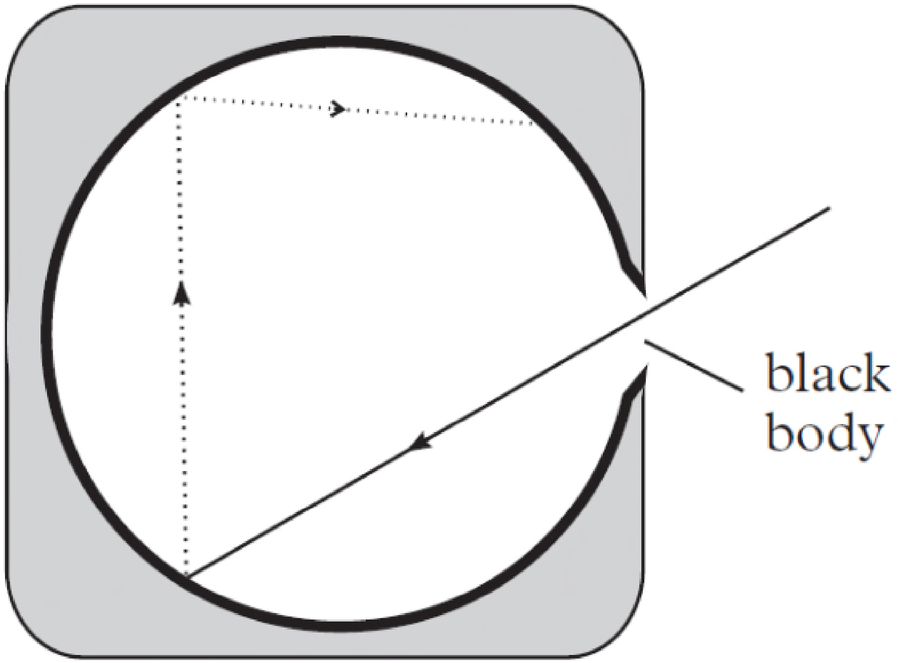
Thermodynamics lecture 8.

# Thermal radiation 1: thermodynamic arguments

1. Black body and UNIVERSALITY of cavity radiation
2. Kirchoff’s Law
3. Equation of state and Stefan-Boltzmann law
4. Entropy, heat capacity, Gibbs function




Constructing a black body (to good approximation) using a hole in a highly absorbent chamber.

