Heat Transfer: Radiation

Example: Radiation transfer between two gray plates

Prof. Dr.-Ing. Reinhold Kneer

Prof. Dr.-Ing. Dr. rer. pol. Wilko Rohlfs

HEATQUIZ

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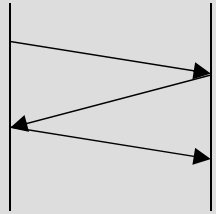
Learning goals

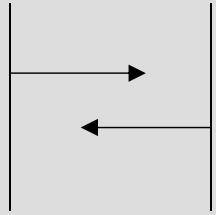
Radiation Tracking:

- Understanding the calculation of the radiation transfer between two surfaces by means of radiation tracking
  (Attention: not useful)

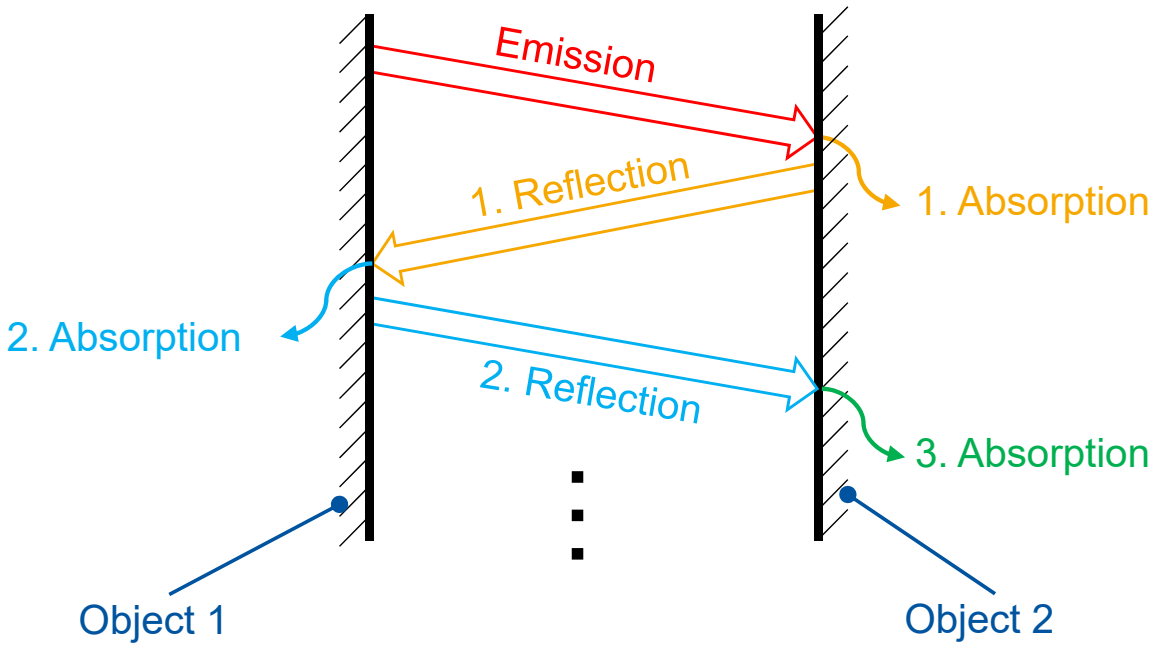


Surface Brightness:

- Ability to describe the radiation exchange by means of surface brightness
  (Method of choice)



Radiation tracking



Question:

- How is calculated the radiation transfer between Object 1 and Object 2?

1. Approach: Radiation Tracking

Procedure

- Trace the radiation emitted
- At the first impact a fraction of the Radiation is absorbed and a fraction is reflected
- At the second impact a fraction of the Radiation is absorbed and a fraction is reflected
- At the third impact a fraction of the Radiation is absorbed

and so on

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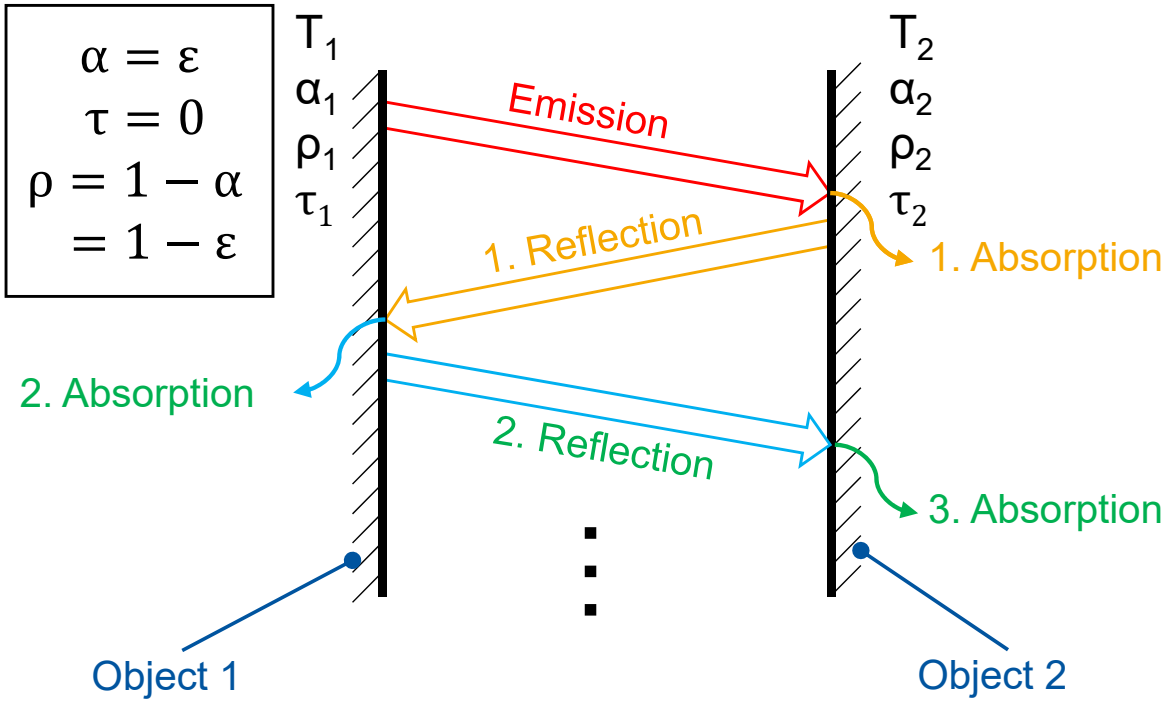
Radiation tracking

$$\alpha = \varepsilon$$
$$\tau = 0$$
$$\rho = 1 - \alpha$$
$$= 1 - \varepsilon$$



