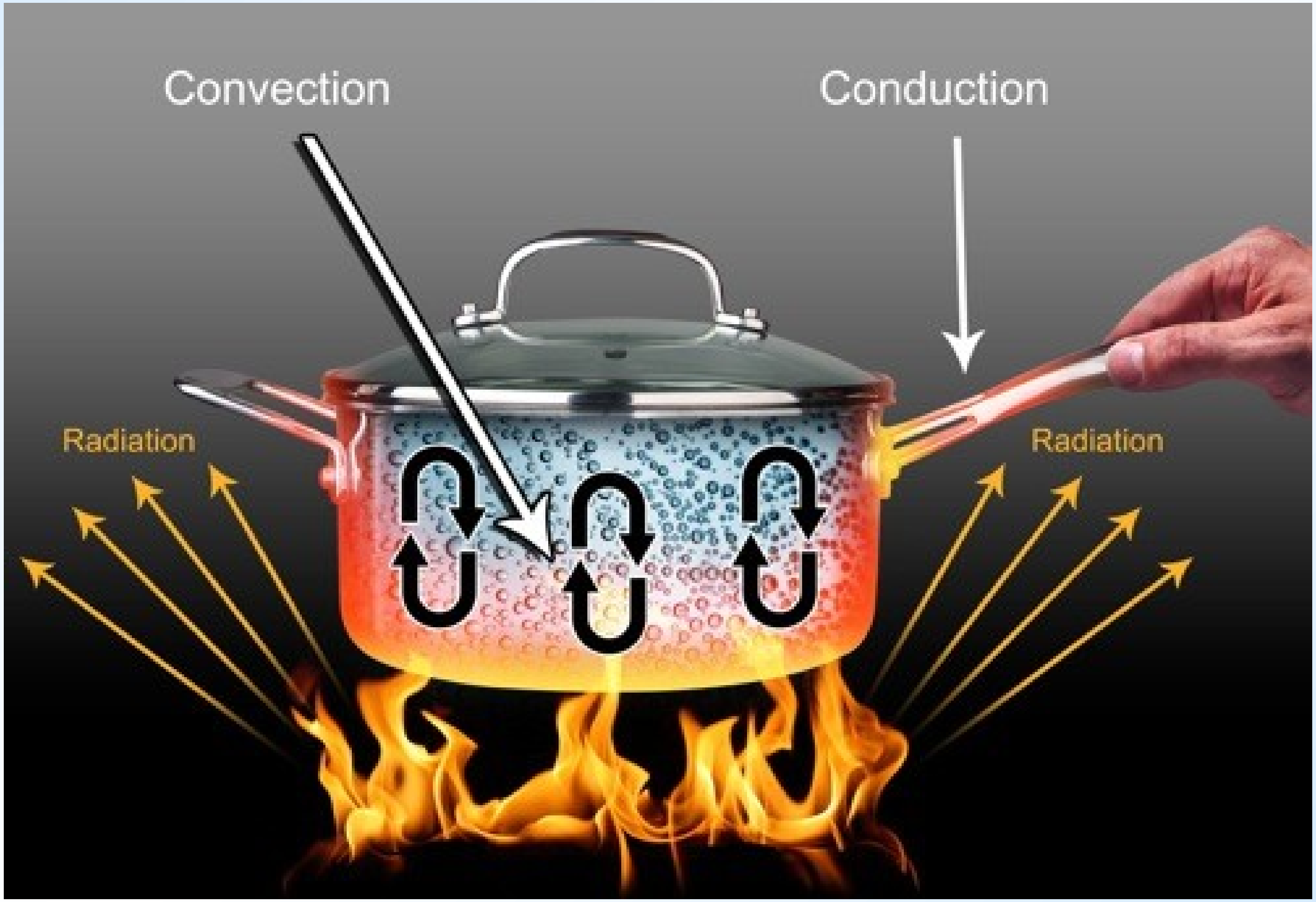
HEAT TRANSFER



RADIATION HEAT TRANSFER

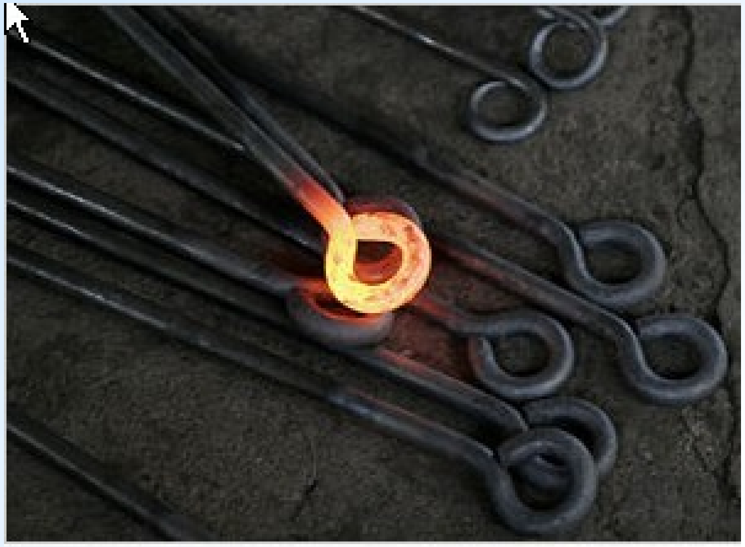
Radiation is the transmission of energy by electromagnetic waves.

All materials emit thermal radiation as long as their temperatures are above absolute zero (0 Kelvin).

Heat is transfered when the radiative energy emitted by one body is absorbed by another and can occur whether or not there is a medium in between.

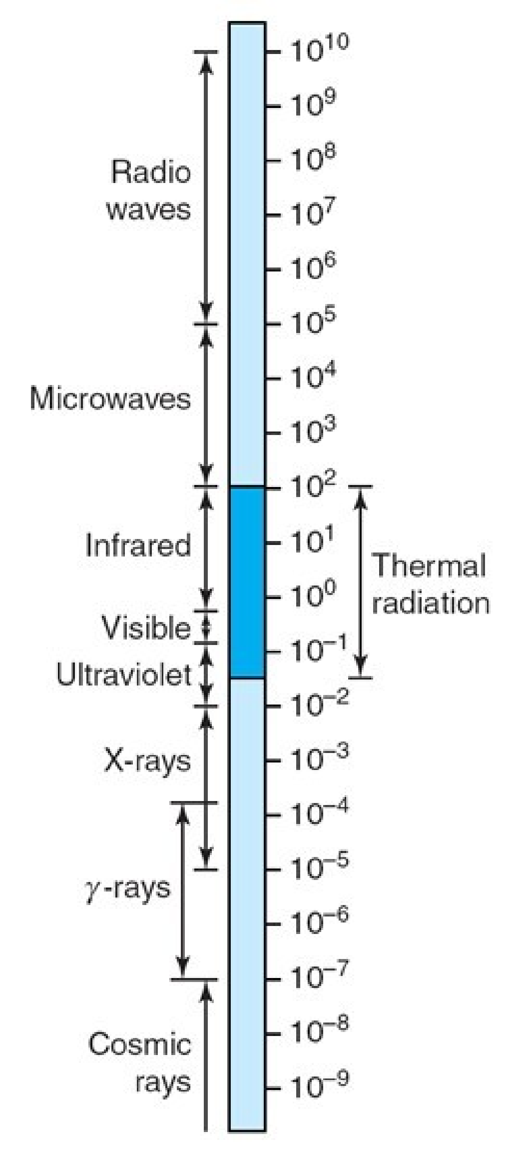
The medium in between may interfere with the heat exchange. For simplicity, we will assume transparent (non-participating) media.

An important new concept is ‘enclosure’, similar to ‘control volume’.



Radiative energy emitted by a body because of its temperature is transmitted in space in the form of electromagnetic waves (Maxwell's classical wave theory) or in the form of discrete-energy photons (Planck's hypothesis). Both concepts are utilized.

Two bodies at different temperatures in vacuum ⇒ no conduction or convection heat transfer is possible. In such cases, heat transfer occurs by thermal radiation only.

