Heat Transfer by "Radiation"

- The transfer of heat across a system boundary by means of electromagnetic waves which is caused by a temperature difference

- All the substance with body temperature above the absolute zero emit energy in the form of radiation

λ wave length.

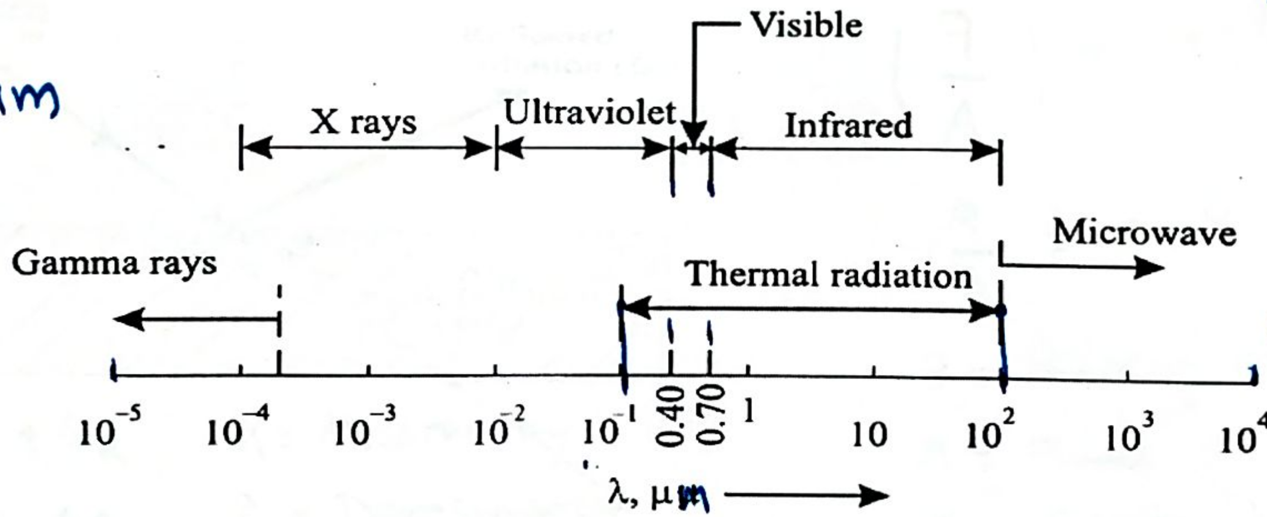
Pharons

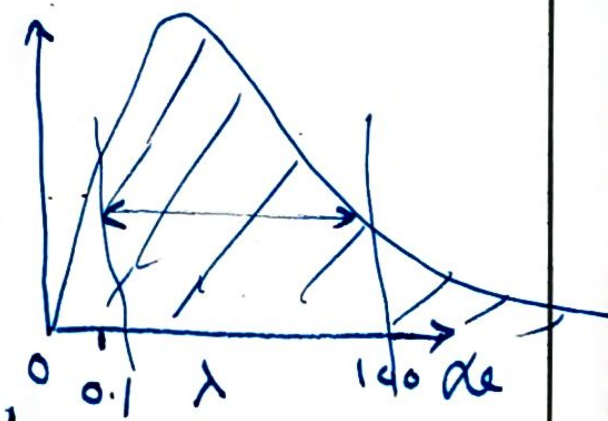
- Out of all radiation, only thermal radiation is our interest and the same will be discussed in this unit

