University of Al-Mustaqbal
College of Science
Department of Medical Physics

Medical Physics

Lecture 7: Energy, Work and Power of the body

Third stage

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Energy, Work and Power of the body

Energy (E): Is the quantitative property that must be transferred to an object in order to perform work on, or to heat, the object. The SI unit of energy is the **Joule(J).** Common forms of energy include the kinetic energy , potential energy, the chemical energy, the radiant energy carried by light, and the thermal energy due to an object's temperature.

Work (W): Is defined as product of the force (F) and the distance (x) over which the force is applied. **Work** is done when a force is applied to an object and the object is moved through a distance, the unite is (1N.m= J).

W = Force × Distance

Power (P): Is the rate of doing work (W) or transferring heat, the amount of energy transferred or converted (E) per unit tim (t) . The SI unit of power is the joule per second (J/s), known as the Watt .

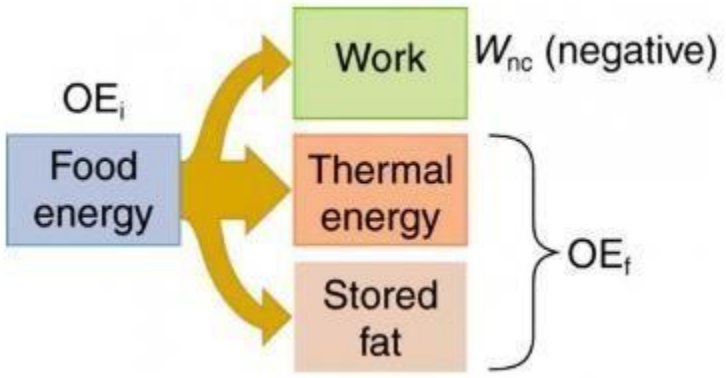
(P = W/t).

The Energy in Human Body

All body activities including thinking, doing work, or keeping the body temperature (temp.). constant involve energy changes, for example under resting conditions the skeletal muscles and the heart using 25% of the body's energy, another 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. Extra food energy will be stored mainly as fat. External heat energy from environment can help maintain the body temp., but it has no use in body function.

The body uses the food energy to:-

1. Operate body various organs.
2. Maintain a constant body temperature.
3. Do external work for example lifting.



Energy consumed by humans is converted to work, thermal energy, and stored fat. By far the largest fraction goes to thermal energy, although the fraction varies depending on the type of physical activity.

Conservation of energy in the body

The conservation of energy in the body is expressed by the first law of thermodynamics: The change in stored energy in the body (food energy, body fat, and body heat) = The heat lost or gained from the body ± Work done

$$\Delta U = \Delta Q \pm \Delta W \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

ΔU: is the change in stored energy. ΔW: is the work done by the body.

ΔQ: is the heat lost or gained (will discussed the heat concept in coming lectures).

The rate of change of energy is given by:

$$\frac{\Delta U}{\Delta t} = \frac{\Delta Q}{\Delta t} \pm \frac{\Delta W}{\Delta t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

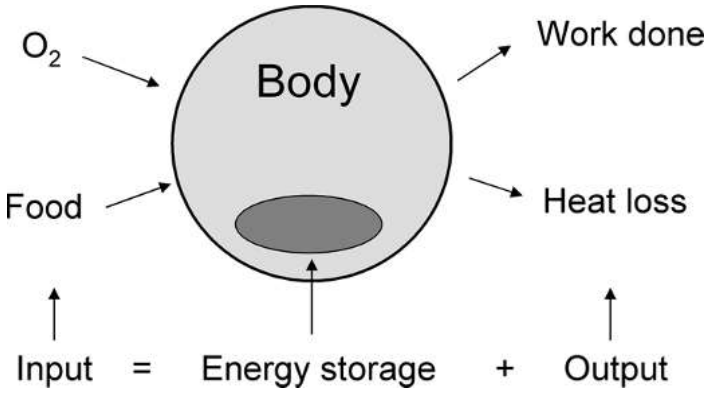
$\frac{\Delta U}{\Delta t}$: Rate of change of stored energy.

$\frac{\Delta Q}{\Delta t}$: Rate of heat loss or gain.

$\frac{\Delta W}{\Delta t}$: 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.

The body's basic source of energy is the food energy; it must be chemically changed by the body to make molecules that can combine with oxygen in the body's cells. Figure below



Energy flow into and from the body

All types of energy have the same units, including heat (often expressed in terms of calories) and work (often expressed in terms of joules). One important conversion between units is

1 calorie (cal) = 4.184 joule (J).

