Heat Transfer: Conduction

Biot number

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HEATQUIZ

UNIVERSITY OF TWENTE.

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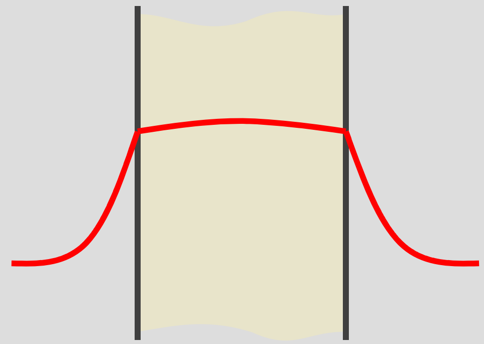
Learning goals

Dimensionless Number: Biot number

- Characterization of the dominant thermal resistances by using the relevant dimensionless number.
- Simplify complex multidimensional heat conduction problems based on the problem-defining thermal resistances.



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Relevance of thermal resistances

Questions:

- Which thermal resistances are relevant?
- Can certain resistances be neglected?

Temperature distribution inside a cylinder:

- Heat is supplied to the cylinder from one side (here by a flame).

Steady state temperature distribution in a cylinder

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Temperature distribution inside a cylinder:

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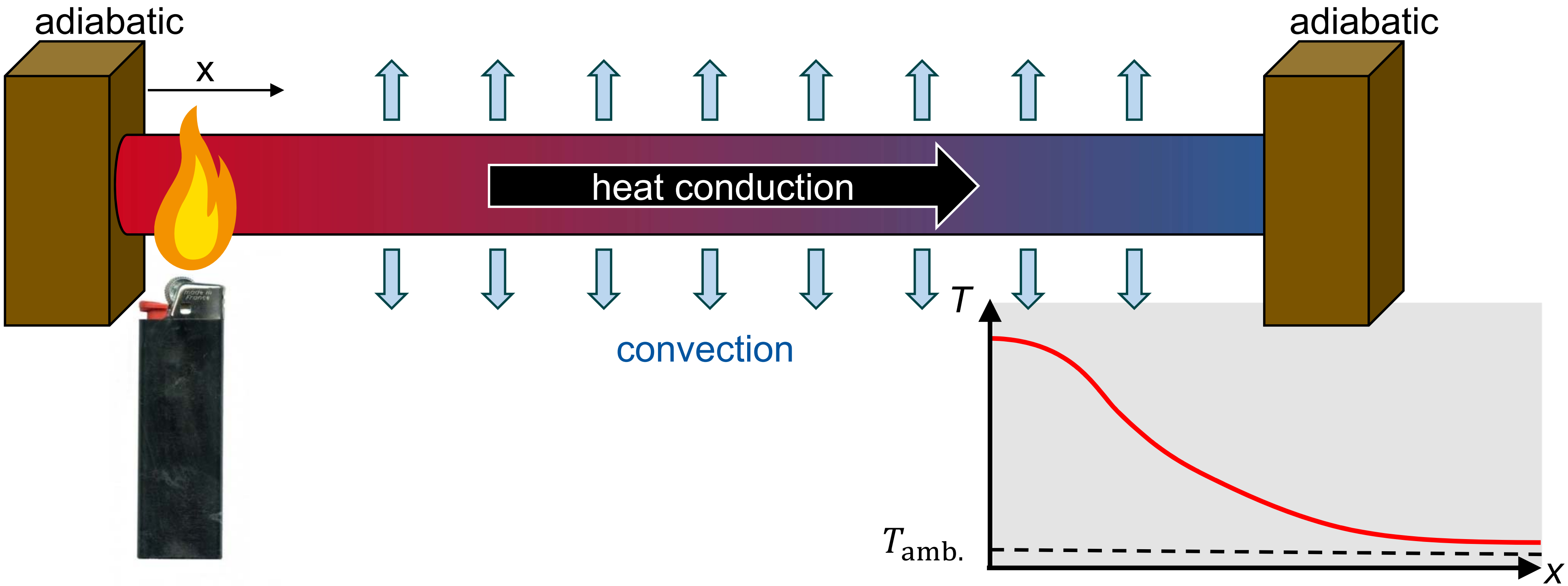
- Heat is transferred by conduction inside the cylinder and by convection across the shell surface.



