Heat Transfer: Radiation

Kirchhoff's Law

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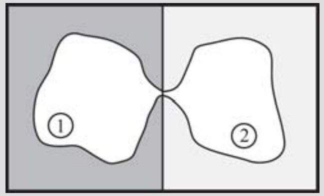
Learning goals

Virtual experiment:

- Relationship between absorptivity and emissivity



Kirchhoff‘s law:

- Conditions where "ε = α" (wavelength independent) is valid?

$$\varepsilon = \alpha$$

Virtual experiment

Enclosed body:

Radiation through cavity opening

$t = 0\,; \qquad T_1 > T_2$

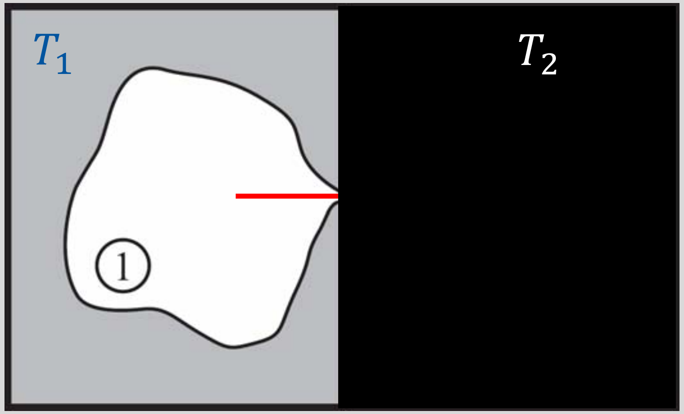
no back reflection through opening from Body ② to Body ① (very small gap)

⇨ complete absorption within the body ②

$t \to \infty;$

$T_1 = T_2$

$\dot{q}''_{1\to 2} = \dot{q}''_{2\to 1}$



The radiation of a **cavity** corresponds to that of a **black body**

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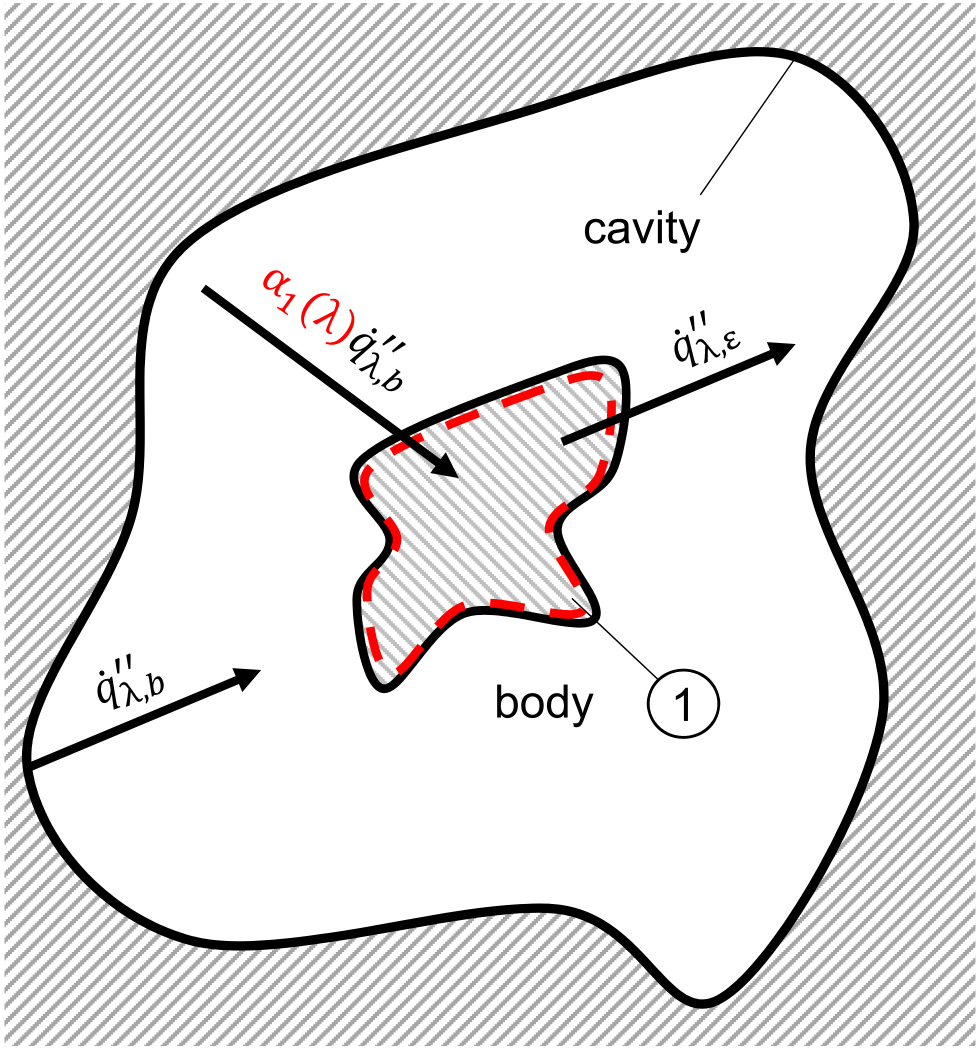
Enclosed Body