0.4 - 0.7 μm

0.1 μm

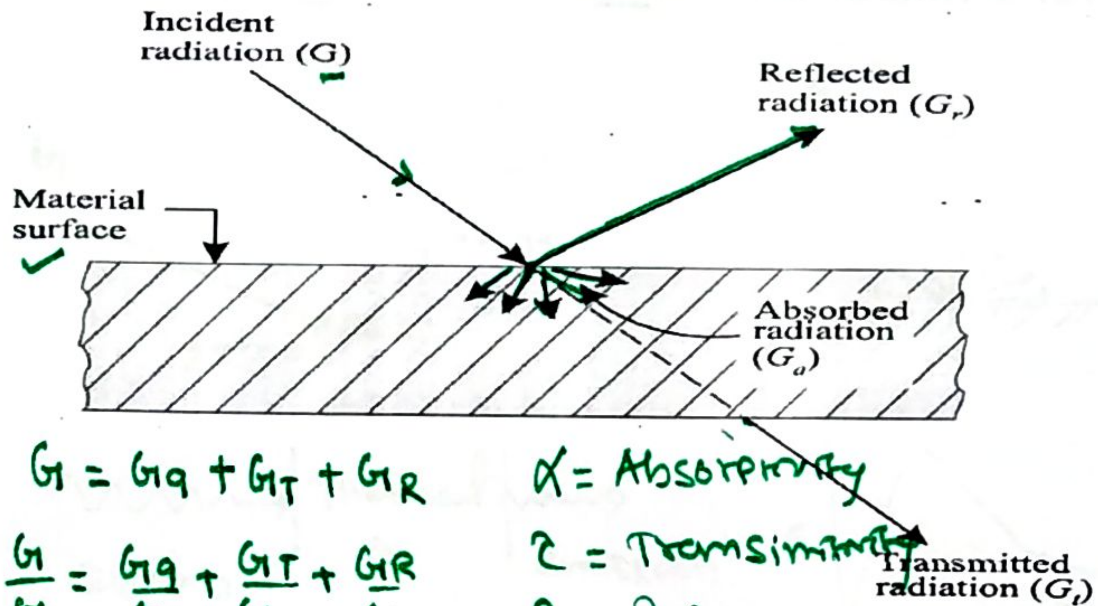
100 μm





$T_s > T_e$ $T_s = T_e$ heat object → T_s enclosure T_e vacuum (air ✗)

- Radiation becomes the only significant mode of heat transfer where no medium is present
- Governing law for heat transfer by radiation is Stefan Boltzman law According to this law the heat flux (emissive power) of black surface is directly proportional to fourth power of its absolute temperature
- Electromagnetic waves approach the receiving surface, reconversion of electromagnetic waves into thermal energy which is partly / fully absorbed, reflected or transmitted according to the nature of surface.



$G = G_a + G_T + G_R$

$\frac{G}{G} = \frac{G_a}{G} + \frac{G_T}{G} + \frac{G_R}{G}$

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

α = Absorptivity

τ = Transmissivity

ρ = Reflectivity

$\left(\frac{q}{A}\right) \propto (T)^4$

$\frac{q}{A} = \sigma T^4$

q = Rate of HT

A = area

σ = Stefan boltzman $= 5.67 \times 10^{-8}\ W/m^2K^4$

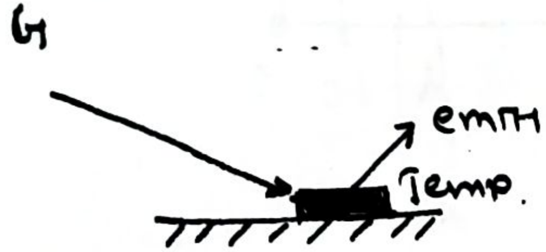
T = Ab. Temp (K)

Term Related to Surface

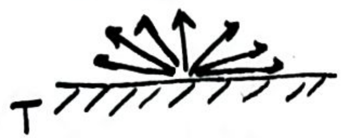
Black Surface: A black surface is an ideal surface that absorbs the entire radiant energy incident on it from all direction with all wave length. It is perfectly absorbing body, It also emit maximum energy.

Total emissive power: at a given temperature, the total amount of heat emitted by a surface in all the directions over entire wave length per unit area, per unit time is called total emissive power.

Emissivity: it is the ratio of total emissive power of any surface to the emissive power of black surface at same temperature.



