SUBJECT NAME : Heat Transfer

SUBJECT CODE : 3151909

Topic: Governing Law in Modes of Heat Transfer

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CONDUCTION

Conduction: The transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles.

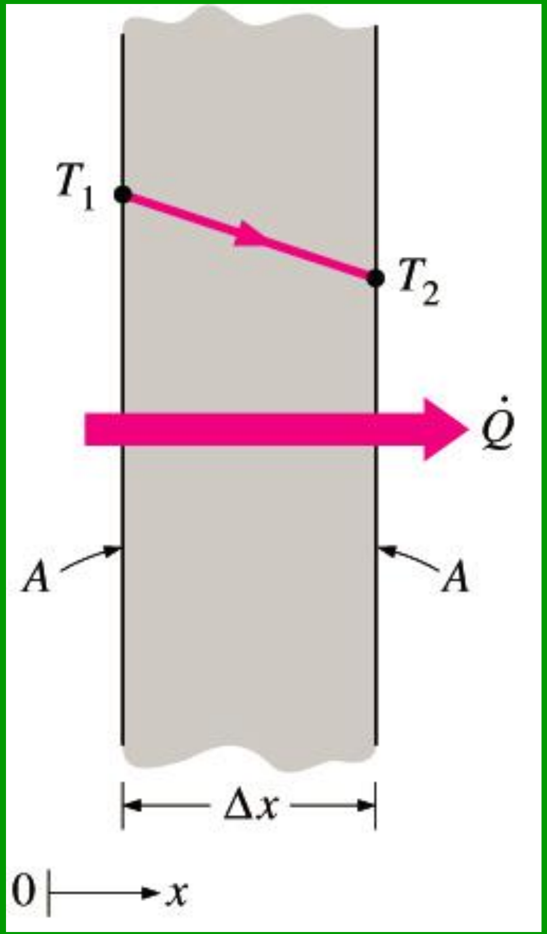
In gases and liquids, conduction is due to the *collisions* and *diffusion* of the molecules during their random motion.

In solids, it is due to the combination of *vibrations* of the molecules in a lattice and the energy transport by *free electrons.*

The rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer.

$$\text{Rate of heat conduction} \propto \frac{(\text{Area})(\text{Temperature difference})}{\text{Thickness}}$$

$$\dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x} \qquad (\text{W})$$



Heat conduction through a large plane wall of thickness Δx and area *A*.

