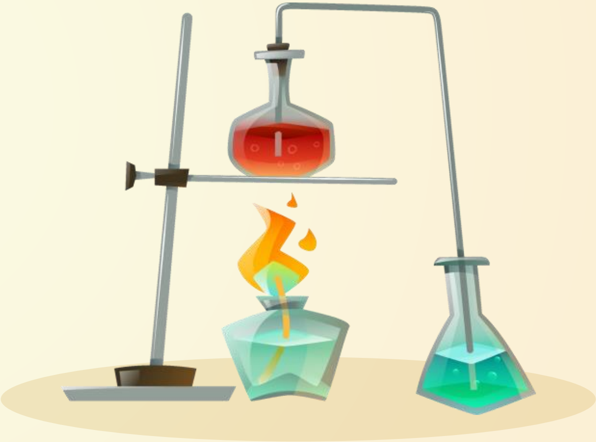
Heat and Energy



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Introduction

The processes involved in the energy intake, storage, and use by the body are collectively called the metabolism; the discipline describing this area is sometimes called bioenergetics. More generally, metabolism is any energy usage by the body, and is the sum of all chemical processes performed by the cells in order to keep the body alive. For a complete picture we need to include input of food and oxygen to the body, energy storage, and loss of energy by the body through the loss of heat and work done by the body.

"Energy cannot be created or destroyed, it can only be changed from one form to another."

—**Albert Einstein**

What is heat?

Thermal energy

Thermal energy is the internal energy present in a system due to its temperature, manifested as the kinetic energy of its molecules and atoms.

Kinetic energy

Kinetic energy is the energy possessed by an object due to its motion.

02 >

Generals

Introduction to System of units of measurement

$$1\ k\ cal = 4184J$$

$$1J = 10^7 ergs$$

$$1\ \frac{kcal}{min} = 69.7W = 0.094hp$$

$$100\ W = 1.43\ \frac{kcal}{min}$$

$$1\ hp = 642\frac{kcal}{hr} = 764W$$

$$1\frac{kcal}{hr} = 1.162\ W$$

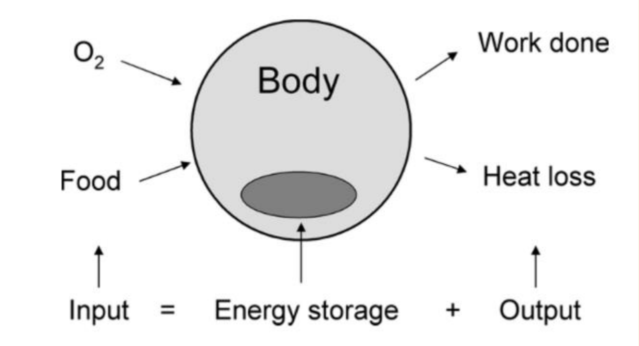
The First Law of Thermodynamics

$$\Delta U = Q - W$$

$$Q = Q_{met} + Q_{loss}$$

$$\Delta U = Q_{met} + Q_{loss} - W$$

$$\frac{dU}{dt} = \frac{dQ_{met}}{dt} + \frac{dQ_{loss}}{dt} - \frac{dW}{dt}$$



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.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 686kcal$$
$$1\ mol + 192\ gr = 264\ gr + 108\ gr + 686\ kcal$$

