Heat Transfer: Conduction

Introduction to the topic of heat conduction

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HEATQUIZ

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Learning Goals

Introduction to heat conduction

- Steady state and transient heat conduction
- Heat conduction with heat source and sink

Fourier‘s law

- Calculation of heat flow inside an object
- Temperature distribution inside an object

[1]

Fundamentals

Heat:

Thermal energy:

- Kinetic energy of random and undirected molecular motion
- The higher the thermal energy, the higher the molecular motion

Heat flow: Energy transferred between two systems due to different temperatures

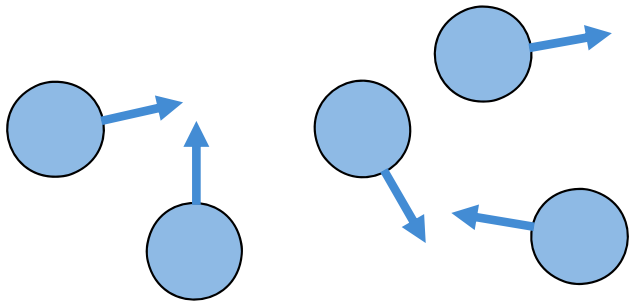
Temperature:

A technical measurement of the potential of thermal energy in a body

Heat conduction:

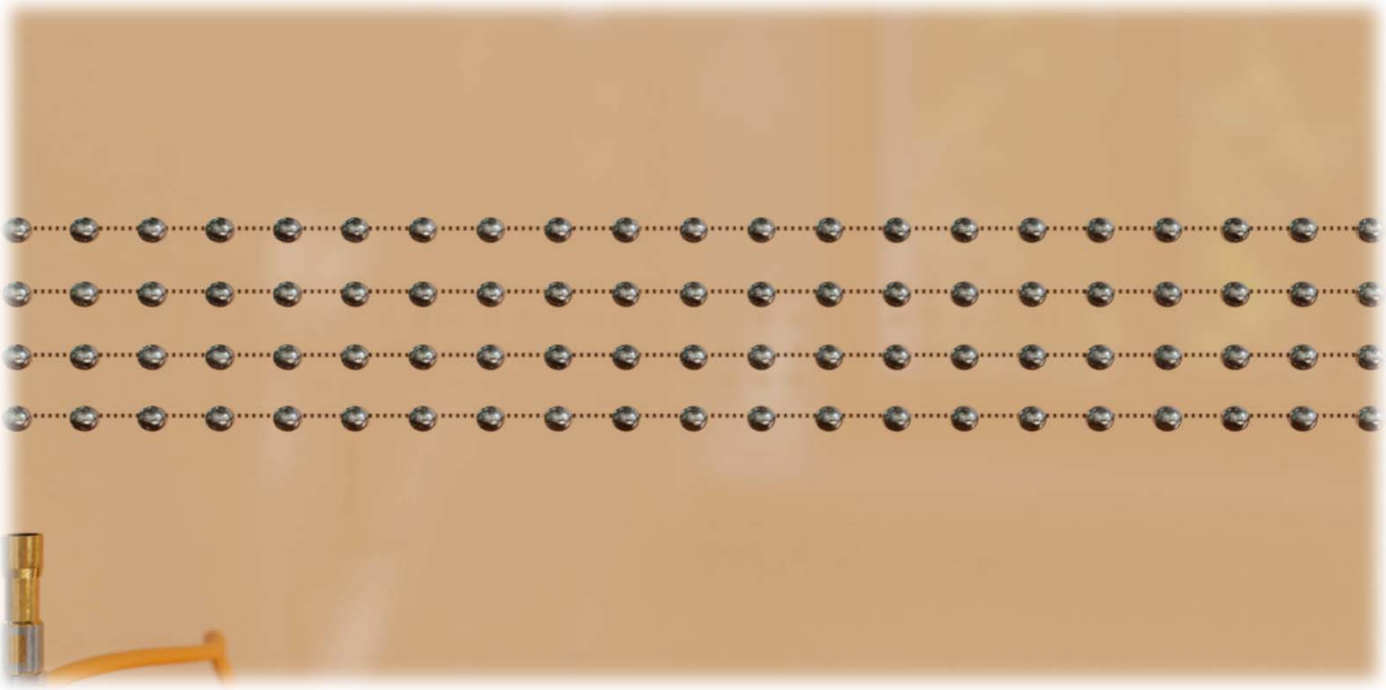
Transfer of thermal energy within a material as a result of a temperature difference through

- Molecular collisions for gas/liquid forms
- Lattice vibrations for solids
- Conduction by electron movement (e.g. for metals)



without thermal energy, molecules have no motion

Heat conduction in solids by vibration of atoms



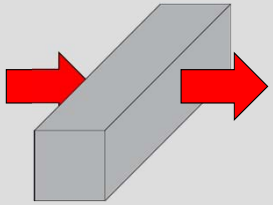
https://www.tec-science.com/de/thermodynamik-waermelehre/waerme/warmeleitung-in-feststoffen/

Heat conduction: Classification

Steady state heat conduction:

- Time independent

Time constant temperature distribution within the object

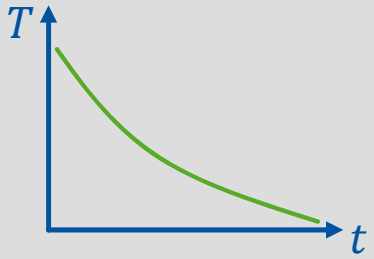


$$\dot{Q}_{in} = \dot{Q}_{out}$$

Unsteady heat conduction:

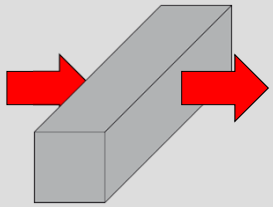
- Time dependent

Temporal temperature change at any fixed location in the body

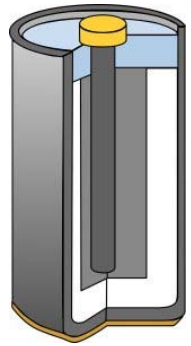


Heat conduction with source or sink:

Inconstant temperature distribution within the object



$$\dot{Q}_{in} \neq \dot{Q}_{out}$$



Fourier‘s law: heat flow in metal rod

Questions:

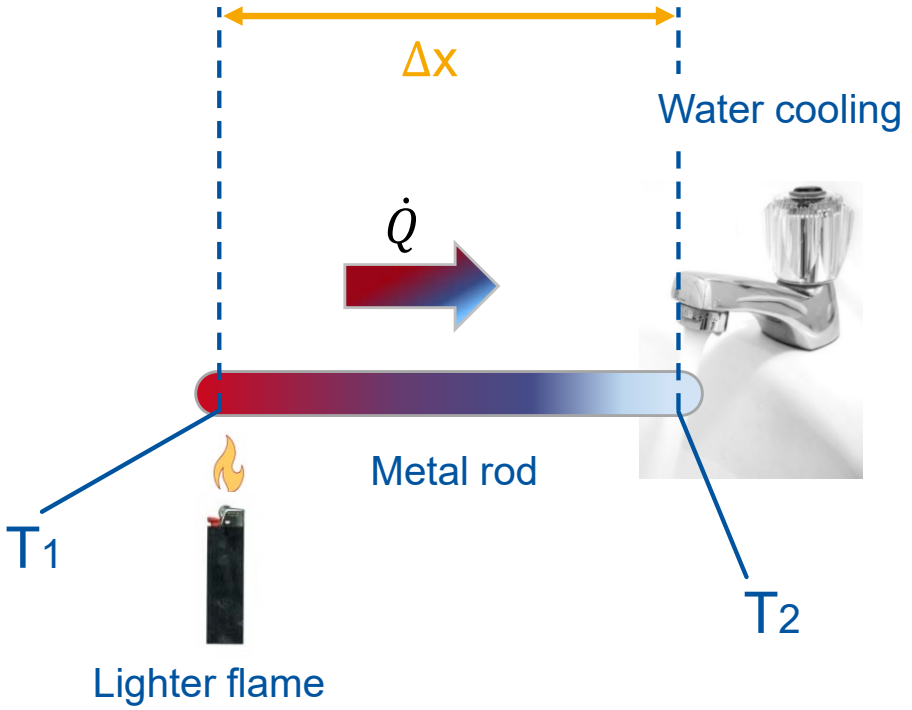
- What amount of heat flows through the metal rod from the hot flame to the cold side?
- How does the temperature change in the metal rod between the hot and cold sides?

Analogy:

Electrical current ⟷ heat flow

$$\textbf{Current} = \frac{\textbf{Potential difference}}{\textbf{Resistance}}$$

$$\textbf{Heat Flow} = \frac{\textbf{Temperature difference}}{\textbf{Heat resistance}}$$



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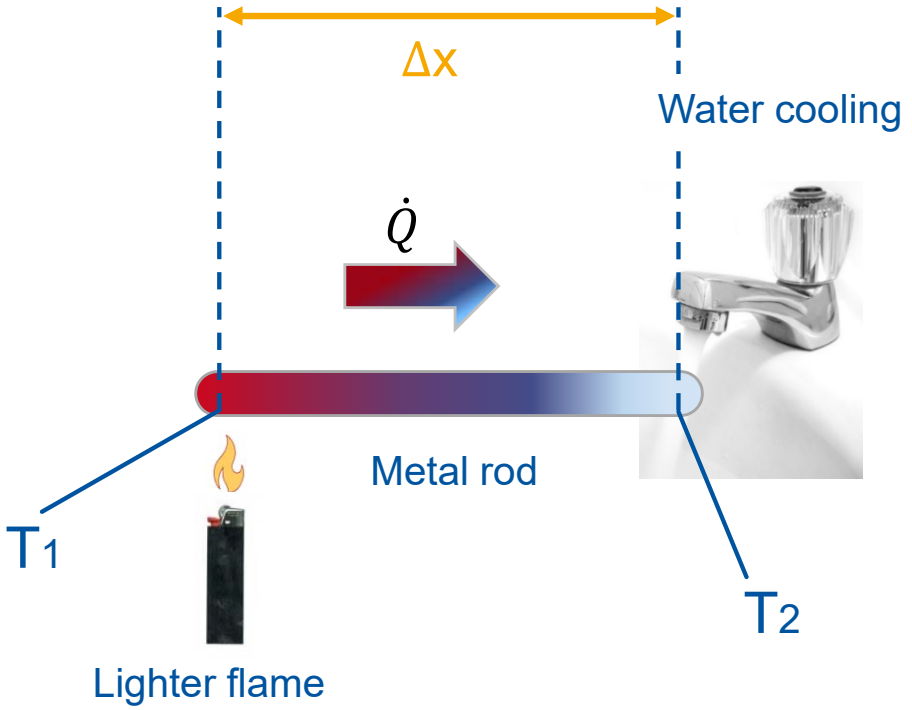
Fourier‘s law: heat flow in metal rod

