Radiation

Radiation

The energy emitted by a body in the form of heat by virtue of its temp is called thermal radiation

All bodies above absolute zero of temperature emit radiant energy .

Sun is a powerful source of radiant energy .

Properties of thermal radiation

i. EM

ii. 3×10^8 m/s

iii. IR 8000Å – 20,000Å

iv. Reflection, refraction , interference, diffraction, polarisation.

Absorptance, Reflectance and Transmittance.

Let Q – incident radiation

Q_1 – qty absorbed, Q_2- reflected,Q_3 – transmitted ($Q = Q_1+Q_2 + Q_3$)

Absorbing power or absorptance $a = Q/Q_1$.

Reflecting power or Reflectance $r = Q/Q_2$.

Transmitting power or transmittance $t = Q/Q_3$.

$$a + r + t = 1, \quad \text{if } t = 0, \; a + r = 1$$

ie. poor reflectors are good absorbers and vice versa.

Absorptive powers

1. i) Dull copper – 13%
2. ii) Indian ink – 85%
3. iii) Shellac – 72%
4. iv) Lamp black – 98%

Note: a, r and t are independent of the nature of material of the body, but depend upon the wavelength of the incident radiation and the nature of the surface.

Absorptance will be different for different wavelengths corresponding to a particular wavelength is called ‘ monochromatic absorptance’ or ‘ spectral absorptive power’ $a_{\lambda.}$

Spectral absorptive power

For a particular λ is defined as the ratio of the heat energy absorbed in a certain time to the total heat energy incident upon it in the same time within a unit wavelength range around the wavelength λ . ie. b/w (λ-1/2) and (λ+1/2)

Fraction of energy absorbed in the **wave length range dλ** b/w (λ-d λ /2) and (λ+d λ/2) = $a_\lambda \, d\lambda$

Emissive power ‘e’

Of a body at a particular temperature is the total energy radiated per sec per unit area.

Spectral emissive power or monochromatic emittance e_λ

Of a body for a particular λ is defined as the quantity of radiant energy emitted per sec per unit area of the surface within **unit wavelength range** around the wavelength λ .

ie. b/w (λ-1/2) and (λ+1/2)

Energy radiated in the **wave length range dλ** b/w (λ-d λ /2) and (λ+d λ/2) = $e_\lambda \, d\lambda$

Radiant emittance or emissive power ‘e’

Radiant emittance e is the total energy emitted by a body /sec / unit area for all possible wavelengths ranging from 0 to infinity .

$e = \int e_\lambda \, d\lambda$ limit 0 to inifinity

Emissivity ε

Is the ratio of the emissive power of a body to the emissive power of a black body at the same temp.

Emissivity $\varepsilon = e/E$

Emissive power $e = \varepsilon E$

Intensity of the radiation

Is defined as the amount of heat energy falling /sec/ unit area held at right angles to the radiation .

I α $1/r^2$. inverse square law.

Intensity also depends on the strength of the source.

Spectral intensity I_λ

Is defined as the amount of heat energy incident /sec/ unit area held at right angles to the radiation in a unit wave length range around λ.

Black body

A perfectly black body is one which absorbs completely the radiations of all wavelengths falling on it hence appears black. ($r = t = 0$, $a = 1$)

Not possible in practice. Lamb black or plantinum black are aproximate – absorb nearly 98%.

Fery Black body - double walled hollow sphere having a small opening and a conical projection opposite to the opening. On heating opening act as black body emitting black body radiation .

Black body (full or total)radiation

Radiation emitted by a perfectly black body, when it is heated to a suitably high temperature is called black body radiation. (contains all possible wavelengths).

Prevost’s theory of Heat exchange

i. All bodies above OK emit heat to the surroundings and gain heat from the surroundings at all times.

ii. The amount of radiation emitted increases with temperature.

iii. Rate of emission depends on the temperature of body and nature of surface.

Prevost's theory of Heat exchange

iv. Rate of emission is not affected by the surroundings.

v. Continuous exchange of heat b/w body and surroundings.

vi. Fall or rise in temperature of a body is the net result of exchange of heat between the body and the surroundings.

A body is in thermal equilibrium with its surroundings. Is it static or dynamic equilibrium . Defend.

Dynamic.

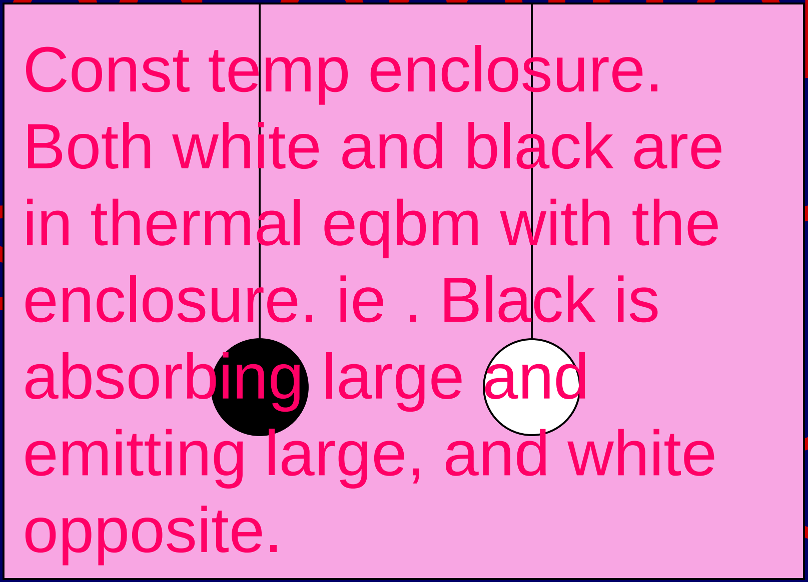
Continuous exchange of heat is going on.