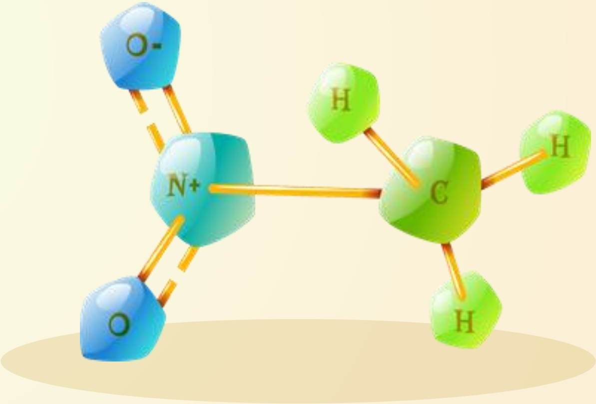
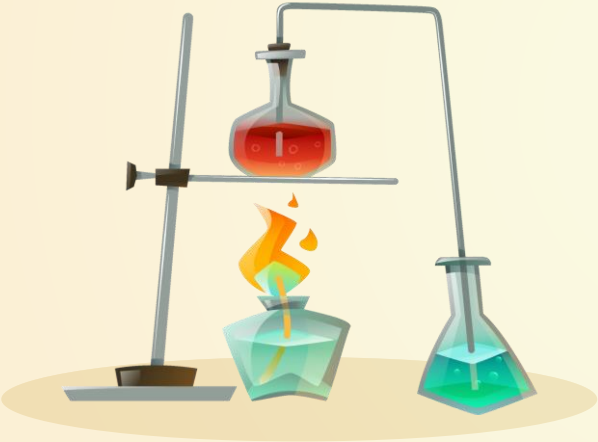


Table 6.2. Average caloric content of food.

Food	Net Caloric value $\left(\frac{kcal}{g}\right)$	Bomb calorimetry energy $\left(\frac{kcal}{g}\right)$	Calorific equivalent $\left(\frac{kcal}{L \times O_2}\right)$	CO_2 production $\left(\frac{kcal}{L \times O_2}\right)$	RER $\left(\frac{L \times CO_2}{L \times O_2}\right)$
Carbohydrate	4.02	4.10	5.05	5.05	1.0
Protein	4.20	5.65	4.46	5.57	0.80
Ethanol	7.00	7.10	4.86	7.25	0.67
Fat	8.98	9.45	4.74	6.67	0.71

RER is the respiratory exchange ratio.



What is BMR?