$$\dot{Q}_{cond} = -kA\frac{dT}{dx}$$

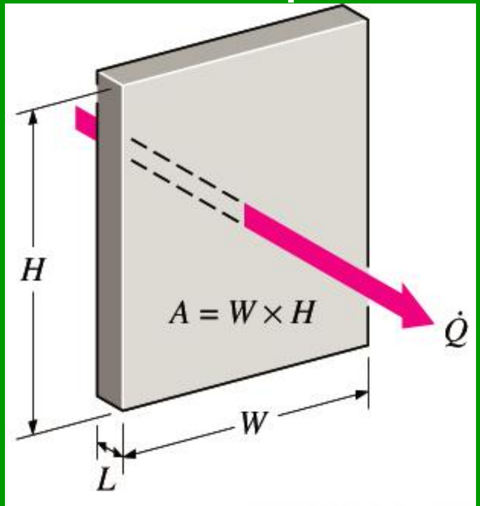
Fourier's law of heat conduction

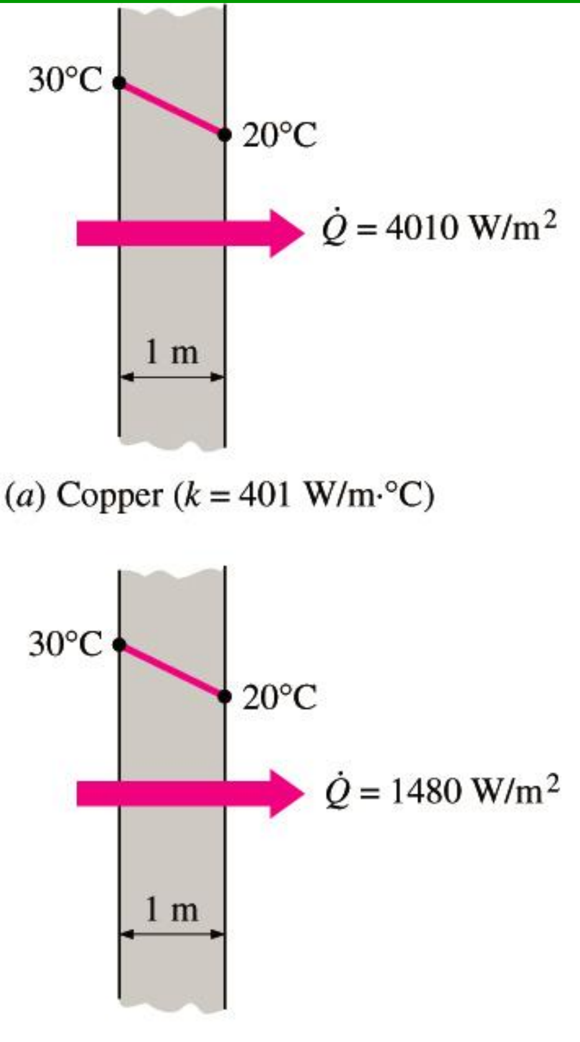
Thermal conductivity, *k*: A measure of the ability of a material to conduct heat.

Temperature gradient *dT/dx*: The slope of the temperature curve on a *T*-*x* diagram.

Heat is conducted in the direction of decreasing temperature, and the temperature gradient becomes negative when temperature decreases with increasing *x*. The *negative sign* in the equation ensures that heat transfer in the positive *x* direction is a positive quantity.

In heat conduction analysis, *A* represents the area *normal* to the direction of heat transfer.





(*a*) Copper ($k = 401$ W/m·°C)

(*b*) Silicon ($k = 148$ W/m·°C)

The rate of heat conduction through a solid is directly proportional to its thermal conductivity.

Thermal Conductivity

Thermal conductivity: The rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference.

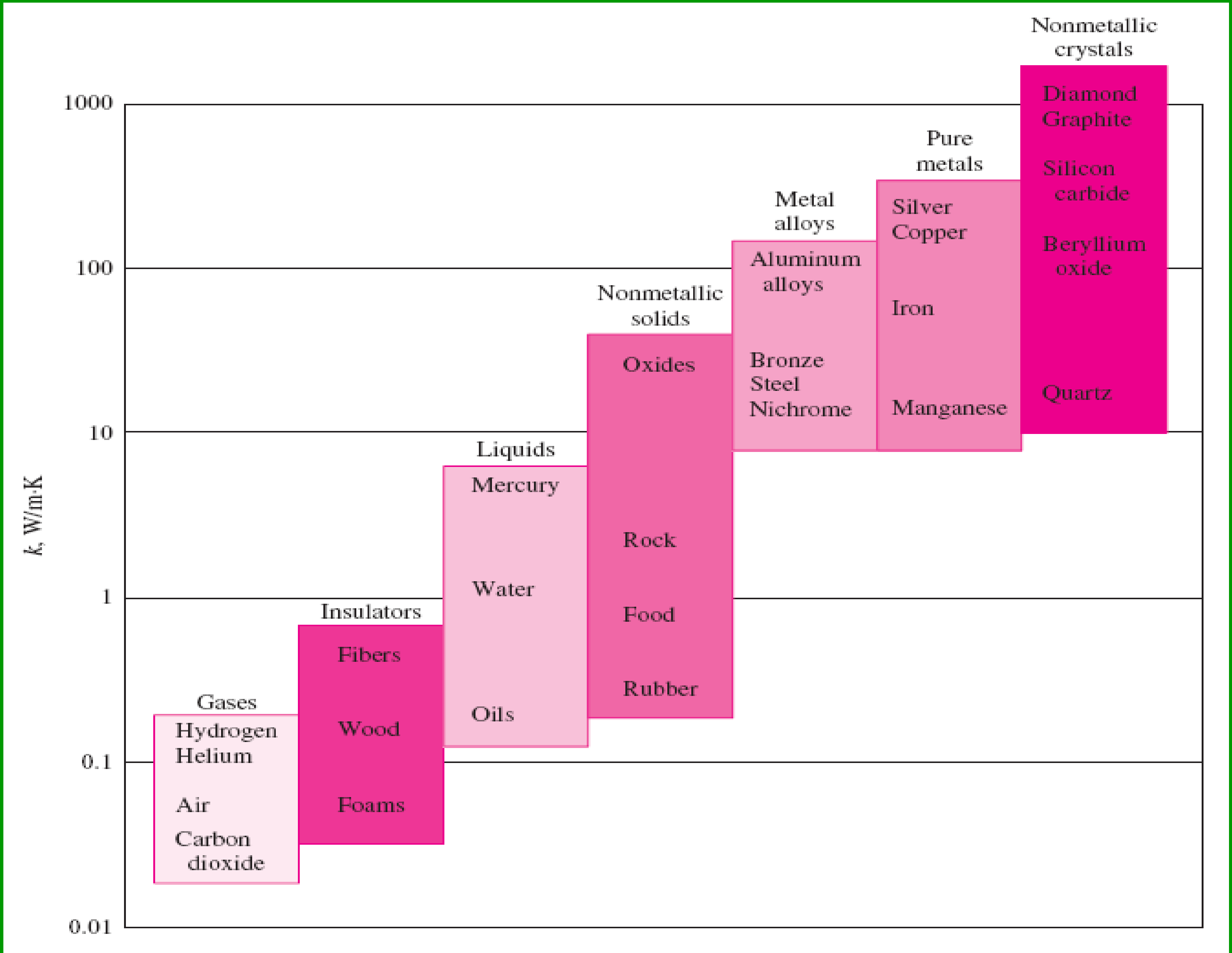
The thermal conductivity of a material is a measure of the ability of the material to conduct heat.