Good absorbers are

Good emitters Poor

abs re Poor

em plain.



Const temp enclosure. Both white and black are in thermal eqbm with the enclosure. ie . Black is absorbing large and emitting large, and white opposite.

Prevost’s theory – dynamic eqbm

Kirchhoff’s Law

At any given temperature , the ratio of the emissive power to the absorptive power corresponding to a certain wavelength is constant for all bodies and this constant is equal to the emissive power of a perfectly black body at the same temperature and corresponding to the same wavelength.

Kirchhoff’s Law - Proof

Consider a uniformly heated enclosure maintained at temp T.

a_λ - absorptive power

dQ – amount of heat having wavelength b/w λ and λ+dλ incident on a **unit surface area** /s.

Energy absorbed = a_λ dQ

Energy reflected or transmitted

$$= dQ - a_\lambda\, dQ = dQ\,(1 - a_\lambda)$$

Energy emitted /s in the wavelength range λ and λ + dλ = $e_\lambda d\lambda$

e_λ - emissive power

Total energy coming from the body /sec/unit area(λ and λ + dλ) = $dQ\,(1 - a_\lambda) + e_\lambda d\lambda$

Body and enclosure are in thermal eqbm. ie. heat coming from body = heat incident.

$$dQ\,(1 - a_\lambda) + e_\lambda d\lambda = dQ$$

$$e_\lambda d\lambda = a_\lambda dQ$$ (general eqn)

For black body $E_\lambda d\lambda = dQ$ $(a_\lambda = 1)$

Ratio gives $e_\lambda / E_\lambda = a_\lambda$

$e_\lambda / a_\lambda = E_\lambda$ Kirchhoff’s law.

Kirchhoff’s Law - Applications

i) Red glass appears red at room temperature as it absorbs green light strongly . If it is heated in a furnace glows with green light.

ii) Fraunhoffer lines in solar spectrum.

iii) Silvered surface of thermos do not absorb as well as radiate much.

iv) Piece of china with dark painting on it , if heated to 1300K and examine in dark room , dark paintings appear much brighter than white portion .

Central photosphere emits continuous. Comparatively cooler chromosphere cnotains H2, N2, O2, Cu, Na etc in gaseaous form absorb some wavelength.

Sefan’s law of black body radiation

‘The total amount of heat energy radiated per second per unit area of a perfect black body is directly proportional to the fourth power of the absolute temperature of the surface of the body . ‘

$E \; \alpha \; T^4$. $E = \sigma T^4$.

‘σ’ = 5.67 x $10^{-8} Wm^{-2}K^{-4}$. - Stefan’s constant .

Note :

- Stefan derived experimentally in 1879 and Boltzmann gave a theortical proof based on thermodynamical considerations. Hence its also known as Stefan – Boltzmann law.

- Not a law of cooling . Tells only about the amount of heat radiated by the body by virtue of its temperature, irrespective of what it gains.

- Applicable for whole range of wavelength.

Newton’s law of cooling

The rate of loss of heat is proportional to the difference of temperature between the body and surroundings.

A BB at abs temp T surrounded by another at T_0.

Inner body's emission is received by outer and vice versa.

Net loss of energy / unit area /sec = E = $\sigma(T^4 - T_o^4)$

$$= \sigma(T^2 - T_o^2)(T^2 + T_o^2)$$

$$= \sigma(T - T_o)(T + T_o)(T^2 + T_o^2)$$

$$= 4\sigma T_o^3 (T - T_o)$$

(taking $T \approx T_o$.) if A is total area ,

Total rate of loss = $4Ae\sigma T_o^3 (T - T_o)$

e- emissivity of the body

ie. rate of loss α $(T - T_o)$

Spectrum of BB radiation - anaysis

i)

Explain the statement :

Stefan’s constant is

5.674×10^{-8} W/m^2/K^4.

Calculate energy radiated /min from the filament of an incandescent lamp at 3000K, if the surface area is 10^{-4} m^2 and its emissivity is 0.425.

$E = \varepsilon\sigma A\ T^4.$

$= \ 11712$ J/min

If the temp of a black body is increased from 300K to 1200K, by what factor will the rate of emission increase?