λ



$\frac{q}{A}$

$E = f(T, \lambda, \epsilon)$

$\varepsilon = \frac{E}{E_b}$

E_b = emissive power black

$\varepsilon = 1$

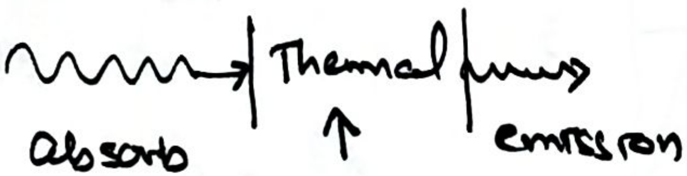
$E_b = \frac{q}{A}$ W/m^2

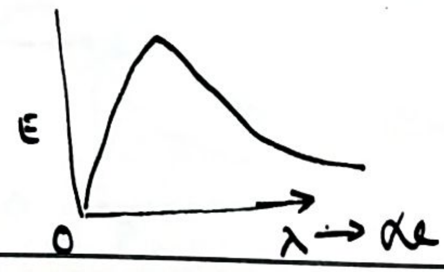
$\varepsilon = 0$

$E_b \propto T^4$

$0 \le \varepsilon \le 1$

$E_b = \sigma T^4$

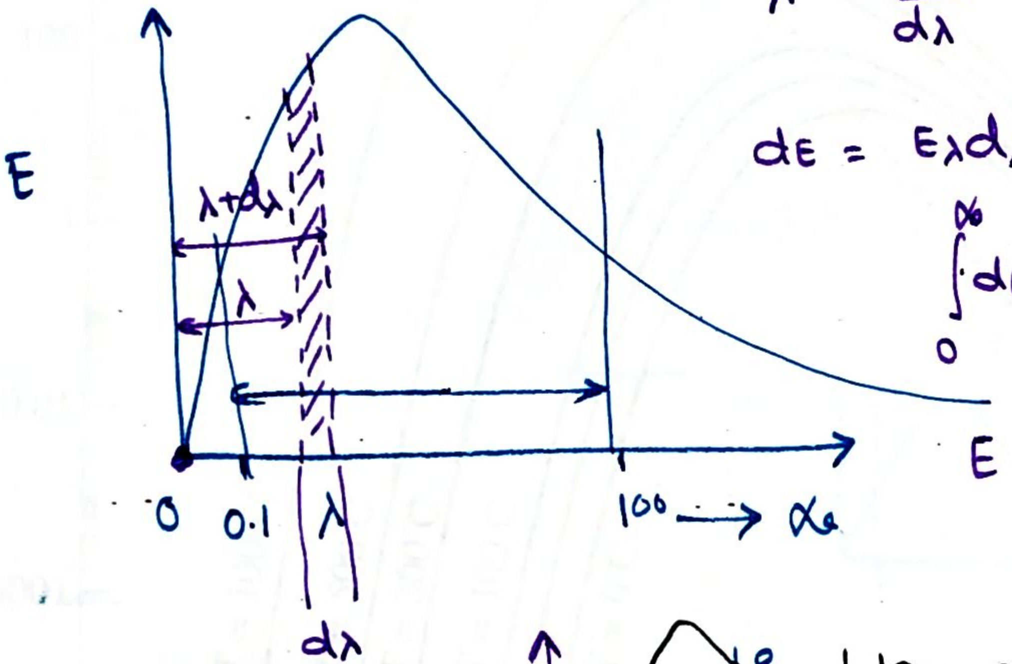




Monochromatic emissive power: The amount of energy emitted from surface at a given temperature per unit area, per unit time and per unit wavelength.

Monochromatic emissivity: it is the ratio of monochromatic emissive power of any surface to the monochromatic emissive power of black surface at same temperature.

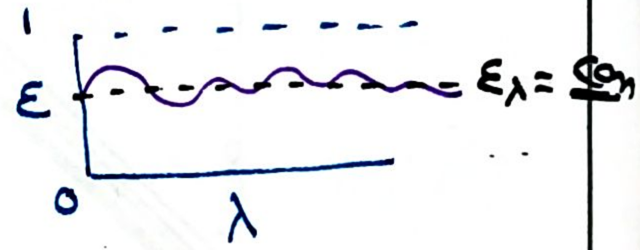
$$E_\lambda = \frac{dE}{d\lambda}$$



$$dE = E_\lambda d\lambda$$

$$\int_0^\infty dE = \int_{\lambda=0}^{\lambda=\infty} E_\lambda d\lambda$$

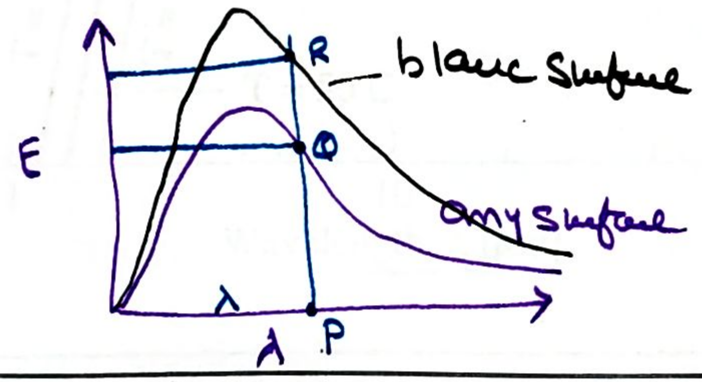
$$E = \int_{\lambda=0}^{\lambda=\infty} E_\lambda d\lambda$$



