Biothermal physics

Third lecture

Methods of heat transfer

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Third Stage

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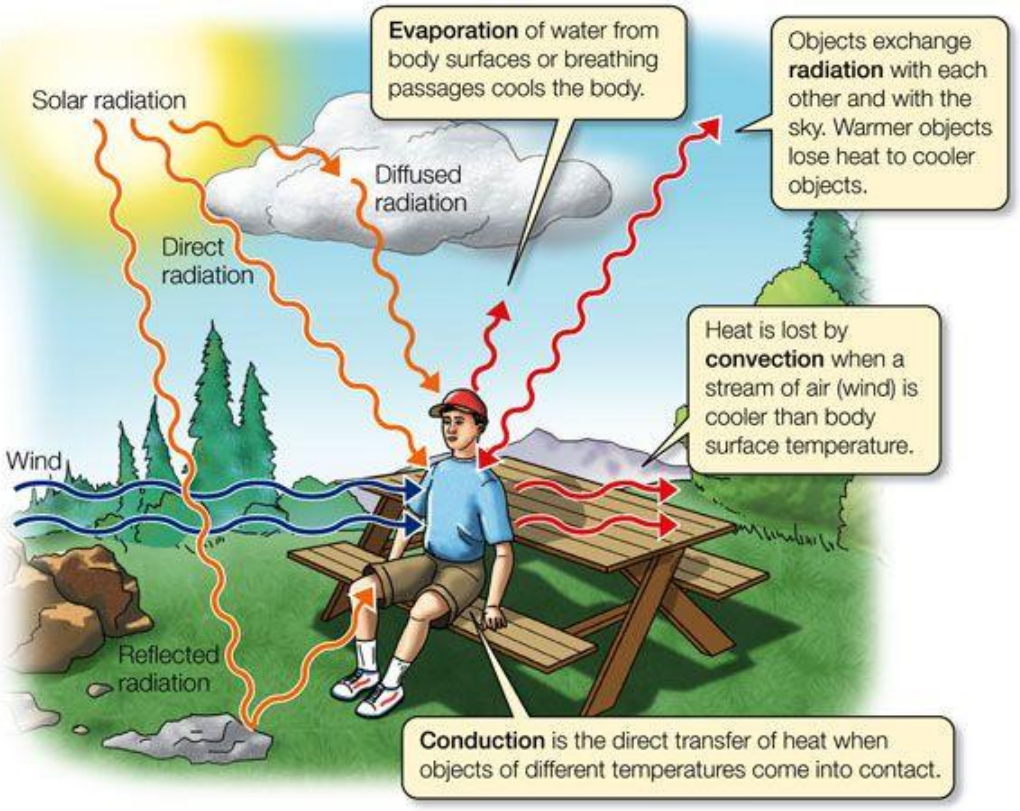
Mechanism of heat exchange

- Heat is the form of energy that can be transferred from one system to another due to a temperature difference or gradient
- The science which deals with the rates of such energy transfer is known as "heat transfer".
- The means by which therapeutic heat is delivered to the target tissues is attributed to the following physical mechanisms:

  1. Conduction 2. Convection 3. Radiation 4. Conversion 5. Evaporation

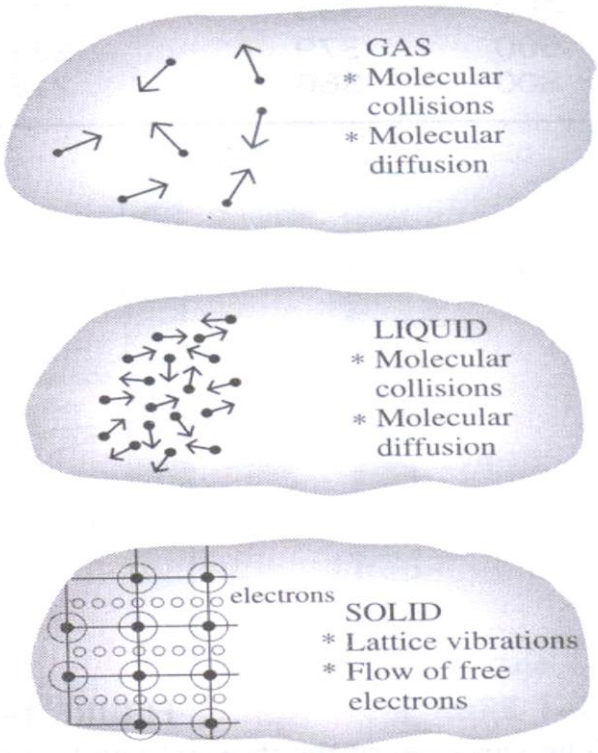


1. Conduction

- Heat is transferred through a material by being passed from one particle to the next.
- Particles at the warm end move faster and this then causes next particles to move faster and so on
- In this way heat in an object travels from hot end to cold end

- Heat gain or loss through direct contact between materials with different temperature is called ***conduction.***
- For example, ***heat is absorbed by the body tissues when using a heating pad.***

- Physically: ***Thermal conduction is the transfer of thermal energy from the high energetic to the low energetic particles of a stationary medium (solids, liquids or gas) due to interactions between the particles.***
- In solids, conduction may be attributed ***to atomic activity in the form of lattice vibrations and energy transport by the free electrons***.
- In fluids, conduction occurs due to the ***collisions and diffusion of the molecules during their random motion.***



- The basic equation for thermal conduction is the ***Fourier's law*.**
- It states that ***the heat flux (Heat Transfer rate per unit area) is directly proportional to the temperature gradient.***

$$q \propto dT/dx \quad \text{or}$$

$$q = -k\ dT/dx$$

- Where, k is thermal conductivity (W/ m K)

  dT/dx is temperature gradient

  q is heat flux (W/m^2)

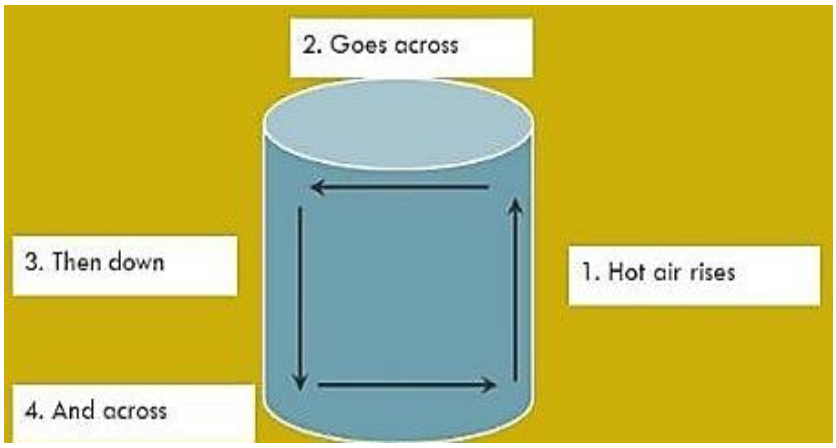
$$Q = -kA\frac{dT}{dx}$$

Thermal Conductivity(k)

- ***It is the measure of the ability of a material to conduct heat.***
- It is one of the ***transport properties*** of a material.
- Its unit is W/m ^oC or W/m K.
- For Solids and Liquids, k f(T). For gases/vapor, k f(p, T)

2. Convection

- it is defined as the ***transference of heat to a body by the movement of air, matter or liquid around the body***.
- The heat is carried by the particles themselves moving ***convection currents.***
- For example: warm or cool whirlpool in which movement of the water around a body part results in a temperature change.
- Hot liquids and gases expand and rise while the cooler liquid or gas falls.



- The sun can cause large convection currents (winds) during daytime the land warms up more than the sea.
- The warm air rises over the land and cool air falls over the sea. So we feel a sea breeze.
- Convection refer to the thermal energy transfer between a solid surface and a moving fluid when they are at different temperature levels.
- Thermal energy transfer by convection is classified as:

  1. Forced convection

  2. Natural convection

- ***Forced convection*** is the transfer of thermal energy when the flow is caused by external means such as a fan a pump or atmospheric winds.