Radiation:

Incident Radiation: $\dot{q}''_{\lambda,b}$

Absorption: $\alpha_1(\lambda)\dot{q}''_{\lambda,b}$

Emission: $\dot{q}''_{\lambda,\varepsilon}$

Energy balance body 1 :

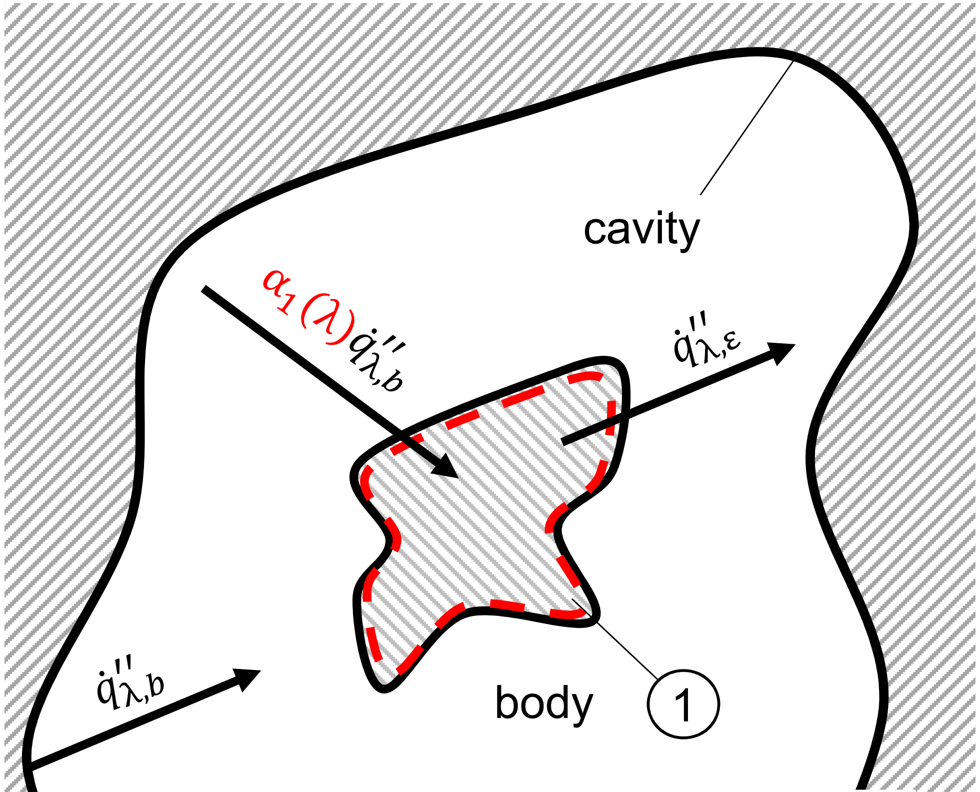
$$\alpha_1(\lambda)\dot{q}''_{\lambda,b}\,A_1 = \dot{q}''_{\lambda,\varepsilon}\,A_1$$