Mechanical Work and Power of the Body

$$\frac{dU}{dt} = \frac{dQ_{met}}{dt} + \frac{dQ_{loss}}{dt} - \frac{dW}{dt}$$

$$W_{External} = F.\Delta x$$

$$P = \frac{W_{External}}{\Delta t} = F\frac{\Delta x}{\Delta t} = F.V$$

$$E = \frac{P_{External}}{Metabolic\ Rate}$$

Heat Loss

Radiation

54%

Respiration

10%

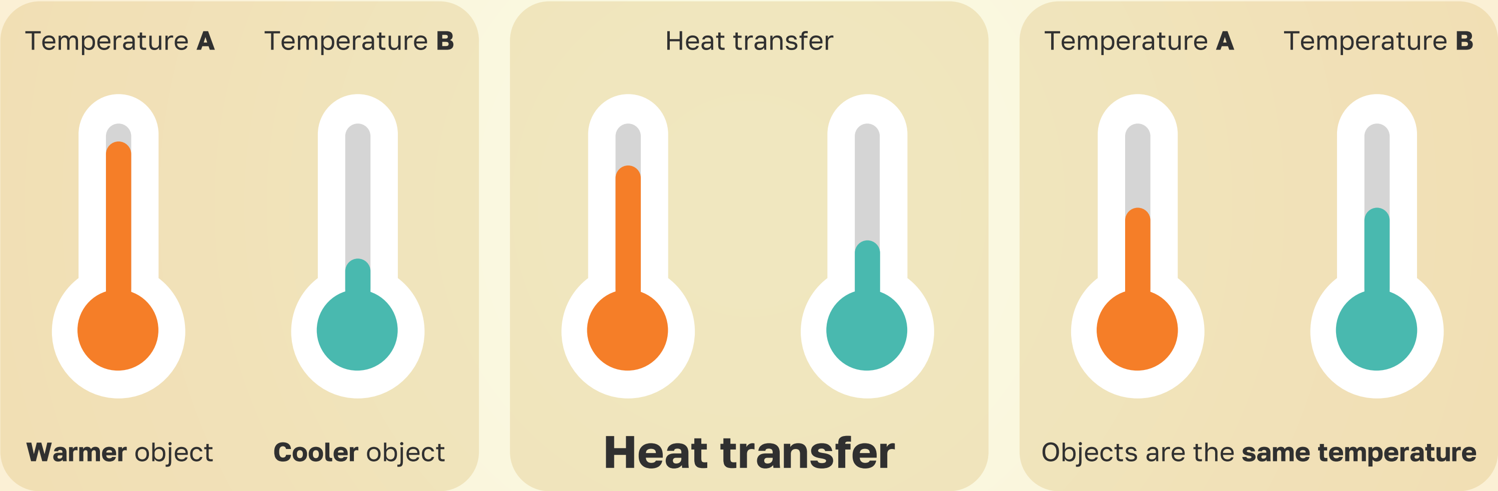
Convection

26%

Evaporation

10%

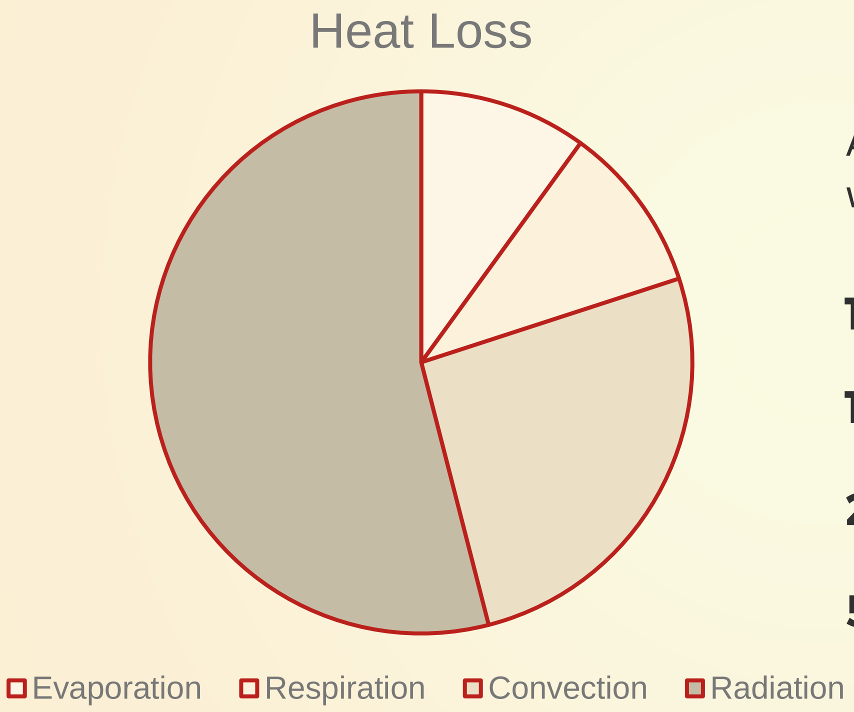
How is heat transferred?



Examples of heat transfer

- Cooking
- Melting ice
- Iron clothes
- Refrigeration
- Hot beverage
- Toasting bread

Pie Chart



And we can easily show the resualt with a pie chart

10% Evaporation energy

10% Respiration energy

26% Convection energy

54% Radiation energy

Loss of Body Heat

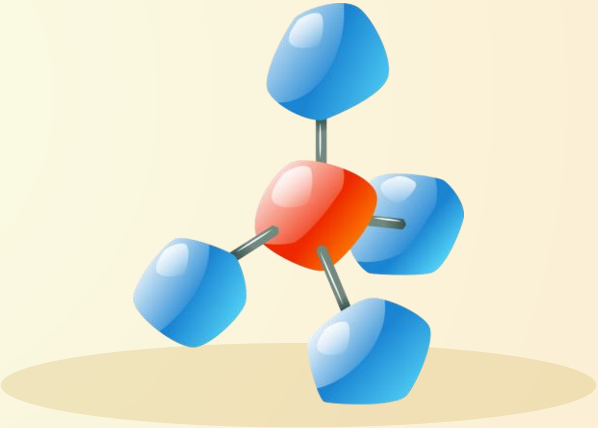
- Heat Loss by Radiation:

$$\frac{dQ}{dt} = A\sigma\zeta(T_{skin}^4 - T_{sur}^4)$$

$$\sigma = 5.67 \times 10^{-8} \frac{W}{(mK)^2}$$

- Heat Loss by Convection:

$$\frac{dQ}{dt} = Ah(T_{skin} - T_{air})$$



Summary

The energy used by the body and body temperature are determined by the body metabolism, which includes the use of food, the energy needed to operate the body, and the production of heat, and by the loss of heat by the body. The energy value of food can be analyzed and compared to the production of ATP by the body and the use of ATP in different activities. The body metabolic rate is composed of many components, each of which can be modeled. This includes analyzing the rate that energy is needed for the operation of body functions for a person who is inactive, which combine to form the BMR, and the rate that energy is needed for the body to engage in physical activity. The body metabolism and food intake can be linked to models of the steady-state body weight and of weight gain and loss. The body can lose heat by radiation, convection, conduction, and the evaporation of water, each of which can be modeled and linked to models that determine the body temperature.

03 >

Examples

Example 3-1

A person with a mass of 70 kg is walking at an average speed and in this case consumes 1.1 min/lit of oxygen. The characteristics of the food that is metabolized during walking are on average as follows:

	Net Caloric value $(\frac{kcal}{g})$	Bomb calorimetry energy $(\frac{kcal}{g})$	Calorific equivalent $(\frac{kcal}{L \times O_2})$	CO_2 production $(\frac{kcal}{L \times O_2})$
Food	4.0	5.0	5.0	1.0

The air temperature is 28 degrees Celsius and the air flow speed of the environment is 2 s/m. The temperature of a person's skin is about 35 degrees Celsius. The total surface area of his body is about 1.75 square meters and the effective area exposed to his environment is 0.8 of this amount.

Example 3-1

A) What is the metabolic rate of this person in kilocalories per minute?
B) What is the metabolic rate of this person?
C) What is the amount of power dissipated through radiation and displacement mechanisms? (Consider the emission coefficient of a person's body as 1)
D) If the amount calculated in part b is about 75% of the total heat dissipated from this person's body through all possible mechanisms, during this activity, assuming stable conditions, calculate the amount of external work done by the person per unit of time and the efficiency of this walk.

Example 3-1

Answer:

$$A)\ MR = 1.1\frac{L\ O_2}{min} \times 5\frac{kcal}{L\ O_2} = 5.5\frac{kcal}{min}$$

$$B)\ BMR = Cm_b^{\frac{3}{4}} = 90\ \times\ 70^{\frac{3}{4}} = 2178.04\frac{kcal}{day}$$

$C \cong 90$

$$BMR = \frac{21178}{60 \times 24} = 1.512\frac{\text{kcal}}{min} \rightarrow \frac{MR}{BME} = 3.637$$

$C)\ C\ will\ be\ left\ as\ your$ $class\ activity$

$D)\ Total\ heat\ loss\ from\ radiation\ and\ convection: 0.9 + 3.691$ $(related\ to\ your\ class\ activity)$

$$Total\ heat\ loss = 4.591\ \times \frac{100}{75} = 4.89\frac{kcal}{min}$$

$$\dot{W}_{External} = 5.5\ - 4.89 = 0.61\frac{kcal}{min}$$

$$E\ = \frac{\dot{W}_{External}}{MR} = \frac{0.61}{5.5} = 0.11$$

Example 3-2

Consider the oxidation of the alcohol (ethanol):

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O + 327\ kcal$$

Find the energy release/g, calorific equivalent, and respiratory exchange ratio (RER) (or respiratory quotient (RQ)).

Example 3-2

Answer:

327 kcal for 1 mol ethanol

Molar mass of ethanol = 46.07 g/mol

$$\frac{327\ kcal}{1\ mol} \times \frac{1\ mol}{46.07\ g} = 7.09\frac{kcal}{g}$$

Calorific energy:
Molar volume for O_2 = 22.4 L/mol

$$\frac{327}{3\ \times 22.4} = 4.8\frac{kcal}{LO_2}$$

Example 3-3

Consider the oxidation of the alcohol (ethanol):

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O + 327\ kcal$$

Find the energy release/g, calorific equivalent, and respiratory exchange ratio (RER) (or respiratory quotient (RQ)).