Energy Content of Body Fuel

There is some similarity between metabolic **oxidation** and combustion, even though the body does not "burn" its fuels in oxygen. It is useful to learn about

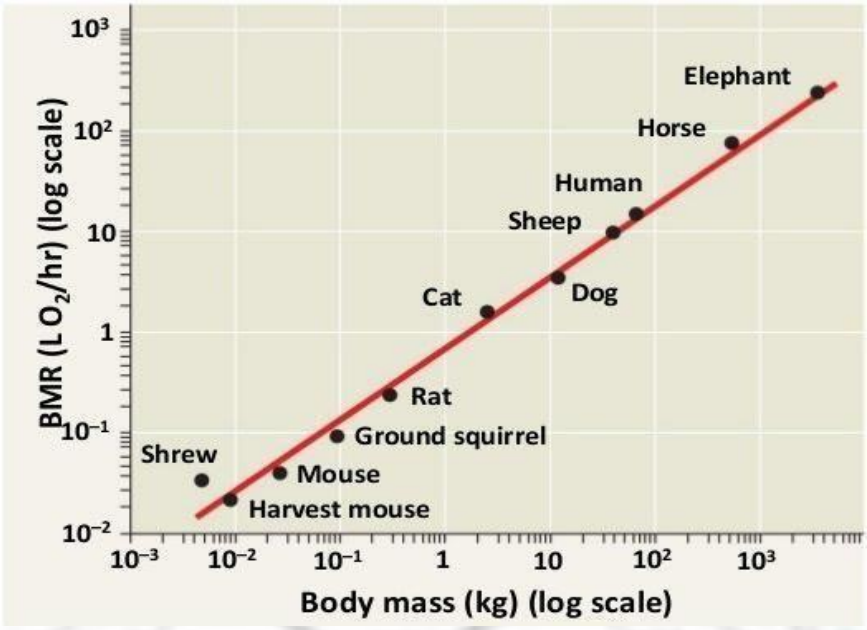
the combustion of these fuels because combustion tells you the maximum amount of energy that is available from breaking and rearranging bonds.

What do you mean oxidation?

A chemical process in which oxygen is used to make energy from carbohydrates (sugars). Also called metabolism. The oxidation process within the body, heat is produced as energy of metabolism**.**

The Basal Metabolic Rate (BMR)

BMR: It is the amount of energy needed to perform minimal body functions (such as breathing and pumping the blood through the arteries). BMR depends primarily upon thyroid function. A person of an over active thyroid has a higher BMR than a person with normal thyroid function. Since the energy used for basal metabolism becomes heat and dissipated from the skin, so BMR is related to the surface area, or the mass of the body. The metabolic rate depends on temperature of the body, and on sex, age, height, and weight. In Figure below the graph represents the change between BMR (kcal/day) and the mass of different beings, the slope of the graph indicates that the BMR is proportional to mass.



Relationship between BMR and body mass for different beings

Mechanical Work and Power

The first law of thermodynamics equation (1) shows that stored energy can be used to supply heat or work. For people, this is mechanical work.

Mechanical work is the force you apply to an object (F) × the distance you push or pull it (x) and it can be also written as:

$$\Delta w = F.\Delta x \quad \text{..... ..... (3)}$$

Or with accurate meaning:

$$\Delta w = F\,\Delta x \cos(\theta) \quad \text{..... ..... (4)}$$

where θ is the angle between F and the direction of movement.

The power is work per unit time.

$$P = \frac{\Delta w}{\Delta t}$$

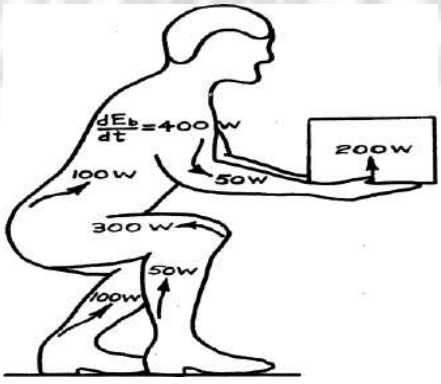
$$= F\frac{\Delta x}{\Delta t}\ ; \qquad \frac{\Delta x}{\Delta t} = v$$

$$P = F\,v \quad \ldots\ldots\ldots\ldots \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

where v is the velocity. When the force is perpendicular to the displacement ($\theta=90^0$) 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 given in the equation below

$$w = mgh \qquad \text{where: } g=9.8\ m/sec^2$$

we can call external work, work is also done about the joints of the body to lift the center of mass of the body itself, which is internal work. Also, concentric muscle contractions are said to do positive (mechanical) work, while eccentric contractions do negative work. Walking on level ground requires equal amounts of positive and negative work. Walking uphill requires relatively more positive work, while walking downhill requires relatively more negative work Figure below. The work efficiencies of positive and negative work are different.