$$\alpha(\lambda) = \frac{\dot{q}''_{\lambda,\varepsilon}}{\dot{q}''_{\lambda,b}}$$

Emissivity definition:

$$\varepsilon(\lambda) = \frac{\text{Heat flux emitted by the body}}{\text{Heat flux emitted by a black body with same temperature}}$$

Enclosed Body



Kirchhoff's law:

$$\alpha(\lambda) = \varepsilon(\lambda)$$

Radiation:

Incident Radiation: $\dot{q}''_{\lambda,b}$

Absorption: $\alpha_1(\lambda)\dot{q}''_{\lambda,b}$

Emission: $\dot{q}''_{\lambda,\varepsilon}$

Energy balance body 1 :

$$\alpha_1(\lambda)\dot{q}''_{\lambda,b}\, A_1 = \dot{q}''_{\lambda,\varepsilon}\, A_1$$

$$\alpha(\lambda) = \frac{\dot{q}''_{\lambda,\varepsilon}}{\dot{q}''_{\lambda,b}}$$

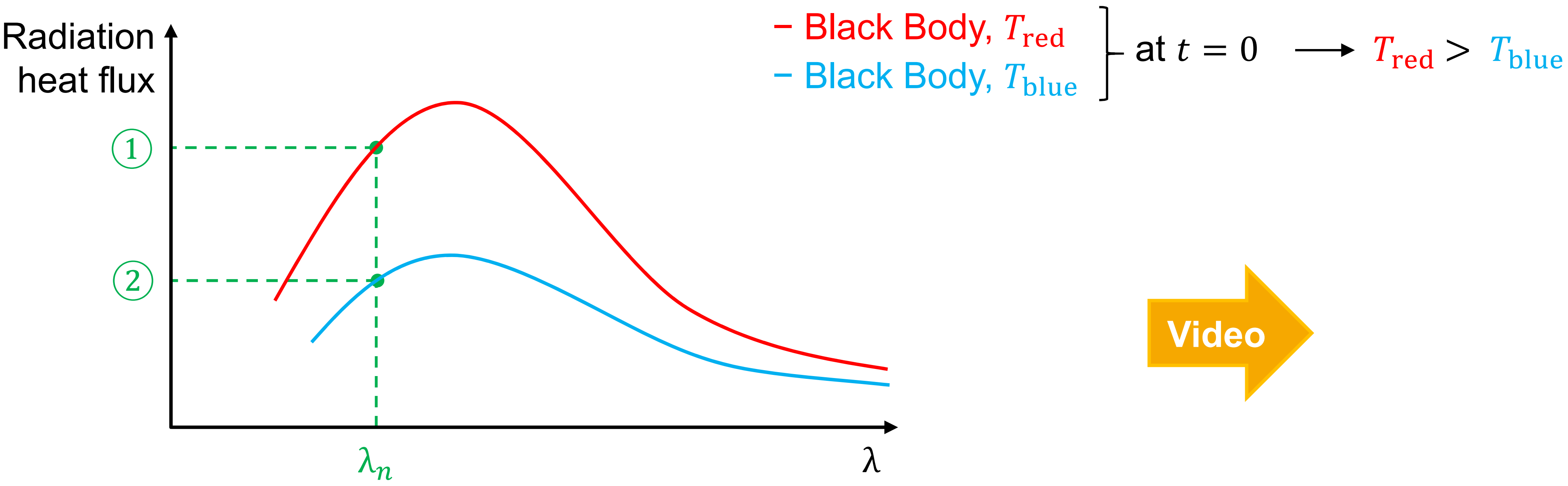
Emissivity definition:

$$\varepsilon(\lambda) = \frac{\dot{q}''_{\lambda,\varepsilon}}{\dot{q}''_{\lambda,b}}$$

Frequently asked question:

When $\alpha(\lambda) = \varepsilon(\lambda)$ is valid, are absorbed and emitted heat flux identical?