Radial thermal resistance

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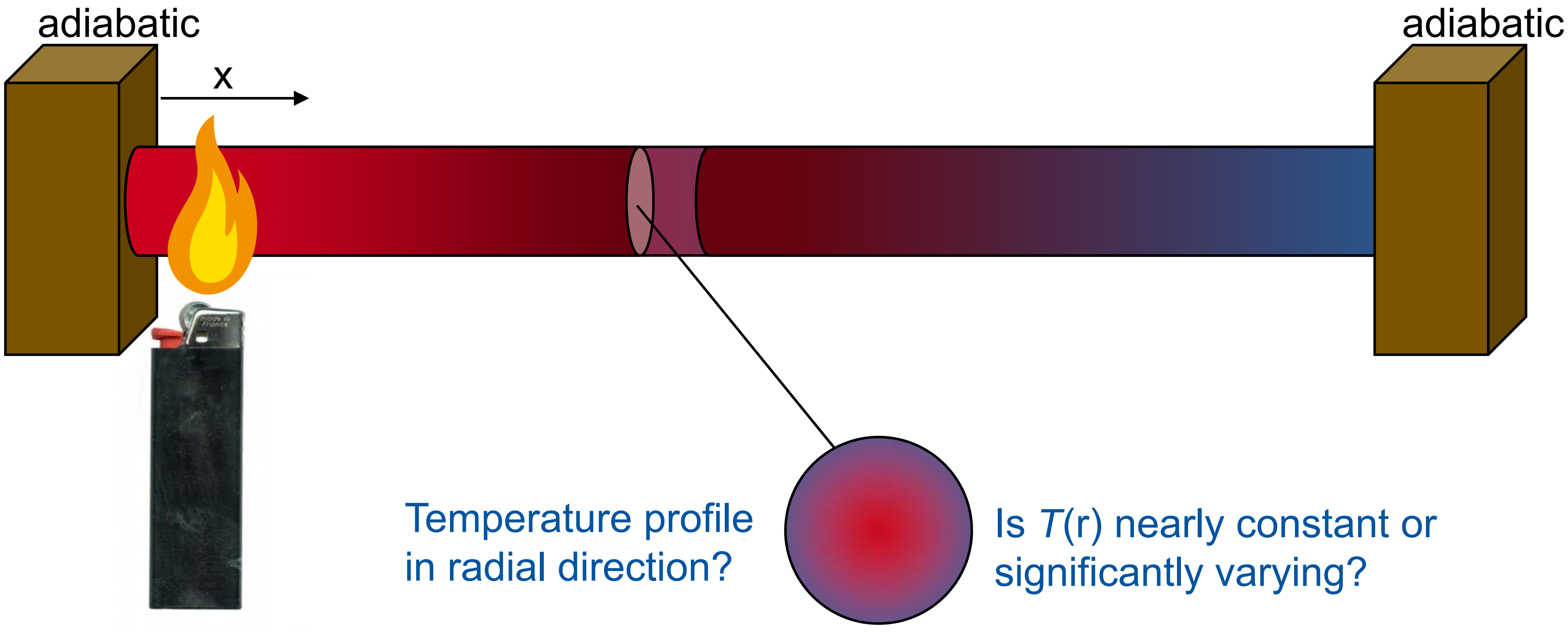

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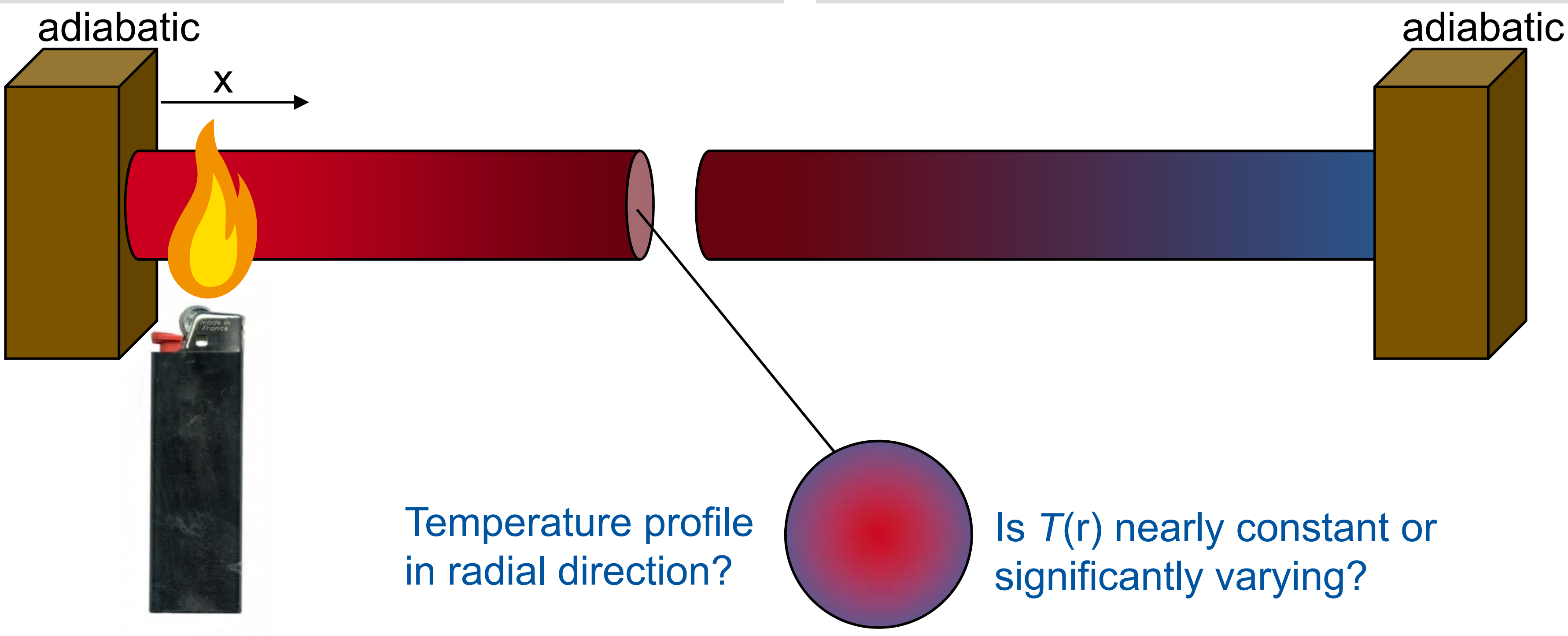