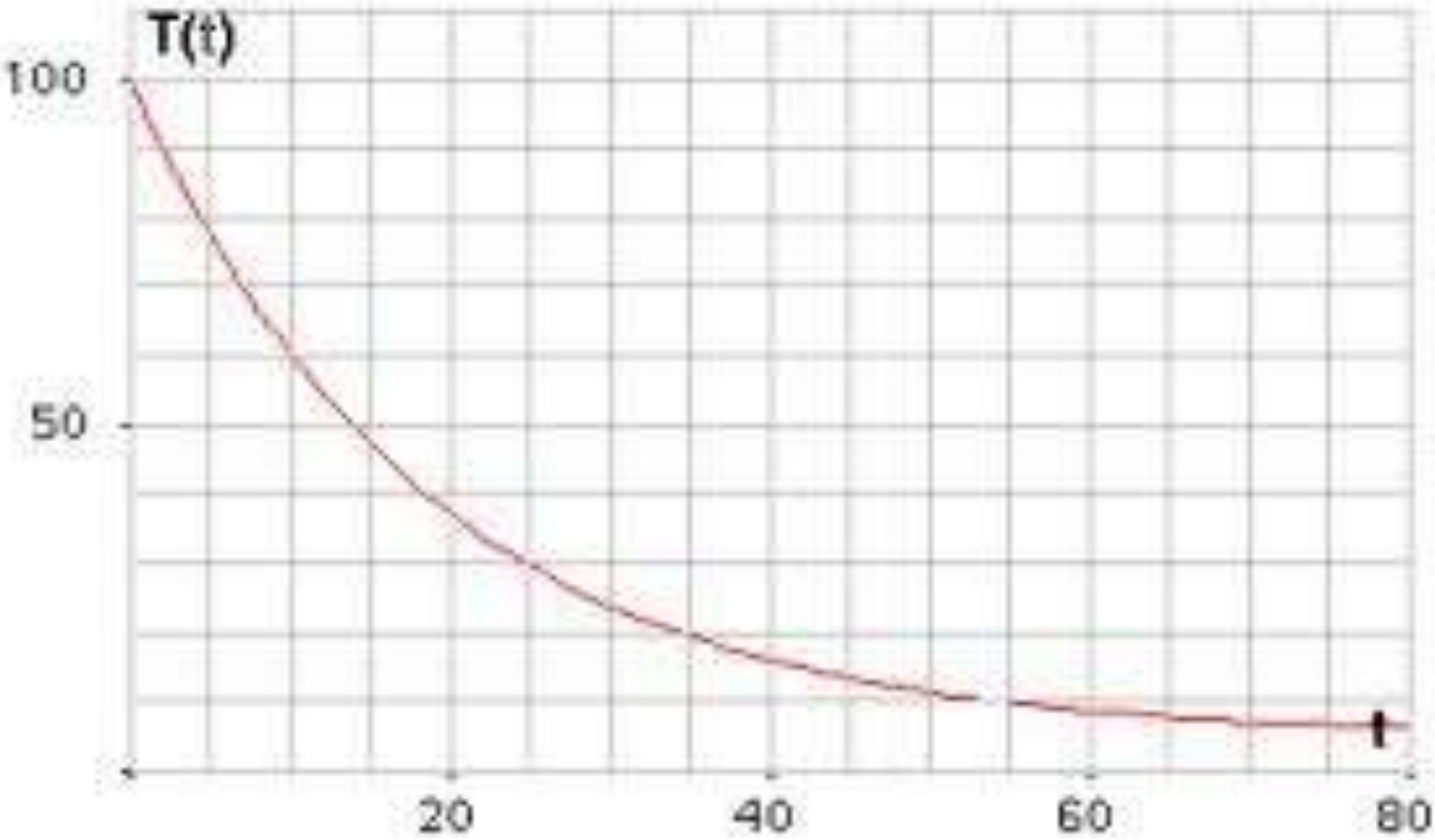
$E = \sigma T^4$.

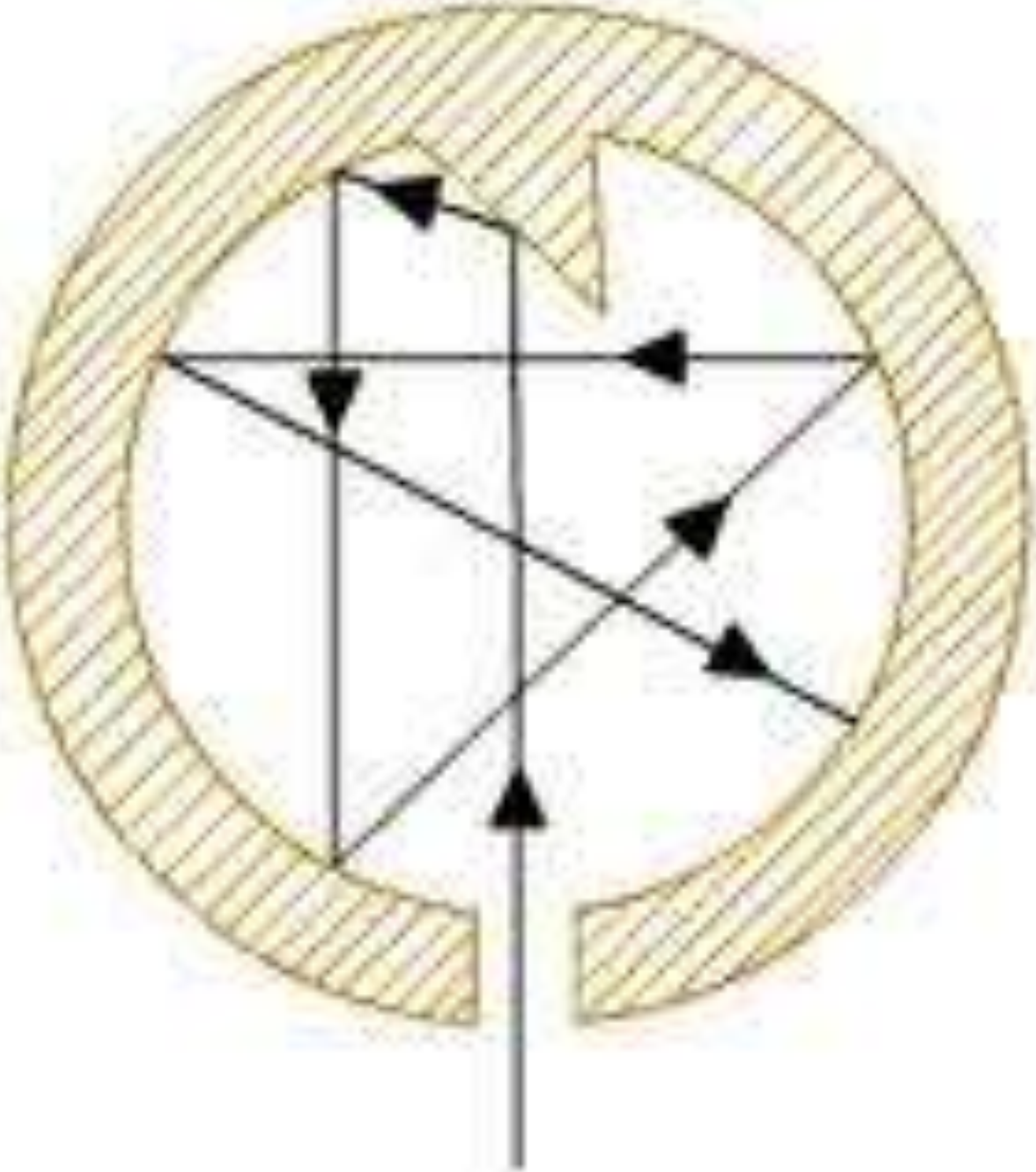
Write unit and dimension of Stefan’s constant?