Example



Video

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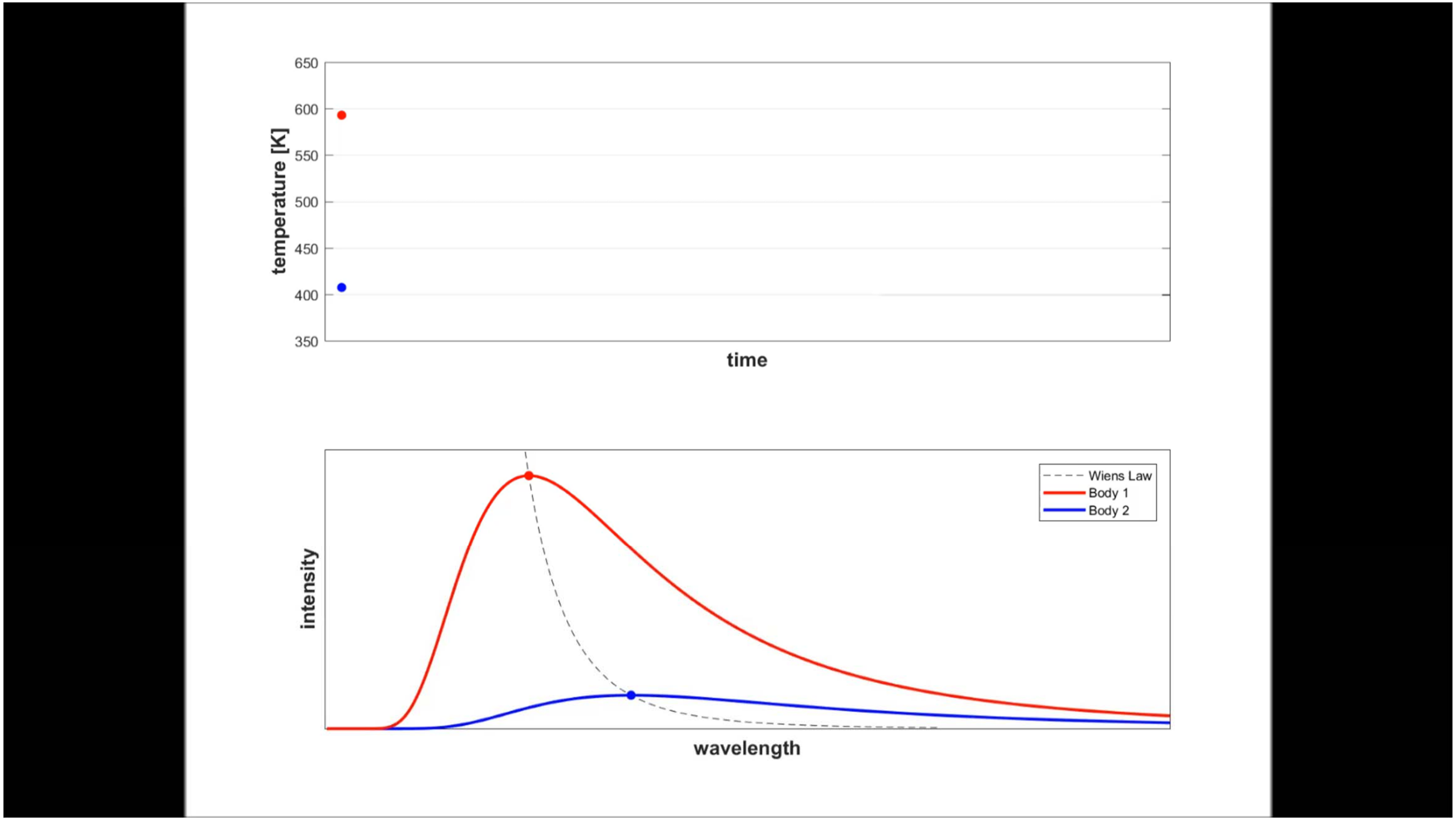
Thermal equilibrium