Net Radiation Transfer:

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Radiation tracking

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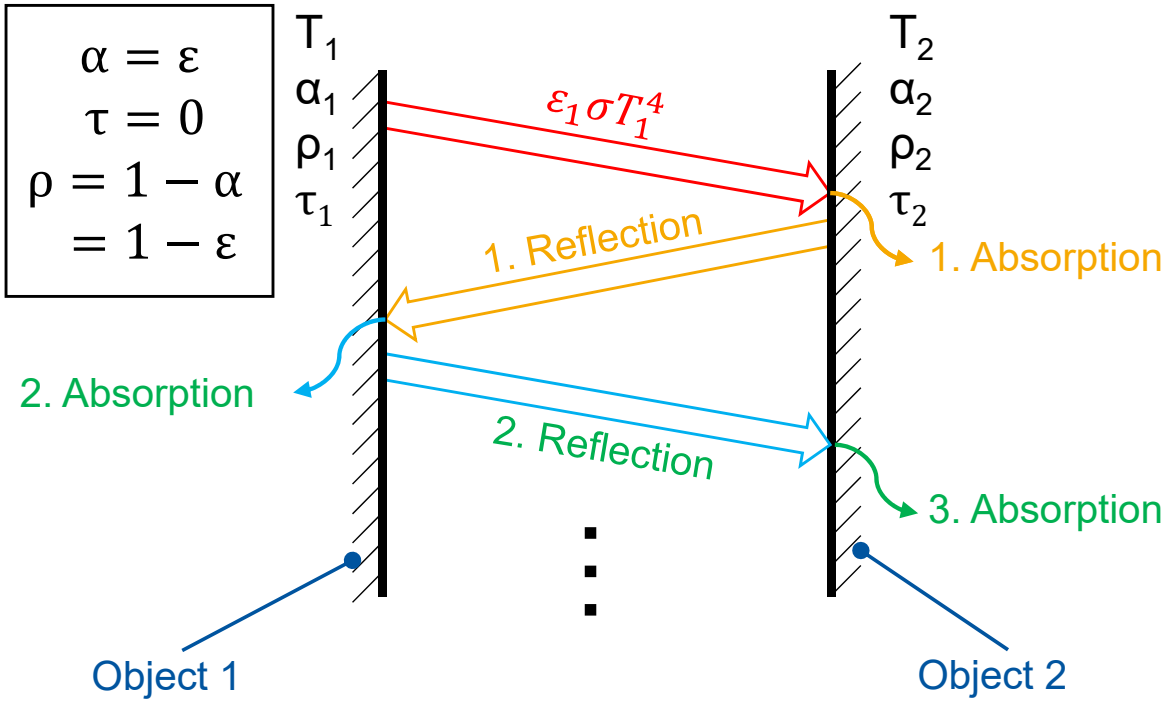

Net Radiation Transfer:

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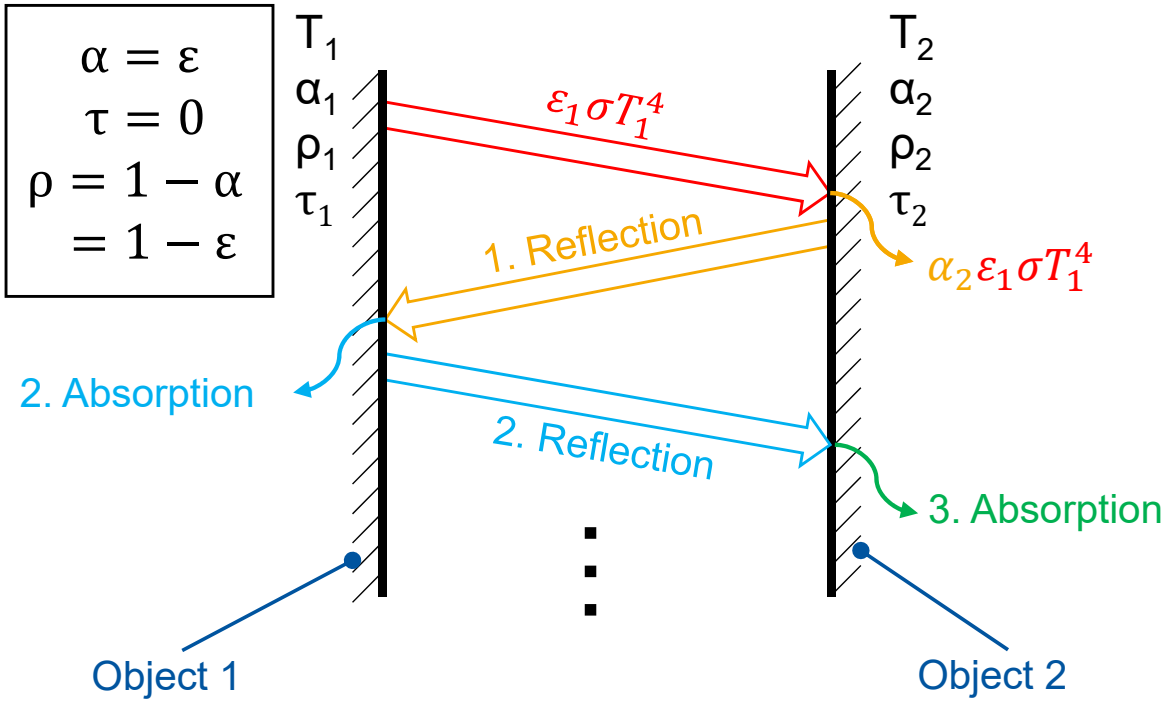