What is emissivity of a BB?

One

Cooling curve





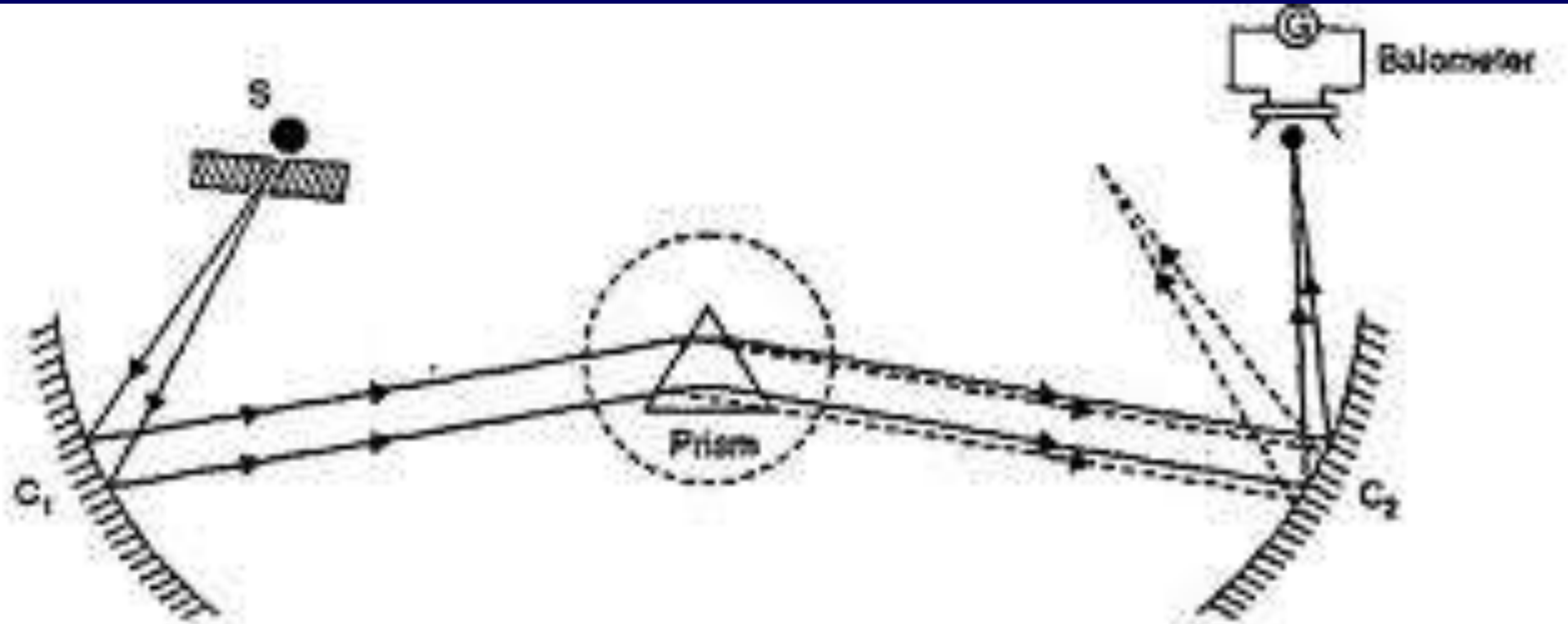


Fig. 27.5. Experimental arrangement for studying the distribution of energy in the spectrum of black body