Explanation for the example

Explanation:

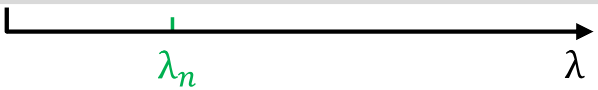
At a fixed wavelength λ the red black body emits a heat flux, which is marked with 1 on the ordinate.
The blue black body absorbs **all incoming** radiation, i.e. exactly this heat flux.

At this wavelength, however, the blue black body can <u>emit</u> with T_{blue} at most the heat flux 2 belonging to the Planck curve marked blue.

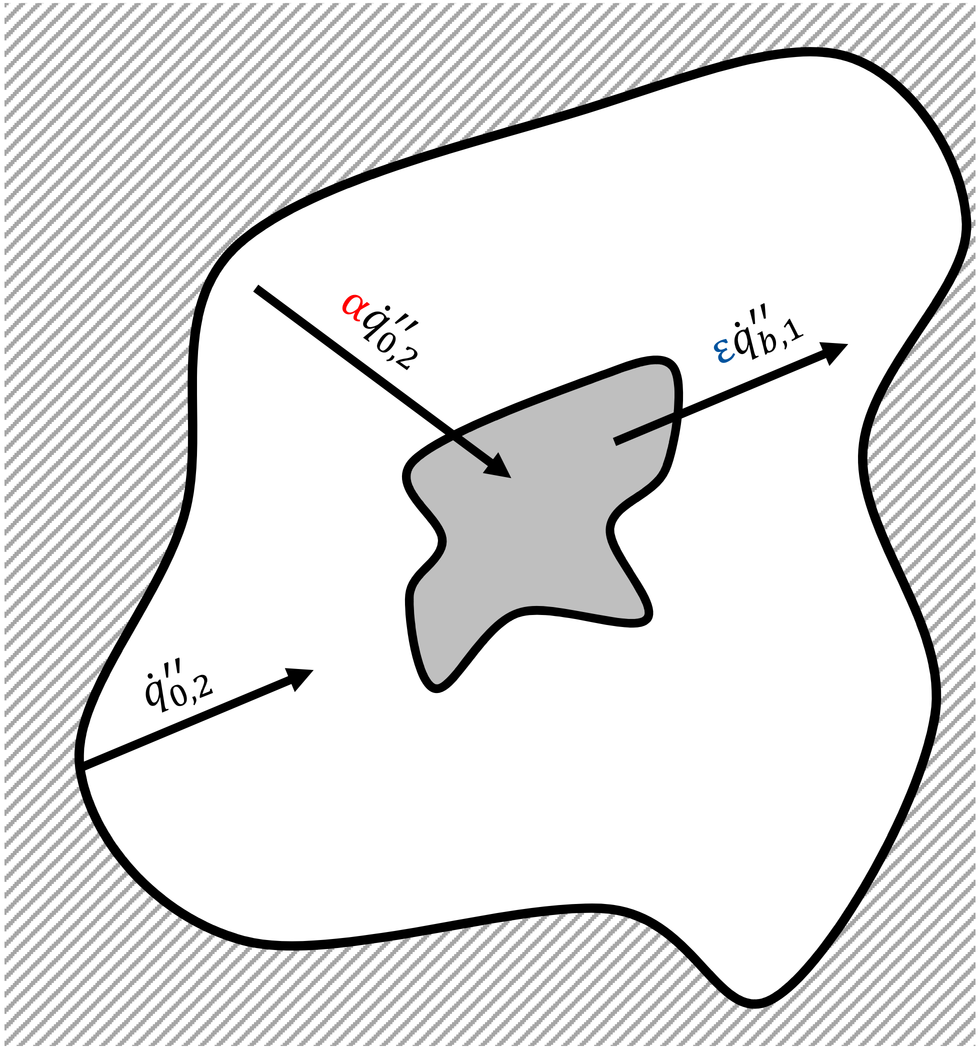
As a result of the difference 1 − 2, T_{blue} increases with time.
The red body receives the heat flux 2 from the blue body, but emits 1.
As a result of the difference 2 − 1, T_{red} decreases over time.