Net Radiation Transfer:

$$\dot{Q}_{1\to2} = A\sigma T_1^4 [\varepsilon_1 \varepsilon_2$$

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Radiation tracking

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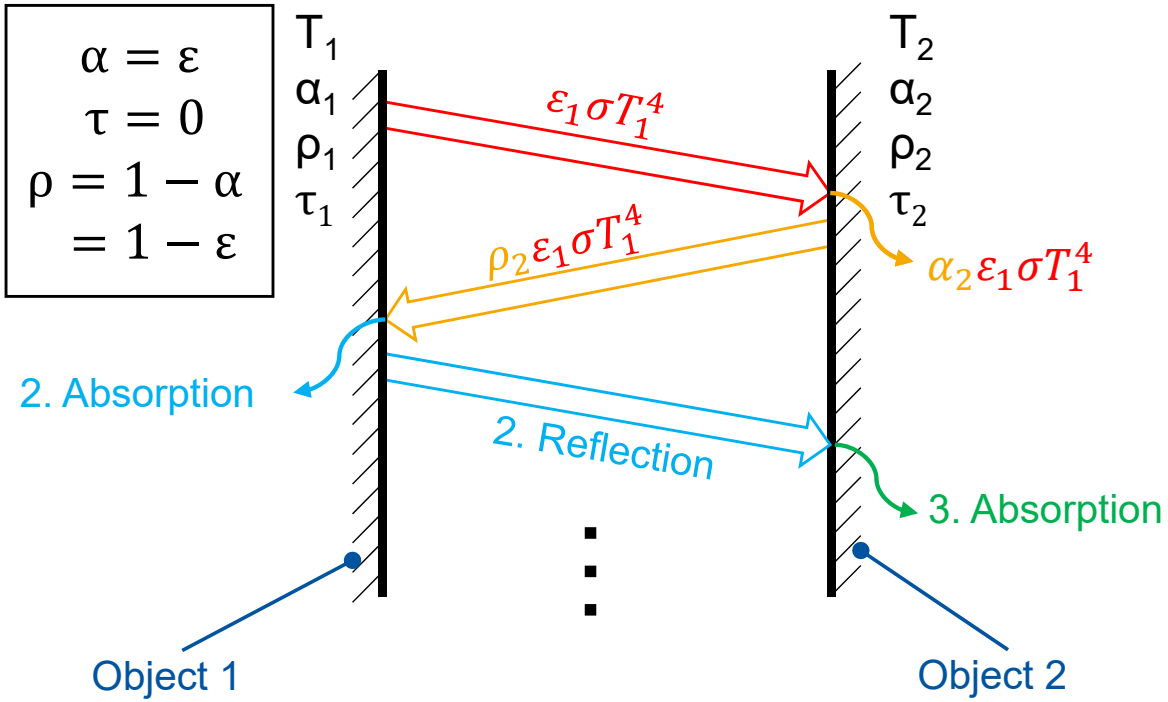

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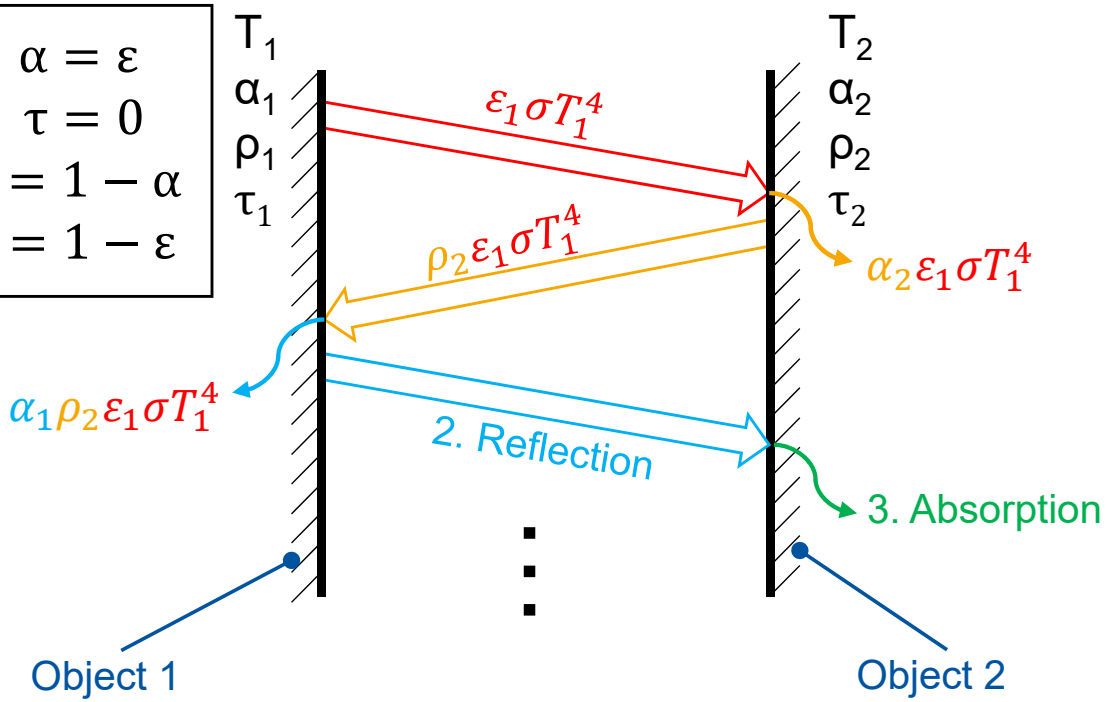

Net Radiation Transfer:

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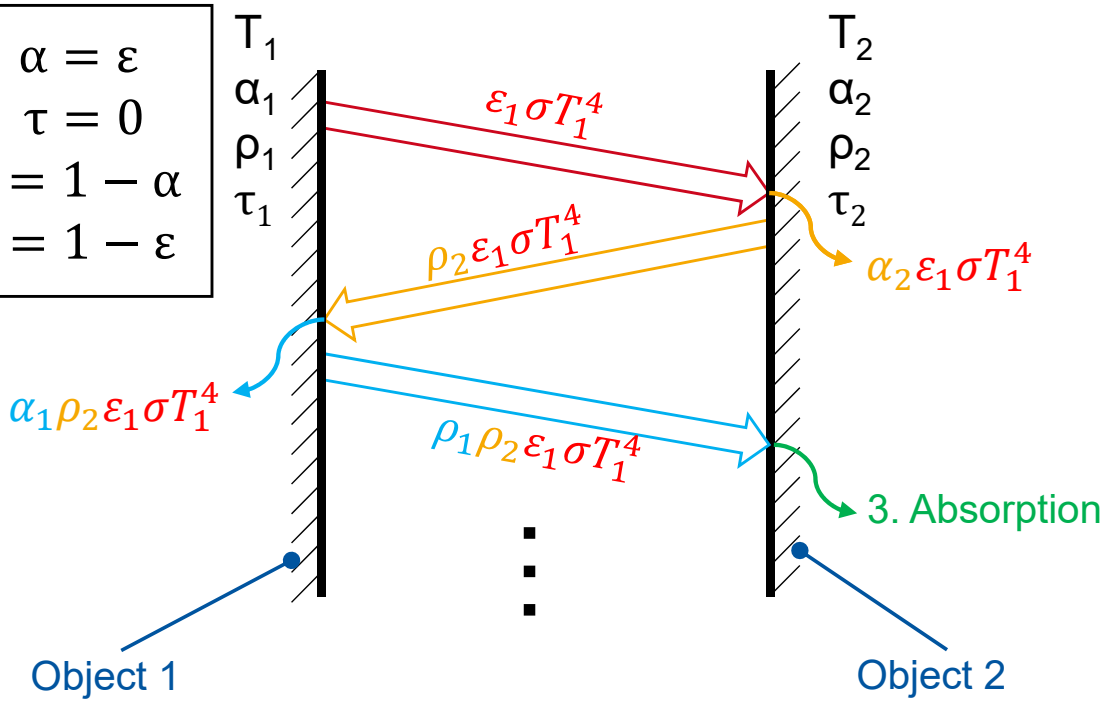

Net Radiation Transfer:

$$\dot{Q}_{1\to2} = A\sigma T_1^4 [\varepsilon_1 \varepsilon_2$$

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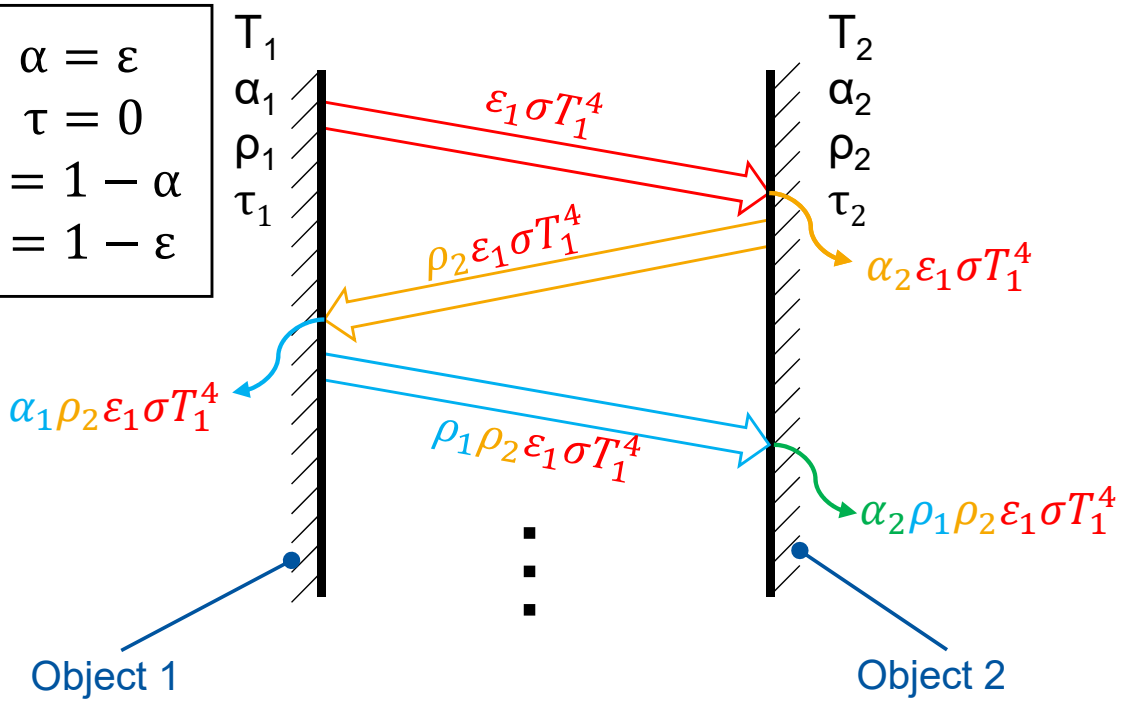

Net Radiation Transfer:

$$\dot{Q}_{1\to2} = A\sigma T_1^4 [\varepsilon_1\varepsilon_2 + \varepsilon_1\varepsilon_2(1-\varepsilon_1)(1-\varepsilon_2) + \varepsilon_1\varepsilon_2(1-\varepsilon_1)^2(1-\varepsilon_2)^2 + \cdots]$$

$$\dot{Q}_{2\to1} = \text{symmetrical}$$

$$\dot{Q}_{1\rightleftarrows2} = \phi_{12}\dot{Q}_{1\to2} - \phi_{21}\dot{Q}_{2\to1}$$

$$= A\varepsilon_1\varepsilon_2\sigma(T_1^4 - T_2^4)\,[1 + (1-\varepsilon_1)(1-\varepsilon_2) + (1-\varepsilon_1)^2(1-\varepsilon_2)^2 + \cdots]$$