$PR = E_{b\lambda}$

$PQ = E_\lambda$

$$\varepsilon_\lambda = \frac{E_\lambda}{E_{b\lambda}}$$



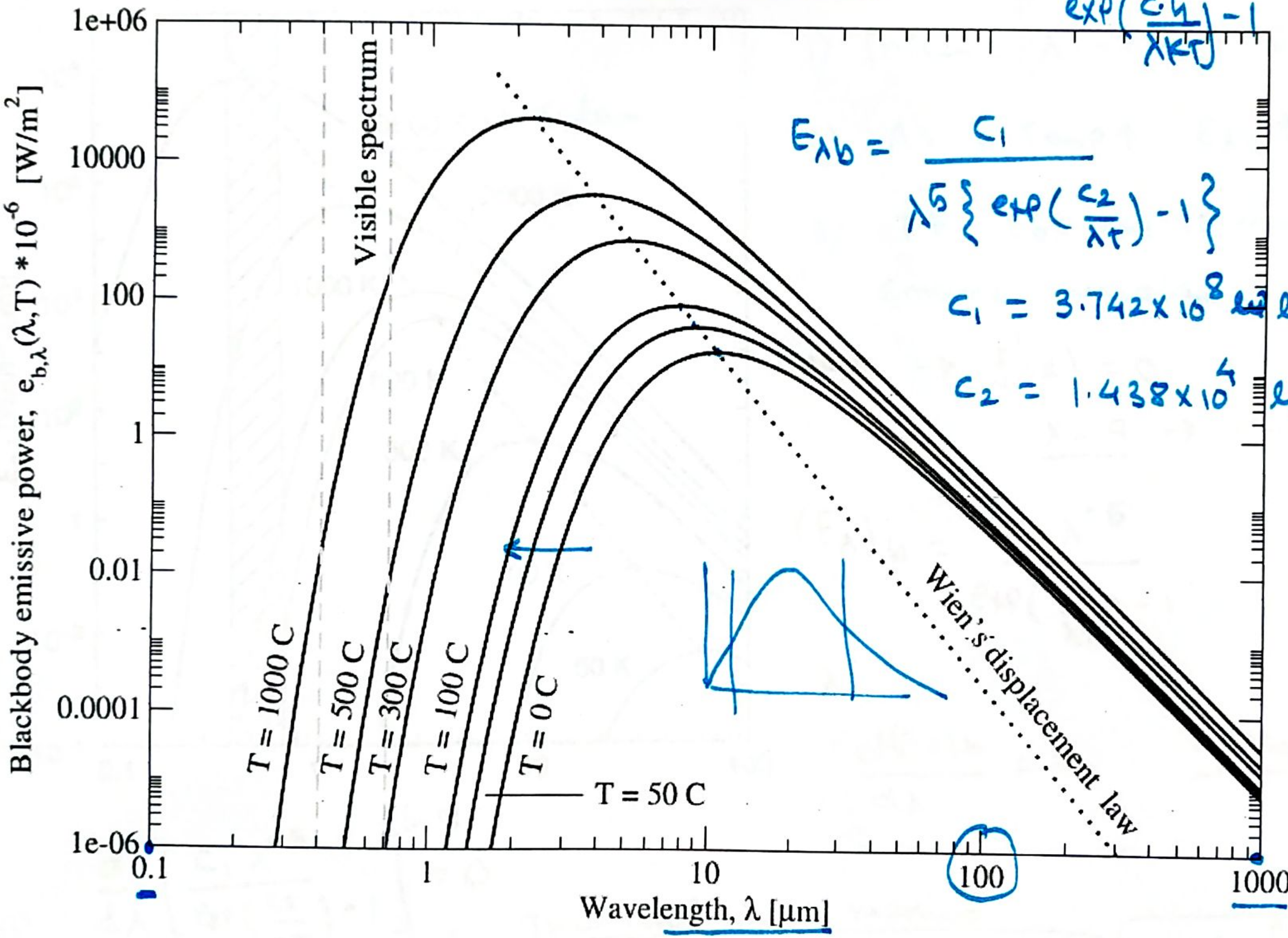
gray surface

ε_λ = constant

Planck's law

$E_{b\lambda} = ?$