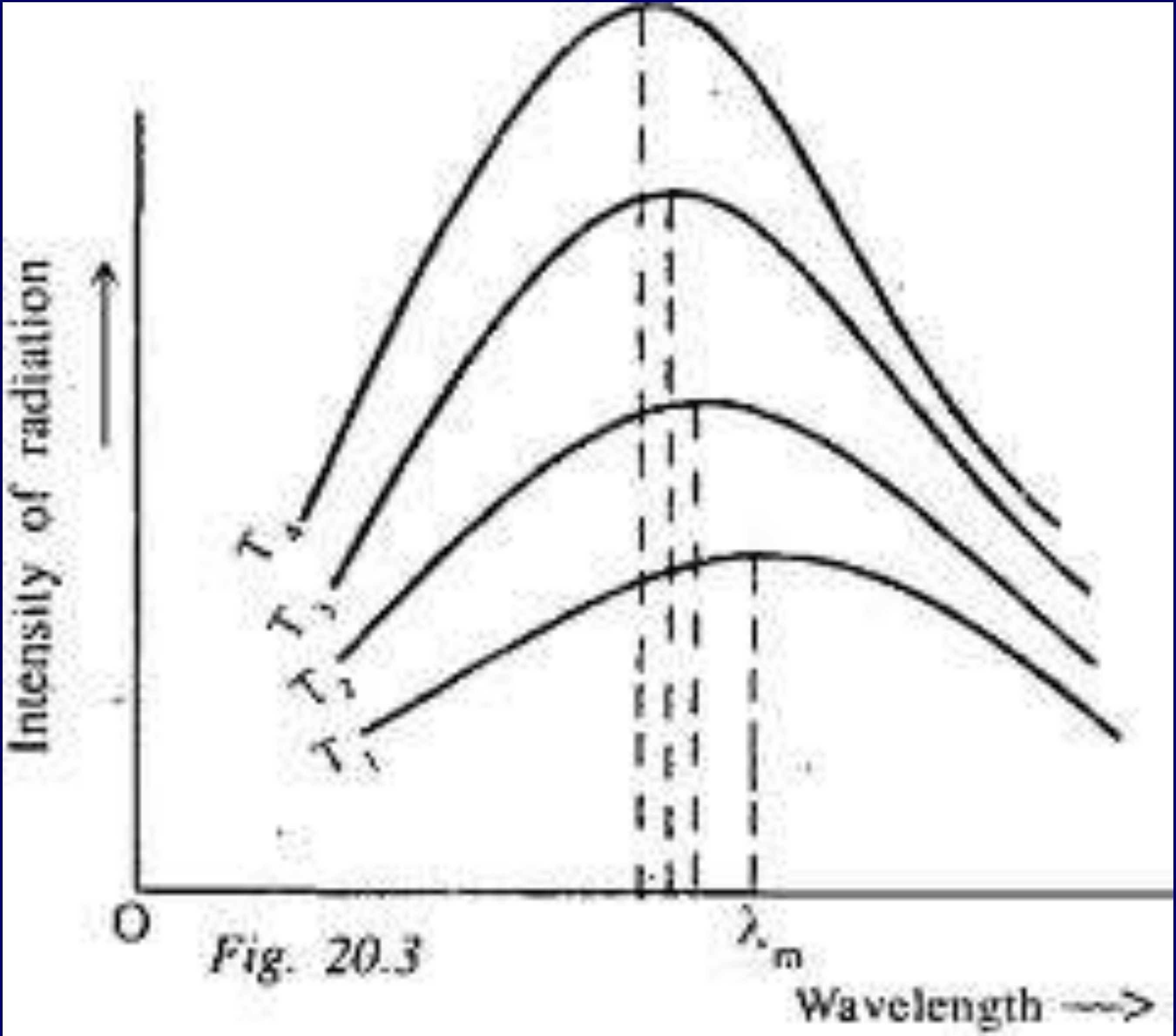
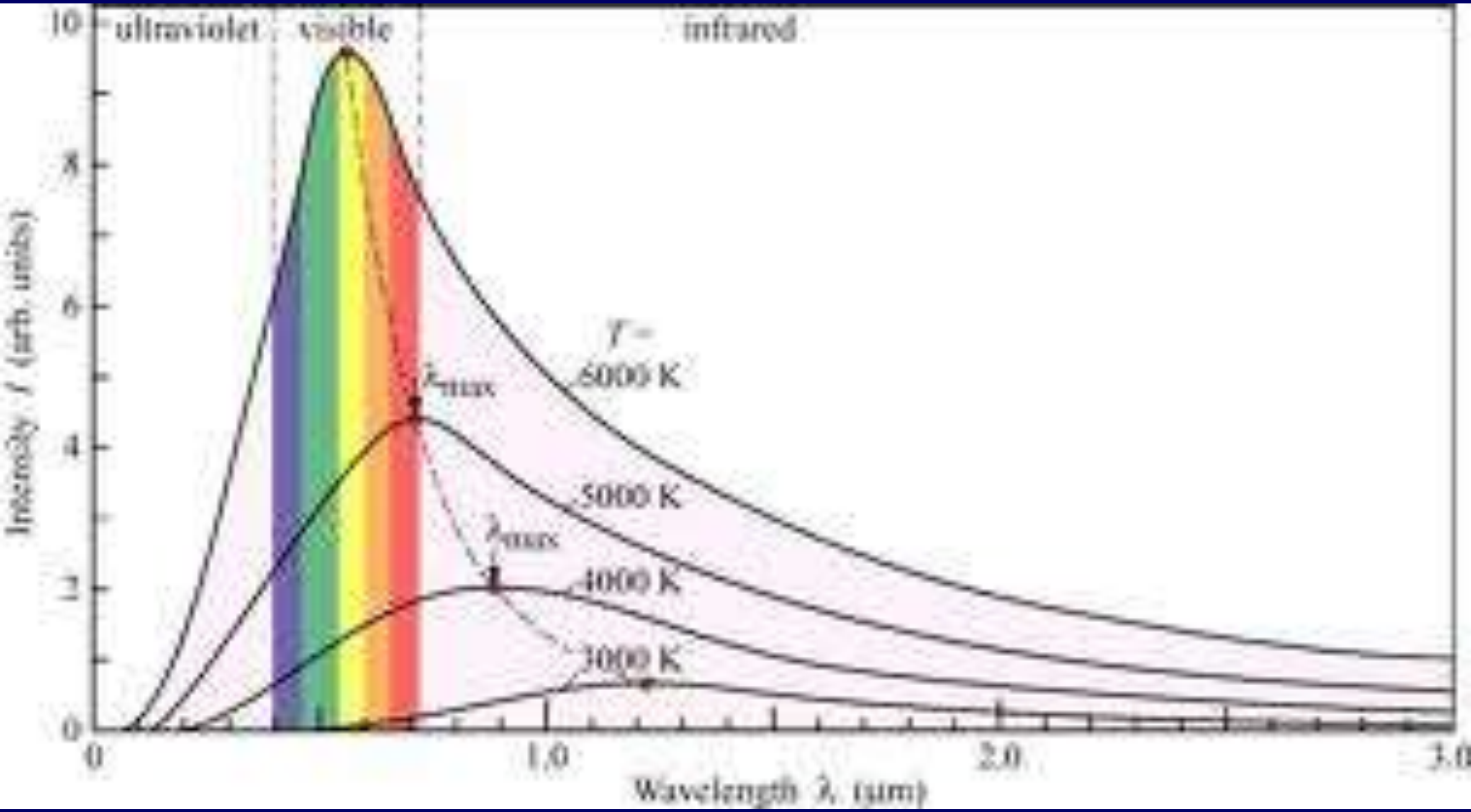
