ENGINEERING PHYSICS

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Department of Science and Humanities

Week #1 Class #4

- Review of Electric and magnetic fields
- EM Wave equation
- Energy transported by EM Waves
- *Max Planck's Black Body Radiation equation*

Class #4

- *Black body radiation*
- *Cavity Oscillators*
- *Classical estimation of energy density*
- *Max Planck's estimation of energy density*

Black Body Radiation

- *Suggested Reading*
  1. *Concepts of Modern Physics, Arthur Beiser, Chapter 2*
  2. *Learning material prepared by the Department of Physics*

- *Reference Videos*
  1. *DrPhysicsA/Blackbody radiation and UV catastrophe*

Blackbody Radiation

Gustav Robert Kirchhoff

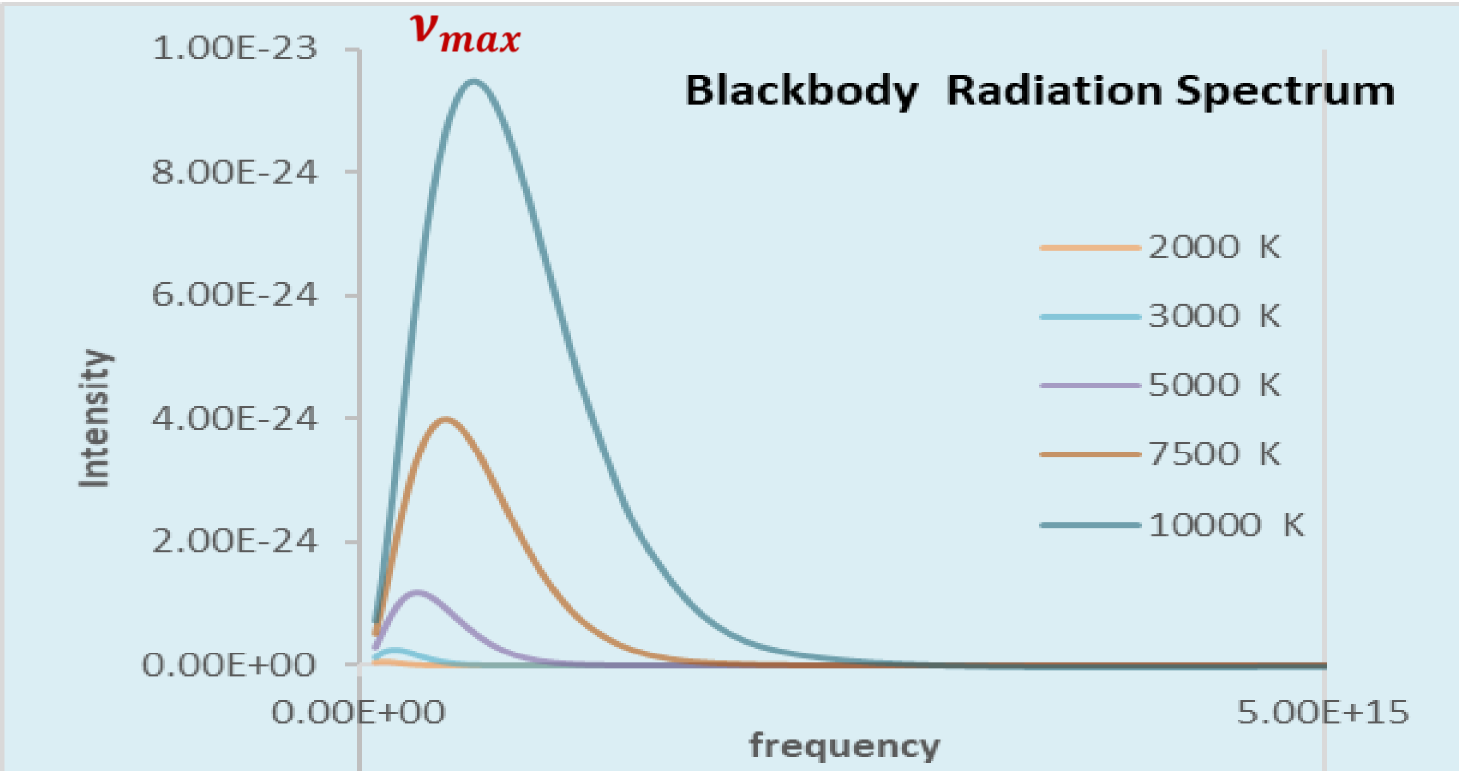
- *Interaction of radiation with materials*