## Stefan-Boltzmann Law:

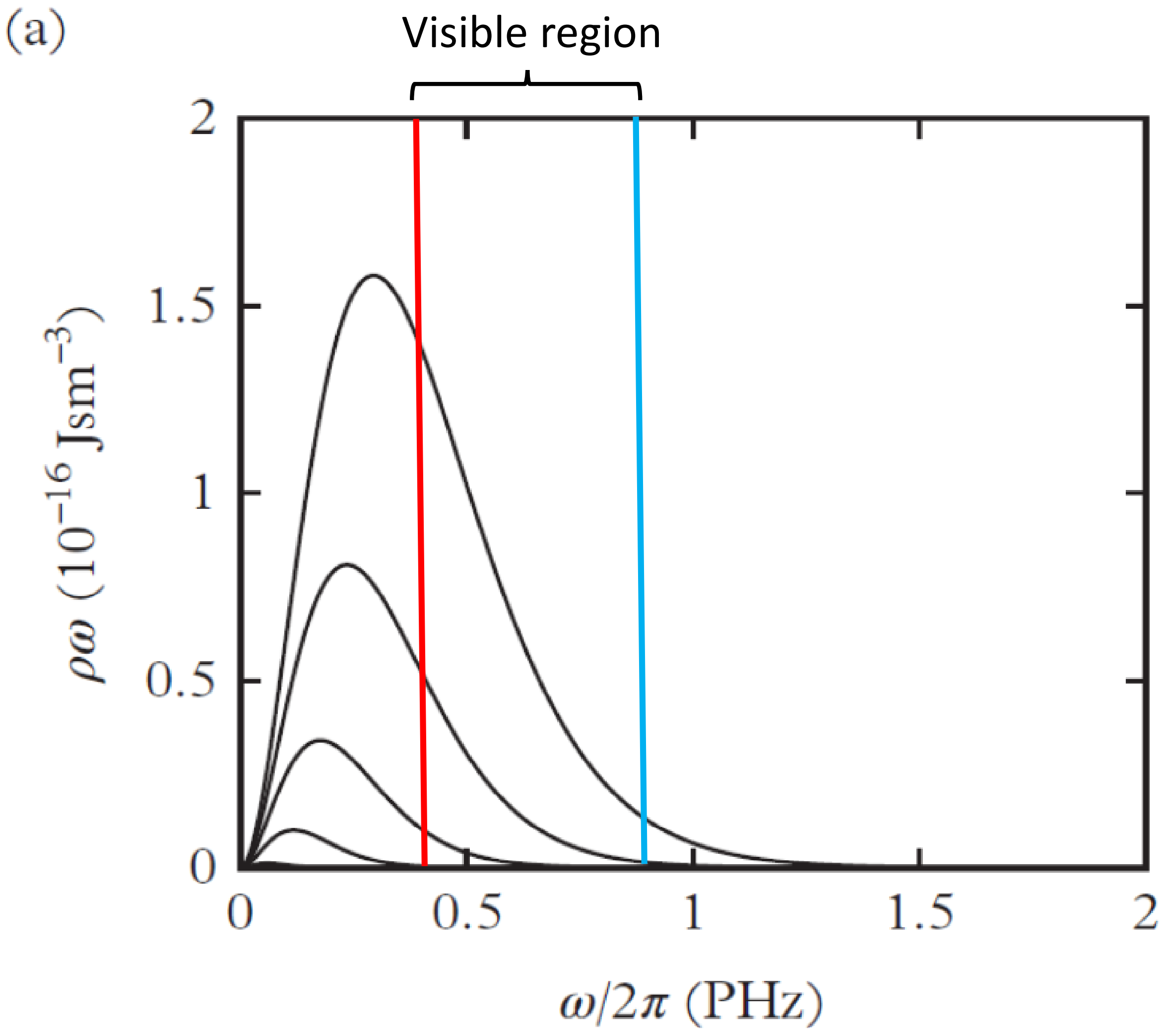
Power emitted from surface area $A$ of a black body in thermal