MUNI
PHARM

Thermic

Biophysics

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Heat, temperature, fundamentals of thermodynamics

The Lord Kelvin

Thermics - macroscopic approach; studying the system as a whole (simplifies the description of thermal processes).

Thermodynamics - concerned with heat and temperature and their relation to energy and work.

Heat is a form of energy, **temperature** state of a system.

The relationship between the change in temperature of the system and the amount of supplied / removed thermal energy: **$\Delta Q = m * c * \Delta T$**

ΔQ (J) heat change, ΔT (K) temperature change, m (kg) weight, c (J/kg.K) specific heat capacity.

Thermodynamic temperature: Kelvin (K), the SI unit. In medicine Celsius scale (°C). USA: Fahrenheit (0°C = 32°F; 100°C = 212°F).

T [K] = t [°C] + 273.15

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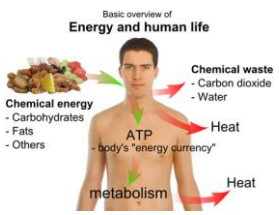
Heat balance of chemical reactions in the body

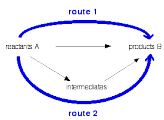
In a living organism take place two thermodynamically opposed processes :

a) **irreversible processes** – degradation of energy and entropy increase (nutrient conversion to CO_2 and water)

b) **open systems** – life processes prevents increase of entropy (they increase the entropy of their environment)



Nutrient conversion to CO_2 and water takes place via a series of reactions. The enthalpy (the maximum amount of heat) of a chemical process is independent of the path taken from the initial to the final state (**Hess's law**).



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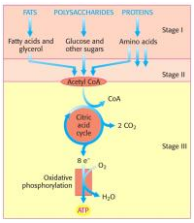
Heat balance of chemical reactions in the body

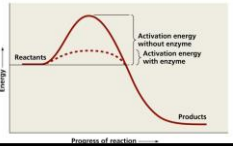
The maximum amount of energy that can be converted into work during a chemical reactions:

$\Delta G = R * T * \ln K$

K (equilibrium constant) = $\frac{[products]}{[reactants]}$

- $\Delta G < 0$ for spontaneous reaction; releases energy into the surroundings.
- When removing reaction products (open system), remains $\Delta G < 0$.
- Spontaneous reaction can be very slow (thermodynamics does not expresses rate). Metabolism of nutrients (carbohydrates, lipids, proteins) occurs only in the presence of enzymes.





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Thermoregulation

The temperature is crucial for the metabolism - a highly temperature sensitive enzymes.

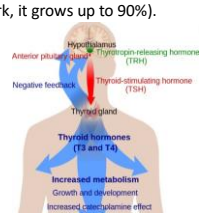
The average body temperature in humans ranges from 36.5 °C to 37.3 °C. Skin temperature ranges from 31 °C to 35 °C.

Heat production:

The relative share of heat production at rest: about 56% internal organs and 18% muscles and skin (during physical work, it grows up to 90%).

a) Basal metabolism
– energy from nutrients is converted mainly into heat

b) Increased metabolism
– muscular work (eg. goosebumps, tremor from cold, digestion)
– regulatory action of hormones (thyroxine, noradrenaline)



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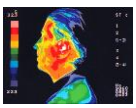
Mechanisms of heat loss

Direct heat loss: radiation, conduction, convection.

Indirect heat loss: evaporation (evaporation from the lungs; perspiration)

Radiation

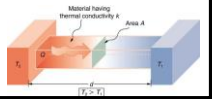
Represents up to 60% of total heat loss (depending on ambient temperature). Every body that is in an environment of lower temperature radiates heat as infrared radiation (5-20 μm).



Conduction

Liquids are well thermally conductive: blood transfers heat from inside the body to the skin.

The amount of transferred energy at time between two points depends on the difference in their temperatures ΔT, coefficient of thermal conductivity and surface area.



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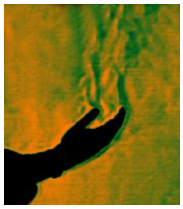
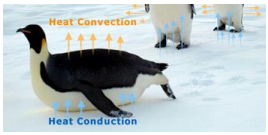
Mechanisms of heat loss

Convection

- is the transfer of heat from one place to another by the movement of fluids (liquids or gases). The heat transfer over time depends on the air fow rate (for example, frostbite occurs at low temperatures faster in the wind than in no wind), surface area, difference in temperatures ΔT and heat transfer coefficient.





