Black Body Radiations

Sun, Earth, Man

Blackbody Radiations : Sun, Earth, Man

Black Body
- absorption, (absorptivity = 1, Reflectivity = 0, Transmitivity = 0)
- Emission (emitivity = 1)

① an idealized physical body, in thermal equilibrium (emissivity equals absorptivity).

② Can emit electromagnetic radiation at all wavelengths (λ) according to Planck's law of black-body radiation. (and frequency $f = \frac{c}{\lambda}$, $c = 3\times10^{8}\ m/s$)

$\Rightarrow$ Continuous spectrum and isotropic emission.

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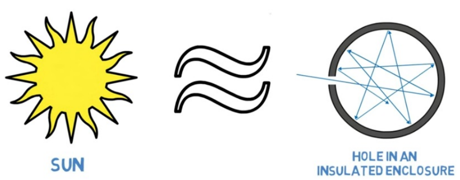
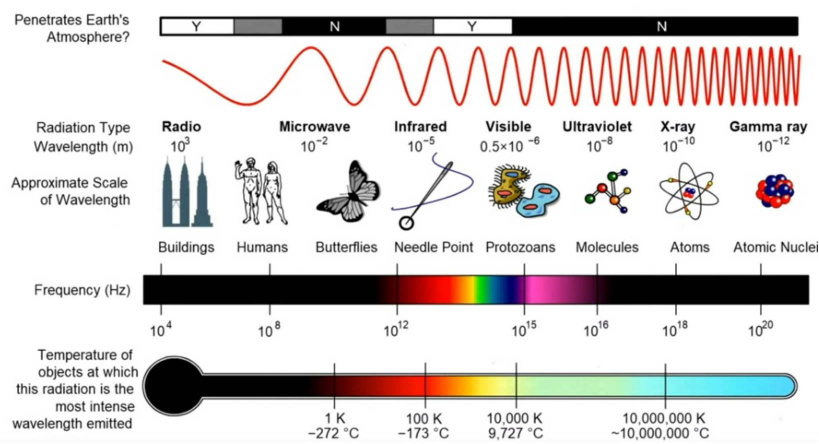
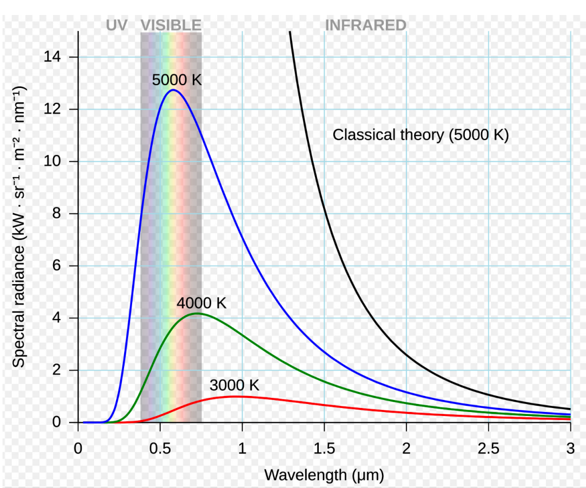
(1) The "bright" Sun is considered as a "Black Body"

① The sun is often approximated as a black body.

② It's emissivity is around 0.96–0.98.

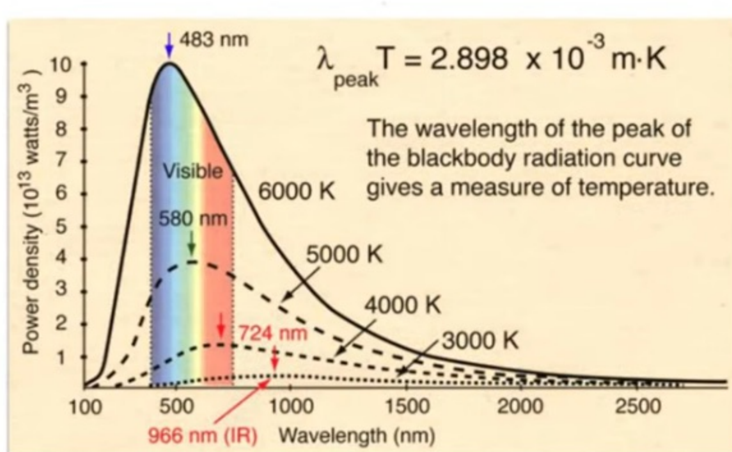






Need Quantum Theory (planck) to explain the observation.

WIEN'S DISPLACEMENT LAW



(2) How to determine the temperature of the Sun?