equilibrium at temperature $T$ is

$$P = \sigma A T^4,$$

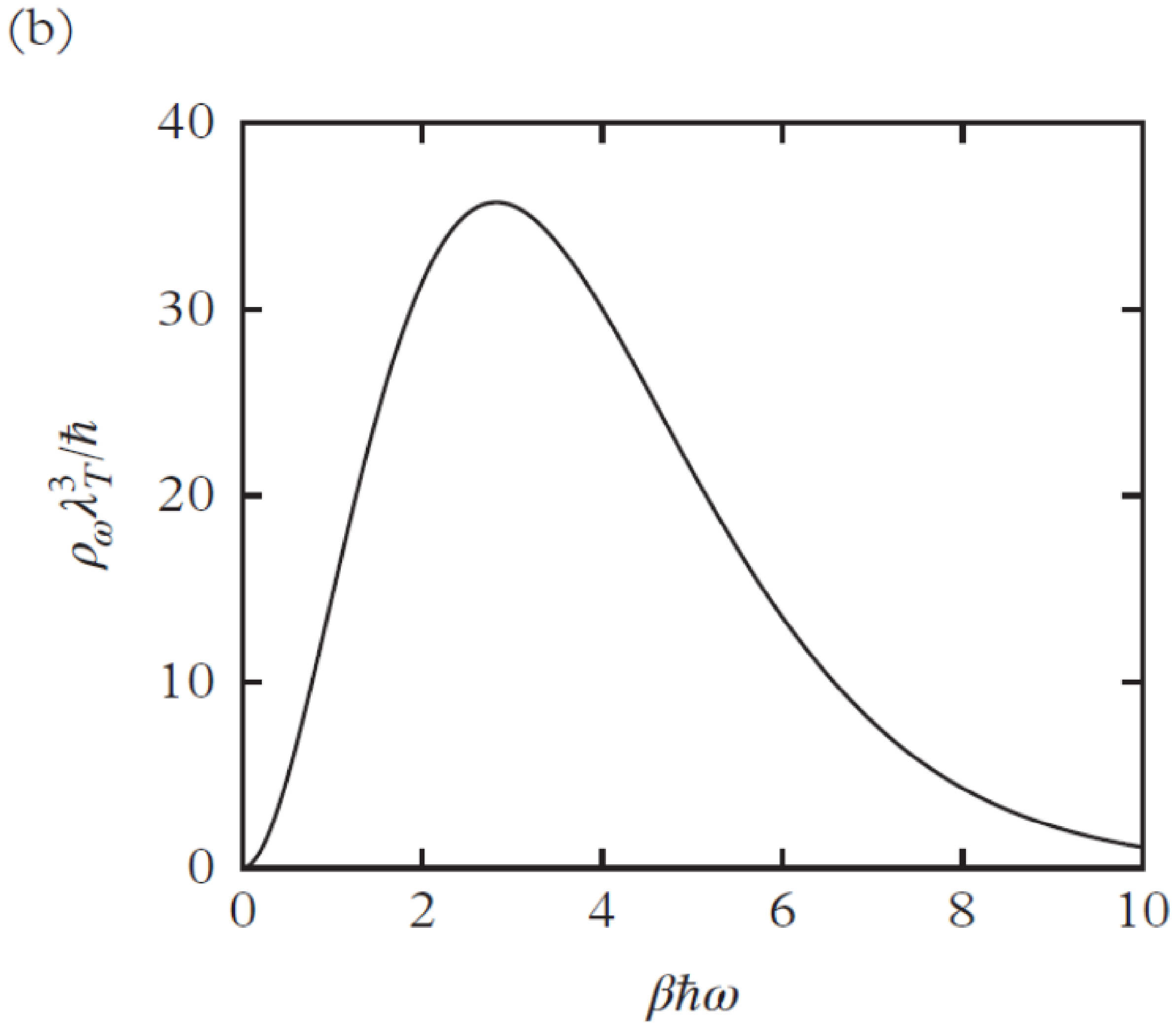
where the *Stefan-Boltzmann constant* is