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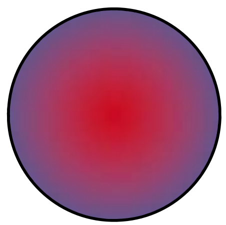

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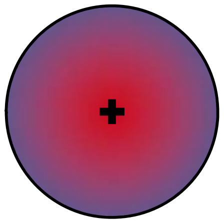

Radial temperature profile

Questions:

- Which thermal resistances are relevant?
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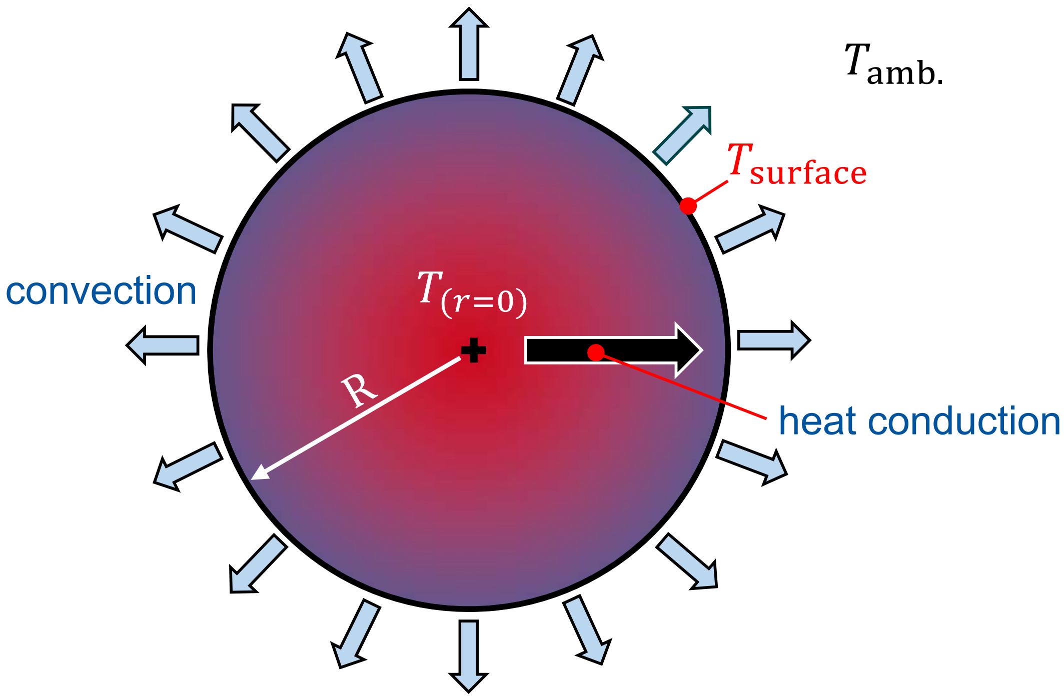
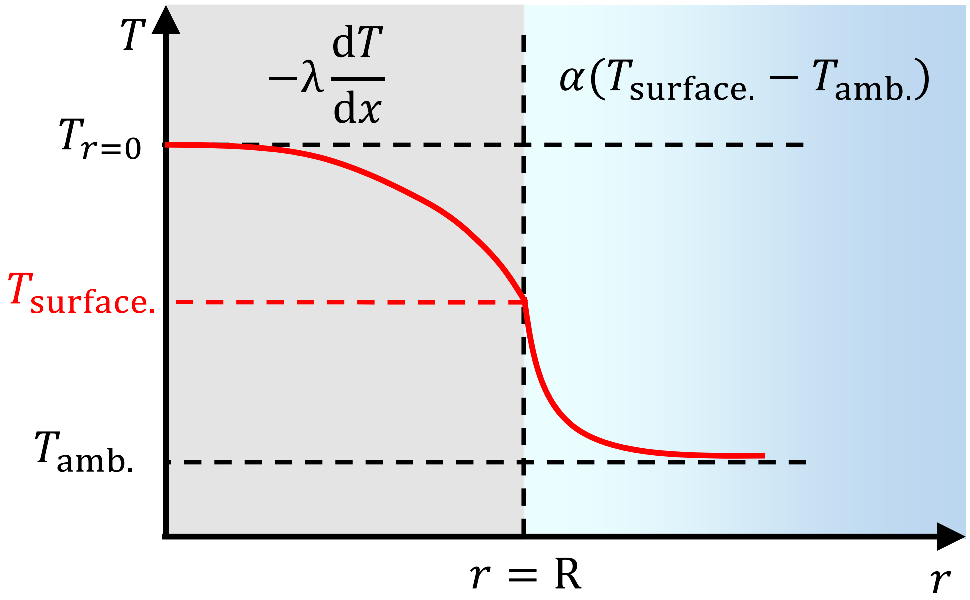
Temperature distribution inside a cylinder:

- Heat flows in both axial and radial directions (2D view inside the cylinder)