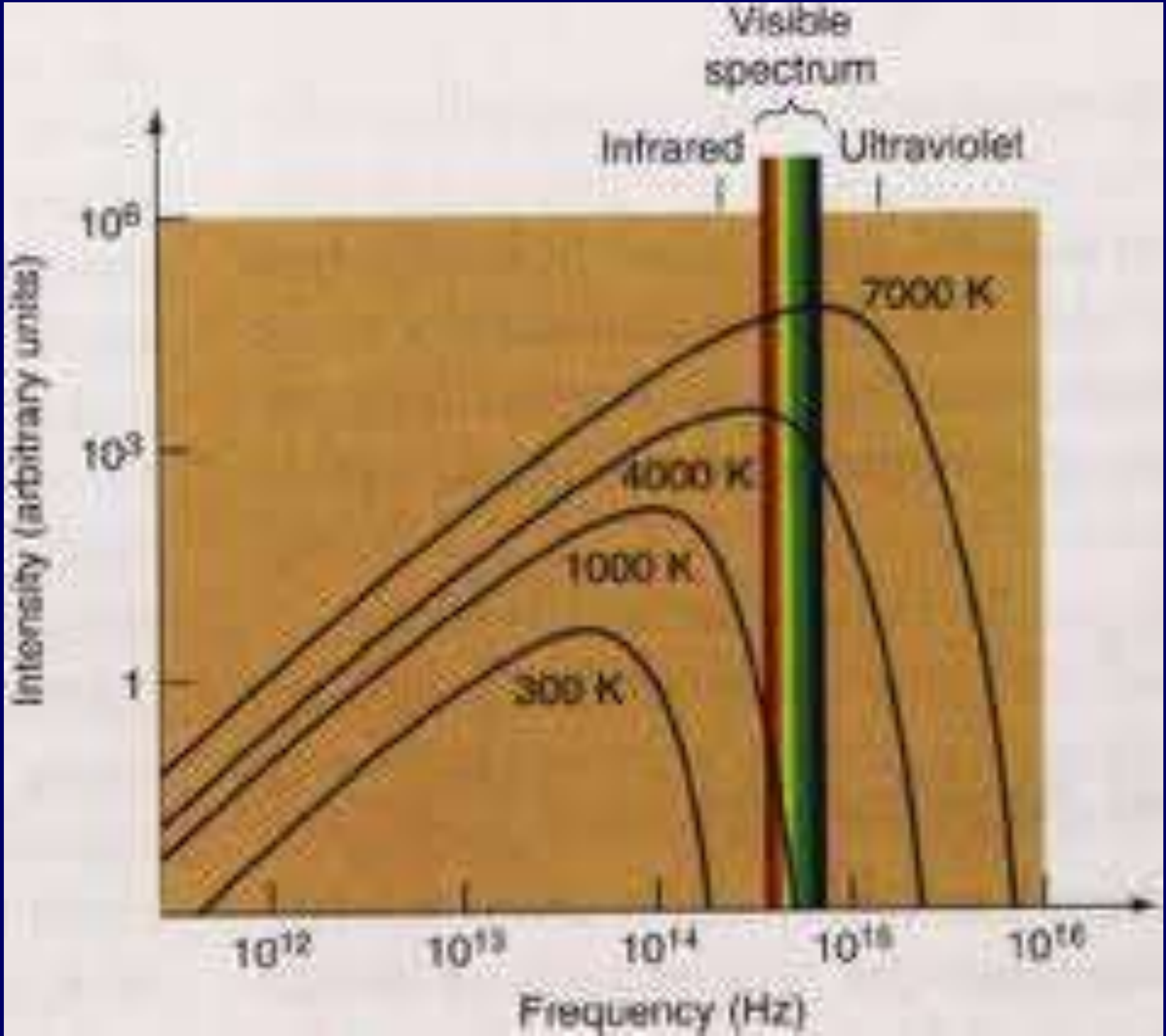