$$\sigma = \frac{\pi^2 k_B^4}{60\hbar^3 c^2} \simeq 5.6704 \times 10^{-8}\ \mathrm{W m^{-2} K^{-4}}$$

→ About 400 watts per metre-squared at room temperature.

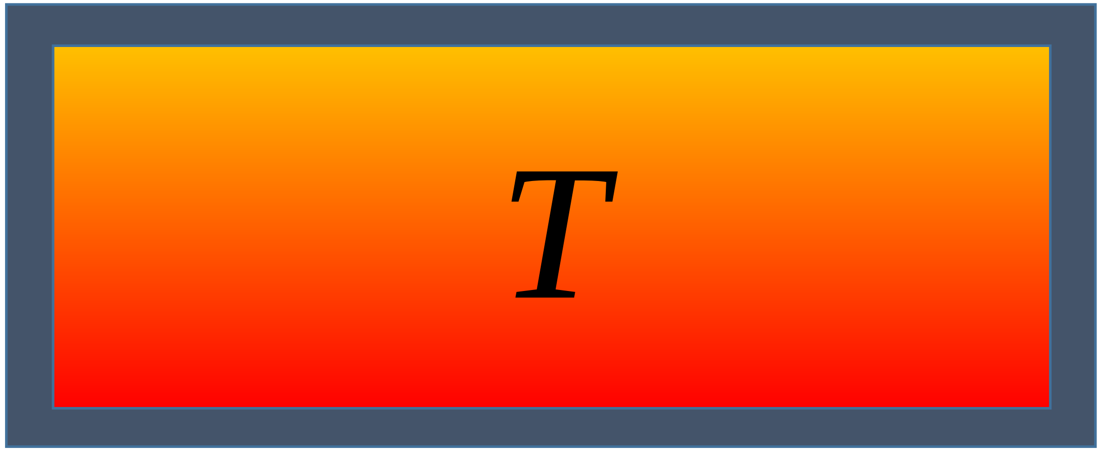



Spectral energy density at
1000, 2000, 3000, 4000, 5000 K




It's the same function each time, scaled by $\lambda_T^3$

$$\lambda_T = 2\pi\hbar c/k_B T.$$

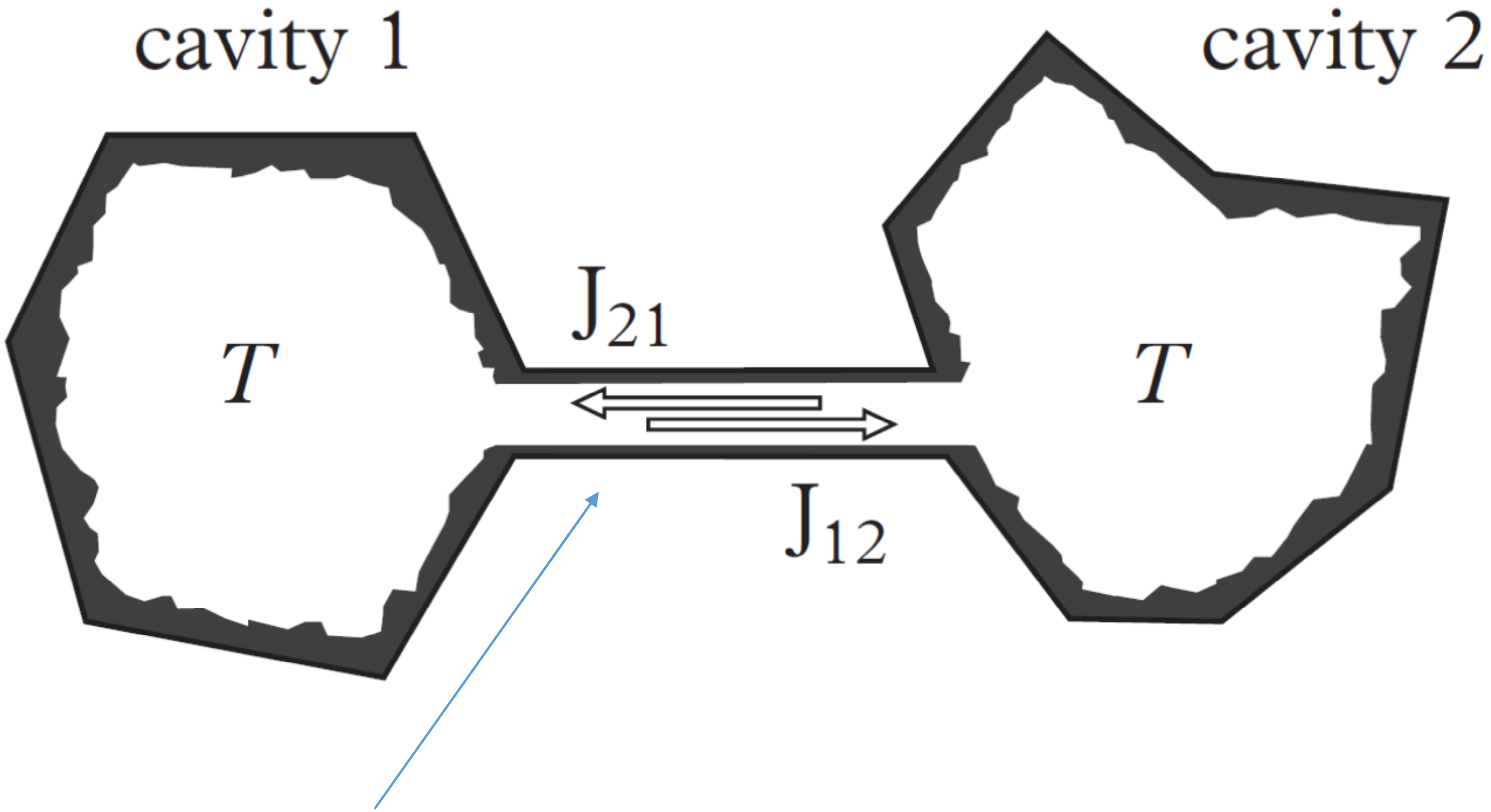