A high value for thermal conductivity indicates that the material is a good heat conductor, and a low value indicates that the material is a poor heat conductor or *insulator.*

The thermal conductivities of some materials at room temperature

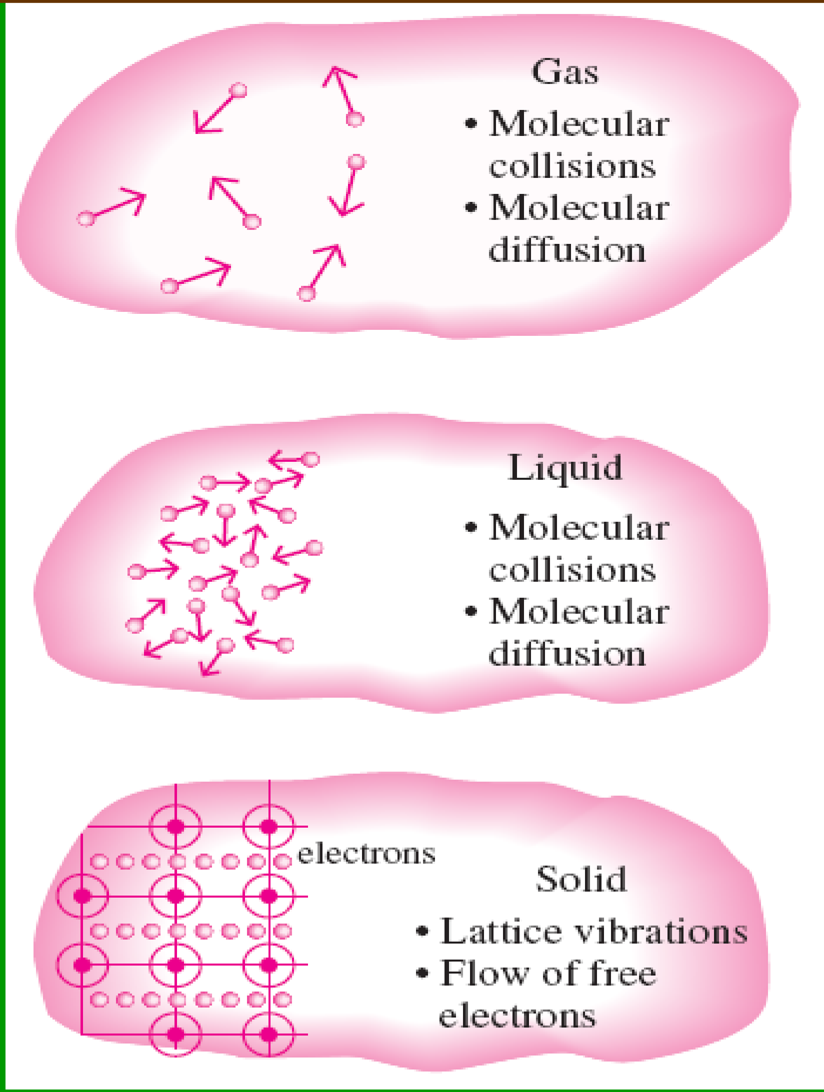
Material	k, W/m · °C*
Diamond	2300
Silver	429
Copper	401
Gold	317
Aluminum	237
Iron	80.2
Mercury (l)	8.54
Glass	0.78
Brick	0.72
Water (l)	0.607
Human skin	0.37
Wood (oak)	0.17
Helium (g)	0.152
Soft rubber	0.13
Glass fiber	0.043
Air (g)	0.026
Urethane, rigid foam	0.026

The range of thermal conductivity of various materials at room temperature.