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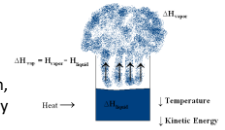
Mechanisms of heat loss



Evaporation

Due to the high specific heat of vaporization, evaporation of water makes up 25% of body heat loss (depending on the air humidity).

Evaporation of sweat from the skin surface has a cooling effect due to evaporative cooling.

Breathing – exhaled air is almost saturated with water vapor.

Perspiration

a) *unnoticeable* (spontaneous diffusion of water through the skin, without the participation of sweat glands); average loss of water 660 ml/day.

b) *noticeable* (via the sweat glands); loss of water to 1.5 l/h. Regulated by the organism; efficiency depends on the environment (e.g. humidity).

Noticeable perspiration is significantly applied when the surrounding temperature is high (> 36 °C) and other mechanisms can not be applied.

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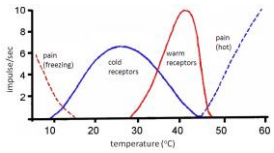
Thermoregulation

Warm-blooded animals maintain temperature using thermoregulatory mechanisms. The main regulatory mechanism is the **negative feedback** – a comparison of the desired temperature (hypothalamus) with the actual body temperature.

- Temperature changes are detected by the thermoreceptors in the skin, in the hypothalamus and also in some organs and vessels.
- In the epidermis are receptors for cold; in the upper part of the corium (dermis) are receptors for heat.



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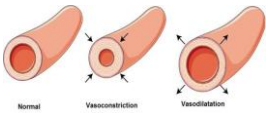
Thermoregulation

The organism produces heat => they need to control heat loss.

Skin and its importance in thermoregulation:

- Skin with subcutaneous fat is a good insulator => small removal of heat by conduction.
- **For thermoregulation is important blood flow from the organs to the periphery (skin)** => The efficiency of heat removal depends on blood supply to the skin (vasodilatation / vasoconstriction).



- Skin sweat glands regulates the body temperature (heat is removed by evaporation).

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Temperature measurement (thermometry)

The temperature as a physical quantity describes the state of the organism as the biological system and is a significant and easily identifiable symptom of a large group of diseases.

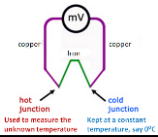
The temperature is NOT measured directly, but uses the known physical phenomena that show temperature dependence

Thermometers based on thermal expansion (eg. volume expansion).

Resistance thermometers: The electrical resistance of metals depends on the temperature.

Radiation thermometers: non-contact temperature sensors that measure the temperature from the amount of thermal electromagnetic radiation (e.g. infrared) emitted from the subject being measured.

Thermocouple thermometry: Thermocouple convert the heat directly into electricity at the junction of different types of wire. Miniaturization - Invasive temperature measurement in medicine (accuracy 0.05-0.01 °C).



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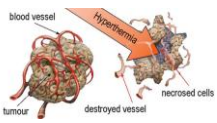
The use of thermal energy in medicine

Hyperthermia

It uses the thermal effect of microwave radiation, ultrasonic waves or laser in combination treatment of cancer.



High hyperthermic effect is achieved in tissues with low blood flow (less cooling) - tumor cells.

Used temperatures 42.5-45 °C (so that no damage to surrounding tissue) for 45-60 min.

Hyperthermia is most often used with radiation therapy (synergy effect).

Complicated computer processing of the absorbed dose and evaluation of the temperature profile limits the use of hyperthermia.

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Cryotherapy

- **Use of cold to relieve pain** (ca 5 °C): vasoconstriction and subsequent vasodilation; Reduced transmission of nerve impulses and subsequent release of muscle spasm.
- Temperature reduction in **heart surgery**: reduce the risk of brain damage (at 30 °C oxygen consumption decreases to ½; at 20 °C to 1/10 compared to 37 °C).
- **Short-term conservation** of blood, serum, organs, etc.: a temperature about 4 °C.
- **Cryosurgery**: destruction of pathological tissues by a freezing probe.
- **Tissue fixation by freezing**: histological examination of the tissue removed during surgery (the result is known during the surgical procedure).

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