**Cavity radiation** = the electromagnetic radiation inside an otherwise empty cavity in thermal equilibrium

We will prove that, for a LARGE cavity with OPAQUE walls,

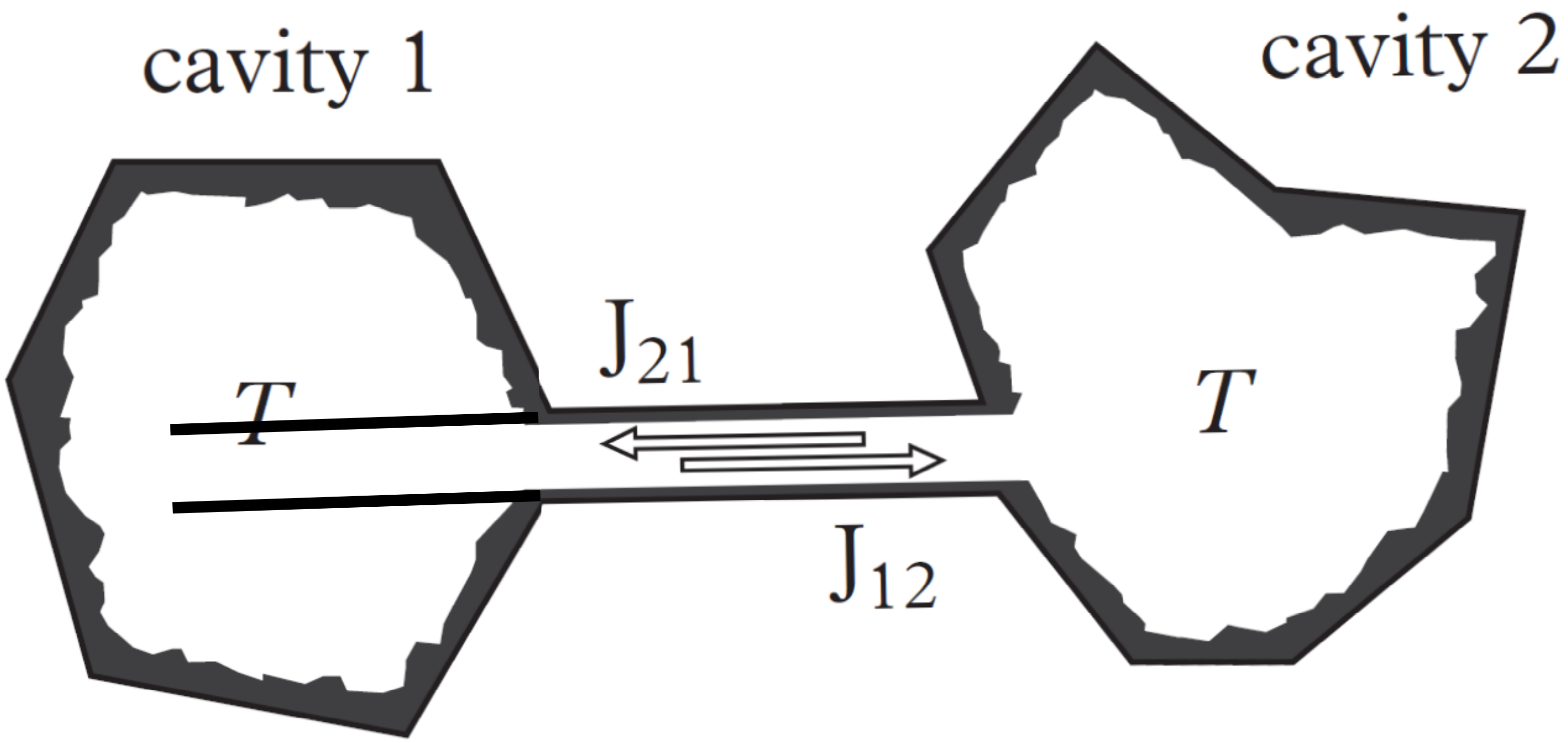
1. Cavity radiation is **universal** (depends only on $T$ )
2. Cavity radiation = black body radiation (i.e. same energy density and other properties.)

Proving that, for cavity radiation, the energy density of the radiation does not depend on the cavity shape or volume or material etc.

