalorie;

thus a diet of 2500 C/day is 2500 Kcal/day.

Energy unit is joule or erg.

Power is given in joule per second or watts (W).

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

Met: is defined as 50 Kcal/m² of body surface are per hour.

For a normal person 1 met is about equal to the energy consumption under resting condition. A typical man has about 1.85m² of surface area (woman has about 1.4m²) And thus for a typical man 1 met ≈ 92 Kcal/hr or 107 W. and in woman 1 met ≈70 Kcal/hr.

1 Kcal =4184j.

1 J =107 ergs.

1 met =50 Kcal/m² hr

Oxygen Consumption:-

Food is oxidized; in oxidation by combustion heat is released. In the oxidation process within the body released as energy of metabolism. The rate 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:-

$$C_6 H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + 686\ Kcal$$

1 mole 6 mole 6 mole 6 mole releasing (heat energy)

(180 g) (192 g) (108 g) (264 g)

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

This table for typical energy relationships for some foods.

Food or fuel	energy released per liter Caloric value 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

Work and Energy:-

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.

$$\Delta w = F \Delta x$$

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

Power: is the rate of work done.

$P = \Delta w / \Delta t = F \Delta x / \Delta t = F v$ (v =velocity)

When the force is perpendicular to the displacement work will be zero, such as walking body, 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, 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 of human body is

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 and rowing.

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.

For healthy man this consumption is 50ml/kg m of body weight each minute. The body can supply an instantaneous energy for short term power needs, this

can be done 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 *__anaerobic__*(without oxygen).

For longer term work requires oxygen *__aerobic__*

Heat loses from the body

(Homeothermic)(Warm-blooded) such as birds and mammals, (poikilothermic)(cold-blooded) such as frog and snake, 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 # of 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 temp. 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.

● For example rectal temp. after hard exercise may be as high as 40°C ,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 in the brain can control the body temp. (thermostat like).After heavy exercise the body is heated the hypothalamus initiate the sweating and vasodilation is the first causes heat loss by evaporation and the second increasing the blood supply to the skin for more loss of heat. On the other hand if the environment temp. drops the thermo receptors on the skin signals to the hypothalamus which in turn induce shivering to increase the body temp. The production of heat in the body for 2400 Kcal/day (assumeing no change in body weight)=1.7Kcal/min=120J/sec =120W. So the body must lose the same amount of heat to stay at constant 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)**

Transfer of heat by radiation

All objects regardless on their temp. emit electromagnetic radiation, the amount of energy emitted by the body is proportional to the absolute temp. raised to the fourth power. The body also receives radiant energy from surrounding objects. The amount of heat difference between the energy radiated by the body and the energy absorbed from the surrounding can be calculated from the equation:

$$H_r = K_r A_r e (T_s - T_w)$$

Where

(H_r) is the rate of heat energy loss or gain

(K_r) is a constant depends upon various physical parameters and it's about =5Kcal/m2 hr C° for man

(A_r) effective body surface area emitting radiation

e is the emissivity of the surface which is nearly=1,independent on the color of the skin indicating that the skin at this wavelength is almost a perfect emitter and absorber of radiation.

(T_s) is the skin temp. in C°

(T_w) is the temp of the surrounding walls

∆ Heat losses by radiation occur even the temp differences is not high.

Example: **for a nude person have a skin temp. 34°C in a room of walls temp. 25°C and his body area 1.2m2 will lose 54 Kcal/hr which is 54% of the total losses. Most of the remaining heat will be by convection.**

Transfer of heat by convection

Heat losses by convection (H_c)

$$H_c = K_c A_c (T_s - T_a)$$

Where

H_c is the amount of heat gained or lost be convection

Ac is the effective surface area

T_s is the skin temp.

T_a is the environment temp. or air temp.

K_c is a constant that depends on the movement of the air, for a resting body and no apparent wind

K_c is about 2.3kcal/ m 2 hr °C.

When the air is moving K_c increases according to the equation

$K_c = 10.45 - v + 10\sqrt{v}$

Where

v is the wind speed in m/sec

This equation is valid for speeds between 2.23m/sec (5mph) and 20m/sec (45mph) (1 mile=1.6 km).

The equivalent temp. due to moving air is called the wind chill factor and is determined by the actual temp. and wind speed. For example for a windy day speed 10 m/sec an-20°C has the same cooling effect on the body as -40°C on a calm day.

Transfer of heat by evaporation

Under normal temp. conditions and in the absence of hard work or exercise, heat loss mainly by radiation and convection, losses by evaporation become of less importance. Under extreme conditions of heat and exercise, a man may sweat more than 1 litter of liquid per hour. Since each gram of water that evaporate carries with it the heat of vaporization of 580 calories, the evaporation of I liter carries with it 580kcal. There is some heat losses by perspiration even if the body does not feel sweaty, it amount to about 7Kcal/hr, equivalent to 7% of the body losses. A similar loss of heat is due to the evaporation of moisture in the lungs, an additional amount of water will be evaporated during expiration. This will cool the body the same as the evaporation from the skin, also when we inspire cold air inside the lungs which also cool down the body. Under typical conditions The total respiratory heat losses is about 14% of the body's heat loss. Under extreme condition of heat and exercise the sweat evaporation is very important, a man may sweat more than 1 lit/hr, this is if all sweat is evaporated, the un evaporated part (running down)does not contribute with cooling.

Counter current heat exchange

Since the radiation of heat from the body and the transfer of heat to the air depend upon the skin temp., any factors that affect the skin temp. also affect the heat loss. The body has the ability to select the path returning blood from the hands and feet. In cold weather blood is returned to the heart through internal veins that are in contract to the arteries carrying blood to the

extremities (hands and feet).In this way some of the heat from the blood going to the extremities is used to heat thee returning blood. This counter current heat exchange lowers the temp. of the extremities and reduces heat loss from the body to the environment. In warm weather the returning venous blood runs near the skin surface raising the skin temp. and thus increasing the heat loss from the body. Most of the previous study involved heat losses from a nude person, if we consider the clothes, the calculation become more complicated, for this reason another unit of clothing is the (clo) is being introduced. One (clo) corresponds to the insulating value of clothing needed to maintain a subject sitting at rest in comfort in a room at 21°C and air movement of 0.1m/sec and humidity of less than 50%. One (clo) is equivalent to lightweight suit an individual in the arctic needs clothing of insulation of 4 clos. (A fox fur has an insulating value of 6 clos).