The thermal conductivities of gases such as air vary by a factor of 10^4 from those of pure metals such as copper.

Pure crystals and metals have the highest thermal conductivities, and gases and insulating materials the lowest.

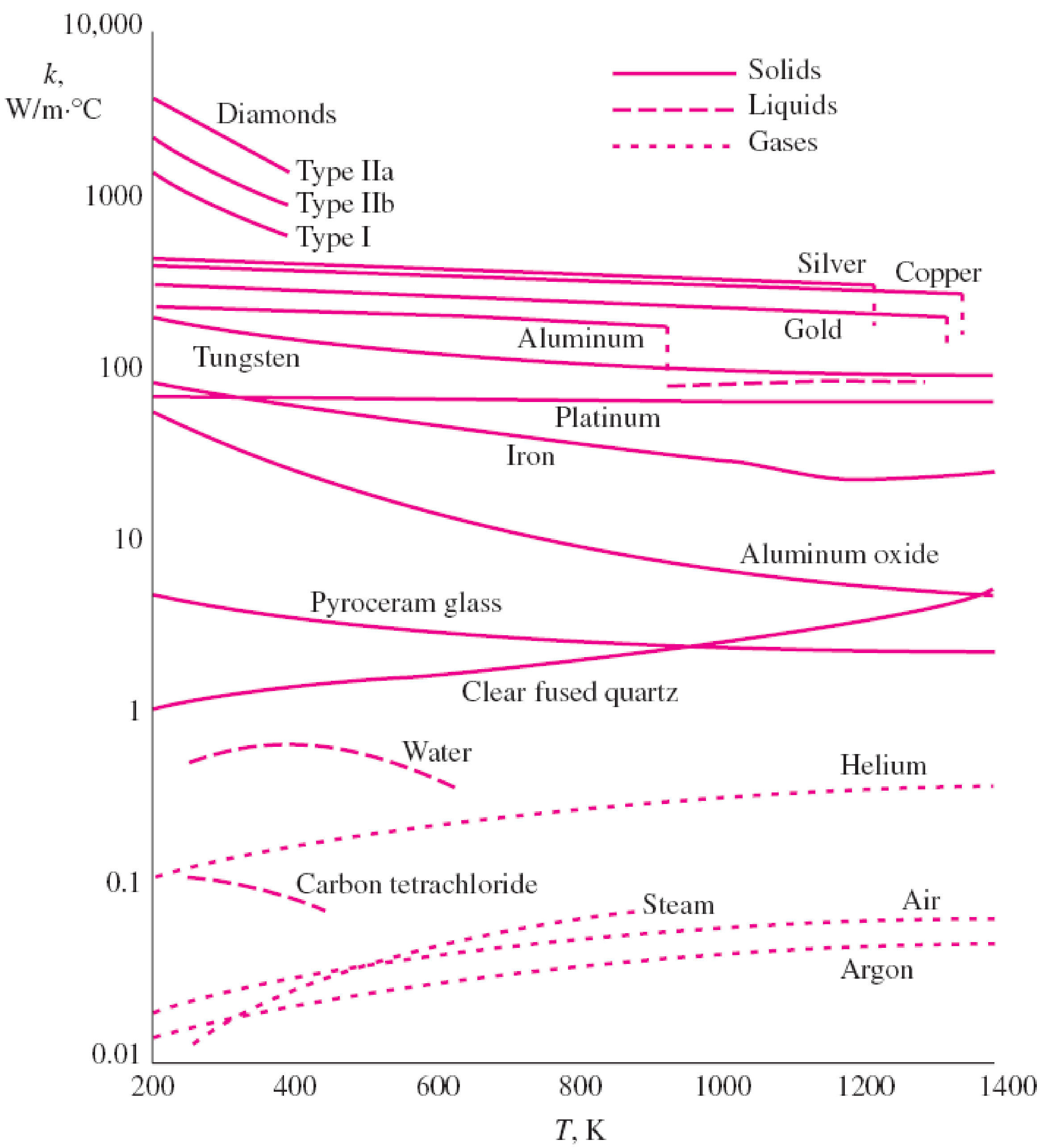


The mechanisms of heat conduction in different phases of a substance.