Example 3-3

Answer:

327 kcal for 1 mol ethanol

Molar mass of ethanol = 46.07 g/mol

$$\frac{327\ kcal}{1\ mol} \times \frac{1\ mol}{46.07\ g} = 7.09\frac{kcal}{g}$$

Calorific energy:

Molar volume for O_2 = 22.4 L/mol

$$\frac{327}{3\ \times 22.4} = 4.8\frac{kcal}{LO_2}$$

$$RER = \frac{L\ CO_2}{L\ O_2} \rightarrow \begin{cases} Volume\ of\ carbon\ dioxide\ produced\ per\ gram\ of\ ethanol: \dfrac{2 \times 22.4}{46.07} = 0.97 \\ Volume\ of\ oxygen\ produced\ per\ gram\ of\ ethanol: \dfrac{3 \times 22.4}{46.07} = 1.45 \end{cases}$$

RER = 0.67

Example 3-4

If you are 45 kg overweight,
A) How long should you do an activity equivalent to consuming 15 kilocalories per minute to lose your excess weight? Each gram of fat is equivalent to 9.3 kcal of energy.

B) If you naturally get 2500 kcal a day with food, how long should you increase your calorie intake to 2000 kcal to lose weight?

Example 3-4

Answer:

A)

$$4.54kg : (4.54 \times 10^3 g) \times \frac{9.3kcal}{1g} = 4.2 \times 10^4 kcal$$

$$T = \frac{4.2 \times 10^4 kcal}{15\frac{kcal}{min}} = 2800\ min \cong 47\ hr$$

B)

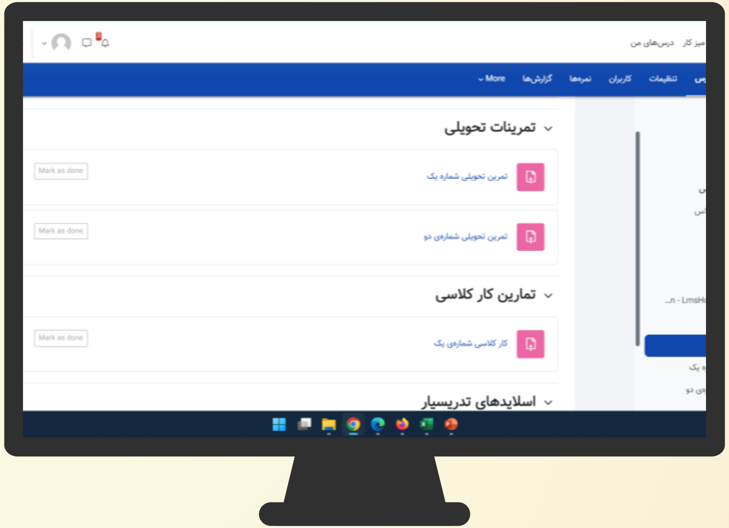
$$T(day) = \frac{4.2 \times 10^4}{2500 - 2000} = 84\ days$$

04 >

Assignment

HWh2

Deadline
Concept
Problems?



Activity 02: Example 3-1 Part C

Be careful about the structure

Upload your answer on courses.

Resources

Dr. Malikeh Nabaei

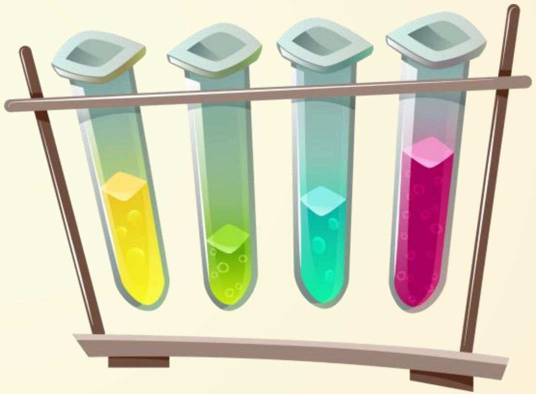
- Slides
- Classes

biological and medical physics, biomedical engineering

- The reference book

Faezeh Jahani

- Slides



Thanks!

Do you have any questions?

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Have a good afternoon