- ***Natural convection*** is induced by buoyancy forces due to density variations as a result of temperature differences.
- There is thermal energy convection by ***latent heat exchange***. This latent heat is due to change of phase from liquid to vapor or vice versa.
- ***Boiling*** and ***condensation*** are examples for such processes.

- The basic equation for convection heat transfer is known as **Newton's law of cooling**:

$$Q = hA(T_s - T_\infty)$$

Where,

T_s is the surface temperature,

T_∞ is the fluid temperature and

A is the surface area of the solid.

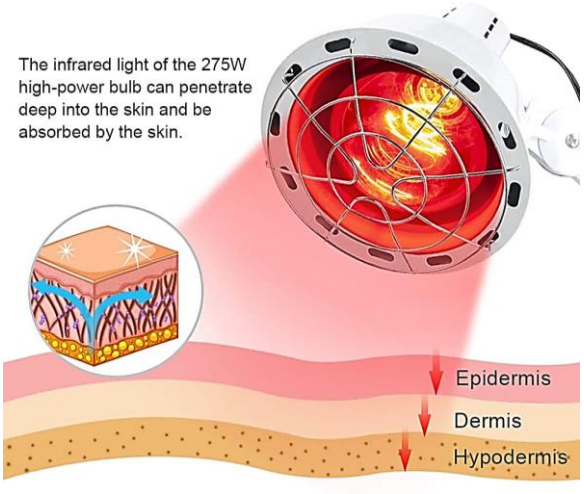
h is the convection heat transfer coefficient in $(^{W}/_{m^2K})$

- h is also called **film heat transfer coefficient** or **surface conductance**.

- The value of 'h' depends upon:
  1. Surface condition: roughness and cleanliness
  2. Geometry and orientation of the surface: plate, cylinder or sphere, placed vertically or horizontally.
  3. Thermophysical properties of the fluid: density, viscosity, specific heat, thermal conductivity etc.
  4. Nature of fluid flow: laminar or turbulant
  5. Boundary layer configuration
  6. Prevailing temp. conditions.

3. Radiation

- Transfer of heat directly from the source to the object by a wave, travelling as rays.
- Heat radiation is also known as infrared radiation.
- All objects that are hotter than their surroundings give out heat as infra-red radiation, e. g. ***infra-red radiation lamp*** (I. R. R).



- Thermal energy transfer by radiation is caused by electromagnetic waves (or photons).
- Thermal radiation is emitted by all surfaces which are kept at a finite temperature level.
- This happens from solids, liquids and gases.
- Rate of emission increases with temp. level.
- Radiant energy does not require a material medium for its transport.
- Moreover, radiation transfer will occur effectively in vacuum.
- The mechanism of heat flow by radiation consists three distinct phases:

  1. Conversion of thermal energy of the hot source into electromagnetic waves.
     - ✓ Photons are propagated through the space as rays.
  2. Passage of wave motion through intervening space.
     - ✓ Photons travel with unchanged frequency in straight paths with speed equal to that of light.

3. Transformation of waves into heat.
   - ✓ Reconversion of wave motion into energy occurs in the receiving surface which may partly absorbed, reflected or transmitted through.

- The basic rate equation for radiation is the ***Stefan-Boltzmann*** law:

$$E_b = \sigma_b A T^4$$

Where, E_b is the energy radiated per unit time.
T is the absolute temp of the surface
σ_b is the Stefan-Boltzman constant

$$\sigma_b = 5.67\ x\ 10^{-8}\ W/m^2K^4$$

4. Conversion

- It refers to the temperature change that results when energy is transformed from one form to another.
- such as the conversion from mechanical or electrical to thermal energy.
- E.g. ultrasound therapy (U. S. T.)

5. Evaporation

- It is defined as the transformation from a liquid state to a gas state.
- Heat is given off when liquids transform to gases.
- E.g. sweating results from heat production within the body.
- Cooling occurs as the perspiration evaporates from the surface of the skin.