The thermal conductivity of an alloy is usually much lower than the thermal conductivity of either metal of which it is composed

Pure metal or alloy	*k*, W/m·K, at 300 K
Copper	401
Nickel	91
Constantan (55% Cu, 45% Ni)	23
Copper	401
Aluminum	237
Commercial bronze (90% CU, 10% Al)	52

The variation of the thermal conductivity of various solids, liquids, and gases with temperature.



Thermal conductivity of pure metal decreases with increase in temperature (uranium, mercury and aluminum are exceptions)

T↑=K↓

$K_t = K_0 (1+\beta T)$

β=Temp. co-efficient of Thermal Conductivity (generally –ve)

Some of solid substance are not allowing Heat Transfer to take place through them. Such material called as insulator.

In case of liquid thermal conductivity mainly depends on viscosity. So in most of liquid the value of thermal conductivity is decreases with increases in temperature (water and glycerin are exception)

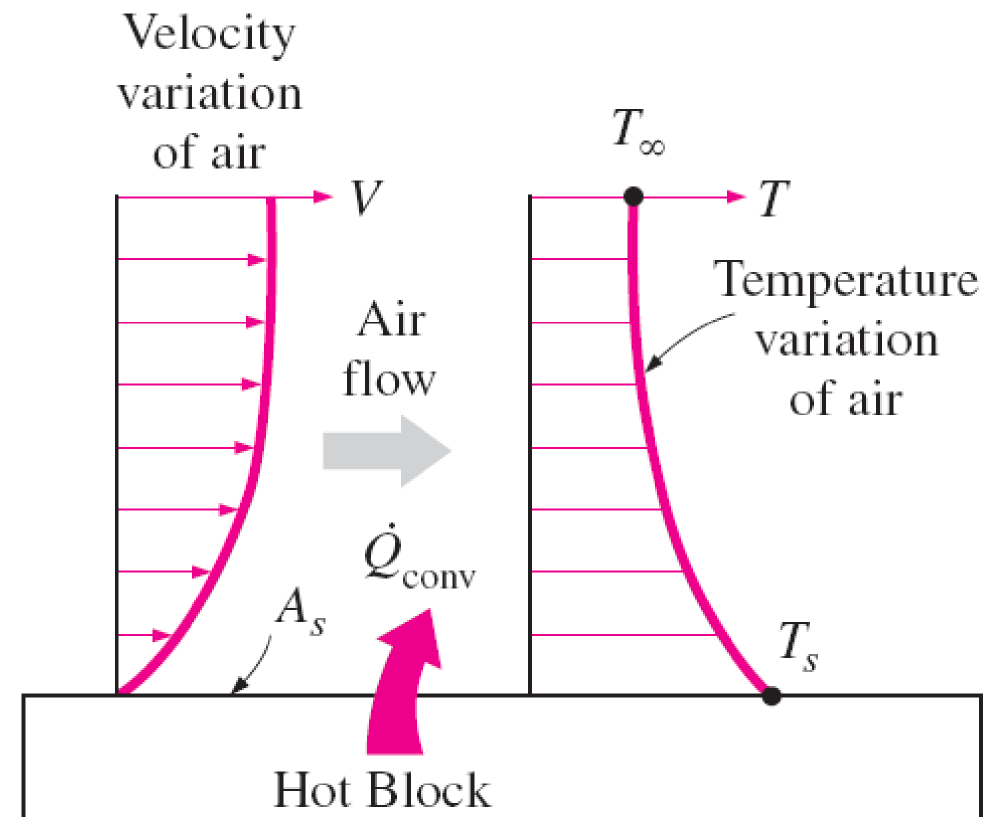
T↑=K↓

Thermal conductivity of all gases are increases with increase in temperature

Thermal conductivity of gas mainly depends on molecular mass T↑=K↑

CONVECTION

Heat transfer from a hot surface to air by convection.



Convection: The mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of *conduction* and *fluid motion.*

The faster the fluid motion, the greater the convection heat transfer.