Final answer:

The absorptivity $\alpha(\lambda)$ and emissivity $\varepsilon(\lambda)$ indicate proportions that do not necessarily refer to the same heat flux.
The heat fluxes can therefore differ from each other.



Kirchhoff's law



Radiation:

Question:

When $\alpha(\lambda) = \varepsilon(\lambda)$ is valid,
can also be said that $\alpha = \varepsilon$ is valid?

Verification:

alpha average:

$$\alpha = \frac{\dot{q}''_\alpha}{\dot{q}''_0} = \frac{\int_0^\infty \alpha(\lambda)\, \dot{q}''_{\lambda,0}\, d\lambda}{\int_0^\infty \dot{q}''_{\lambda,0}\, d\lambda}$$

epsilon average:

$$\varepsilon = \frac{\dot{q}''_\varepsilon}{\dot{q}''_b} = \frac{\int_0^\infty \varepsilon(\lambda)\, \dot{q}''_{\lambda,b}\, d\lambda}{\int_0^\infty \dot{q}''_{\lambda,b}\, d\lambda}$$

In which case is following equation valid?

$$\alpha = \varepsilon$$

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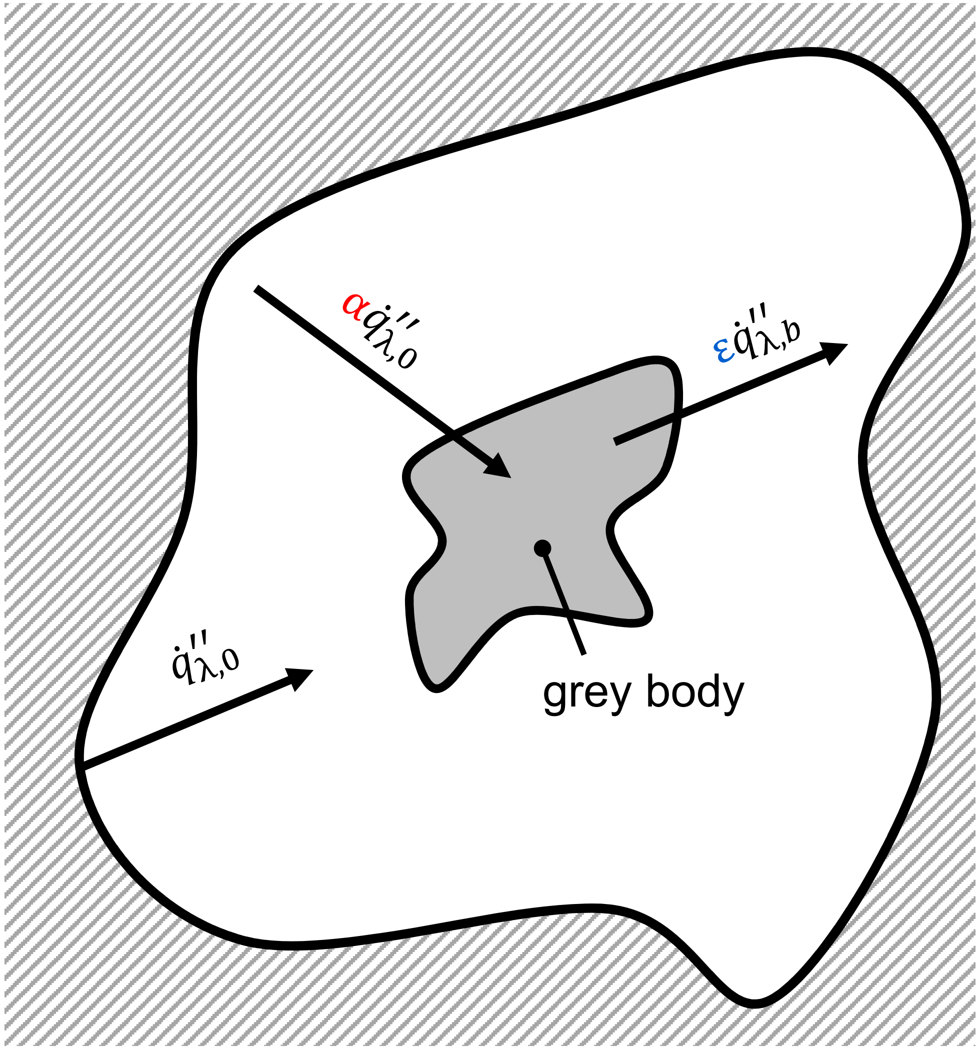
Kirchhoff's law – special cases