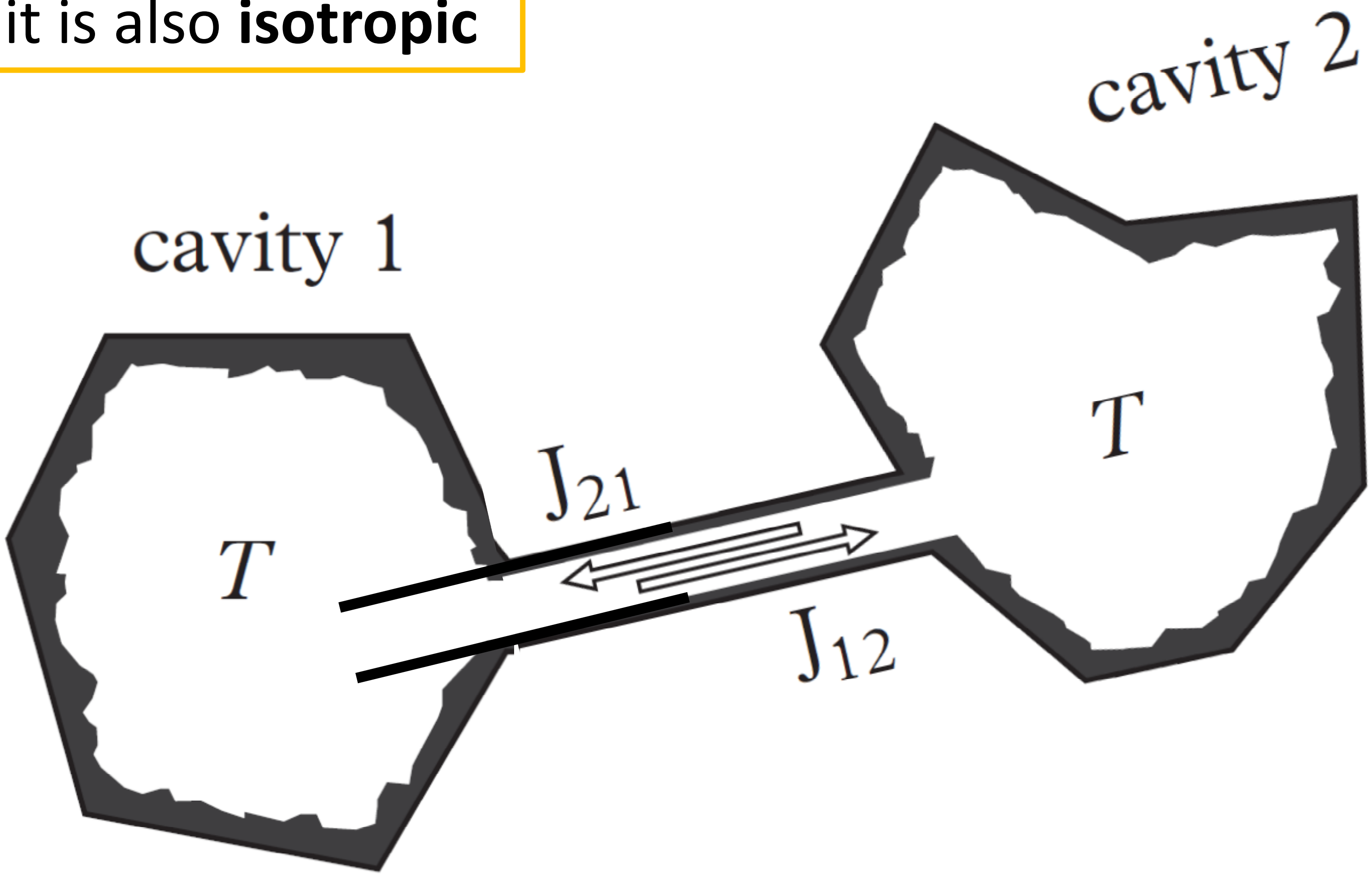



The pipe is wide compared to wavelengths in the radiation, so the radiation can pass freely.

