- **Metals**
- **Theory of radiation**

Reference Notes:

https://egyankosh.ac.in/bitstream/123456789/65774/1/Unit-11.pdf

Metals

In physics, a metal is generally regarded as any substance capable of conducting electricity at a temperature of absolute zero.

Physical Properties of Metals

- good conductors of heat and electricity.
- Ductile: can be stretched into a wire.
- Malleable: can be changed into new shape
- Sonorous: produces a ringing sound when struck with hard object
- shiny appearance
- Most metals are hard. {Sodium and potassium can be cut by knife whereas mercury is a liquid at room temperature}

What is radiation ?

In physics, radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium.

Examples:

- EM radiation
- Particle radiation (alpha, beta, neutron)
- Acoustic radiation
- Gravitational radiation

Normal camera

Thermal camera

All bodies emit thermal radiation.

Thermal radiation is the emission of electromagnetic waves from all matter that has a temperature greater than absolute zero.

Thermal camera

What is a Black Body?

Idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence.

What is a Black Body Radiation?

spectral distribution of radiant energy

Blackbody radiation is thermal radiation. It is a special / idealized case that it absorbs all incident radiation with no reflection.

Experimental results of spectral distribution of radiant energy

Spectroscopic analysis:

- For a given wavelength, spectral energy density increases with temperature.
- For each temperature, the spectral energy density plot shows a maximum. It shifts to shorter wavelengths with increase in temperature
- The spectral energy density becomes zero as wavelength tends to either zero or infinity.

Spectral energy density gives energy per unit volume per unit range of wavelength.

Correct explanation of these results was a huge challenge!!

Stefan-Boltzmann law

He gave formula to calculate total energy density of all photons in blackbody Spectrum.

It states that total rate of emission of radiant energy per unit area is related to energy density as fourth power of temperature:

$$E = \sigma T^4$$

Stefan's constant

$$5.672 \times 10^{-8}\,\mathrm{Jm^{-2}K^{-4}s^{-1}}$$

<u>Limitation:</u>

It does not give any information about the spectral distribution of radiant energy

Plank's law

h is Planck's constant
kB is Boltzmann constant

He presented the formula for energy density of blackbody radiation. It also gives spectral distribution of radiant energy.

$$u_\nu d\nu = \frac{8\pi\nu^2}{c^3}\left(\frac{h\nu}{\exp(h\nu / k_B T) - 1}\right) d\nu$$

$$u_\lambda d\lambda = \frac{8\pi hc}{\lambda^5}\left(\frac{1}{\exp(hc / \lambda k_B T) - 1}\right) d\lambda$$

He considered

- emission and absorption of radiation as a discontinuous process

Novel prize in 1918

Nature does not allow
half wavelength.

Plank's hypothesis:

- The exchange of energy between matter (walls) and radiation (cavity) could take place only in bundles of a certain size.
- The quantum of exchange is directly proportional to its frequency.

$$E = h\nu = \frac{hc}{\lambda}$$

This led to the birth of quantum mechanics

Novel prize in 1918

Planck's law provides most general description of blackbody radiation

Rayleigh-Jeans law and **Wien's law** are its limiting cases in the region of longer and shorter wavelengths, respectively.

Wien's law

- For $\lambda << hc / k_B T$, Planck's law reduces to Wien's law:

$$u_\lambda d\lambda = \left(\frac{8\pi hc}{\lambda^5}\right)\exp(-hc / \lambda k_B T)\, d\lambda$$

Rayleigh-Jeans law

- For $\lambda >> hc / k_B T$, Planck's law reduces to Rayleigh-Jeans law:

$$u_\lambda\, d\lambda = \frac{8\pi hc}{\lambda^5} \times \left(\frac{\lambda k_B T}{hc}\right) d\lambda = \frac{8\pi k_B T}{\lambda^4}\, d\lambda$$

Plank's formula analysis :

$$u_\nu d\nu = \frac{8\pi\nu^2}{c^3}\left(\frac{h\nu}{\exp(h\nu / k_B T) - 1}\right)d\nu$$

$$u_\nu d\nu = n_\nu \varepsilon_\nu \mathrm{d}\nu$$

ε_ν average energy of a mode of oscillation in Plank's theory

$n_\nu d\nu$ number of modes per unit volume in the frequency range

Calculate the number of modes of oscillations in a chamber of volume $100\,\text{cm}^3$ in the frequency range $4.02\times10^{14}\,\text{Hz}$ to $4.03\times10^{14}\,\text{Hz}$.

Formula used:

$$N_\nu d\nu = \frac{8\pi V\nu^2}{c^3}d\nu$$

SOLUTION ■ It is given that $V = 100\text{ cm}^3 = 10^{-4}\text{m}^3$, $\nu = 4.02\times10^{14}\text{Hz}$, $d\nu = 0.01\times10^{14}\text{Hz}$ and $c = 3\times10^8\text{ms}^{-1}$. On substituting these values in the expression given in Eq. (11.6c), we get

$$N_\nu d\nu = \frac{8\times3.14\times(4.02\times10^{14}\text{Hz})^2\times(10^{-4}\text{m}^3)\times(0.01\times10^{14}\text{Hz})}{(3\times10^8\text{ms}^{-1})^3} = 1.5\times10^{13}$$

An oscillator vibrates with frequency 1.51×10^{14} Hz at $T = 1800$ K. Compare the values of its average energy by treating it as (a) a classical oscillator and (b) Planck's oscillator. Take $h = 6.62 \times 10^{-34}\ \mathrm{Js^{-1}}$, and $k_B = 1.38 \times 10^{-23}\ \mathrm{JK^{-1}}$.

SOLUTION ■ (a) The average energy of a classical oscillator is given by

$$\bar{\varepsilon} = k_B T = (1.38 \times 10^{-23}\ \mathrm{JK^{-1}}) \times (1800\,\mathrm{K})$$

$$= 2.48 \times 10^{-20}\ \mathrm{J}$$

(b) The average energy of Planck's oscillator is given by

$$\bar{\varepsilon} = \frac{h\nu}{e^{h\nu/k_BT} - 1} = \frac{k_BT(h\nu/k_BT)}{e^{h\nu/k_BT} - 1}$$

We note that $\dfrac{h\nu}{k_BT} = \dfrac{(6.62\times10^{-34}\,\text{Js})\times(1.51\times10^{14}\,\text{s}^{-1})}{(1.38\times10^{-23}\,\text{JK}^{-1})\times(1800\ \text{K})}$

$$= \frac{9.99\times10^{-20}\,\text{J}}{2.48\times10^{-20}\,\text{J}} = 4.03$$

Hence, $\bar{\varepsilon} = \dfrac{(2.48\times10^{-20}\,\text{J})\times(4.03)}{e^{4.03} - 1} = \dfrac{9.99\times10^{-20}\,\text{J}}{53.6} = 1.81\times10^{-20}\,\text{J}$

Note that the average energy of Planck's oscillator is less than that of a classical oscillator.

Thank you