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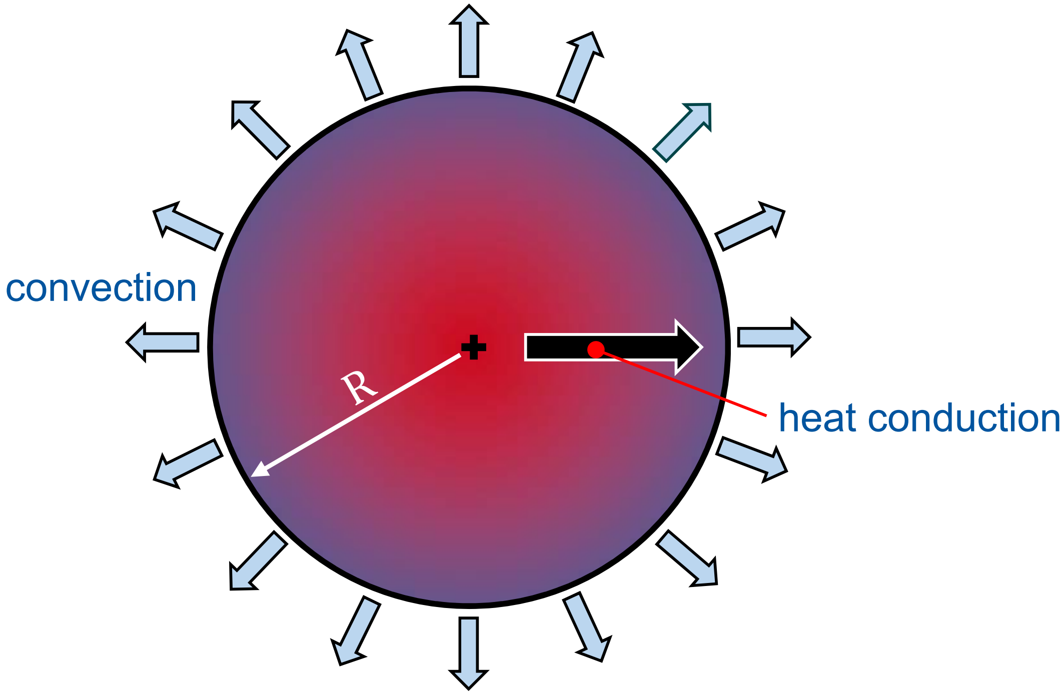

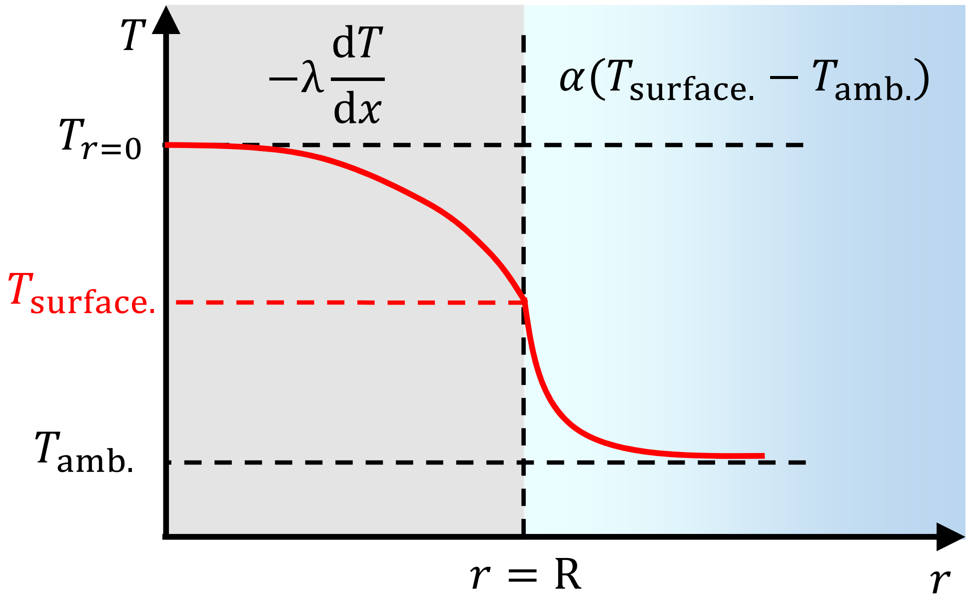

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Change of temperature profile with increase of thermal conductivity

Questions:

- Which thermal resistances are relevant?
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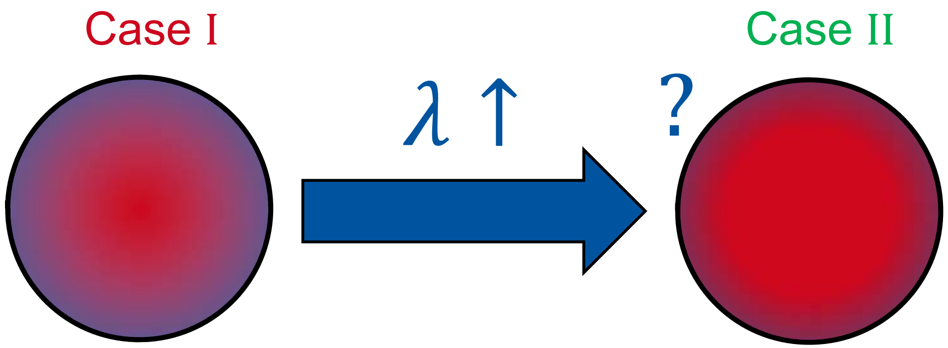
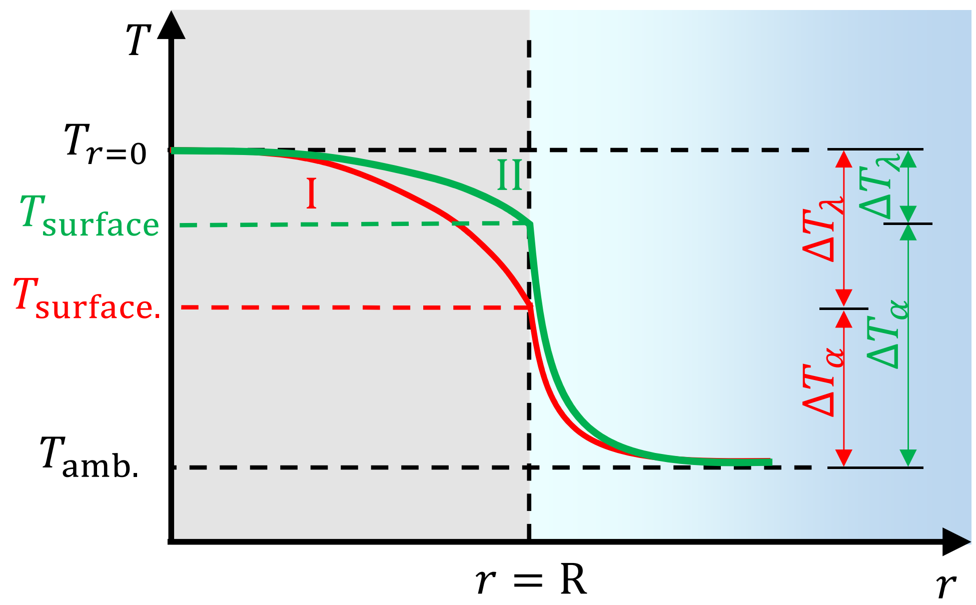
Temperature distribution inside a cylinder:

- Heat flows in both axial and radial directions (2D view inside the cylinder)

The greater the thermal conductivity becomes, the lower the thermal resistance becomes due to conduction.





Case II:

- Thermal resistance lower than resistance due to convection: $\Delta T_\lambda < \Delta T_\alpha$

Change of temperature profile with reduction of the diameter

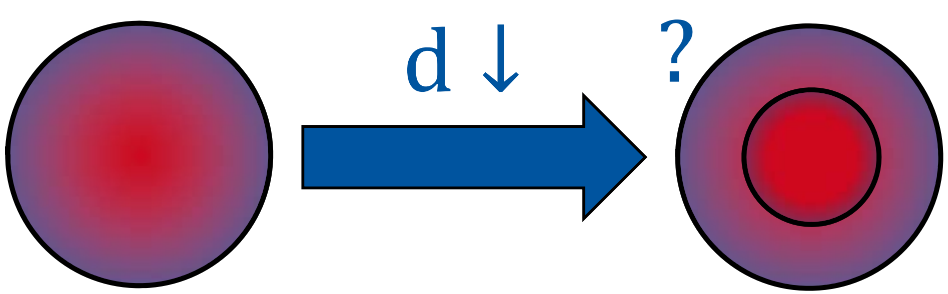
Questions:

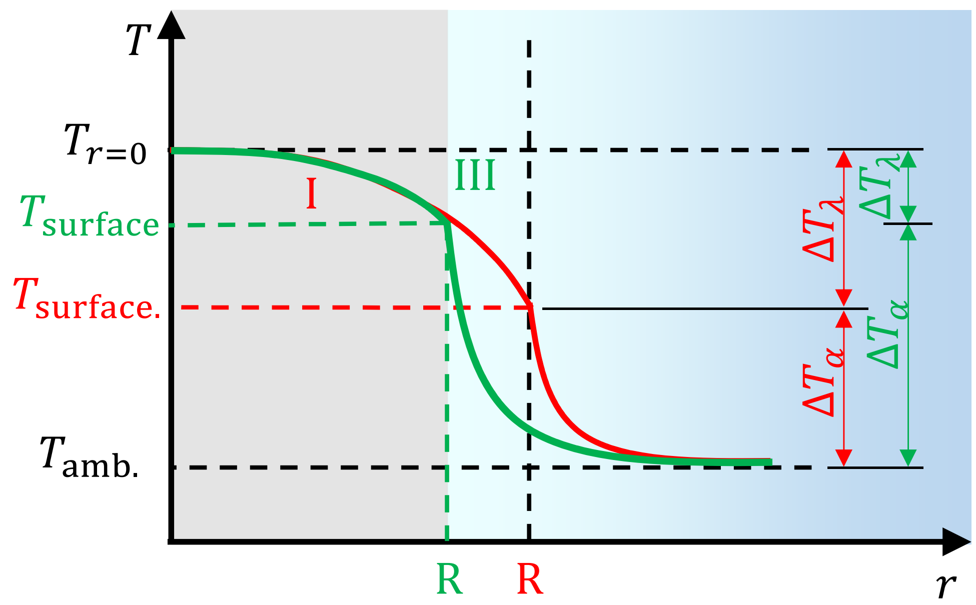
- Which thermal resistances are relevant?
- Can certain resistances be neglected?

Temperature distribution inside a cylinder:

- Heat flows in both axial and radial directions (2D view inside the cylinder)

The smaller the diameter becomes, the lower the thermal resistance becomes due to conduction in the radial direction.