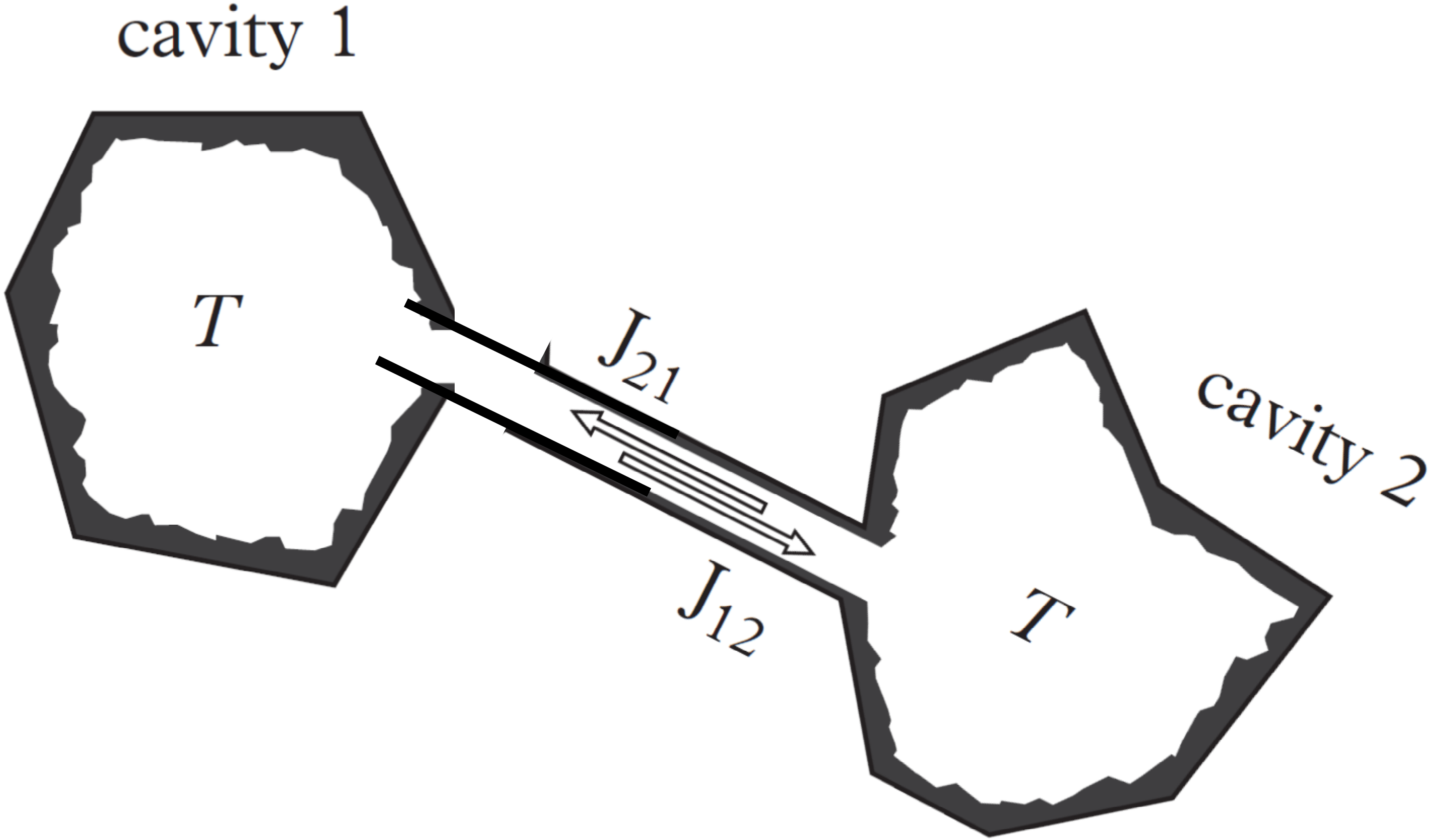
Proving that, for cavity radiation, the energy density is **homogeneous** (i.e. uniform over space)