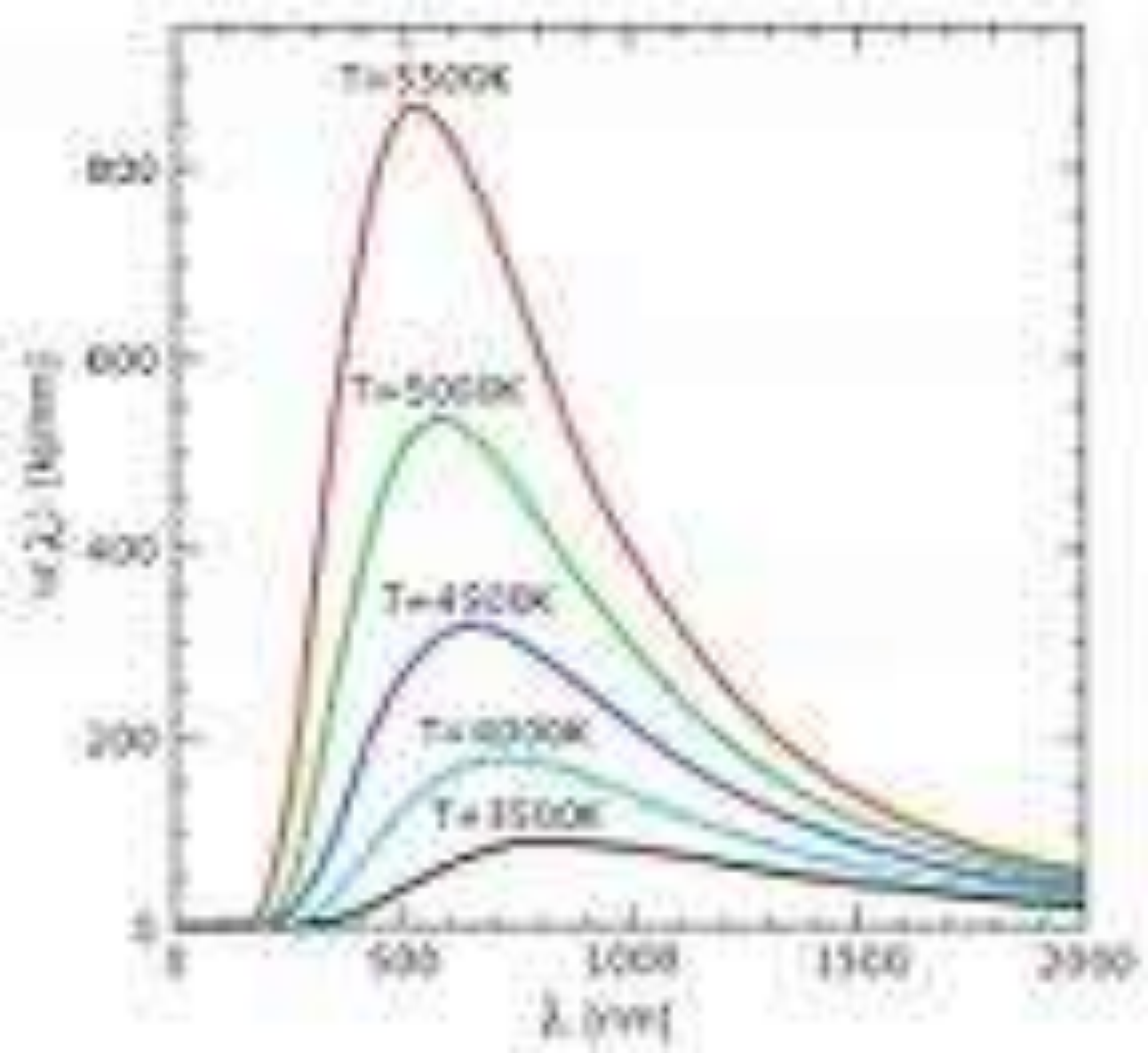
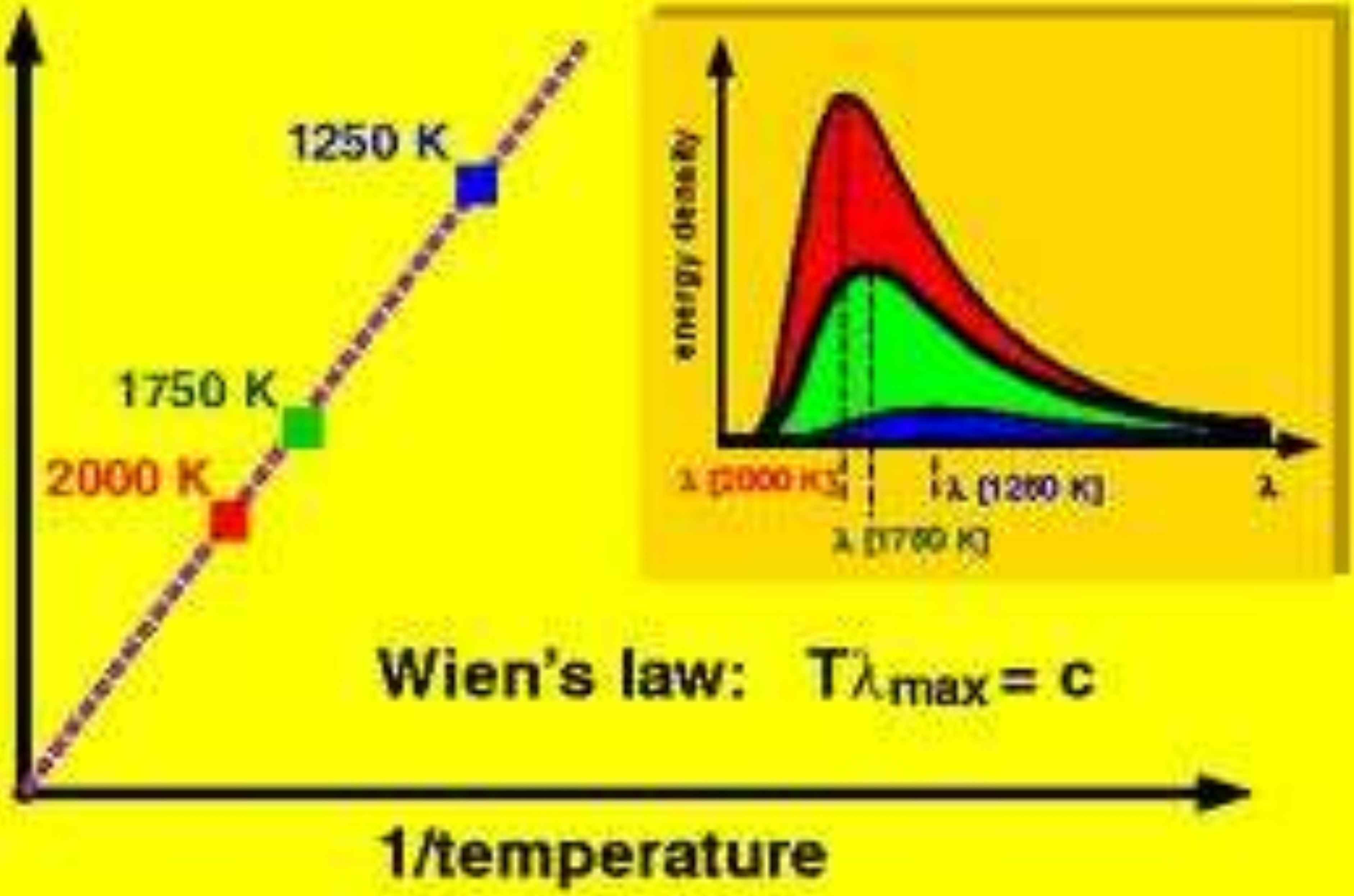