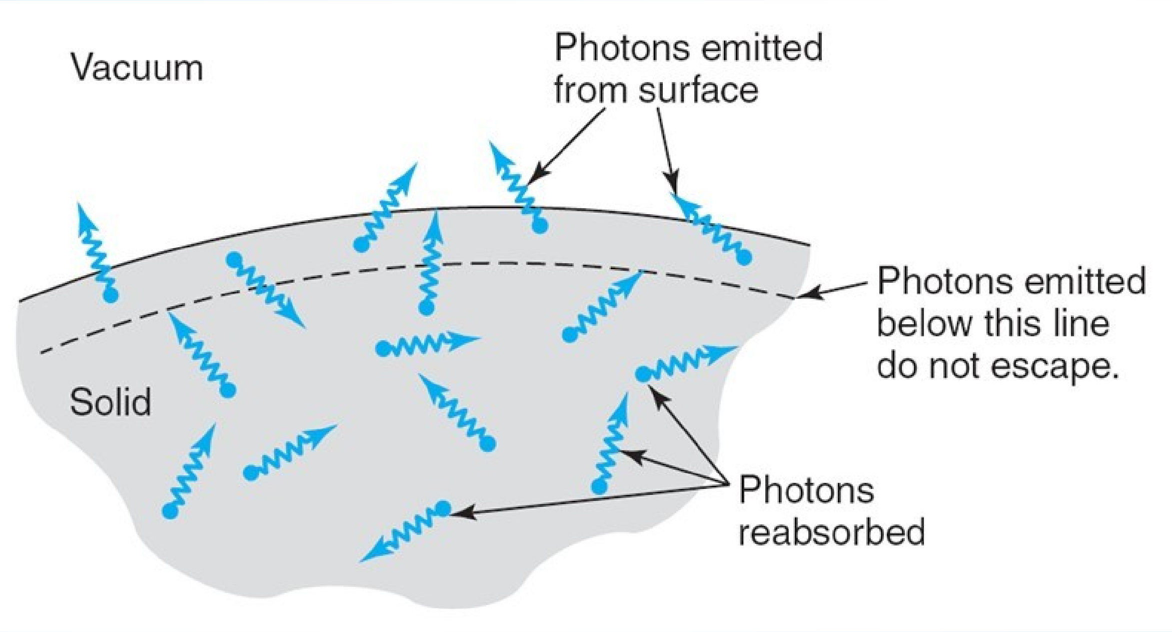


Radiation has a dual character – Sometimes behaving like a wave, sometimes behaving like a particle (photon).

Thermal radiation arises when electrons transition among vibrational and rotational energy bands within an atom or molecule. The level of electron excitation in these bands determines the temperature of the material.

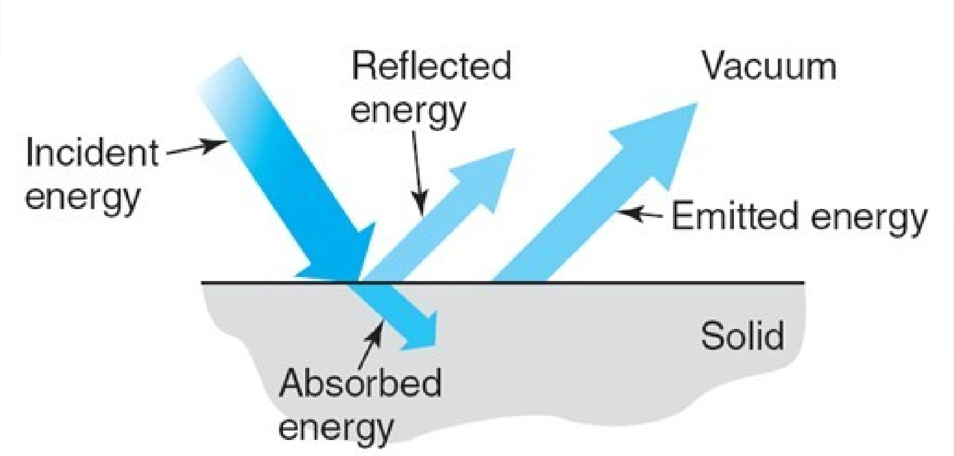
Thermal radiation is part of the electromagnetic spectrum as shown in the figure.