In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction.

$$\dot{Q}_{conv} = hA_s(T_s - T_\infty) \quad (W)$$

Newton's law of cooling

h convection heat transfer coefficient, $W/m^2 \cdot °C$

A_s the surface area through which convection heat transfer takes place

T_s the surface temperature

T_∞ the temperature of the fluid sufficiently far from the surface.

The convection heat transfer coefficient *h* is not a property of the fluid.

It is an experimentally determined parameter whose value depends on all the variables influencing convection such as

- the surface geometry
- the nature of fluid motion
- the properties of the fluid
- the bulk fluid velocity

Typical values of convection heat transfer coefficient

Type of convection	h, $W/m^2 \cdot °C$*
Free convection of gases	2–25
Free convection of liquids	10–1000
Forced convection of gases	25–250
Forced convection of liquids	50–20,000
Boiling and condensation	2500–100,000

RADIATION

Radiation: The energy emitted by matter in the form of *electromagnetic waves* (or *photons*) as a result of the changes in the electronic configurations of the atoms or molecules.

Unlike conduction and convection, the transfer of heat by radiation does not require the presence of an *intervening medium.*

In heat transfer studies we are interested in *thermal radiation,* which is the form of radiation emitted by bodies because of their temperature.

All bodies at a temperature above absolute zero emit thermal radiation.

Radiation is a *volumetric phenomenon,* and all solids, liquids, and gases emit, absorb, or transmit radiation to varying degrees.

However, radiation is usually considered to be a *surface phenomenon* for solids.

$$\dot{Q}_{\text{emit, max}} = \sigma A_s T_s^4 \qquad \text{(W)}$$

Stefan–Boltzmann law

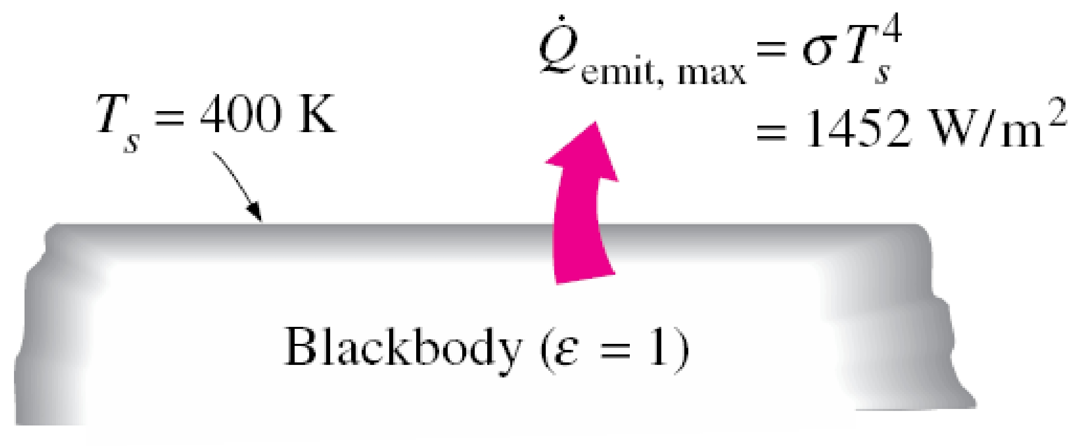
$\sigma = 5.670 \times 10^{-8}$ W/m$^2 \cdot$ K^4 *Stefan–Boltzmann constant*

Blackbody: The idealized surface that emits radiation at the maximum rate.

$$\dot{Q}_{\text{emit}} = \varepsilon \sigma A_s T_s^4 \qquad \text{(W)}$$

Radiation emitted by real surfaces

Emissivity ε : A measure of how closely a surface approximates a blackbody for which ε = 1 of the surface. **$0 \leq \varepsilon \leq 1$**.



Emissivities of some materials at 300 K

Material	Emissivity
Aluminum foil	0.07
Anodized aluminum	0.82
Polished copper	0.03
Polished gold	0.03
Polished silver	0.02
Polished stainless steel	0.17
Black paint	0.98
White paint	0.90
White paper	0.92–0.97
Asphalt pavement	0.85–0.93
Red brick	0.93–0.96
Human skin	0.95
Wood	0.82–0.92
Soil	0.93–0.96
Water	0.96
Vegetation	0.92–0.96

Blackbody radiation represents the *maximum amount of radiation that can be emitted from a surface at a specified temperature.*


THANK
YOU