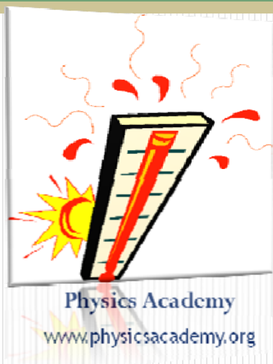
Selected Topics in Physics for Medical Sciences Students



Unit 4

Temperature and Heat

Lecture 15

Heat Transfer

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Contents

- Temperature
- Thermal expansion of solids and Liquids
- Ideal Gas Equation
- Heat and the first law of thermodynamics
- Heat Transfer

Heat Transfer

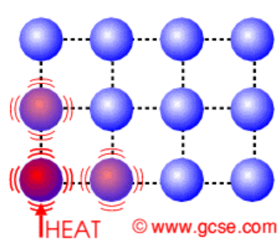
- The heat is a transfer of the energy from a high temperature object to a lower temperature one.
- Heat transfer changes the internal energy of both systems
- **Heat can be transferred by three ways:**
  1. **conduction,**
  2. **convection**
  3. **radiation.**

Heat conduction

- Conduction is heat transfer by means of molecular agitation within a material without any motion of the material as a whole.

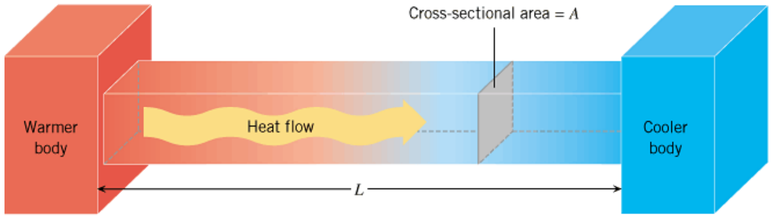
Conduction is the transfer of heat within a substance, molecule by molecule.

If you put one end of a metal rod over a fire, that end will absorb the energy from the flame. The molecules at this end of the rod will gain energy and begin to vibrate faster. As they do their temperature increases and they begin to bump into the molecules next to them. The heat is being transfered from the warm end to the cold end.



Heat conduction

- **Conduction – when two objects are in physical contact.**



$$H = \frac{Q}{t} = kA\left(\frac{\Delta T}{L}\right)$$

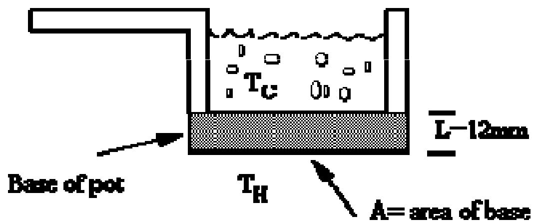
H = rate of conduction heat transfer (Watt)
k = thermal conductivity (W/m/K)
Q = heat transferred
A = cross sectional area
t = duration of heat transfer
L = length
ΔT = temperature difference between two ends

The thermal conductivity coefficient

Substance	$(W\ m^{-1}K^{-1})$	Substance	$(W\ m^{-1}K^{-1})$
Silver	427	Ice	2
Copper	397	Water	0.6
Aluminum	238	Wood	0.08
Gold	314	Air	0.023
Concrete	0.8	Hydrogen	0.1
Glass	0.8	Helium	0.138

Example

- An aluminum pot contains water that is kept steadily boiling (100 °C). The bottom surface of the pot, which is 12 mm thick and $1.5\text{x}10^4$ mm^2 in area, is maintained at a temperature of 102°C by an electric heating unit. Find the rate at which heat is transferred through the bottom surface. Compare this with a copper based pot.



Solution

$$H = kA\left(\frac{\Delta T}{L}\right)$$

- For the aluminum base: $T_H = 102$ °C, $T_C = 100$ °C, $L=12$ mm $= 0.012$ m, $K_{Al} = 238\,Wm^{-1}K^{-1}$, Base area $A = 1.5\text{x}10^4$ mm^2 = $0.015\ m^2$.

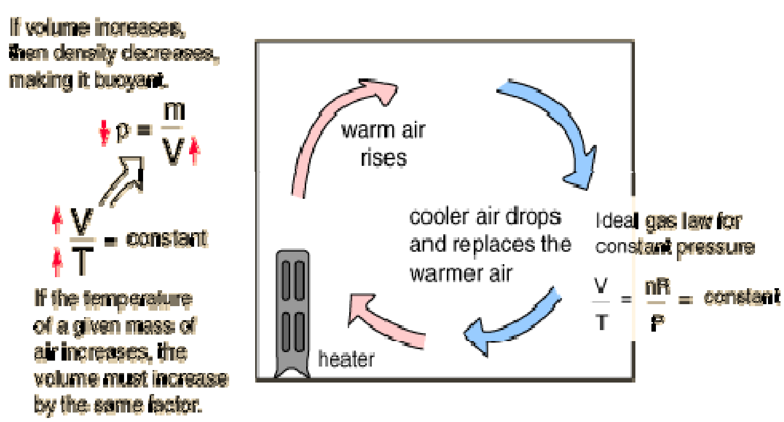
$$H_{Al} = 238\,(0.015)\,\frac{(102-100)}{0.012} = 588W$$