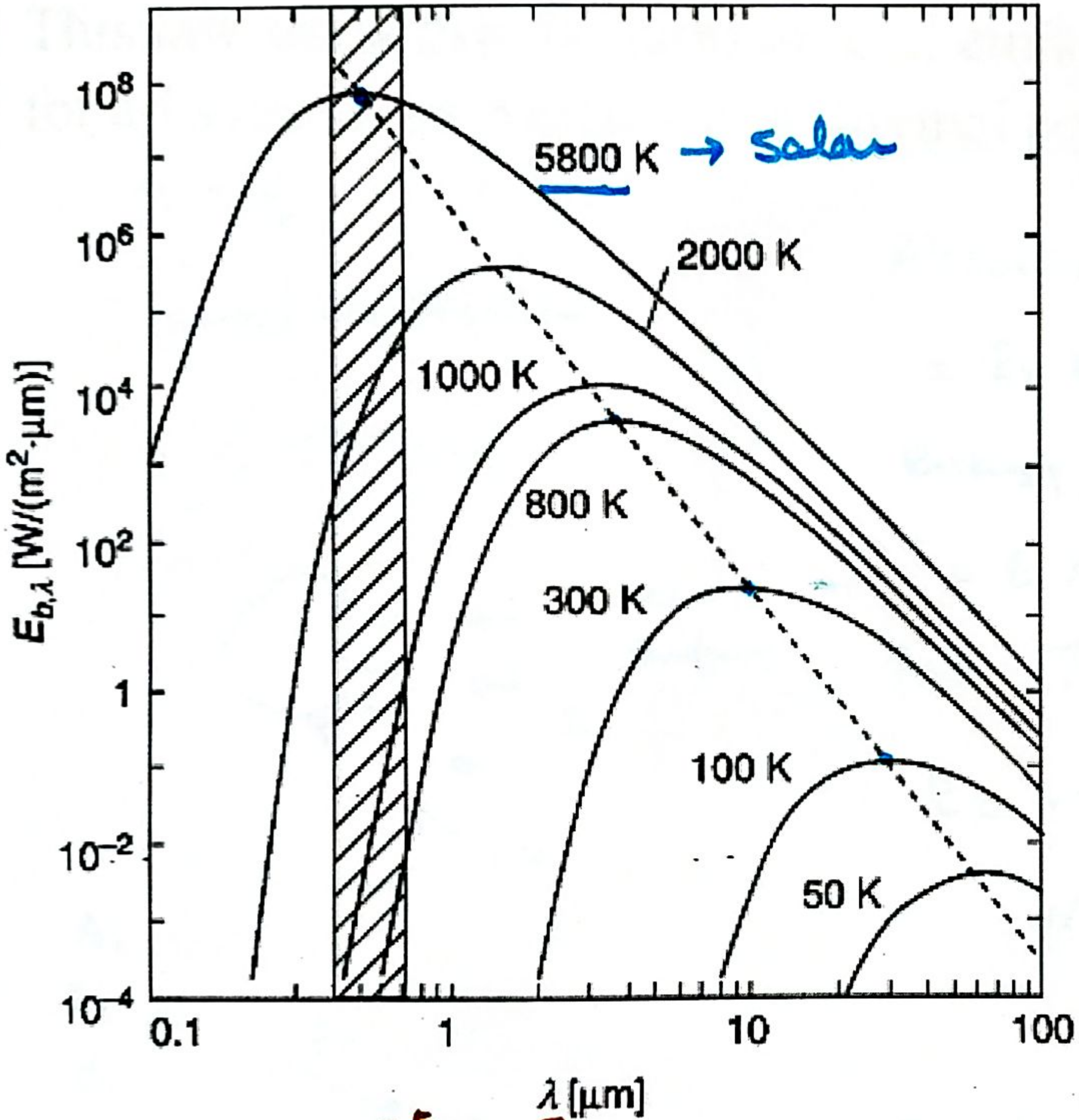
$$E_{\lambda b} = \frac{2\pi c^2 h \lambda}{\exp\left(\frac{c \cdot h}{\lambda k T}\right) - 1}$$



$$E_{\lambda b} = \frac{c_1}{\lambda^5 \left\{ \exp\left(\frac{c_2}{\lambda T}\right) - 1 \right\}}$$