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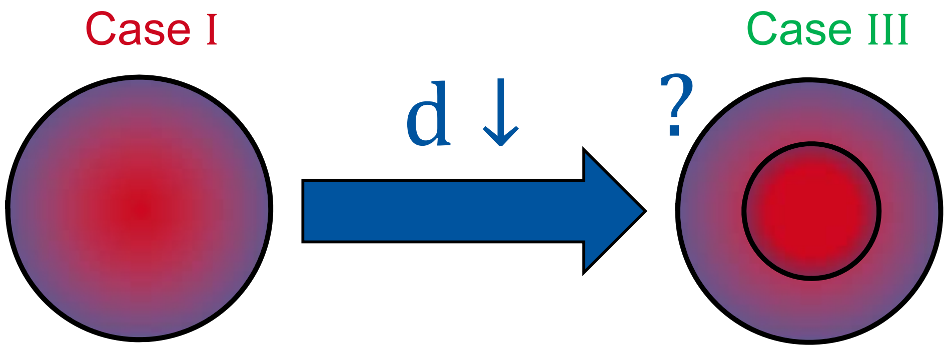

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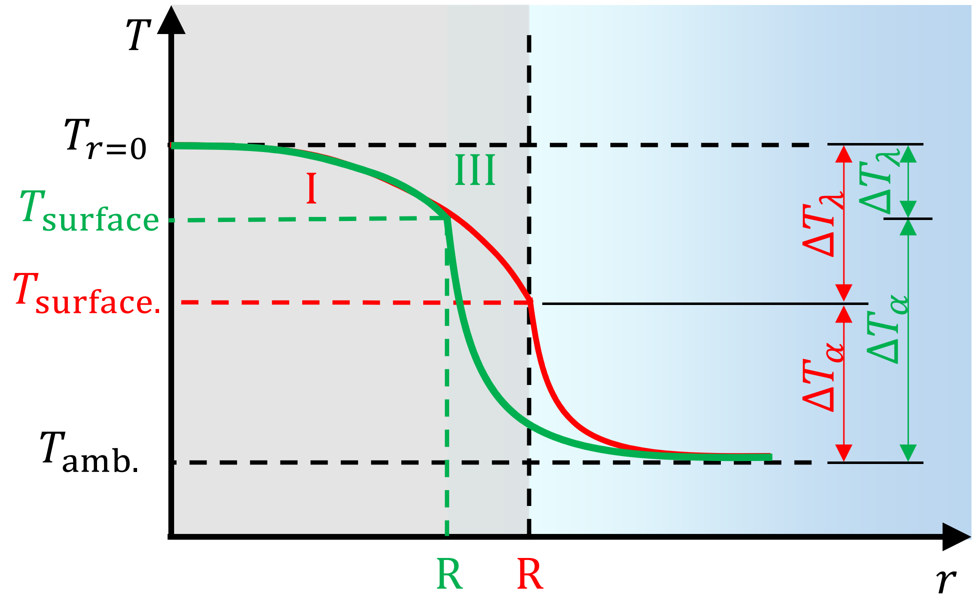

Change of temperature profile with reduction of convection

Questions:

- Which thermal resistances are relevant?
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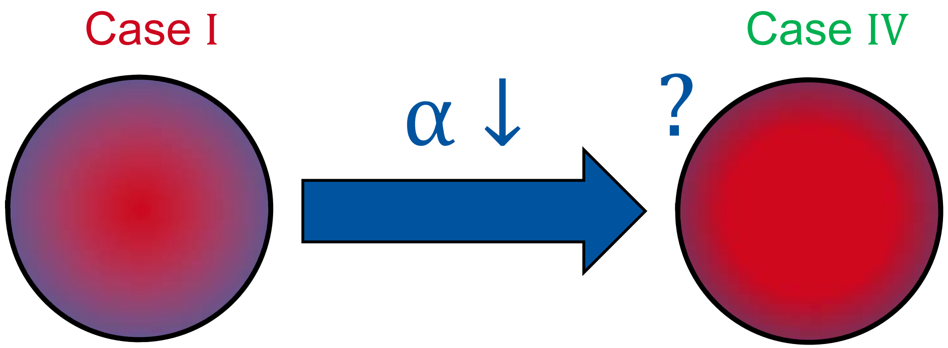
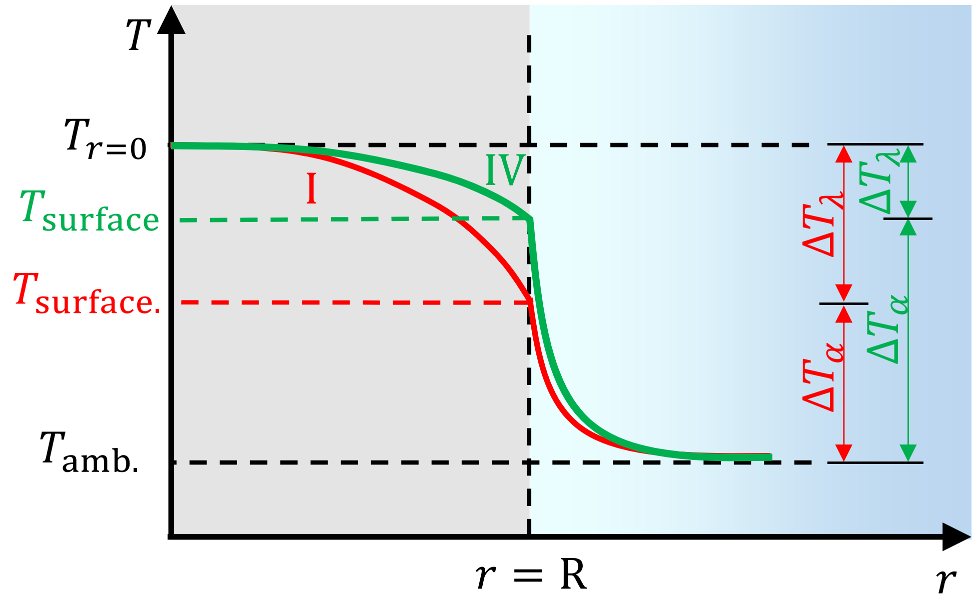
Temperature distribution inside a cylinder:

- Heat flows in both axial and radial directions (2D view inside the cylinder)

The lower the convection, the more it becomes the limiting factor in heat transfer.