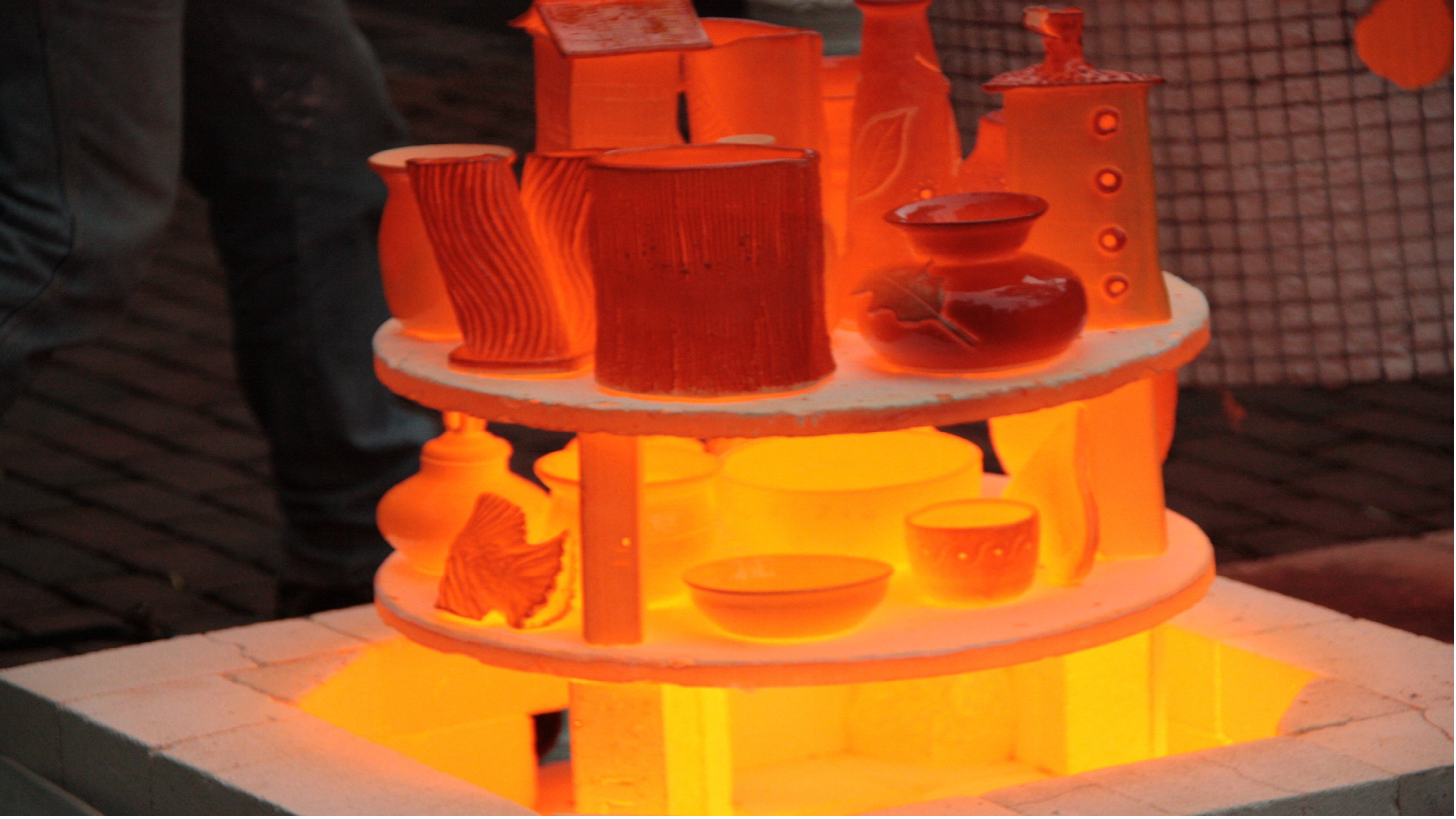


Proving that it is also **isotropic**



Proving that it is also **isotropic**

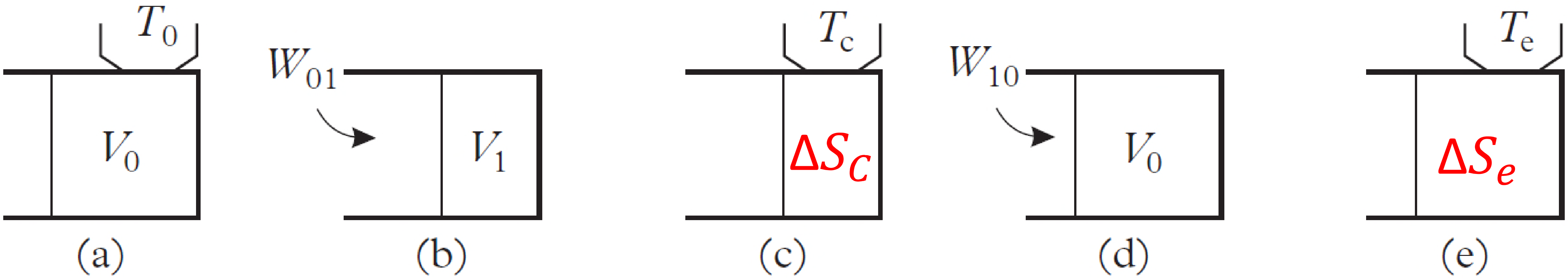





dreamstime

# Adiabatic expansion of cavity radiation: does it remain in a thermal equilibrium state?

## Wien’s argument to show the answer is *yes*:




Stages (a), (c) and (e) : we pick Tc and Te such that the radiation comes to equilibrium **with no net ΔU**

Stages (b) and (d):
Do work or receive work, adiabatically

**Argument:**

**ΔU = 0 →** $\Delta S_C$ **>= 0,** $\Delta S_e$ **>= 0**
But no net change in state →
$\Delta S_{tot} = 0$
→ $\Delta S_C = \Delta S_e = \ 0$