Fig. 20.3


ultraviolet
visible
infrared
T =
6000 K
5000 K
4000 K
3000 K
λ_{max}
λ_{max}
Intensity I (arb. units)
Wavelength λ (μm)
0
2
4
6
8
10
0
1.0
2.0
3.0


Visible spectrum
Infrared
Ultraviolet
Intensity (arbitrary units)
10^6
10^3
1
7000 K
4000 K
1000 K
300 K
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
Frequency (Hz)


T=5500K
T=5000K
T=4500K
T=4000K
T=3500K
800
600
400
200
0
0
500
1000
1500
2000
λ [nm]



Wien's law: $T\lambda_{max} = c$

Distribution of energy in Black body radiation - Salient points.

i) Energy distribution is not uniform . Energy initially increases with wavelength , becomes max corresponding to λ_{max} and then begins to decrease.

ii) Most of energy is associated with intermediate wavelength.

iii) Corresponding to each wavelength , there is an increase in energy emission with increase in temperature .

iv) The area under each curve represents total energy $\int e_\lambda \, d\lambda$ limit 0 to λ. Area increases with increase in temperature and is directly proportional to fourth power of temperature.(Stefan’s law)

vi. With increase in temperature of BB, the maxima of the curves shift towards shorter wavelengths. **ie. λ_{max} α 1/T.**

Wein's law - Product of max wavelength corresponding to maximum radiant energy and the corresponding absolute T is a constant.

$\lambda m\ T = b$, constant .

b - Wein's constant = 2.88×10^{-3} mK

Eg: when a body is heated more and more , colour changes from red to yellow.

Stars with low surface temperature appear red and higher surface temperature appear yellow and extremely high surface temperature appear blue.

Importance of Wein’s displacement law.

Can be used to determine temperature of heavenly bodies like sun, stars , moon etc.

For sun $\lambda_{max} \approx 4753$ Å,

$T_{sun} = 6076$ K

For moon $\lambda_{max} \approx 14$micron.

$T_{moon} = 206.3$ K

Sketch typical black body radiation curves for temperature T_1 and T_2, where $T_1 > T_2$.

Which is hotter – a red star or a green star ?

Green

In a coal oven , the cavities in the burning coal pieces look brighter than the surface of the coal. Explain.

Cavity behaves like a black body

‘Black body radiations are white‘ . comment.

White radiation is one which includes all wavelengths. BB emits continuous spectrum having all wavelengths.

Describe an experiment to show that good emitters are good absorbers.

A body with a large reflectivity is a poor emitter . Why ?

Poor absorber , hence.

Why does a BB appear brighter than the polished surface, when both are heated to the same temperature ?

BB emits more.

Why does a piece of red glass when heated and taken out glow with green light ?

At low temp, red glass absorbs green colour strongly.

At high temp, emits green strongly .

Heat is generated continuously in an electric heater but its tempbecomes constant after some time .why ?

Stage is reached , when the rate at which heat is generated by electric current becomes equal to the rate at which heat is lost by radiation .(thermal eqbm)

A sphere , a cube and a thin circular plate, all made of the same material and having the same mass are initially heated to a temp of 200^{o}C . Which of these objects will cool fastest ad which one slowest when left in air at room temp. ? GR

Thin circular plate has largest surface area.

Sphere has smallest surface area.

Animals curl into a ball when they are very cool. Why ?

To minimise surface area and radiation loss .

What is perfect white and perfect black body ?

A hot body radiates hot radiations? Do cold bodies radiate cold radiations?