Parameters influencing the heat flow:

- Temperature difference ΔT [K]
- Material property
  (Thermal conductivity λ [W/mK])
- Cross-sectional area through which
  the heat flow passes (Area A [m²])
- The distance between heat source
  and heat sink (Δx [m])



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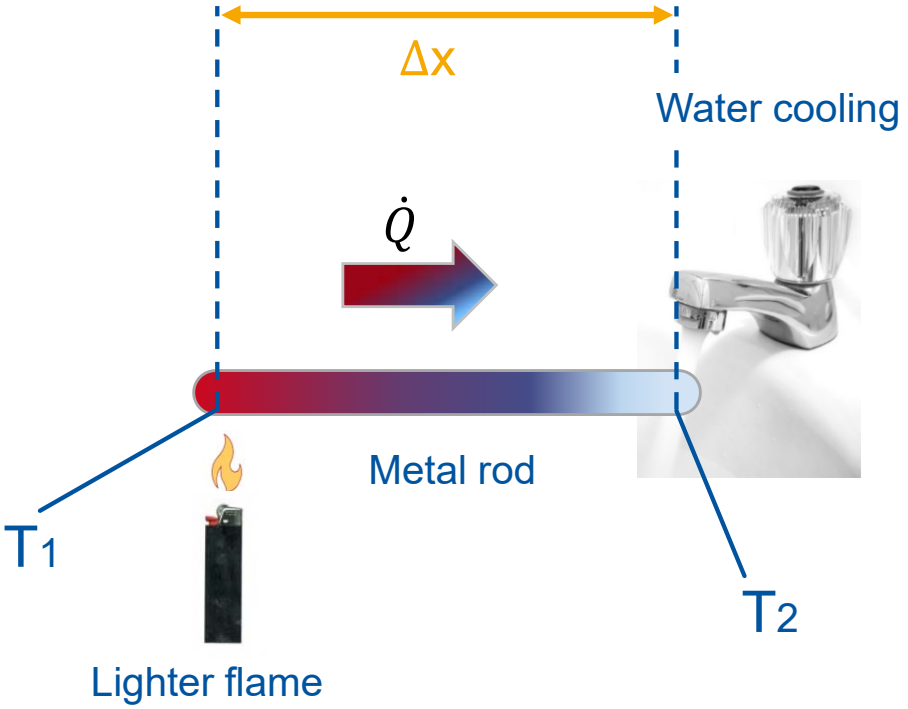
Fourier‘s law: heat flow in metal rod

How is the heat flow influenced?	$\dot{Q}$
▶ Temperature difference ΔT [K]	↑
▶ Material property (Thermal conductivity λ [W/mK])	↑
▶ Cross-sectional area through which the heat flow passes (Area A [m²])	↑
▶ The distance between heat source and heat sink (Δx [m])	↓



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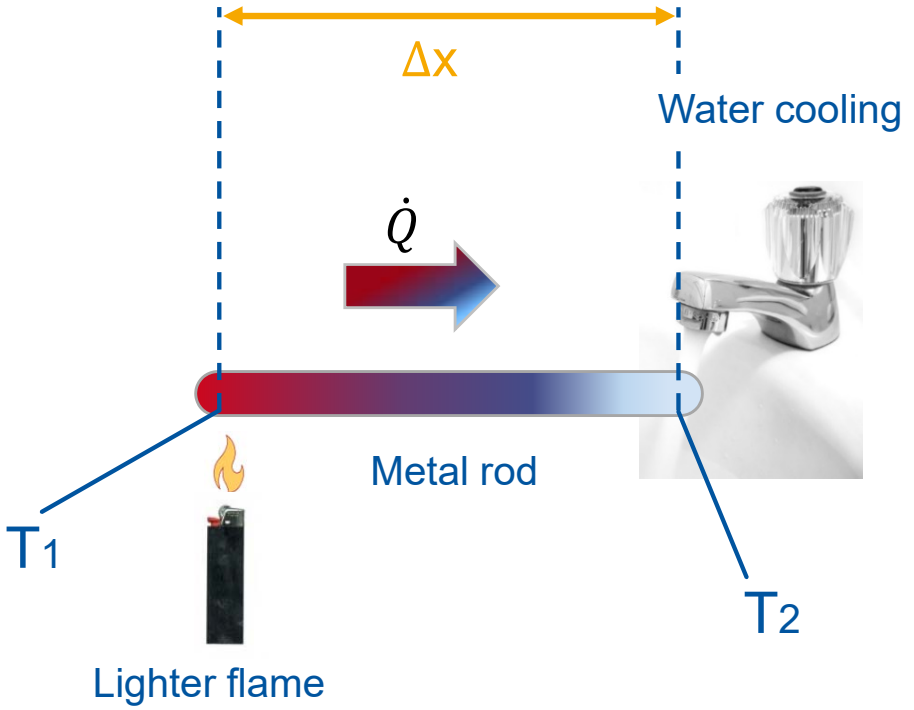
Heat flow and temperature:

$\dot{Q}_x$: Heat flow in 1-D [W]

$\frac{\Delta T}{\Delta x}$: Temperature gradient [K/m]