① By Wien's displacement law

$$\boxed{\lambda_{max} T = b}$$ where $b = 2.898 \times 10^{-3}$ m·K

$\Rightarrow$ T of the Sun's surface is about 5778 °K.

② By Stefan-Boltzmann law

the total energy radiated per unit surface are of a black body per unit time

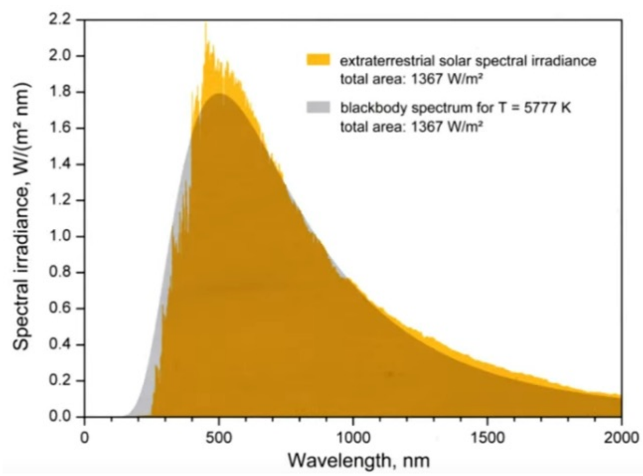
$$\boxed{J = \sigma T^4}$$ where $\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$

Note: The luminosity of the Sun is $L = 4\pi R^2 J$, where the Sun's radius $R = 6.96 \times 10^8$ m, and the solar luminosity L has been measured to be

$L = (4\pi d^2) S$, where d is the distance from the Sun to the Earth, and S is the solar constant

$\simeq 3.83 \times 10^{26}$ W

$$\Rightarrow T = \left(\frac{L}{4\pi R^2 \sigma}\right)^{1/4} \simeq 5778 \text{ °K}$$



The Sun — an approximate Blak Body

$S = 1361 \frac{W}{m^2}$

The solar constant is defined as the amount of solar electromagnetic radiation energy received per unit time on a unit area perpendicular to the direction of the Sun's rays at the average distance of the Earth from the Sun in the absence of the Earth's atmosphere.

The generally accepted value of the solar constant is approximately 1361 watts per square meter

Earth can be approximated as a Black Body

- Suppose that the Earth absorbed 100% of the incident energy from the Sun and then radiated all the energy back into space, just as a blackbody would.

PROBLEM:

- What would the temperature of the surface of Earth be?

SOLUTION:

- The intensity of sunlight arriving at the Earth is approximately $S = 1400\ \mathrm{W/m^2}$.
- The Earth absorbs energy as a disk with the radius of the Earth, R, whereas it radiates energy from its entire surface area of $4\pi R^2$.

- At equilibrium, the energy absorbed equals the energy emitted:
  $S(\pi R^2) = (\sigma)(1)(4\pi R^2)T^4$
- Solving for the temperature, we get:

$$T = \sqrt[4]{\frac{S}{4\sigma}} = \sqrt[4]{\frac{1400\ \mathrm{W/m^2}}{4\left(5.67 \cdot 10^{-8}\ \mathrm{W/(K^4 m^2)}\right)}} = 280\ \mathrm{K}$$

- This simple calculation gives a result close to the actual value of the average temperature of the surface of the Earth, which is about 288 K.

$\Rightarrow 288\,K = (288-273)\,^\circ C = 15\,^\circ C$

The human body can be approximated as a "low-temperature Black Body"

(1) The emissivity of the human body is around 0.98.
As an approximate black body, human body can absorb and emit electromagnetic waves.

(2) The thermal energy radiated by human body:

1. as infrared light (electromagnetic wave)
2. The net power radiated is

$$P_{net} = P_{emit} - P_{absorb}$$
$$= A\sigma\varepsilon\left(T^4 - T_0^4\right)$$

Assuming the body surface area $A = 2\ m^2$,
the emissivity $\varepsilon = 1$

Human skin temperature is about $33°C$ ($91°F$), but clothing reduces the surface temperature to about $28°C$ ($72°F$) when the ambient temperature is $20°C$ ($68°F$). Since T has to be in the unit of Kelvins,

$$P_{net} = (2\ m^2)\left(5.67\times10^{-8}\ \frac{W}{m^2K^4}\right)\left[(28+273)^4 - (20+273)^4\right]$$
$$\simeq 100\ W$$

The total energy radiated in one day is about
$(100\ W)\times(86400\ sec) = 8\ MJ$ or 2000 kcal (food calories).

$1\ W = 1\ J/sec$