Thermal Expansion

linear expansion

$$\Delta l = \alpha \cdot l_1 \cdot (T_2 - T_1) = \alpha \cdot l_1 \cdot (t_2 - t_1)$$

$$\Delta l = l_2 - l_1$$

$$l_2 = l_1 \cdot [\ 1 + a \cdot (T_2 - T_1)] = l_1 \cdot [\ 1 + \alpha \cdot (t_2 - t_1)]$$

volumetric expansion

$$\Delta V = w$$

$$\Delta V = V_2 - V_1$$

$$V_2 = V_1 \cdot [\ 1 + \gamma \cdot (T_2 - T_1)] = V_1 \cdot [\ 1 + \gamma \cdot (t_2 - t_1)] \qquad \gamma = 3\ \alpha$$

l_1	initial length [m]	V_1	initial volume [m³]
l_2	final length [m]	V_2	final volume [m³]
α	coefficient of linear expansion [1/K]	γ	coefficient of volumetric expansion [1/K]

Ideal Gas Law

Boyle-Mariotte

$$p \cdot V = \text{const.} \qquad T = \text{const.}$$

$$p \cdot v = \text{const.}$$

$$p_1 \cdot V_1 = p_2 \cdot V_2$$

p	absolute pressure [Pa]
V	volume [m³]
v	specific volume [m³/kg]
T	thermodynamic temperature [K]

Gay-Lussac

$$\frac{V}{T} = \text{const.} \qquad p = \text{const.}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

Amontons

$$\frac{p}{T} = \text{const.} \qquad V = \text{const.}$$

$$\frac{p_1}{p_2} = \frac{T_1}{T_2}$$

Ideal Gas Law

combined gas law

$$\frac{p \cdot V}{T} = \text{const.}$$

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

ideal gas law

$$p \cdot V = m \cdot R_i \cdot T$$

individual gas constant

$$R_i = \frac{p \cdot v}{T}$$

$$R_i = \frac{R}{M}$$

$$R_i = c_p - c_v$$

R_i	individual gas constant [J/(kg·K)]	c_p	heat capacity, if p = const.
M	molar mass [kmol/kg]	c_v	heat capacity, if V = const.
R	universal gas constant		R = 8,314 kJ/(kmol·K)

Heat Flow

quantity of heat

$$Q = m \cdot c \cdot \Delta t$$

heat flow / thermal rating / refrigeration capacity

$$\dot{Q} = \frac{Q}{\tau}$$

$$\dot{Q} = \dot{m} \cdot \Delta h = \dot{m} \cdot (h_2 - h_1)$$

$$\dot{Q} = \dot{m} \cdot c \cdot \Delta t$$

$$\dot{Q} = k \cdot A \cdot \Delta t$$

Q	heat [kJ]	Δh	enthalpy differential [kJ/kg]
$\dot{Q}$	heat flow [kW]	c	heat capacity [kJ/(kg K)]
m	mass [kg]	U	heat transmission coefficient [W/(m²·K)]
$\dot{m}$	mass flow [kg/s]	A	heat transfer surface [m²]

Heat Flow

freeze

$$Q = Q_{cooling} + Q_{solidification} + Q_{aftercooling}$$

$$\dot{Q} = \dot{Q}_{cooling} + \dot{Q}_{solidification} + \dot{Q}_{aftercooling}$$

$$Q_{cooling} = m \cdot c_v \cdot \Delta t_v$$

$$Q_{solidification} = m \cdot \Delta h_f$$

$$Q_{aftercooling} = m \cdot c_n \cdot \Delta t_n$$

$$\Delta t_v = t_1 - t_S$$

unfreeze

$$Q = Q_{heating} + Q_{melting} + Q_{heating2}$$

$$\dot{Q} = \dot{Q}_{heating} + \dot{Q}_{melting} + \dot{Q}_{heating2}$$

$$Q_{heating} = m \cdot c_n \cdot \Delta t_n$$

$$Q_{melting} = m \cdot \Delta h_f$$

$$Q_{heating2} = m \cdot c_v \cdot \Delta t_v$$

$$\Delta t_n = t_S - t_2$$

$Q_{cooling}$	heat to be dissipated before solidification
$Q_{aftercooling}$	heat to be dissipated after solidification
$Q_{heating}$	loaded heat before melting
$Q_{heating2}$	loaded heat after melting

Δh_f	heat of fusion [kJ/kg]
$\Delta h_f = 335$ kJ/kg	water
$t_S = 0$ °C	water

Heat Transfer

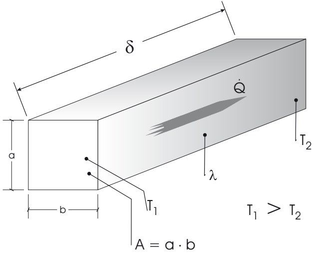
heat conduction

$$\dot{Q} = \frac{\lambda}{\delta} \cdot A \cdot \Delta T$$

$$\dot{Q} = \frac{\lambda}{\delta} \cdot A \cdot \Delta t$$

$$q = \frac{\dot{Q}}{A} = \frac{\lambda}{\delta} \cdot \Delta t$$

$$\Delta T = T_1 - T_2$$



heat transfer

$$\dot{Q} = \alpha \cdot A \cdot \Delta T$$
$$\dot{Q} = \alpha \cdot A \cdot \Delta t$$

$$q = \frac{\dot{Q}}{A} = \alpha \cdot \Delta t$$

λ	thermal conductance [W/(m·K)]		
δ	layer thickness [m]	A	heat transfer surface area [m²]
α	heat transfer coefficient [W/(m² K)]	q	specific heat flow [W/m²]

heat transmission and thermal transmittance coefficient

$$\dot{Q} = U \cdot A \cdot \Delta T$$

$$\dot{Q} = U \cdot A \cdot \Delta t$$

$$q = \frac{\dot{Q}}{A} = U \cdot \Delta t$$

$$\frac{1}{U} = \frac{1}{\alpha_a} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \ldots + \frac{\delta_n}{\lambda_n} + \frac{1}{\alpha_i}$$

$$t_1 = t_a - \Delta t = t_a - \frac{\dot{Q}}{\alpha \cdot A}$$ surface temperature

$$t_{11} = t_1 - \Delta t = t_1 - \frac{\delta_1 \cdot \dot{Q}}{\lambda_1 \cdot A}$$ interface temperature