The emission or absorption of radiative energy by a body is a bulk process, i.e., the radiation originated from the interior of the body is emitted through its surface; conversely, the radiation incident on the surface of a body penetrates into the medium where it is attenuated. (Example: gases)



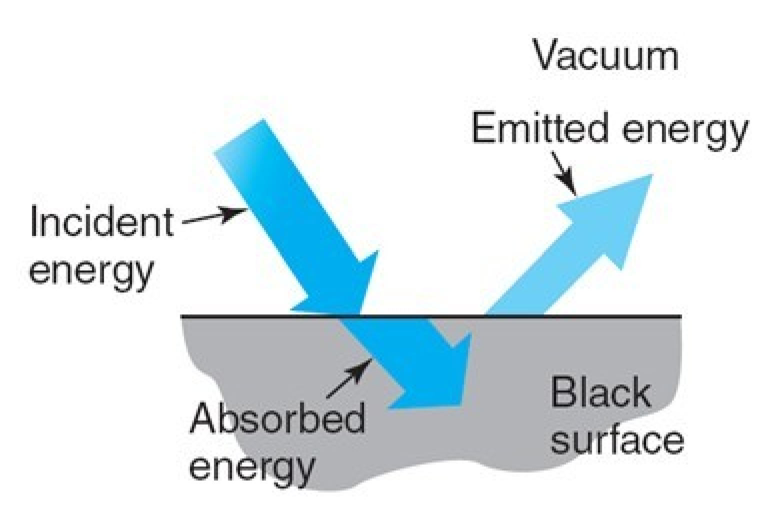
If a large proportion of the radiation is attenuated within a very short distance in the material, we may speak of radiation being absorbed or emitted by the surface. (Example: metals)

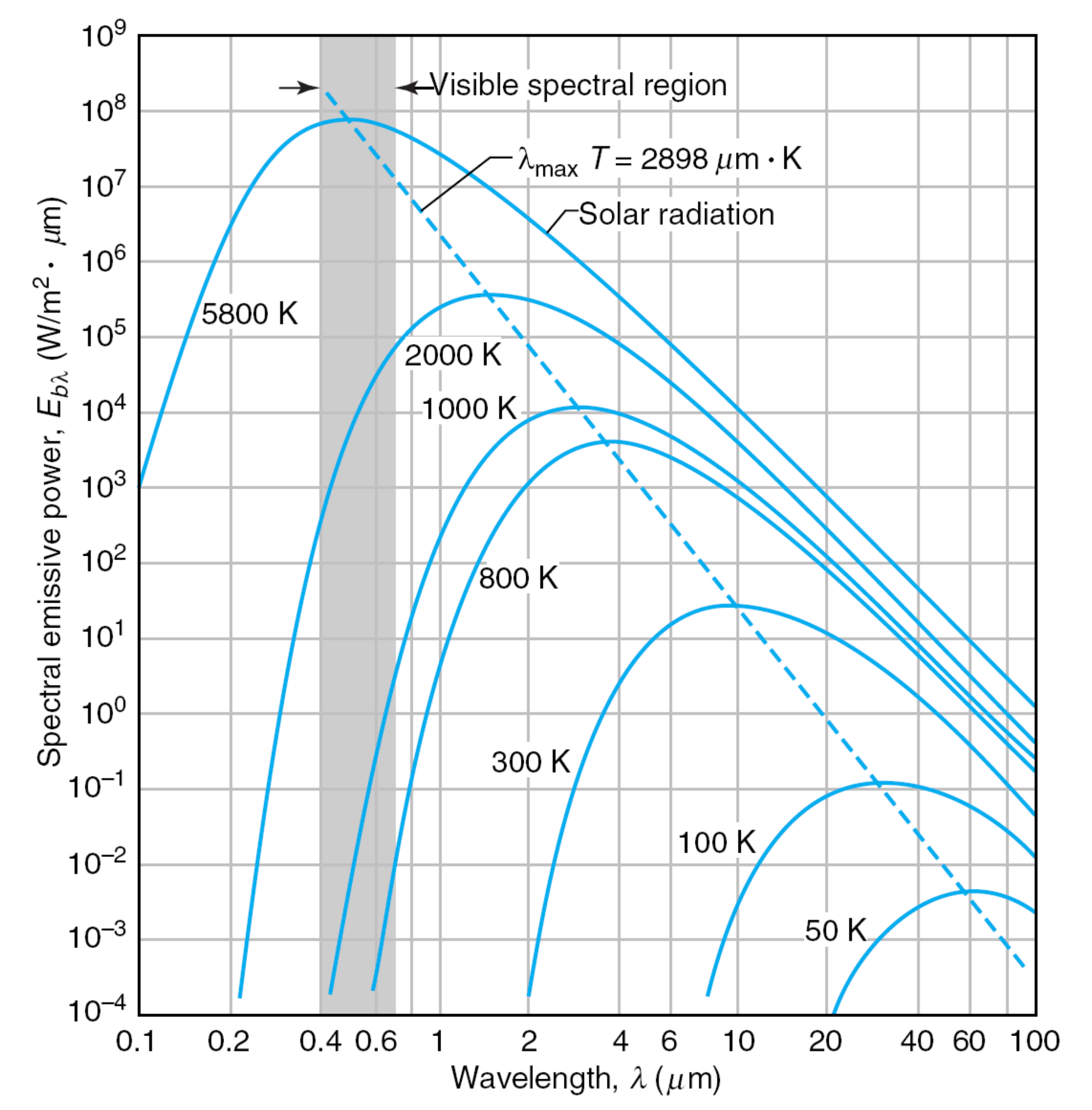
Interaction of radiation with a real surface