Body is grey (case 1):

Grey Body: $\alpha, \varepsilon \neq f(\lambda)$

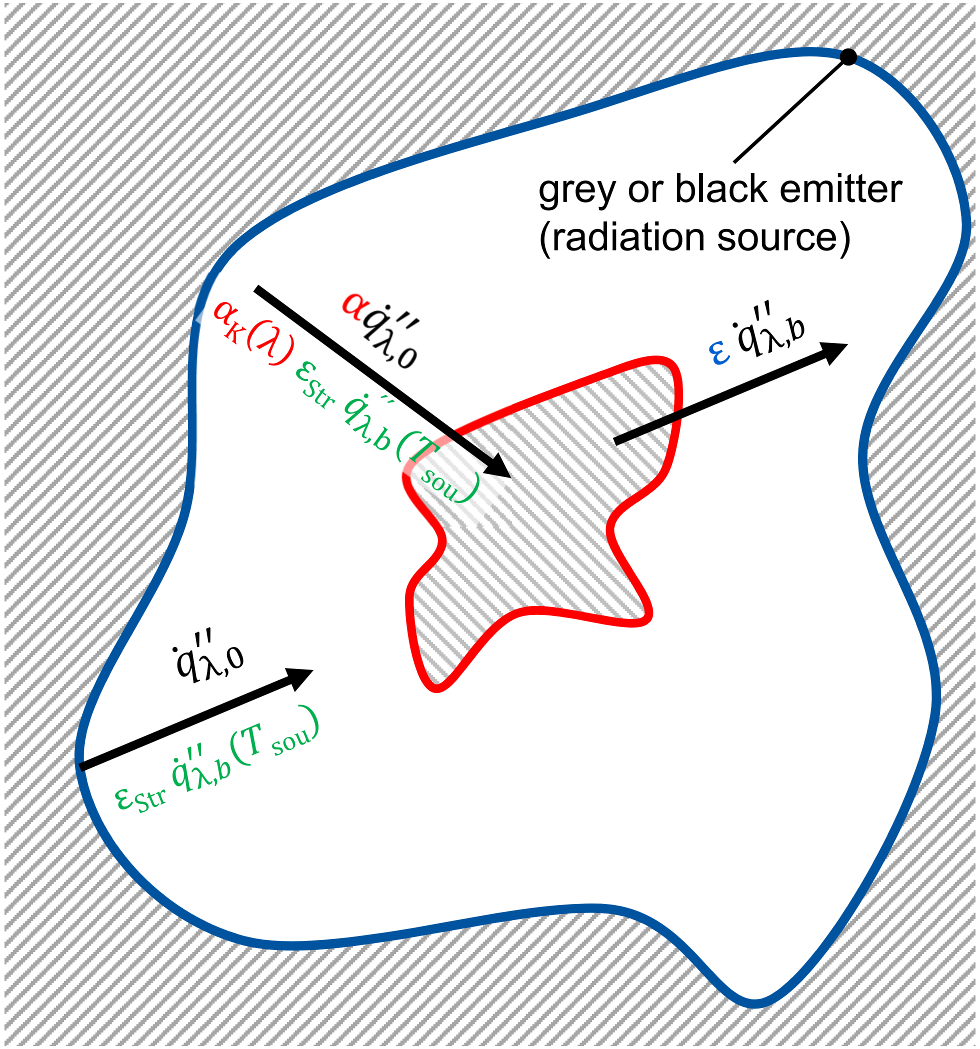
$$\frac{\int_0^\infty \alpha(\lambda)\, \dot{q}''_{\lambda,0}\, \mathrm{d}\lambda}{\int_0^\infty \dot{q}''_{\lambda,0}\, \mathrm{d}\lambda} = \frac{\int_0^\infty \varepsilon(\lambda)\, \dot{q}''_{\lambda,b}\, \mathrm{d}\lambda}{\int_0^\infty \dot{q}''_{\lambda,b}\, \mathrm{d}\lambda}$$

