Lec: Energy, Work and Power of the Body

- Energy, work, and power are three important concepts in physics that can be applied to the human body. In simple terms, energy is the ability to do work, work is the application of force over a distance, and power is the rate at which work is done.
- In the context of the human body, energy can be classified into different forms such as chemical energy, electrical energy, and thermal energy. The food we consume provides the body with the necessary chemical energy required to perform various tasks such as muscle movement, digestion, and brain function.
- All activities of the body, including thinking, involve energy changes. Conversion of the energy into work occurs continuously in the body.

- Under resting (basal) conditions about 25% of body's energy is being used by skeletal muscle and heart, 19% is being used by the brain, 10% is being used by the kidneys and 27% is being used by the liver and spleen.

- The body's basic energy (fuel) source is the food, where it must be chemically changed in the body to make molecule that can combine with oxygen in the body cells.

-The body uses the food energy to:

1. Operates its various organs.
2. Maintain a constant body temperature.
3. Do external work, for example, lifting, thinking.

- A small percentage (5%) of food energy is excreted in the feces and urine; any energy that is left over is stored as fat.

- Energy which used to operate the body organ appears as heat in the body.

Conservation of Energy in the Body:

The law of conservation of energy states that energy cannot be created or destroyed, only transformed from one form to another. This law applies to the human body as well, where energy is constantly being transformed to support various functions and activities.

The body is constantly using energy to perform tasks such as breathing, digesting food, and maintaining a constant body temperature. This energy is obtained from the food we consume, which is converted into chemical energy through a process called metabolism. Metabolism is the set of biochemical reactions that occur in the body to maintain life and sustain bodily functions.

$$\left(\begin{array}{c}\text{Change in stored}\\ \text{energy}\\ \text{In the body (i.e. food}\\ \text{energy, body fat}\end{array}\right) = \left(\text{Heat lost from the body}\right) + \left(\text{Work done}\right)$$

This equation can be written, assumes that no food or drink is taken in and no feces is excreted during the time interval being considered. There are continuous energy changes in the body both when it is doing work and when it is not.

- The first law of thermodynamics can be written as follows:

$$\Delta U = \Delta Q - \Delta W \text{.....(1)}$$

Where **ΔU** is the change in the stored energy, **ΔQ** is the heat lost or gained and **ΔW** is the work done by the body in some interval of time.

The equation (1) can also be written as follow:

$$\Delta U/\Delta t = \Delta Q/\Delta t - \Delta W/\Delta t \text{.....(2)}$$

ΔU/Δt is the rate of change of stored

energy.

ΔQ/Δt is the rate of heat loss orgain.

ΔW/Δt is the rate of doing work.

Energy Changes In The Body:

- Energy: is the measure of a system's ability to do work, it is measured in joule (J).

-Energy can be classified into two forms:

1. **Potential energy**: It is the energy that is stored in a body or a system. This includes gravitational energy, electrical energy and chemical energy.

2. **Kinetic energy**: It is the energy of motion and is usually defined as the work that will be done by the body.

- Kilo-calories (kcal) it is an expression of food energy and kilocalories per

minute for the rate of heat production.

Unit of energy

- The most widely accepted physics units for energy is Newton-meter or joule (J).

- Unit of power is given in joule per second or watt (W).

- The unit of energy in cgs (centimeter-gram-second) system is the **erg.**

- A convenient unit for expressing the rate of energy consumption of the body is the **met**. The met is defined as 50 kcal/m2 of body surface area per hour. For a normal person 1 met is about equal to the energy consumption under resting conditions.

A typical man has about 1.85 m^2 of surface area and for a woman about 1.4 m^2 thus1 met for a typical man is 92 kcal/hour or 107w. The units can be summarized as follows:

1 kcal = 4184 J

1 J = 10^7 ergs

1 kcal/hr = 1.162 W

1 met = 50 kcal/m^2 hr = 58 W/m^2

Metabolic rate

Metabolic rate refers to the amount of energy that an organism or tissue uses over a given period of time to carry out various physiological processes such as maintaining body temperature, powering organ function, and synthesizing molecules.

Metabolic rate can be expressed in different units, such as joules per second (J/s), also known as watts (W), or kilocalories per hour (kcal/h).

Metabolic rate can vary depending on a variety of factors such as age, sex, body size, genetics, activity level, and environmental conditions such as temperature and

altitude. In humans, the basal metabolic rate (BMR) refers to the minimum amount of energy required to sustain basic bodily functions while at rest, and it accounts for approximately 60-70% of daily energy expenditure. Physical activity and food intake also contribute to overall metabolic rate.

Example:

Let us consider the oxidation of glucose, a common form of sugar. The oxidation equation for 1 mole of glucose ($C_6H_{12}O_6$) is

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

That is 1 mole of glucose (180g) combines with 6 moles of O_2 (192g) to produce 6 moles each of H_2O (108g) and CO_2 (264g) releasing 686 kcal of heat energy.

Basal metabolic rate (BMR)

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.

- Typical person consumes energy at a rate of about 92 kcal/h or 107W or 1met

- **Factors effecting BMR:**

1. The BMR depends primarily upon thyroid function. A person with an overactive thyroid has a higher BMR than a person with normal thyroid function.
2. The BMR is related to the surface area or to the mass of the body. The energy used for basal metabolism becomes heat which is primarily dissipated from the skin. BMR is proportional to mass$^{3/4}$.
3. The metabolic rate depends to a large extent on the temperature of the body. Chemical processes are very temperature dependent. If the body temperature changes by 1^{o}C, there is a change of about 10% in the metabolic rate.

Work and Power

Chemical energy stored in the body is converted into external mechanical work as well as into life-preserving functions. The external work **ΔW** defined as a force **F** moved through a distance **ΔX**

$$\Delta W = F\,\Delta X \ldots\ldots\ldots\ldots (1)$$

The force (**F**) and motion **(ΔX) must be in the same direction.**

The rate of doing work is the **Power**, thus for a constant force:

$$P\ (Watt) = \Delta W/\Delta t \ldots\ldots (2)$$

- External work is done when a person is climbing a hill or walking up stairs. We can calculate the work done by multiplying the person's weight (mg) by the vertical distance moved (h).
- The efficiency of human body as a machine can be obtained from the usual definition of the efficiency ξ:

  ξ= Work done/ energy consumed

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

Example

A 70 kg hiker متسلق climbed a mountain 1000 m high. He reach the peak in 3 hrs .

1) Calculate external work done by climber? 2) Calculate power generated during 3 hrs.

Solution:

1)$\Delta W = F\ \Delta X$

F = Weight (N) = mass(kg) × g (m/s^2)

F = 70 kg × 9.8 m/s^2 = 686 N

$\Delta W = F\ \Delta X$ = 686 N × 1000 m = 686000 Joule(J)

2) Power (W)= $\Delta W/\Delta t$ = 686000 J/ 3×60×60

Second P = 686000 J/10800 second = 63.518 W