Interaction of radiation with an ideal surface called black surface or black body.

A black body (or surface) emits the maximum possible radiation at a given temperature.





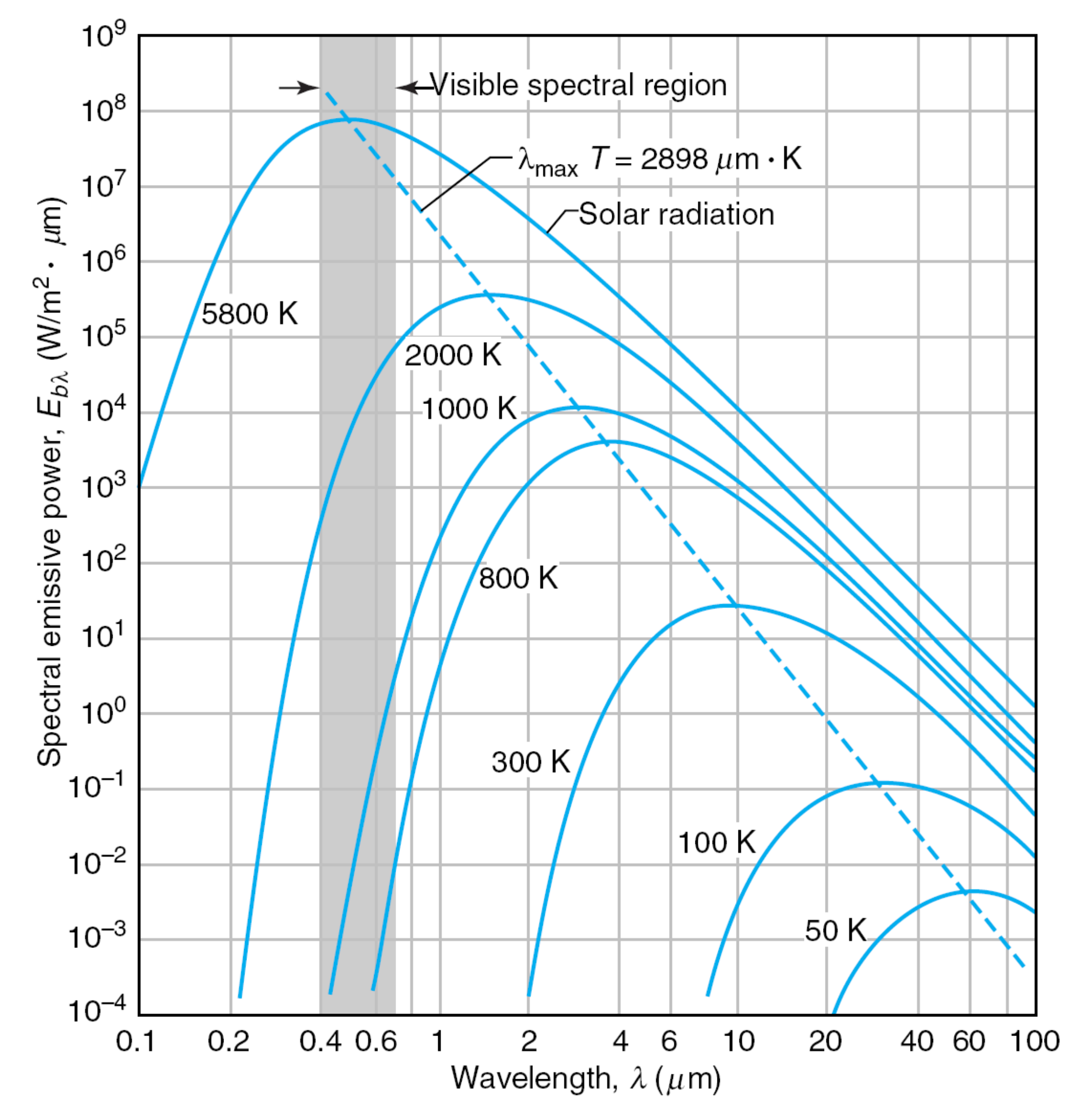
Thermal radiation is emitted over a wide range of wavelengths.