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Change of temperature profile with reduction of convection

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- Heat flows in both axial and radial directions (2D view inside the cylinder)

The lower the convection, the more it becomes the limiting factor in heat transfer.

$$\text{Temperature profile} = f(\alpha, \mathrm{d}, \lambda)$$

Dimensionless number: Biot number

Biot number:

To characterize the problem dominant resistance, the **resistances of heat conduction inside the body and convection outside the body are brought into relation.**

Dimensionless parameter: **Biot number**.

$$Bi = \frac{R_\lambda}{R_\alpha} = \frac{\frac{L}{\lambda}}{\frac{1}{\alpha}}$$

$$\mathrm{Bi} = \frac{\alpha\,\mathrm{L}}{\lambda}$$

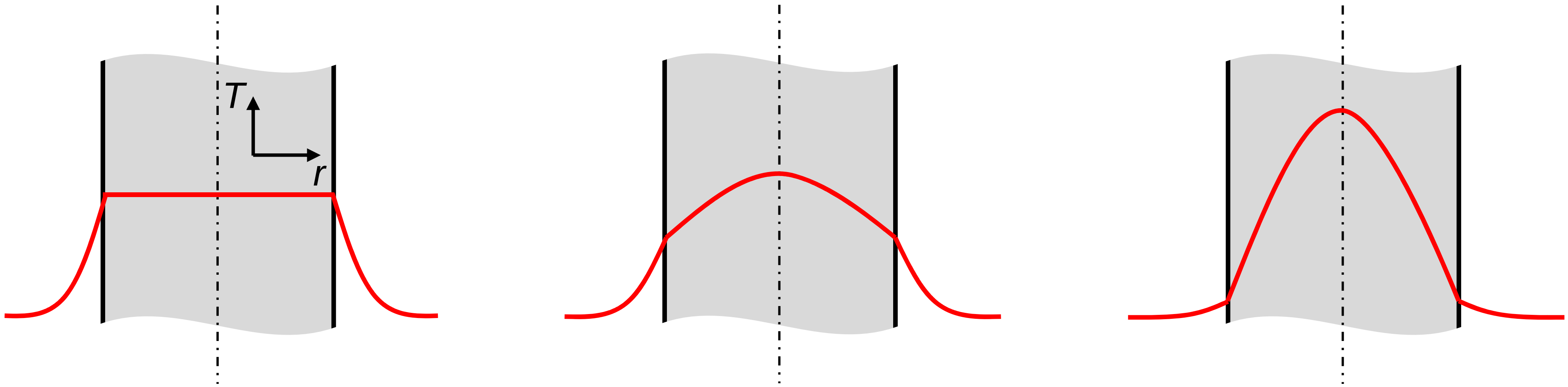
$$\mathrm{Bi} = \frac{\text{Thermal resistance inside the body}}{\text{Convective thermal resistance at the surface}}$$

Explannation:

L:	Characteristic length determining thermal resistance $[m]$
λ:	Thermal conductivity $\left[\frac{\mathrm{W}}{\mathrm{m\ K}}\right]$
α:	Heat transfer coefficient $\left[\frac{\mathrm{W}}{\mathrm{K}}\right]$

Regime classification by Biot number:

The Biot number: $Bi = \frac{\alpha\, L}{\lambda}$



Bi ≪ 1 :

- Homogeneous temperature in the body
- R_λ negligible
- Small bodies or bodies with high thermal conductivity

Bi ≈ 1 :

- Similar contributions of heat conduction and convection
- $R_\lambda \approx R_\alpha$