  Absorption and emission

- *Materials emit radiation of all wavelengths around the visible range when heated*
- *Black body – (not necessarily black)*
  - *absorbs all radiations falling on it*
  - *Emits all wavelengths (frequencies) as it absorbed*
  - *Emissivity is unity*

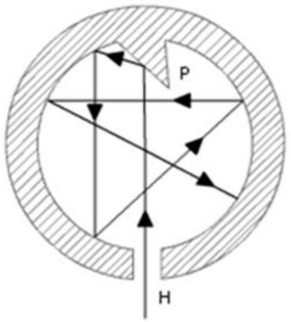
Blackbody Radiation Spectrum

- *Intensity of emitted radiations distributed about* ν_{max}
- ν_{max} *temperature dependent*
- ν_{max} *shifts to higher values at higher temperatures*



Blackbody radiators

- ***Black body model***
- ***Radiation entering the cavity is trapped***
- ***When heated can emit radiation of all wavelengths***
- ***Intensity of radiations for different wavelengths***

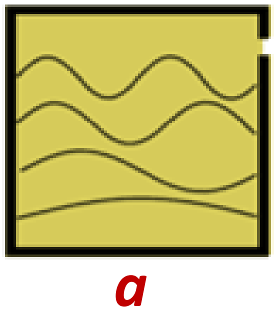


Cavity as blackbody

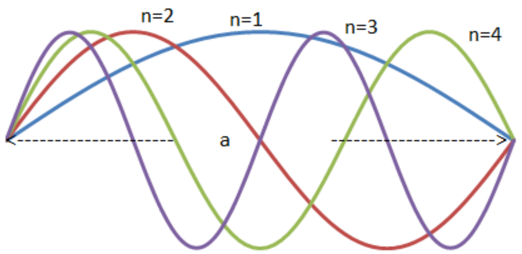
Image courtesy **Hyperphysics, Wikipedia**

Cavity Oscillators

- *Cubical cavity of side* a
- *Many harmonic oscillators on the surface of the cavity*
- *Standing waves satisfying* $a = n\frac{\lambda_n}{2}$
- *Frequency emitted* $\nu_n = n\frac{c}{2a}$



Standing waves in cavity



Allowed states in the cavity

Image courtesy **Hyperphysics, Wikipedia**

Cavity Oscillators

- ***3D cavity***
- ***Frequency emitted*** $\nu_r = r\frac{c}{2a}$
- $r = \sqrt{n_x^2 + n_y^2 + n_z^2}$

Number of standing waves in cavity

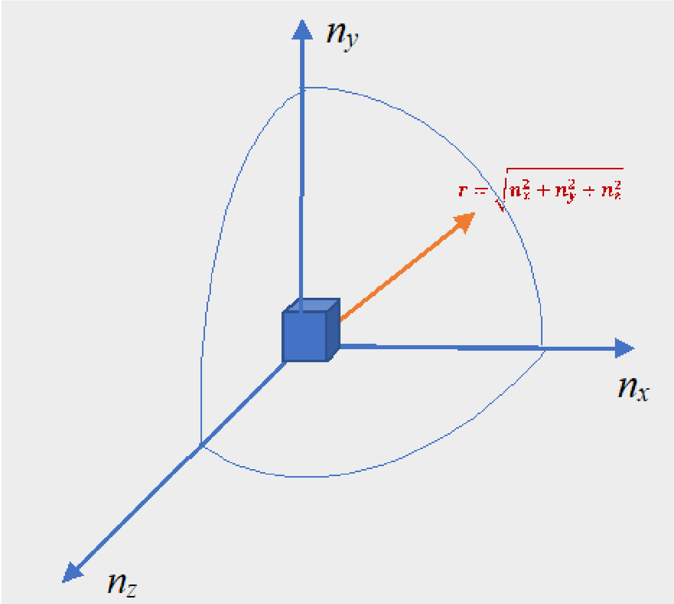


Image courtesy **Hyperphysics**

Cavity Oscillators

Changes in r by dr can give count of oscillators with frequencies $d\nu_r$

$$d\nu_r = dr\frac{c}{2a}$$

The number of oscillators with frequencies between ν_r *and* $\nu_r + d\nu_r$ *can be estimated as the volume of a shell of radius r and thickness dr*