Planc's law (1900):

$$E_{b,\lambda} = \frac{C_1\ \lambda^{-5}}{e^{C_2/\lambda} - 1}$$

$C_1 = 3.742\ 10^8\ W.\mu m^4/m^2$

$C_2 = 1.439\ 10^4\ \mu m.K$



Total energy emitted at all wavelengths:

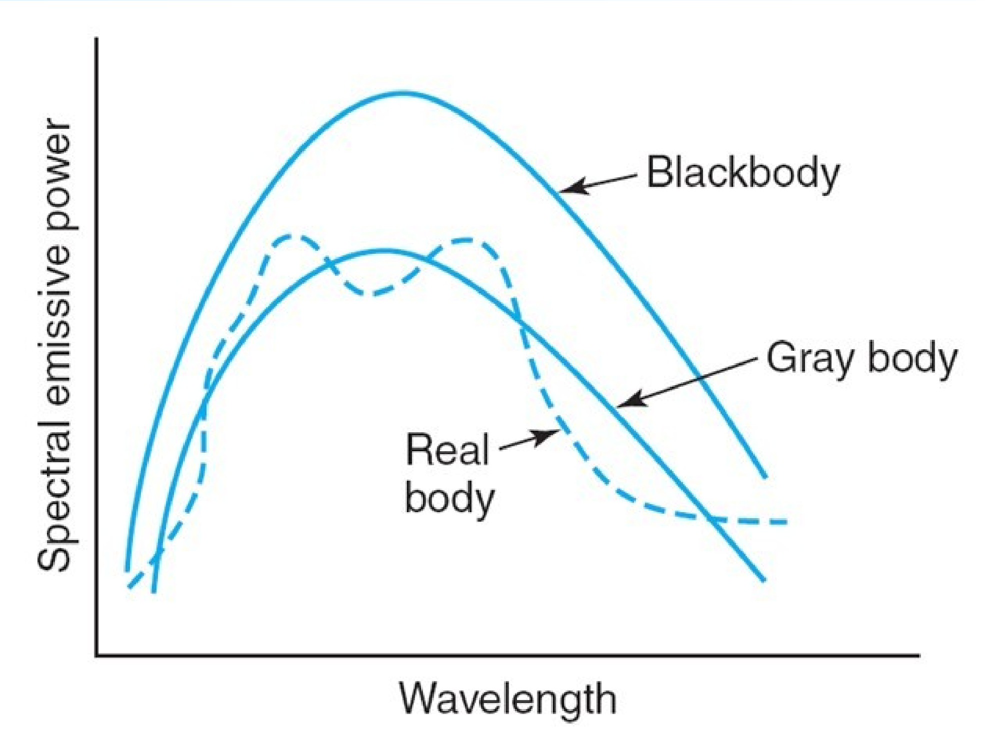
$$E_b = \int_0^\infty E_{b,\lambda}\, d\lambda = \sigma T^4$$

$$E_b = \frac{\dot{Q}_{emitted}}{A} = \sigma T^4$$

Where σ is Stephan-Boltzmann constant

$$\sigma = 5.669\ 10^{-8}\ W/m^2.K^4$$

Real surfaces emit less radiation than black surfaces.