$c_1 = 3.742 \times 10^8$ W μm^4/m^2

$c_2 = 1.438 \times 10^4$ μm K



$E_{\lambda b}$

1) increase λ - max - decrease

2) As T temp ↑ $E_{\lambda b}$ ↑

3) T ↑ $E_{b\lambda}$ max is move toward smaller wavelength.

max. → $f'(x) = 0$

$x = 9$ → max.

$$(E_\lambda)_b = \frac{c_1 \lambda^{-5}}{\exp\left(\frac{c_2}{\lambda T}\right) - 1}$$

λ

$$\frac{d(E_\lambda)_b}{d\lambda} = 0$$

$\lambda_{max} T = 2900$ μmK

$$\frac{d}{d\lambda}\left[\frac{c_1 \lambda^{-5}}{\exp\left(\frac{c_2}{\lambda T}\right) - 1}\right] = 0$$

Trial and error method

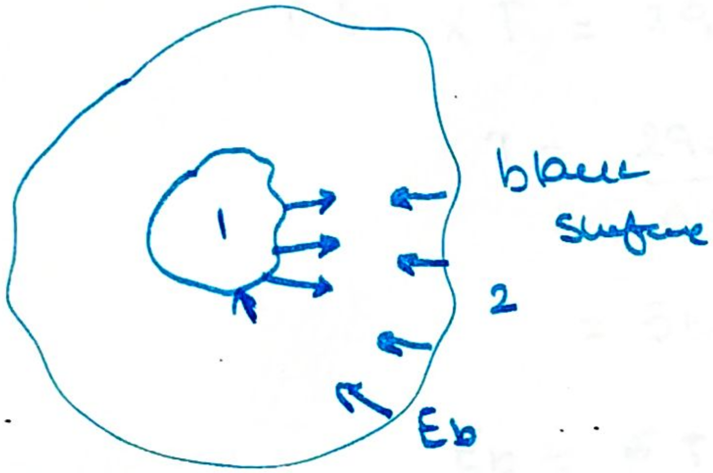
$\lambda_{max} T = 2898$ μmK — Wien's law

Kirchhoff's Law

This law states that the ratio of total emissive power to absorptivity is constant for all substances which are in thermal equilibrium with surroundings.

$\alpha_1 = \varepsilon_1$

Thermal equilibrium.

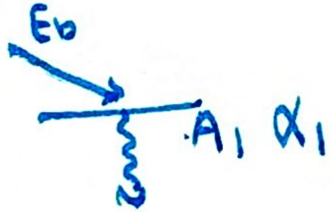


A_1

E_1

α_1

E_b



Absorbed energy by surface 1

$= E_b \times A_1 \times \alpha_1$

energy emit by surface 1

$= E_1 \times A_1$

For, Thermal equilibrium

$$E_b \times A_1 \times \alpha_1 = E_1 \times A_1$$

$$\alpha_1 = \frac{E_1}{E_b} = \varepsilon_1 \qquad \boxed{\alpha_1 = \varepsilon_1}$$

$$\varepsilon = \text{emissivity} = \frac{E}{E_b}$$

Q.1 sun emits maximum radiation at $\lambda = 0.52\mu m$. Assuming sun as black body, find the surface temperature of the sun and emissive power at that temperature

(May 2018) 4 mark

$\lambda_{max} T = 2900\ \mu mK$

$\lambda_{max} = 0.52\ \mu m$

$0.52 \times T = 2900$

$T = \frac{2900}{0.52}$

$= 5580K$

$E_b = \sigma T^4$

$E_b = 5.67 \times 10^{-8} \times (5580)^4$

$= 5.67 \times 10^{7}\ W/m^2$

$= 56.7\ MW/m^2$