$$= \frac{1}{8}\left(4\pi r^2.dr\right) = \frac{1}{2}\left(\pi r^2.dr\right)$$

Considering 2 polarization states for the radiation the number of oscillators

$$= \pi r^2.dr$$

Cavity Oscillators

The number of oscillators with frequencies between ν_r and $\nu_r + d\nu_r$ can be estimated as the volume of a shell of radius r and thickness dr

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

where a^3 is the volume of the cavity

The number of oscillators per unit volume with frequencies between ν and $\nu + d\nu$

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

Average energy of Cavity Oscillators

The probability function or the partition function of oscillators with energy E in thermal equilibrium

$$P(E) = \frac{e^{-E/kT}}{kT}.$$

Average energy of these oscillators using the Boltzmann distribution function

$$\langle E \rangle = \frac{\int E * P(E)dE}{\int P(E)dE} = kT$$

Rayleigh Jean's classical distribution of the energy density of radiation

$$\rho(\nu)d\nu = \langle E \rangle * dN = \frac{8\pi}{c^3}\nu^2 d\nu k_B T$$

Max Planck's analysis of Cavity Oscillators

- *Harmonic oscillators have frequency which is an integer multiple of a fundamental frequency*
- *Energy states are discrete and not continuous*
- *Average energy of oscillators* $\langle E \rangle \Rightarrow kT$ *as* $\nu \Rightarrow 0$
- *Average energy of oscillators* $\langle E \rangle \Rightarrow 0$ *as* $\nu \Rightarrow \infty$
- *Average energy has to be evaluated by a summation and not an integration*

Max Planck's analysis of Cavity Oscillators

The average energy of these oscillators using the Boltzmann distribution function

$$\langle E \rangle = \frac{\sum E * P(E)}{\sum P(E)}$$

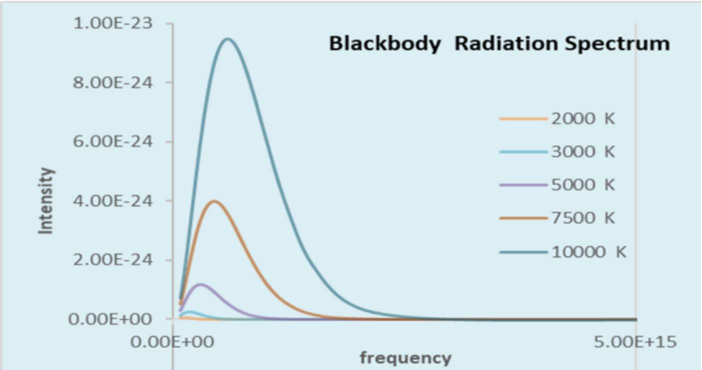
$$= \frac{h\nu}{exp^{h\nu/kT} - 1}$$

The energy density of radiation

$$\rho(\nu)d\nu = \langle E \rangle * dN$$

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

$$= \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{exp^{\left(h\nu/kT\right)} - 1} d\nu$$



Max Planck's analysis of Cavity Oscillators

Max Planck could fit the experimental results with a value of

$h = 6.57 \times 10^{-34}$ Js ...

very close to more accurate estimations of $h = 6.626 \times 10^{-34}$ Js

Quantization of energy of radiation introduced by Planck even before Einstein's photon hypothesis!

The foundation stone of the era of quantum physics ....

Class #4 …….. Quiz….

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The black body radiation concepts which are correct …

1. Every body which is black is a blackbody
2. Rayleigh and Jeans could explain the radiation curves for the higher wavelengths and not the lower wave lengths
3. The radiation density is dependent of the volume of the cavity under consideration
4. Classically the average energy of the oscillators cannot be found
5. Max Planck suggested that the average energy of oscillators have to evaluated using a summation of energies and probabilities

THANK YOU

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