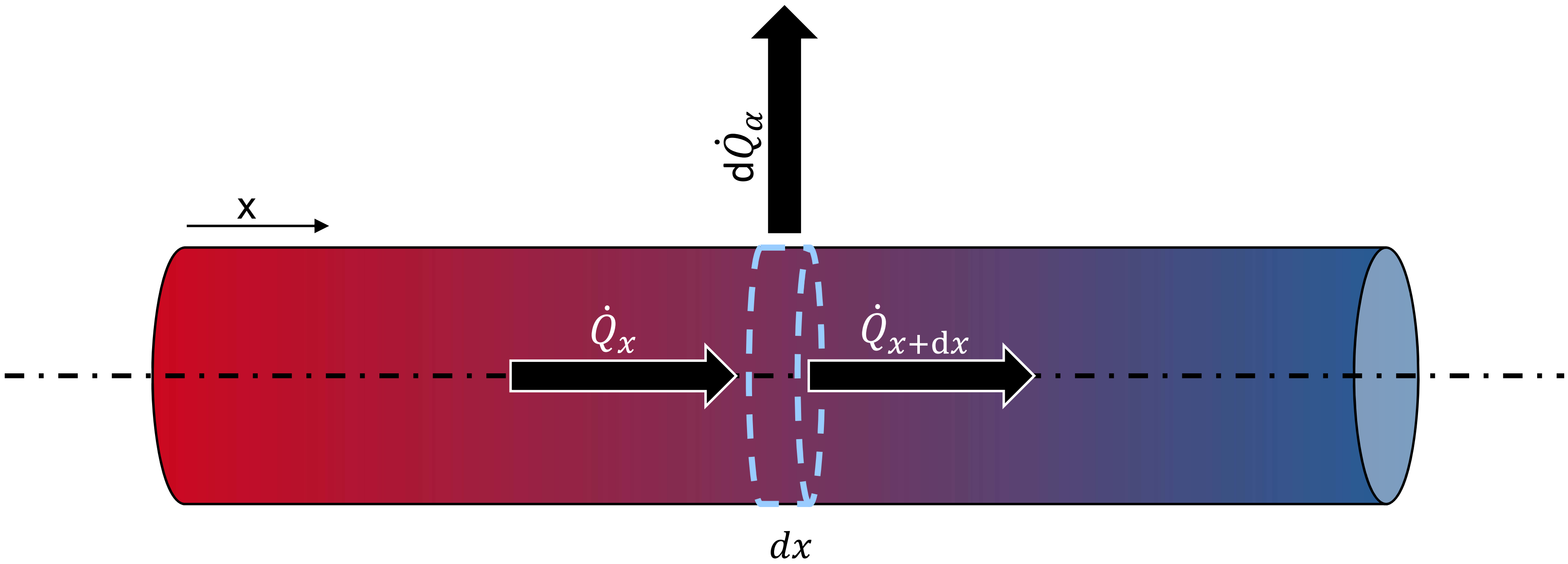
Bi ≫ 1 :

- Higher thermal resistance
- $R_\lambda \gg R_\alpha$
- Frequent in bodies with low thermal conductivity

Bi ≪ 1: One-dimensional approach

Bi ≪ 1 :

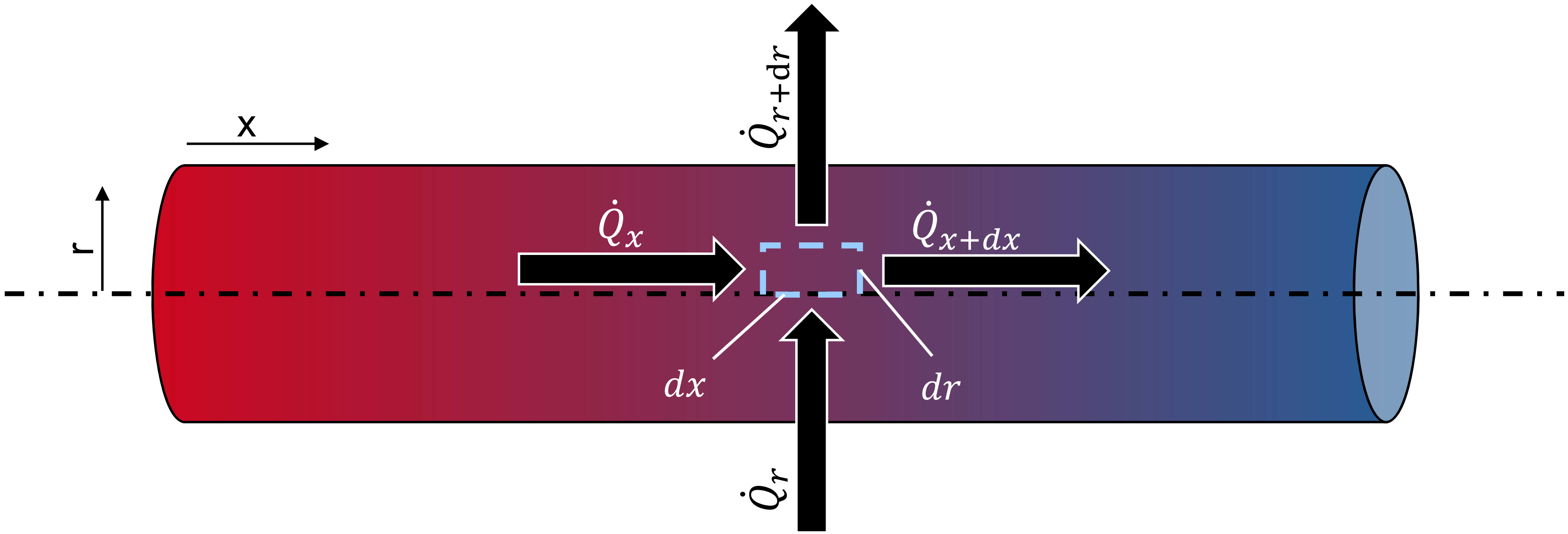
Bi ≪1 thus leads to a one-dimensional approach within the cylinder



Bi ≈ 1 or Bi ≫ 1: Two/Three-dimensional approach

Bi ≈ 1 and Bi ≫ 1:

Bi ≈ 1 and Bi ≫1 leads to a two-dimensional approach inside the cylinder



Comprehension questions

What information does the Biot number provide?

Which assumptions may be made for $Bi \ll 1$?

For a classical fin problem, is the Biot number high or low?