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Radiation tracking

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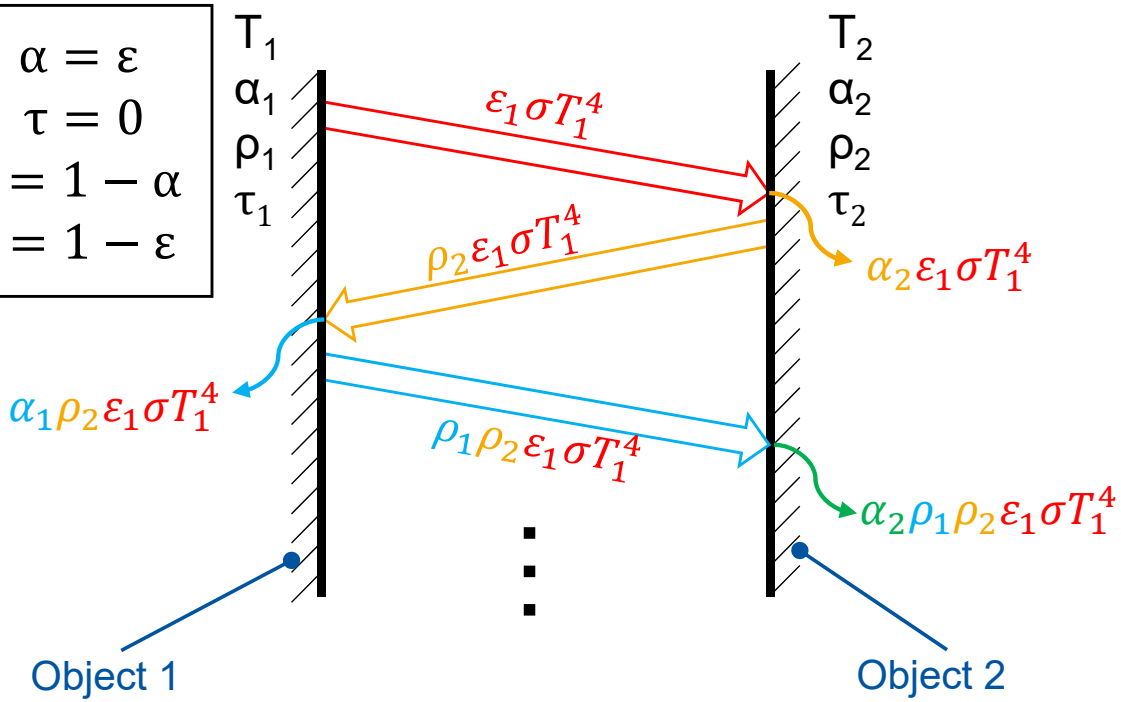

Net Radiation Transfer:

$$\dot{Q}_{1\to2} = A\sigma T_1^4 [\varepsilon_1\varepsilon_2 + \varepsilon_1\varepsilon_2(1-\varepsilon_1)(1-\varepsilon_2) + \varepsilon_1\varepsilon_2(1-\varepsilon_1)^2(1-\varepsilon_2)^2 + \cdots]$$

$$\dot{Q}_{2\to1} = \text{symmetrical}$$

$$\dot{Q}_{1\rightleftarrows2} = \phi_{12}\dot{Q}_{1\to2} - \phi_{21}\dot{Q}_{2\to1}$$
$$= A\varepsilon_1\varepsilon_2\sigma(T_1^4 - T_2^4)\,[1 + (1-\varepsilon_1)(1-\varepsilon_2) + (1-\varepsilon_1)^2(1-\varepsilon_2)^2 + \cdots]$$

Substitution:

$$x = (1-\varepsilon_1)(1-\varepsilon_2)$$

For $|x| < 1 \Rightarrow \sum_{n=0}^{\infty} x^n = \frac{1}{1-x}$

Insert results given:

$$\dot{Q}_{12} = A\,\sigma\,\varepsilon_1\,\varepsilon_2\,(T_1^4 - T_2^4)\,\frac{1}{1-(1-\varepsilon_1)(1-\varepsilon_2)}$$

This was the complicated way.

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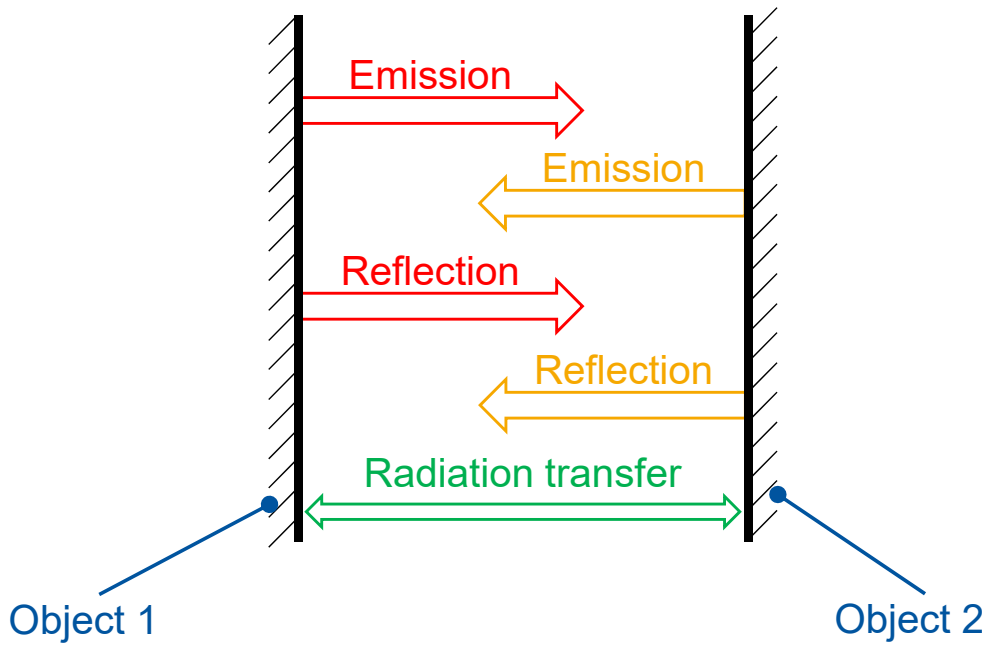
Radiation tracking



Question:

- How is calculated the radiation transfer between Object 1 and Object 2?

