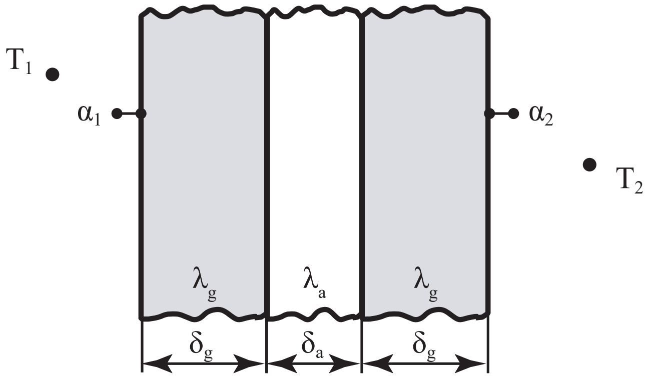
Exercise 21.4 (Window insulation ⋆)**:**

Consider a 1.2-m-height and 2-m-wide double-pane window consisting of two layers of glass separated by a stagnant air space. Convection occurs at the inside and outside of the pane window. Disregard any heat transfer by radiation.



Given parameters:

- Conductivity of glass: $\lambda_g = 0.78$ W/mK
- Conductivity of air: $\lambda_a = 0.026$ W/mK
- Thickness of glass layer: $\delta_g = 3$ mm
- Thickness of air layer: $\delta_a = 15$ mm
- Inside convection coefficient: $\alpha_1 = 10$ W/m^{2}K
- Outside convection coefficient: $\alpha_2 = 25$ W/m^{2}K
- Inside temperature: $T_1 = 22$ °C
- Outside temperature: $T_2 = -7$ °C

Tasks:

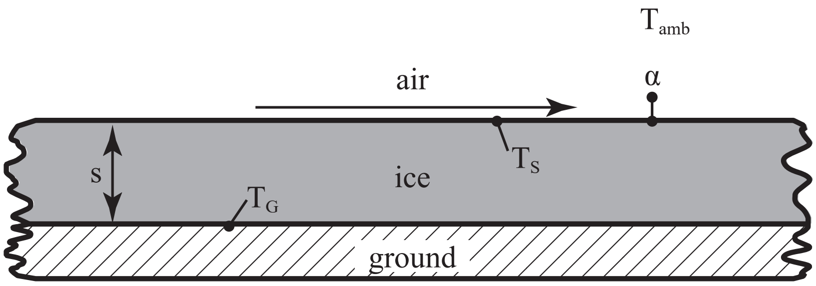
a) Determine the steady heat transfer rate through this double-pane window and the temperature of its inner surface.

b) Compare your results with a three-layer glass (3-mm-thickness) with two stagnant air spaces filled with krypton ($\delta_k = 8\,\text{mm}$, $\lambda_k = 0.00949\,\text{W/m K}$).

c) Discuss the reason for choosing a three-layer glass and scrutinize all assumptions made in tasks a) and b).

Exercise 21.5 (Ice layer ⋆⋆):

During a cold winter day, the ground is covered with an ice layer of thickness s. Air is flowing over the ice layer. The problem is one-dimensional and steady-state. No layer of water is forming on top of the ice.



Given parameters:

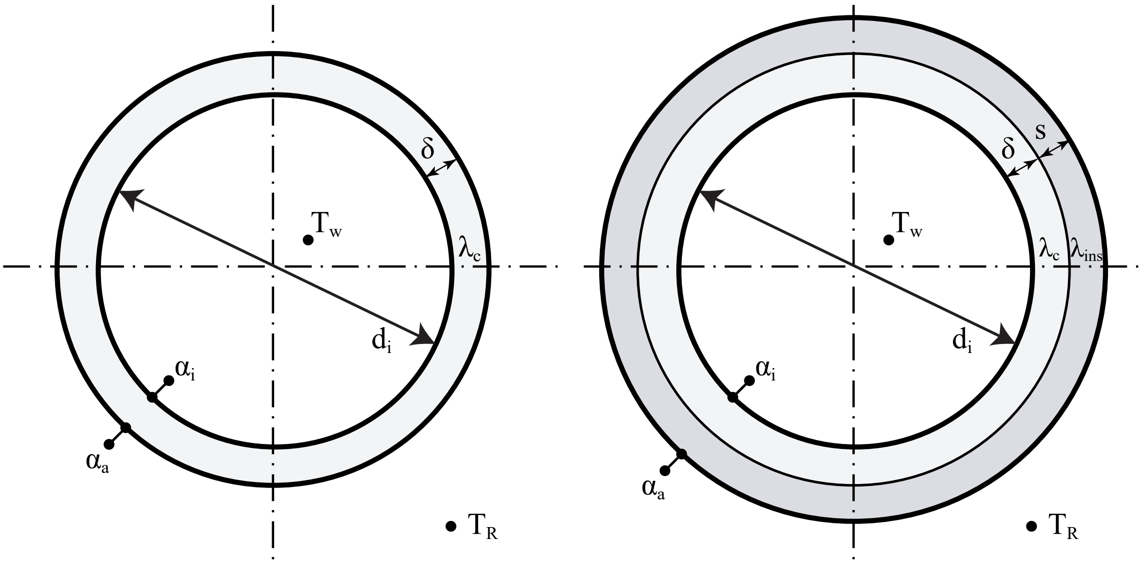
- Conductivity of ice: $\lambda = 2.2$ W/mK
- Heat transfer coefficient at the ice surface: $\alpha = 10$ W/m^{2}K
- Temperature of the air: $T_{\text{amb}} = 5$ °C
- Temperature of the ice at the surface: $T_{\text{S}} = -3$ °C
- Temperature of the ice at the ground: $T_{\text{G}} = -10$ °C
- Temperature of the air: $T_{\text{amb}} = 5$ °C

Tasks:

a) Determine the thickness s of the ice layer.

Exercise 21.6 (Warm-water pipe ⋆⋆⋆):

In a room, a copper warm-water pipe is utilized to contain water. This copper pipe features an inner diameter of d_i and a wall thickness denoted as δ. During a chilly winter day, insulation measures are taken, involving the addition of an extra insulation layer with a thickness of s.



Given parameters:

- Heat transfer coefficient at the inner side of the pipe: $\alpha_\mathrm{i} = 2300\ \mathrm{W/m^2K}$
- Heat transfer coefficient at the outer side of the pipe: $\alpha_\mathrm{a} = 6\ \mathrm{W/m^2K}$
- Temperature of the room: $T_\mathrm{R} = 20\ °\mathrm{C}$
- Temperature of the water: $T_\mathrm{W} = 80\ °\mathrm{C}$
- Conductivity of copper: $\lambda_\mathrm{c} = 372\ \mathrm{W/mK}$
- Conductivity of insulation material: $\lambda_\mathrm{ins} = 0.042\ \mathrm{W/mK}$
- Inner diameter of the copper pipe: $d_\mathrm{i} = 6\ \mathrm{mm}$
- Thickness of the copper pipe: $\delta = 1\ \mathrm{mm}$
- Thickness of the insulation layer: $s = 4\ \mathrm{mm}$

Hints:

- Changes to the heat transfer coefficient at the outer side of the pipe as a function of the diameter are disregarded.

Tasks:

a) Calculate the heat transferred per unit length of the pipe, denoted as $\dot{q}'$, for both an uninsulated pipe and an insulated pipe. What noteworthy observations can be made from your findings?

b) Qualitatively sketch the heat emission profile $\dot{q}'$ as a function of the insulation thickness for different thermal conductivities of the insulation material. Explain the underlying physical principles.

c) Calculate the required thermal conductivity for the insulating material to always achieve a reduction in heat loss, regardless of the thickness of the insulation.