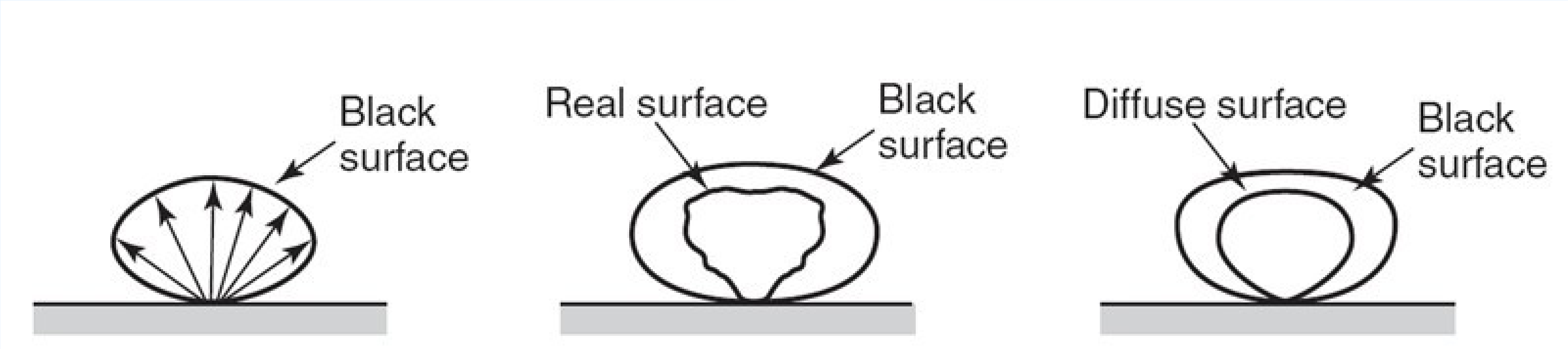
Define emissivity:

$$\varepsilon = \frac{\text{Actual energy emitted}}{\text{Energy emitted from a bb}}$$

Gray body (or surface) – emits with the same pattern as a black body, except less amount of energy.

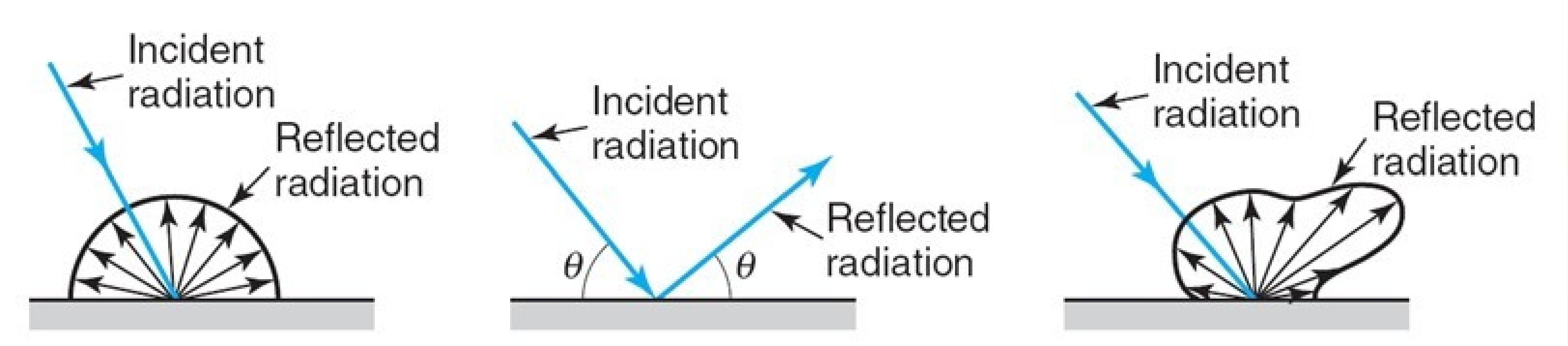
A diffuse surface is the one that emits (and absorbs) radiation with same pattern (same in all directions).

We will assume bodies (surfaces) to be gray (less emissive power) and diffuse (same in all directions) as compared with a black body.