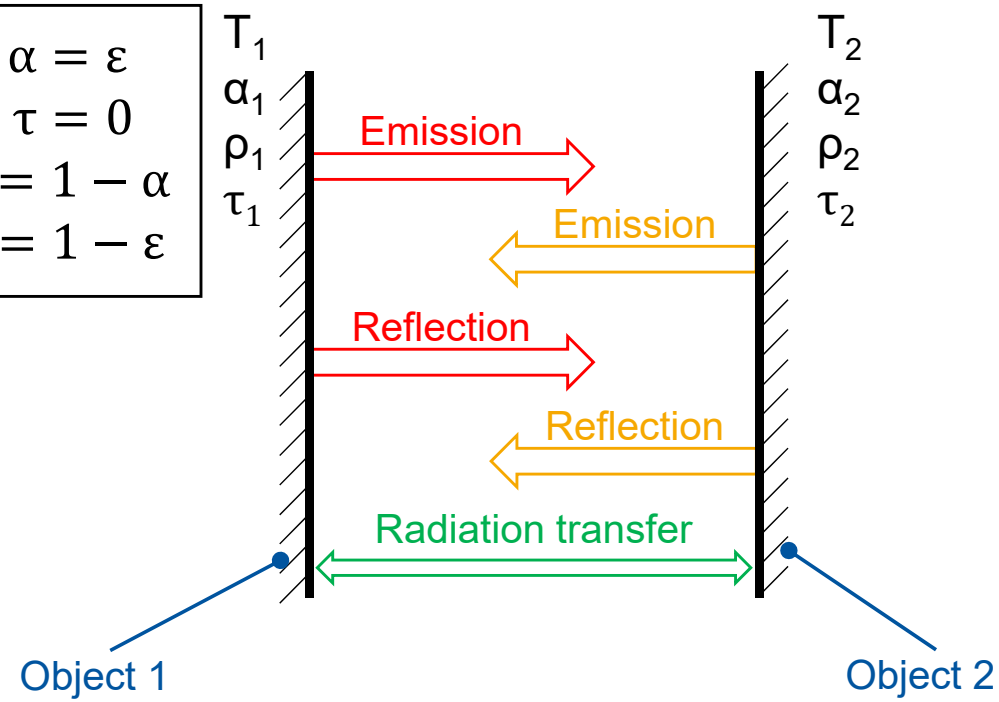
2. Approach: Surface Brightness

Procedure

- Setting up the Surface brightness
- Surface Brightness (SB) Object 1:
  Emission from Object 1
  Reflection of SB from Object 2
- Surface Brightness (SB) Object 2:
  Emission from Object 2
  Reflection of SB from Object 1
- Net Radiation transfer =
  Surface Brightness 1 –
  Surface Brightness 2

Surface brightness

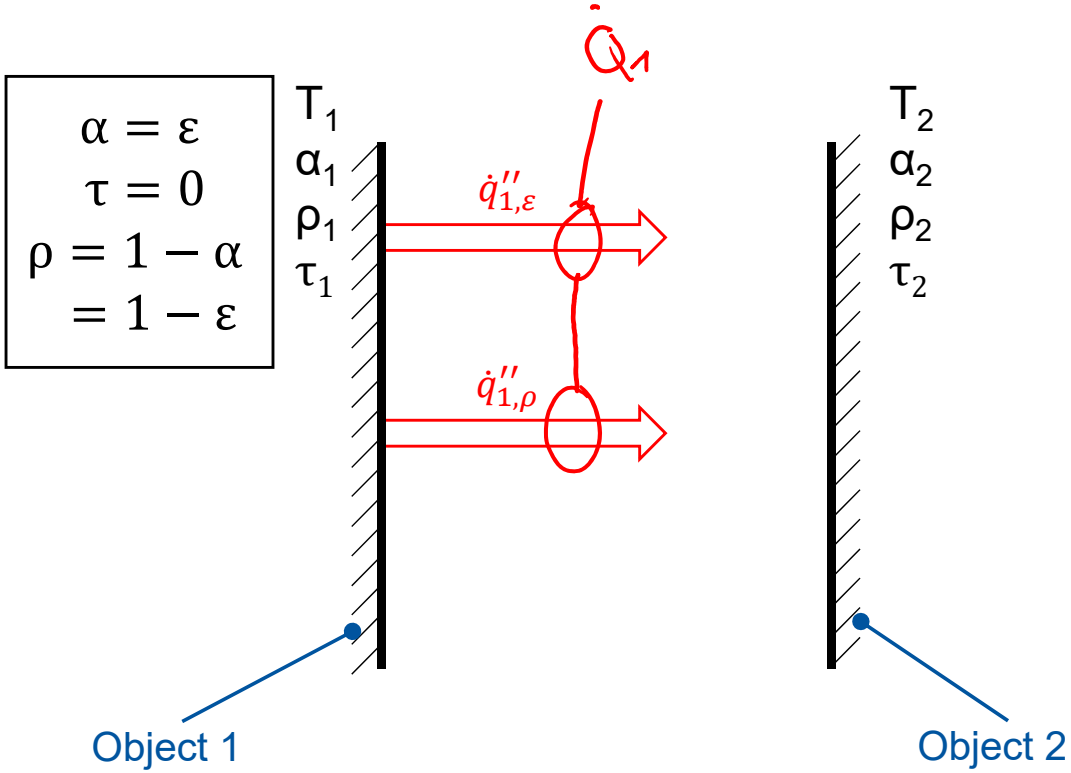
$$\alpha = \varepsilon$$
$$\tau = 0$$
$$\rho = 1 - \alpha$$
$$= 1 - \varepsilon$$



Surface brightness:

Surface brightness

$$\alpha = \varepsilon$$
$$\tau = 0$$
$$\rho = 1 - \alpha = 1 - \varepsilon$$

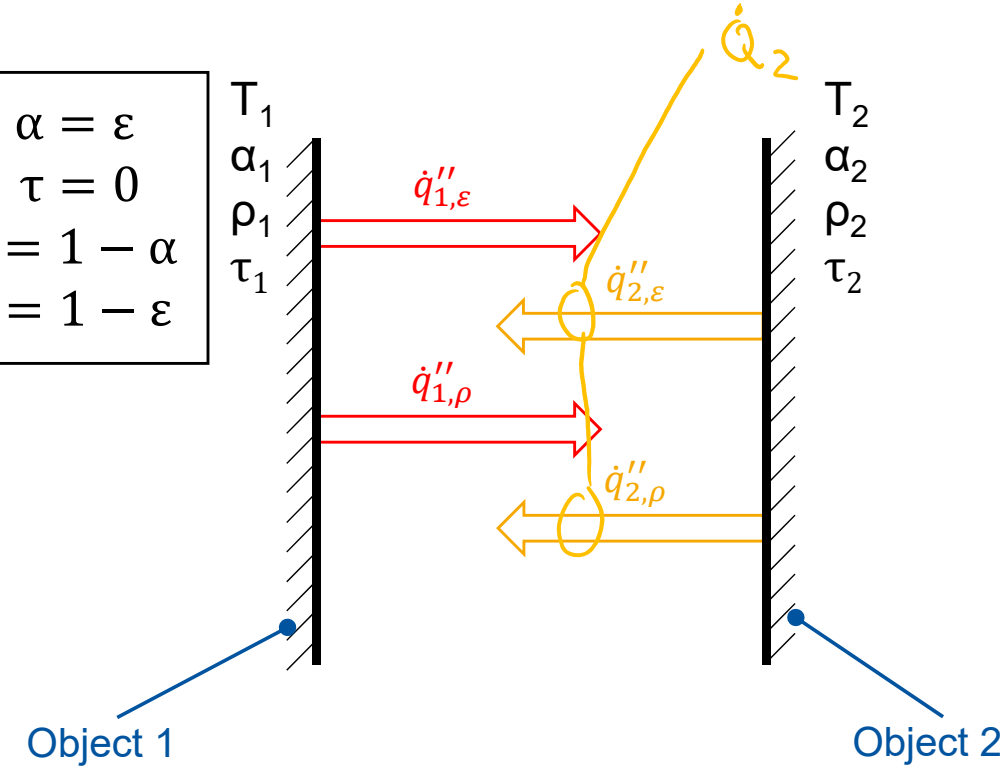


Surface brightness:

$$\dot{Q}_1 = A_1 \, \dot{q}''_1 = A_1 \, [\varepsilon_1 \, \dot{q}''_{b,1} + (1 - \varepsilon_1) \dot{q}''_2]$$

Surface brightness

$$\alpha = \varepsilon$$
$$\tau = 0$$
$$\rho = 1 - \alpha$$
$$= 1 - \varepsilon$$



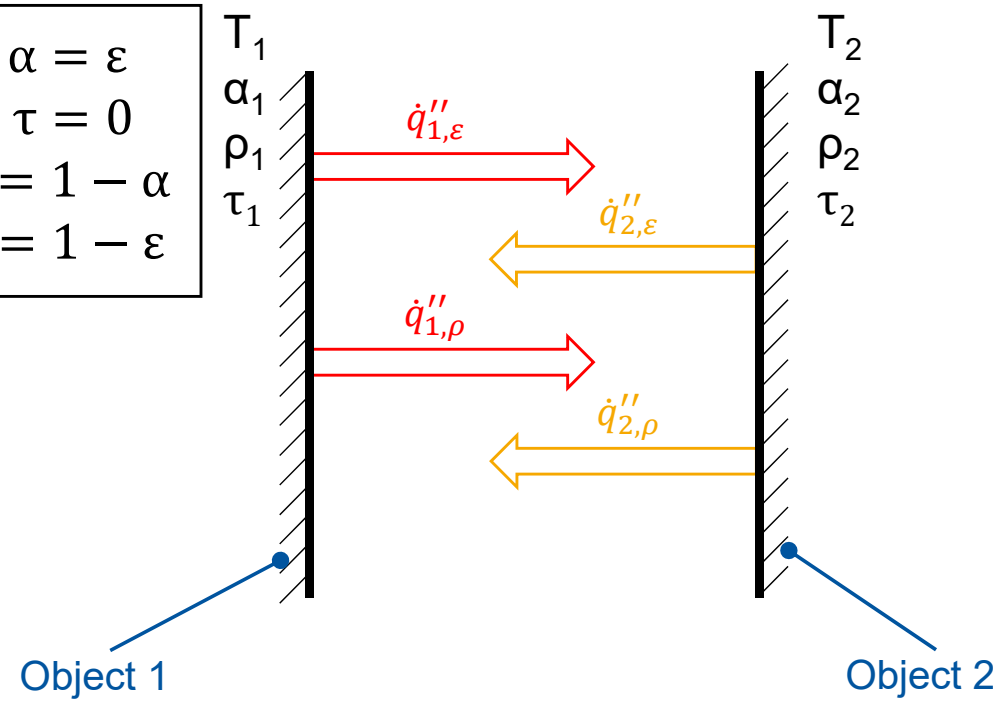
Surface brightness:

$$\dot{Q}_1 = A_1\,\dot{q}''_1 = A_1\left[\varepsilon_1\,\dot{q}''_{b,1} + (1-\varepsilon_1)\dot{q}''_2\right]$$

$$\dot{Q}_2 = A_2\,\dot{q}''_2 = A_2\left[\varepsilon_2\,\dot{q}''_{b,2} + (1-\varepsilon_2)\dot{q}''_1\right]$$

Surface brightness

$$\alpha = \varepsilon$$
$$\tau = 0$$
$$\rho = 1 - \alpha$$
$$= 1 - \varepsilon$$



Surface brightness:

$$\dot{Q}_1 = A_1\,\dot{q}''_1 = A_1\left[\varepsilon_1\,\dot{q}''_{b,1} + (1-\varepsilon_1)\dot{q}''_2\right]$$

$$\dot{Q}_2 = A_2\,\dot{q}''_2 = A_2\left[\varepsilon_2\,\dot{q}''_{b,2} + (1-\varepsilon_2)\dot{q}''_1\right]$$