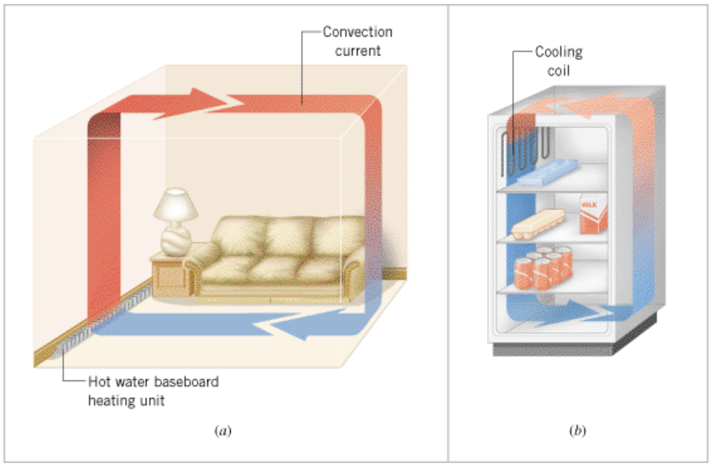
- For the copper base $K_{Cu} = 397\,Wm^{-1}K^{-1}$.

$$H_{Cu} = 397\,(0.015)\,\frac{(102-100)}{0.012} = 1003W$$

Heat Convection

- Convection is heat transfer by mass motion of a fluid such as air or water when the heated fluid is caused to move away from the source of heat, carrying energy with it.
- Convection above a hot surface occurs because hot air expands, becomes less dense, and rises. Hot water is likewise less dense than cold water and rises, causing convection currents which transport energy.





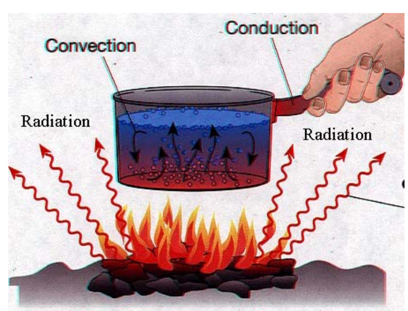
Q: In the living room, the heating unit is placed in the floor but the the refrigerator has a top-mounted cooling coil. Why?

A: Air warmed by the baseboard heating unit is pushed to the top of the room by the cooler and denser air. Air cooled by the cooling coil sinks to the bottom of the refrigerator.

Heat Radiation

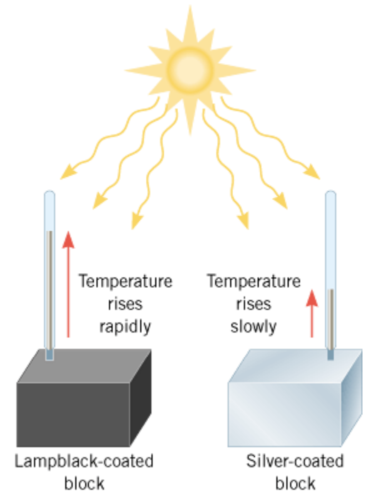
- Energy is transferred by electromagnetic radiation. All of the earth's energy is transferred from the Sun by radiation.

Our bodies radiate electromagnetic waves in a part of the spectrum that we can't see called the infra-red. However, there are some cameras that can actually see this radiation.



Heat Radiation

- The color and texture of different surfaces determines how well they absorb the radiation.
- (1) Black objects absorb more radiation than white objects.
- (2) Matt and rough surfaces absorb more than shiny and smooth surfaces.



Heat Radiation

- The relationship governing radiation from hot objects is called the Stefan-Boltzmann Law:

$$P = e\,\sigma\,A\,(T^4 - T_S^4)$$

P is the net radiated power measured in Watt,
e is the emissivity (=1 for ideal radiator),
A is the radiation area in m^2,
T is the temperature of the radiator in Kelvin,
Ts is the temperature of the surroundings in Kelvin,
$\sigma = 5.67x10^{-8}\,Watt/m^2\,K^4$ is a constant called Stefan-Boltzmann constant.

Example

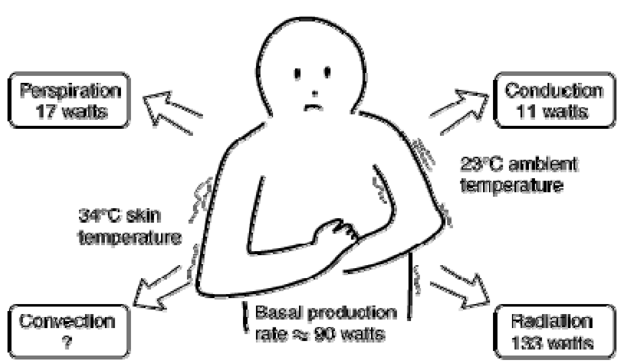
- A student tries to decide what to wear is staying in a room that is at 20°C. If the skin temperature is 37°C, how much heat is lost from the body in 10 minutes? Assume that the emissivity of the body is 0.9 and the surface area of the student is 1.5 m^2.
- **Solution**
- Using the Stefan-Boltzmann's law

$$P_{net} = e\,\sigma\,A\,(T^4 - T_s^4) = (5.67\times10^{-8})(0.9)(1.5)(310^4 - 293^4) = 143\,watt.$$

- The total energy lost during 10 min is

$$Q = P_{net}\,\Delta t = 143\times600 = 85.8\,kJ$$

Cooling of the Human Body



unclothed person at rest in a room temperature of 23 Celsius would be uncomfortably cool. The skin temperature of 34 C is a typical skin temperature taken from physiology texts, compared to the normal core body temperature of 37 C.