For a gray and diffuse body: $$E = \frac{\dot{Q}_{emitted}}{A} = \varepsilon \, \sigma \, T^4$$

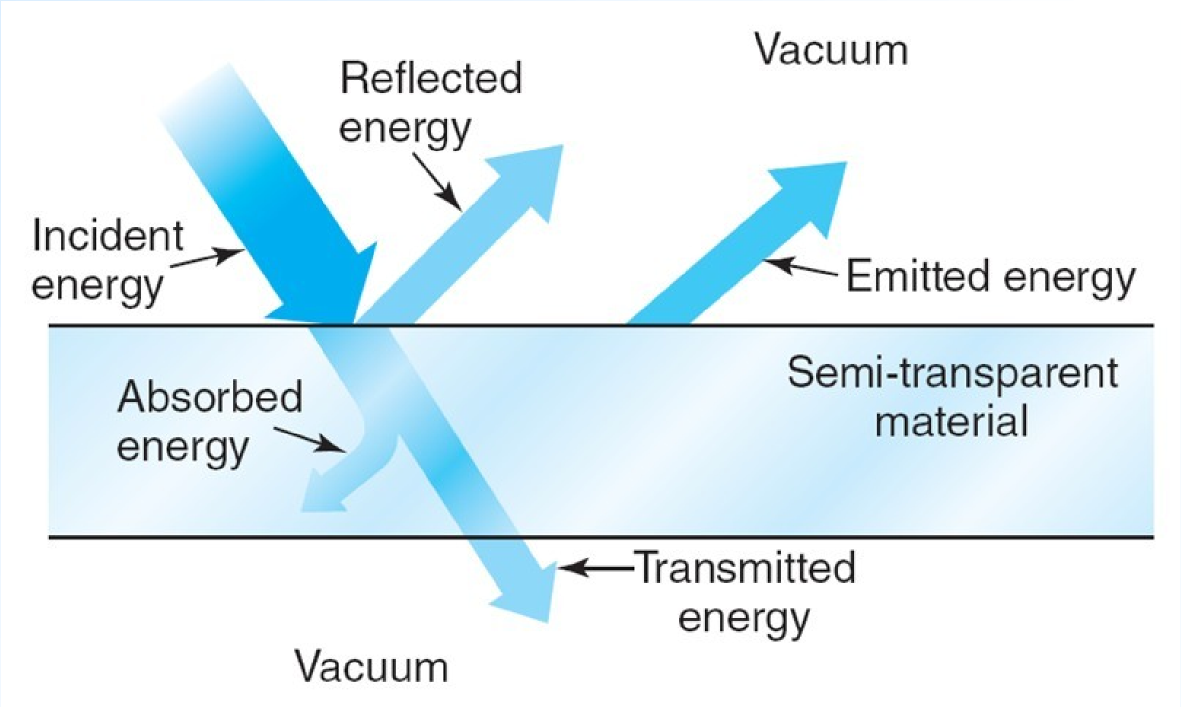
Define reflectivity: $\rho = \dfrac{\text{Reflected energy}}{\text{Incident energy}}$



Diffuse reflection   Specular reflection   Reflection from a real surface

Define absorptivity: $\alpha = \dfrac{\text{Absorbed energy}}{\text{Incident energy}}$

Define transmissivity: $\tau = \dfrac{\text{Transmitted energy}}{\text{Incident energy}}$



$\alpha + \rho + \tau = 1$

For an opaque surface:

$\alpha + \rho = 1$

Kirshow's law:

$\alpha = \varepsilon$

Dependence of emissivity on surface condition and type of material

Material	Approximate Emissivity
Nonmetals	0.8–0.99
Heavily oxidized or very dirty metals	0.7
Lightly oxidized or dirty metals	0.5
Clean, shiny metals	0.1–0.3
Bright, polished metals	0.001–0.1

Example P.14-4

Radiation from the Sun incident on the Earth's outer atmosphere has been measured as 1353 W/m^2. This is incident radiation flux on a unit surface perpendicular to the solar rays and is called the solar constant. The average distance between the Sun and the Earth is $1.5\ 10^{11}$ m. If the planet Pluto is at a distance of $5.87\ 10^{9}$ km from the Sun, find the solar flux incident on a unit surface perpendicular to the solar rays on Pluto