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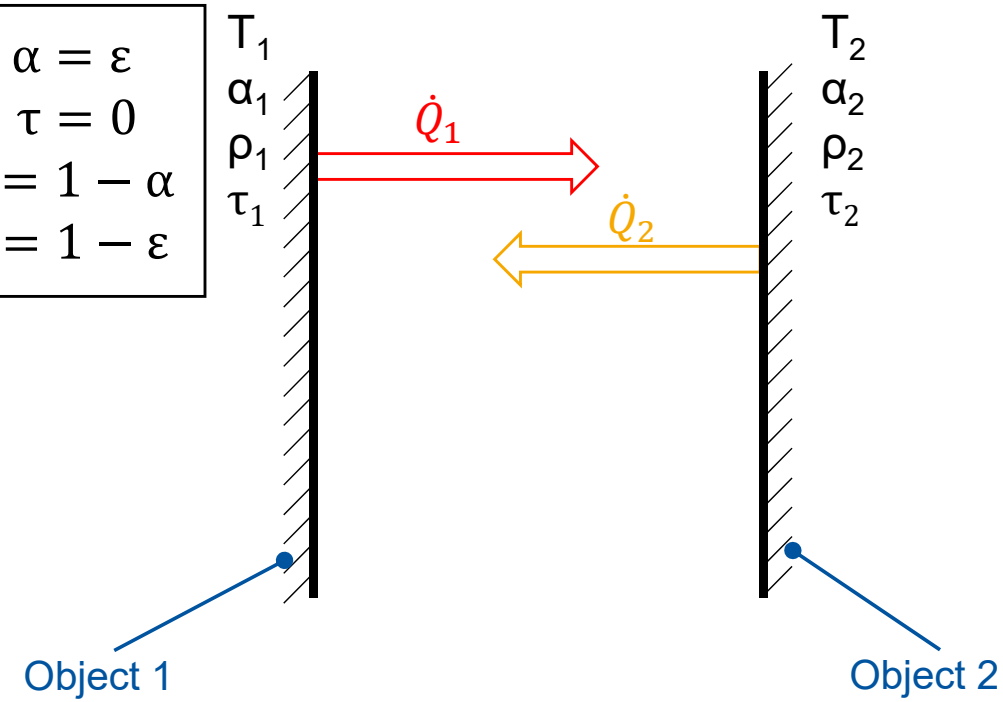
Surface brightness

$$\alpha = \varepsilon$$
$$\tau = 0$$
$$\rho = 1 - \alpha$$
$$= 1 - \varepsilon$$



Surface brightness:

$$\dot{Q}_1 = A_1 \, \dot{q}_1'' = A_1 \left[\varepsilon_1 \, \dot{q}_{b,1}'' + (1 - \varepsilon_1) \dot{q}_2'' \right]$$

$$\dot{Q}_2 = A_2 \, \dot{q}_2'' = A_2 \left[\varepsilon_2 \, \dot{q}_{b,2}'' + (1 - \varepsilon_2) \dot{q}_1'' \right]$$

Surface brightness

$$\alpha = \varepsilon$$
$$\tau = 0$$
$$\rho = 1 - \alpha$$
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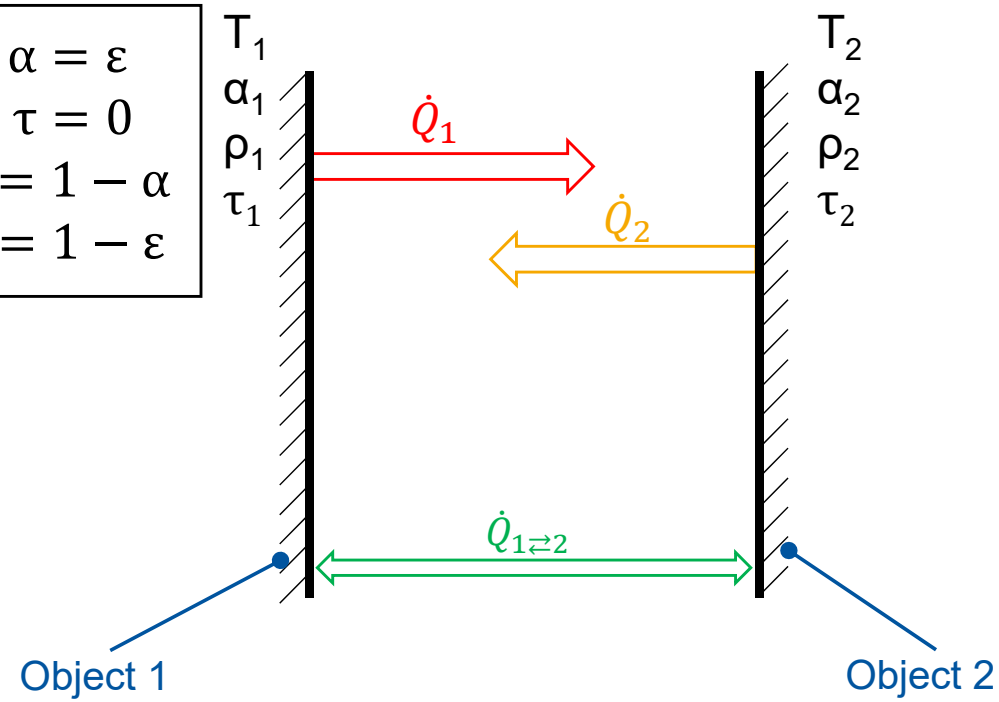

Surface brightness:

$$\dot{Q}_1 = A_1\,\dot{q}_1'' = A_1\,[\varepsilon_1\,\dot{q}_{S,1}'' + (1-\varepsilon_1)\dot{q}_2'']$$

$$\dot{Q}_2 = A_2\,\dot{q}_2'' = A_2\,[\varepsilon_2\,\dot{q}_{S,2}'' + (1-\varepsilon_2)\dot{q}_1'']$$

$$\dot{q}_1'' = \frac{\varepsilon_1\,\dot{q}_{b,1}'' + (1-\varepsilon_1)\,\varepsilon_2\,\dot{q}_{b,2}''}{1-(1-\varepsilon_1)(1-\varepsilon_2)}$$

$$\dot{q}_2'' = \frac{\varepsilon_2\,\dot{q}_{b,2}'' + (1-\varepsilon_2)\,\varepsilon_1\,\dot{q}_{b,1}''}{1-(1-\varepsilon_1)(1-\varepsilon_2)}$$

Net radiative heat transfer:

$$\dot{Q}_{1\rightleftarrows 2} = \dot{Q}_1 - \dot{Q}_2 \quad \text{because} \quad A_1 = A_2 \quad \rightarrow \quad \dot{q}_{1\rightleftarrows 2}'' = \dot{q}_1'' - \dot{q}_2'' = \frac{\varepsilon_1\varepsilon_2\left(\dot{q}_{b,1}'' - \dot{q}_{b,2}''\right)}{1-(1-\varepsilon_1)(1-\varepsilon_2)} = \frac{\sigma\,(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}$$

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Comprehension Questions

In which case is Radiation Tracking a reasonable method for calculation?

Why is the use of surface brightness the more elegant method for calculating radiation transfer?