$$\alpha \cancel{\frac{\int_0^\infty \dot{q}''_{\lambda,0}\, \mathrm{d}\lambda}{\int_0^\infty \dot{q}''_{\lambda,0}\, \mathrm{d}\lambda}} = \varepsilon \cancel{\frac{\int_0^\infty \dot{q}''_{\lambda,b}\, \mathrm{d}\lambda}{\int_0^\infty \dot{q}''_{\lambda,b}\, \mathrm{d}\lambda}}$$

$$\alpha = \varepsilon$$

Kirchhoff's law – special cases

no rad. exchange



Emitter is grey or black and temperatures are equal (case 2):

$T_{sou} = T_K$

$\varepsilon_{sou} \neq f(\lambda)$

$$\alpha(\lambda) = \varepsilon(\lambda)$$

$$? \Rightarrow \quad \alpha = \varepsilon$$

$$\frac{\int_0^\infty \alpha_K(\lambda)\ \dot{q}''_{\lambda,sou}\ d\lambda}{\int_0^\infty \dot{q}''_{\lambda,sou}\ d\lambda} = \frac{\int_0^\infty \varepsilon_K(\lambda)\ \dot{q}''_{\lambda,b}(T_K)\ d\lambda}{\int_0^\infty \dot{q}''_{\lambda,b}(T_K) d\lambda}$$

$$\frac{\int_0^\infty \alpha_K(\lambda)\ \cancel{\varepsilon_{sou}}\ \dot{q}''_{\lambda,b}(T_{sou})\ d\lambda}{\int_0^\infty \cancel{\varepsilon_{sou}}\ \dot{q}''_{\lambda,b}(T_{sou})\ d\lambda} = \frac{\int_0^\infty \varepsilon_K(\lambda) \dot{q}''_{\lambda,b}\ (T_K)\ d\lambda}{\int_0^\infty \dot{q}''_{\lambda,b}(T_K)\ d\lambda}$$

$$\dot{q}''_{\lambda,b}(T_{sou}) = \dot{q}''_{\lambda,b}(T_K)$$

$$\alpha = \varepsilon$$

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Comprehension questions

In which case can it be assumed that both $\alpha(\lambda) = \varepsilon(\lambda)$ and $\alpha = \varepsilon$ are valid?

To which part of radiation does the emissivity refer and to which part the Absorptivity?

When $\alpha(\lambda) = \varepsilon(\lambda)$ is valid, is then the absorbed and emitted heat flux identical?

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