1.2

HEAT TRANSFER MODES

(*heat transfer = energy transfer due to a temperature difference*)

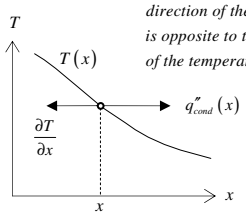
Heat flux $q'' = \frac{q}{A} \quad \left[\frac{W}{m^2}\right]$

Rate of heat transfer $q = q'' \cdot A \quad [W]$

Rate of heat transfer per unit length $q' = \frac{q}{L} \quad \left[\frac{W}{m}\right]$

I CONDUCTION

transfer of energy by interaction of molecules (thermal diffusion)



direction of the heat flux is opposite to the direction of the temperature gradient

Fourier's Law

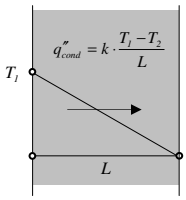
$$q''_{cond} = -k\frac{\partial T}{\partial x}$$

Joseph Fourier (1766 – 1830)

$k \left[\frac{W}{m \cdot K}\right]$ ***thermal conductivity*** (*p.4,70*)

Typical values of k

	k, W/m·K
air	0.03
water	0.6
brick	0.7
steel	15
copper	400



steady state conduction through the plane wall

II CONVECTION

*transfer of energy from a surface to fluid due to conduction and bulk motion of fluid (**advection**)*

positive direction of the heat flux is from the surface:

$q''_{conv} > 0 \quad if \quad T_s > T_\infty$

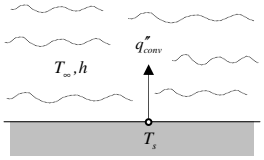
$q''_{conv} < 0 \quad if \quad T_s < T_\infty$

Newton's Law

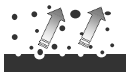
$$q''_{conv} = h(T_s - T_\infty)$$

Isaac Newton (1643 – 1727)

$h \left[\frac{W}{m^2 \cdot K}\right]$ ***convection heat transfer coefficient*** (*p.8*)



ablation



Type of convection / *Typical values of h*

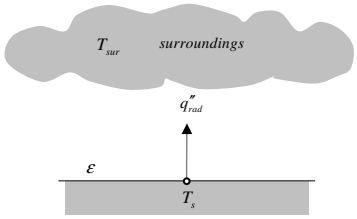
	gases :	liquids :
free (natural)	2 – 25	50 – 1000
forced	25 – 250	100 – 20,000
boiling		2,500 – 100,000
condensation		

III RADIATION

energy transfer by electromagnetic waves

Stefan - Boltzmann's Law

$$q''_{rad} = \varepsilon\sigma(T_s^4 - T_{sur}^4)$$



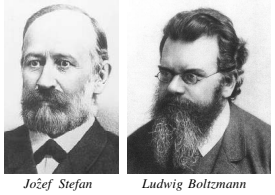
positive direction of the heat flux is from the surface:

$q''_{rad} > 0 \quad if \quad T_s > T_{sur}$

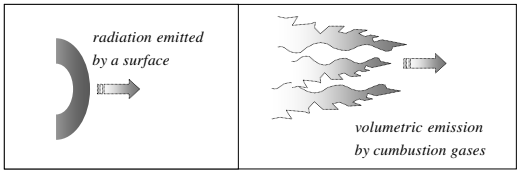
$q''_{rad} < 0 \quad if \quad T_s < T_{sur}$

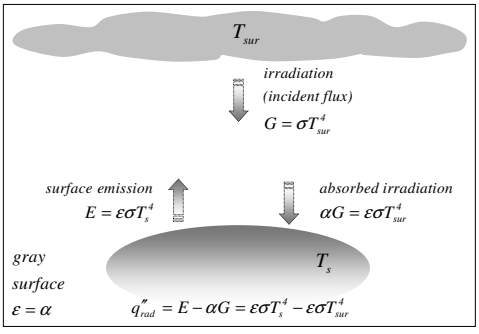
$\sigma = 5.67e-8 \left[\frac{W}{m^2 \cdot K^4}\right]$ ***Stefan - Boltzmann constant***

ε = ***total emissivity of the surface,*** $0 \le \varepsilon \le 1$



Jožef Stefan (1835-1893) — *Ludwig Boltzmann (1844 – 1906)*





Note that the heat flux is a directional quantity: in 1-D the direction is defined by the sign ±