Fourier‘s law:

$$\dot{Q}_x =$$



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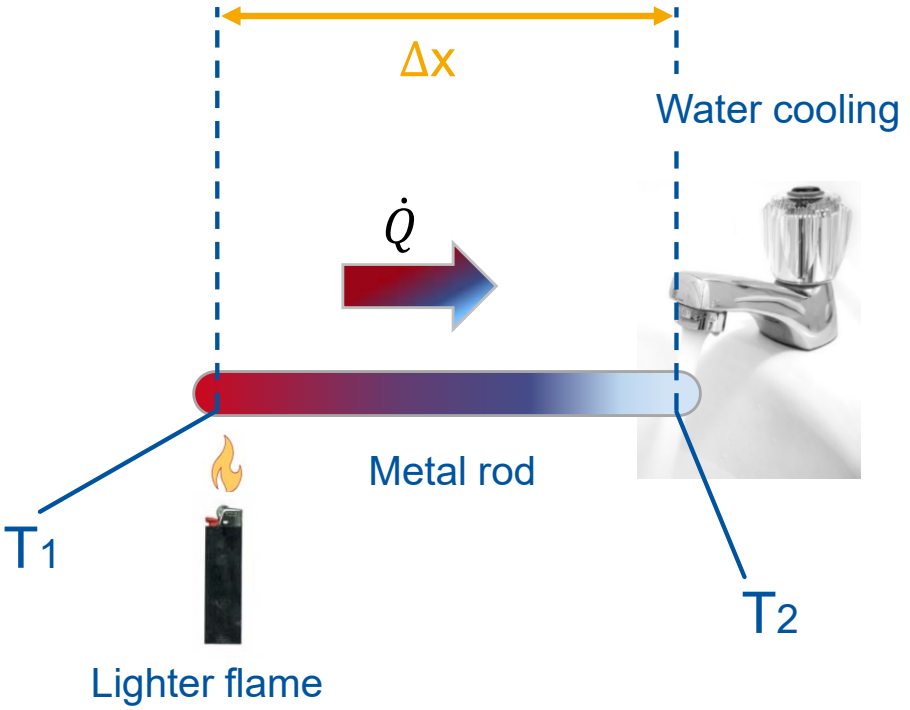
Heat flow and temperature:

$\dot{Q}_x$: Heat flow in 1-D [W]

$\frac{\Delta T}{\Delta x}$: Temperature gradient [K/m]

Fourier's law:

$$\dot{Q}_x = -A\,\lambda\,\frac{\Delta T}{\Delta x}$$



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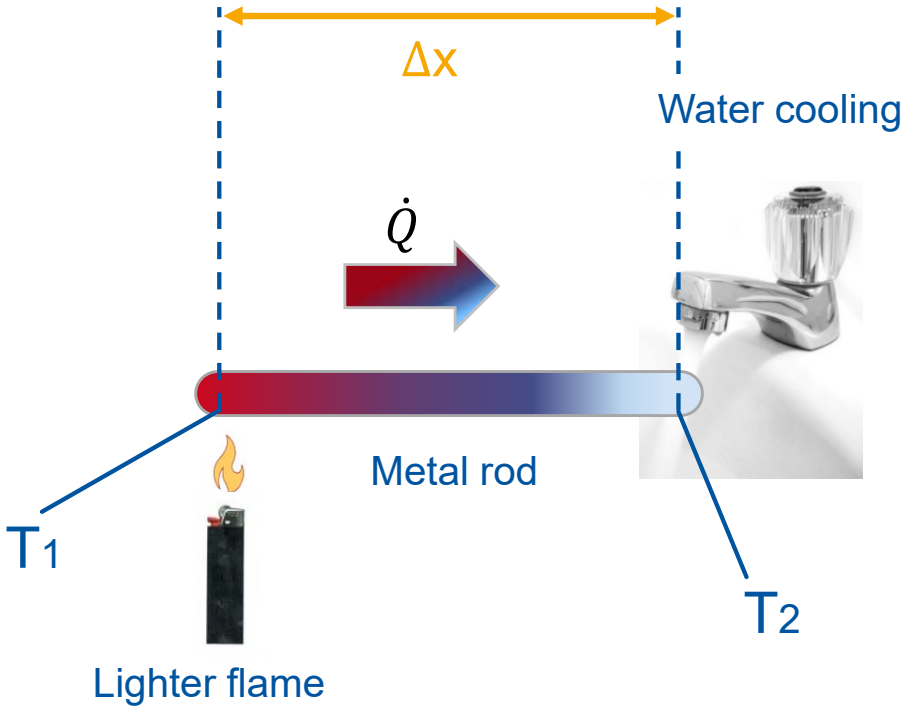
Fourier's law: heat flow in metal rod

Fourier‘s law:

$$\dot{Q}_x = -A\,\lambda\,\frac{\Delta T}{\Delta x}$$

Explanation:

$\dot{Q}_x$:	Heat flow in 1-D [W]
A :	Area [m^2]
λ:	Thermal conductivity [W/mK]
$\frac{\Delta T}{\Delta x}$:	Temperature gradient [K/m]