"Internal" vs. "external" work in lifting an object.

The efficiency of human body can be obtained from the law:

$$Efficiency\ (\mathcal{E}) = \frac{\text{The work done (output)}}{\text{The energy consumed (input)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(6)}$$

$$\mathcal{E} = \frac{w=mgh}{E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Energy consumed = Metabolic Rate

Example:

Person raising a box of mass (15 kg) to a table is (2 m) from the ground, Calculate the necessary energy in the units of calories, assuming that the efficiency of this person is (25%) and acceleration of the gravitational is (g=9.8 m/sec^2).

Solution

$$\mathcal{E} = \frac{mgh}{E} \quad \rightarrow \quad E = \frac{mgh}{\mathcal{E}}$$

$$E = \frac{15 * 9.8 * 2}{0.25} \quad \rightarrow \quad E = 1176\ J$$

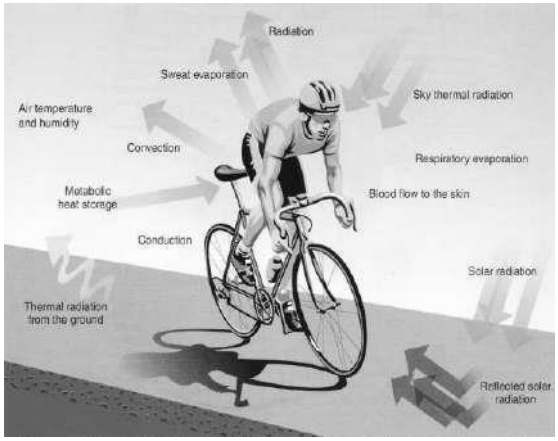
1 cal = 4.184 J

$$E = \frac{1176\ J}{4.184\ J/cal} \quad \rightarrow E = 281.07\ cal$$

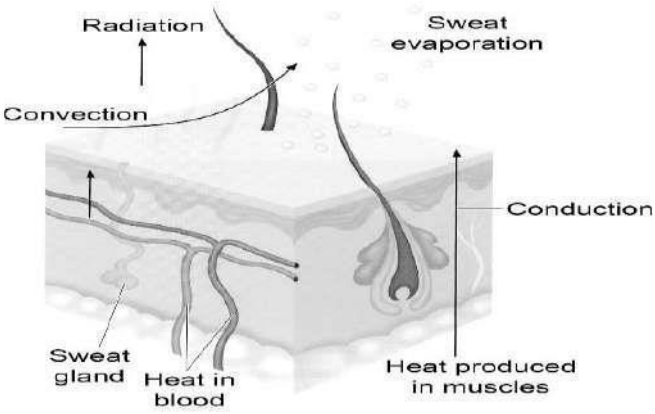
Modes of Heat Loss

There are four modes of heat loss. -Figures (below).

1. Radiation loss.
2. Convection and Conduction of air from the body .
3. The Evaporation of sweat .
4. The Evaporation of water through breathing



Overall body modes of loss of heat



More microscopic view of modes of heat loss by removal from the skin.

1. What is Energy?

A) The ability to sleep
B) The ability to do work
C) The ability to stop motion
D) The ability to cool objects

Answer: B) The ability to do work

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2. What is the SI unit of energy?

A) Watt
B) Newton
C) Joule
D) Meter

Answer: C) Joule

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3. Work is defined as:

A) Force × Time
B) Force × Distance
C) Mass × Velocity
D) Energy × Time

Answer: B) Force × Distance

4. What is Power?

A) Energy stored in the body
B) Rate of doing work
C) Force applied on object
D) Distance moved

Answer: B) Rate of doing work

5. The formula for power is:

A) $P = F \times x$
B) $P = W \times t$
C) $P = W / t$
D) $P = mgh$

Answer: C) $P = W / t$

6. The main source of energy in the human body is:

A) Water
B) Air
C) Food
D) Sunlight

Answer: C) Food

7. Basal Metabolic Rate (BMR) refers to:

A) Energy used during exercise
B) Energy used for basic body functions
C) Energy stored as fat
D) Energy lost as heat

Answer: B) Energy used for basic body functions

8. The work done in lifting an object is given by:

A) $W = F \times t$
B) $W = mgh$
C) $W = v/t$
D) $W = P \times t$

Answer: B) W = mgh

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9. Efficiency is defined as:

A) Input / Output
B) Output / Input
C) Work × Time
D) Energy × Force

Answer: B) Output / Input

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10. Which of the following is NOT a mode of heat loss?

A) Radiation
B) Conduction
C) Evaporation
D) Compression

Answer: D) Compression