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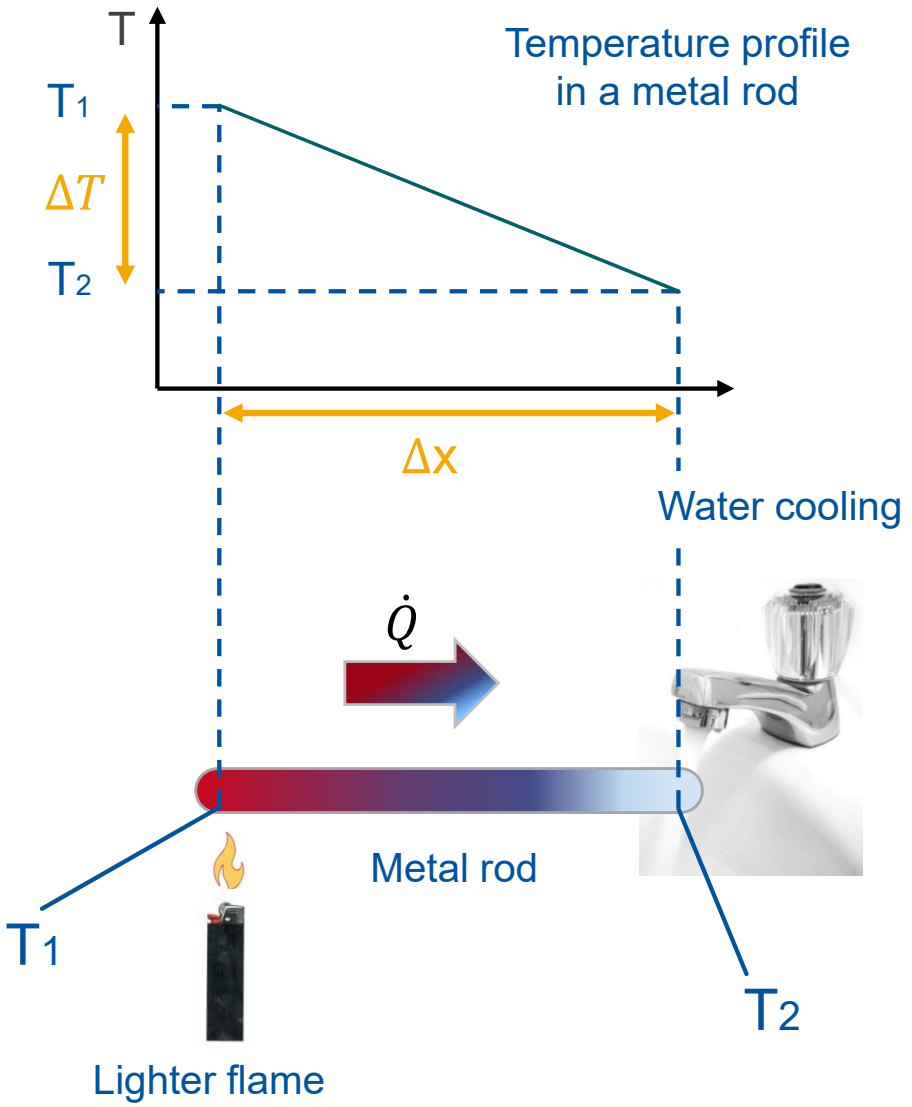

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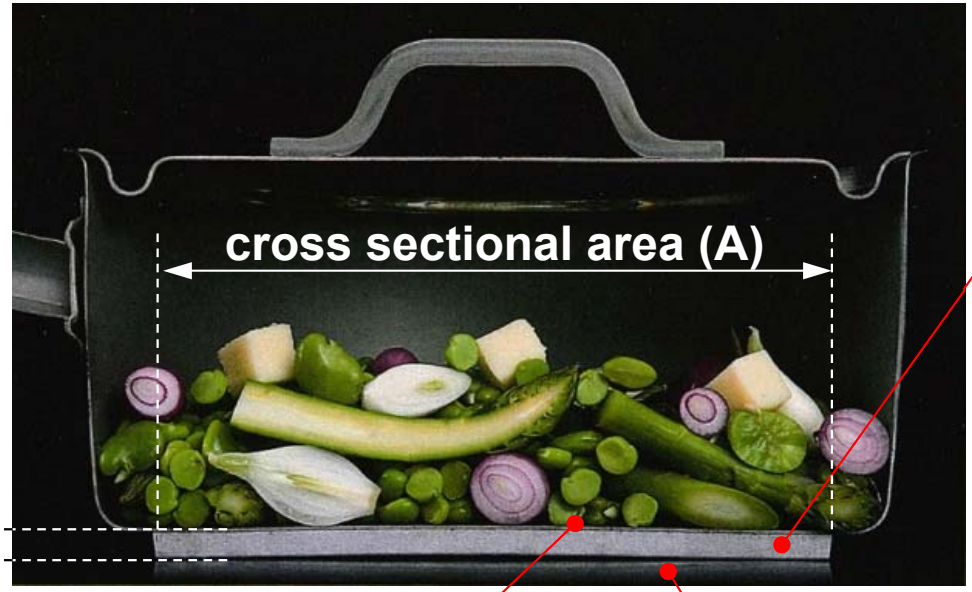
Example: Heat conduction during cooking

Fourier's law:

Heat flow = - Area * Thermal conductivity * Temperature gradient | $\dot{Q}_x = -A\,\lambda\,\frac{\Delta T}{\Delta x}$



material (thermal conductivity, λ)

x

thickness (Δx)

temperature (x_2) – temperature (x_1) = temperature difference (ΔT) , ($x_1 < x_2$)

Influence of material properties

Copper:

Very high thermal conductivity

$$\lambda_{Cu} = 350 \frac{W}{m\,K}$$

Aluminium:

Good thermal conductivity

$$\lambda_{Al} = 236 \frac{W}{m\,K}$$

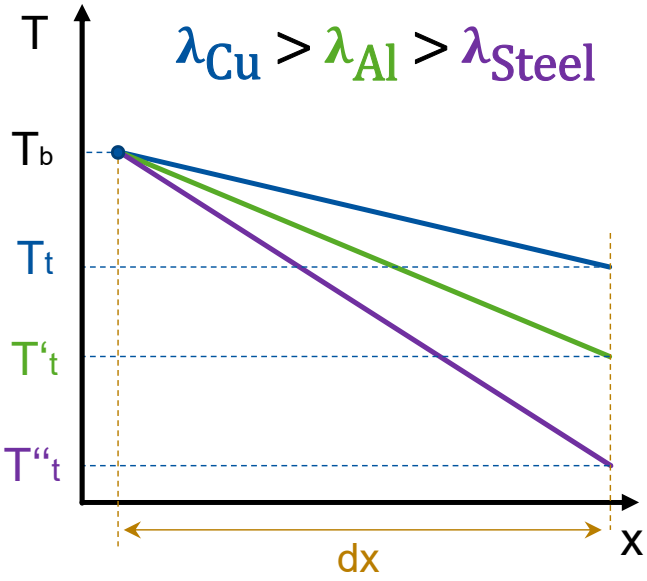
Stainless steel:

Low thermal conductivity

$$\lambda_{Steel} \approx 15 \frac{W}{m\,K}$$

$\dot{Q} = \text{constant}$

$\lambda_{Cu} > \lambda_{Al} > \lambda_{Steel}$

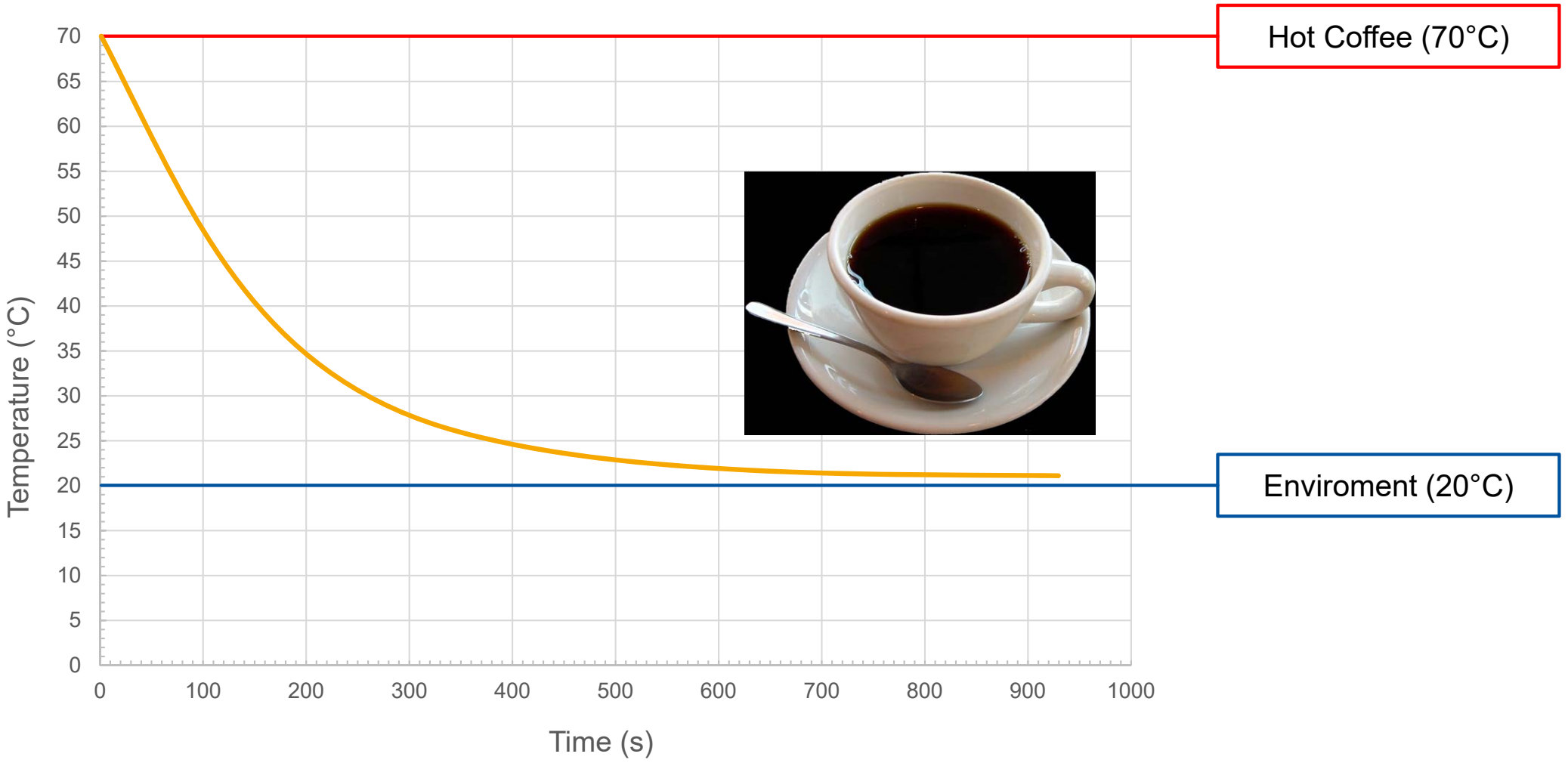


Transient processes: When should I put the milk in the coffee?

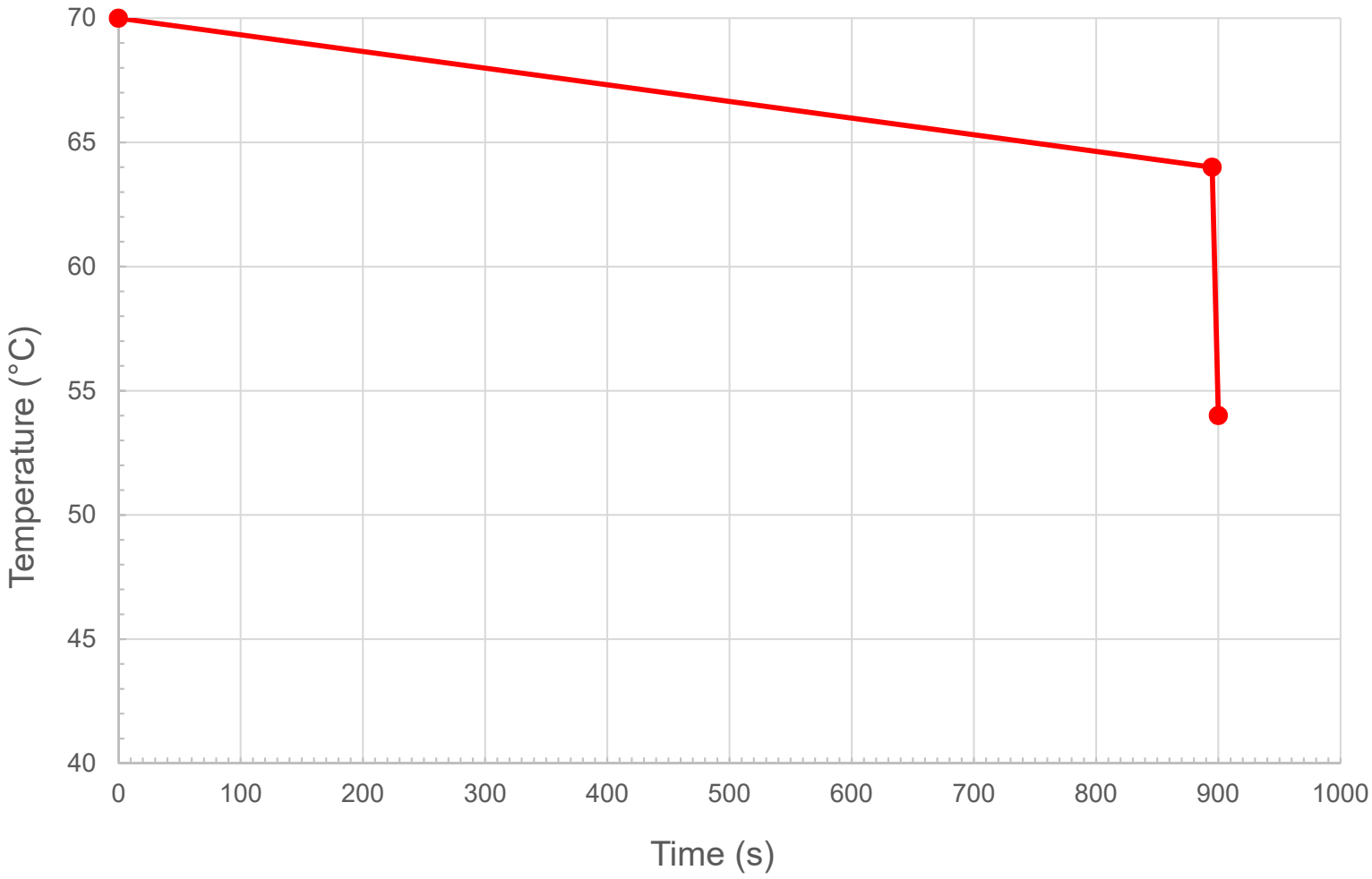
Add milk before drinking?

Add milk immediately after brewing?

Transient processes: When to add milk?



Transient processes: When to add milk?



T = 53°C

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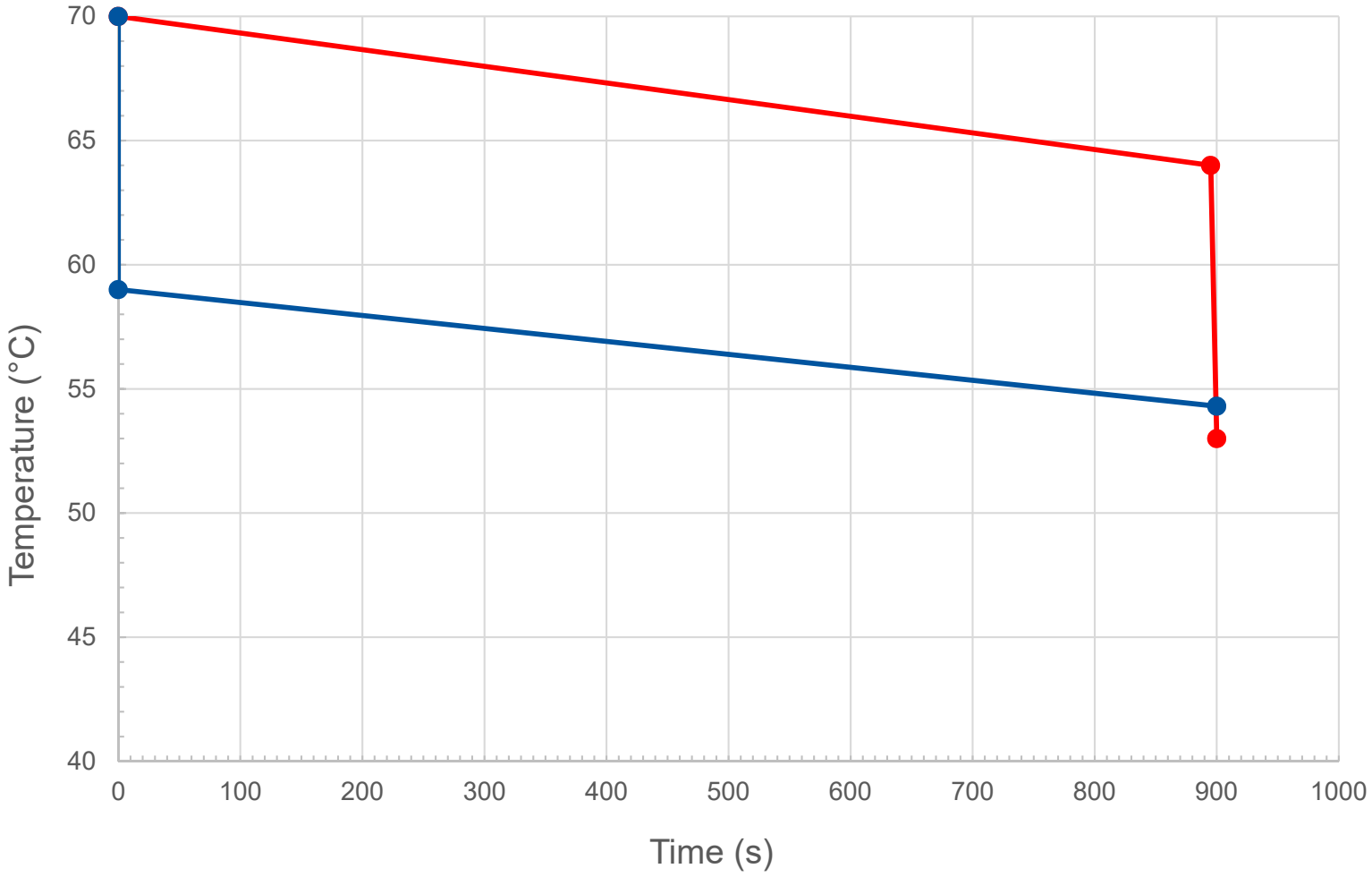
Transient processes: When to add milk?



T = 54°C

T = 53°C

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Human perception of temperature and heat flow

Heat flow

Humans do not feel temperatures,
people feel heat flows

$$\dot{Q} = -A\,\lambda\,\frac{dT}{dx}$$

Cold tap water feels warmer when washing hands after a winter walk

Perception of temperatur

Why does metal feel warmer or colder than wood?

$$\lambda_{\text{Wood}} \ll \lambda_{\text{Metal}}$$

At room temperature the door handle feels colder than the wood door

Comprehension questions

What is the driving potential of heat conduction?

Which three influencing variables determine a heat flow transferred by heat conduction according to Fourier's law?

Why must the temperature gradient in a positive coordinate system have a negative sign?

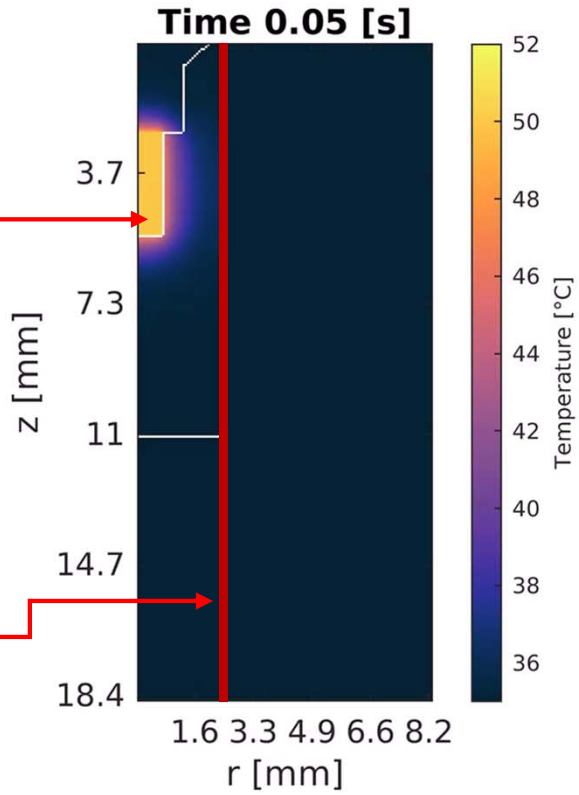
Which material property is decisive for heat conduction?

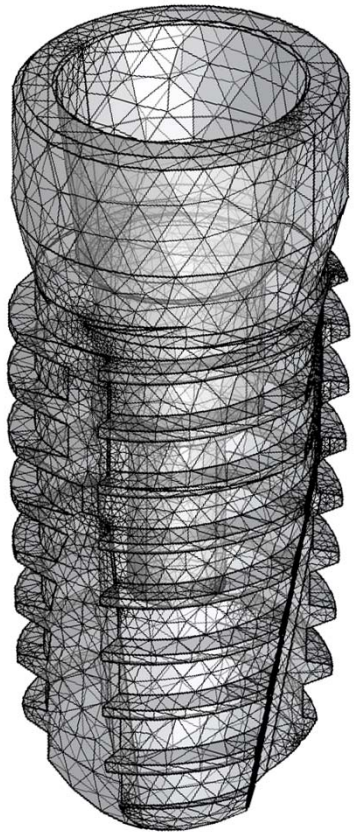
Transient heat conduction with source

Heating of a solid body

High thermal conductivity

Low thermal conductivity





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