Engineering Physics
PHY 1701

Module-1

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Course plan for this Lecture

Introduction of particle properties of waves: QUALITATIVE ideas about blackbody radiation (blackbody spectrum); Ultraviolet catastrophe

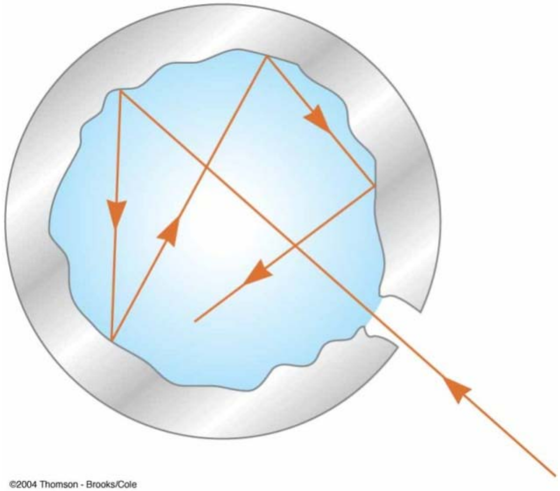
Introduction of Planck's hypothesis to resolve the UV catastrophe.

What is black body radiation?

- One that absorbs all radiation incident upon it, regardless of frequency. Such a body is called a black body.

- A **black body** is an ideal system that absorbs all radiation incident on it.

- The electromagnetic radiation emitted by a black body is called **blackbody radiation**



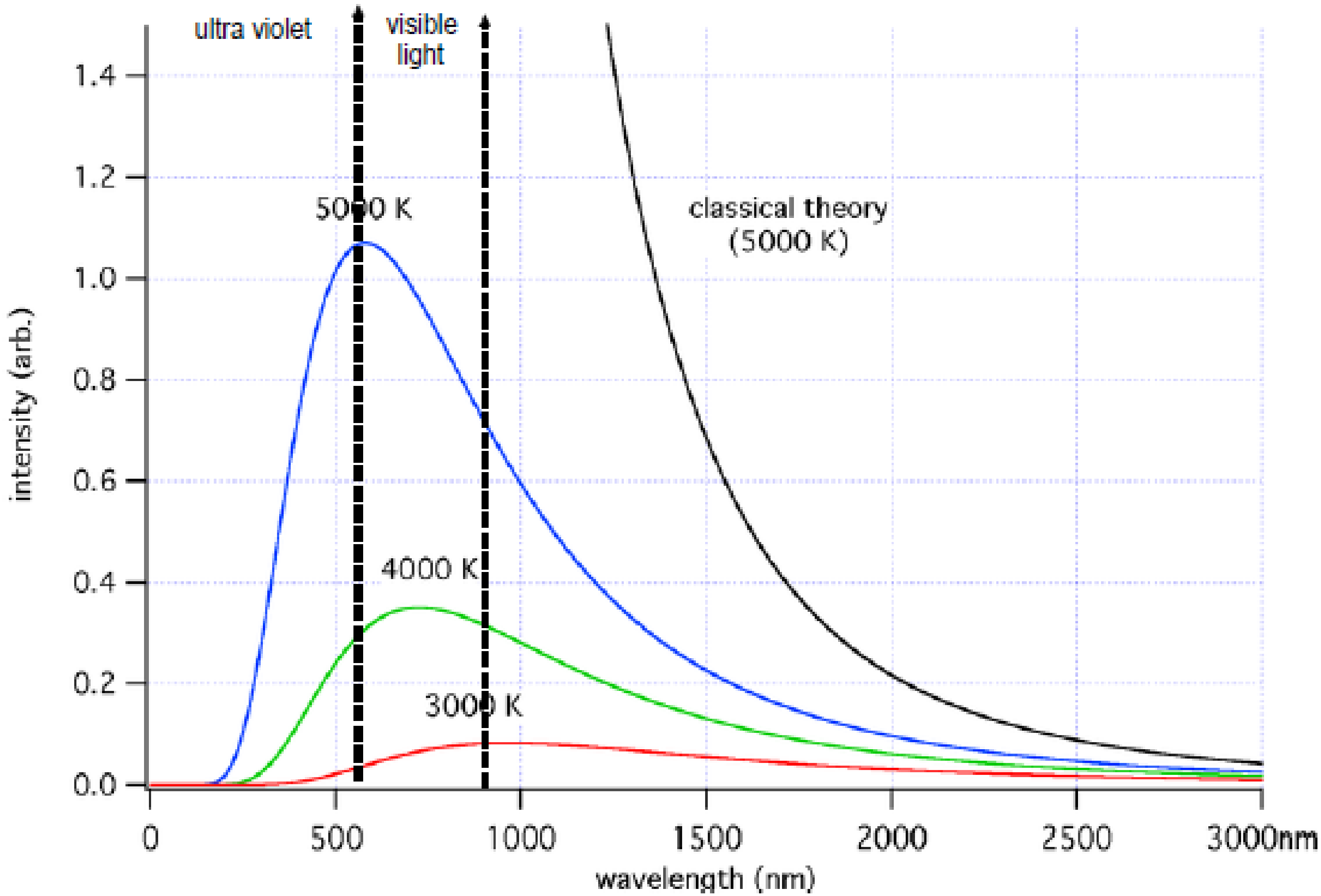
Example: Black Holes

- A good approximation of a black body is a small hole leading to the inside of a hollow object

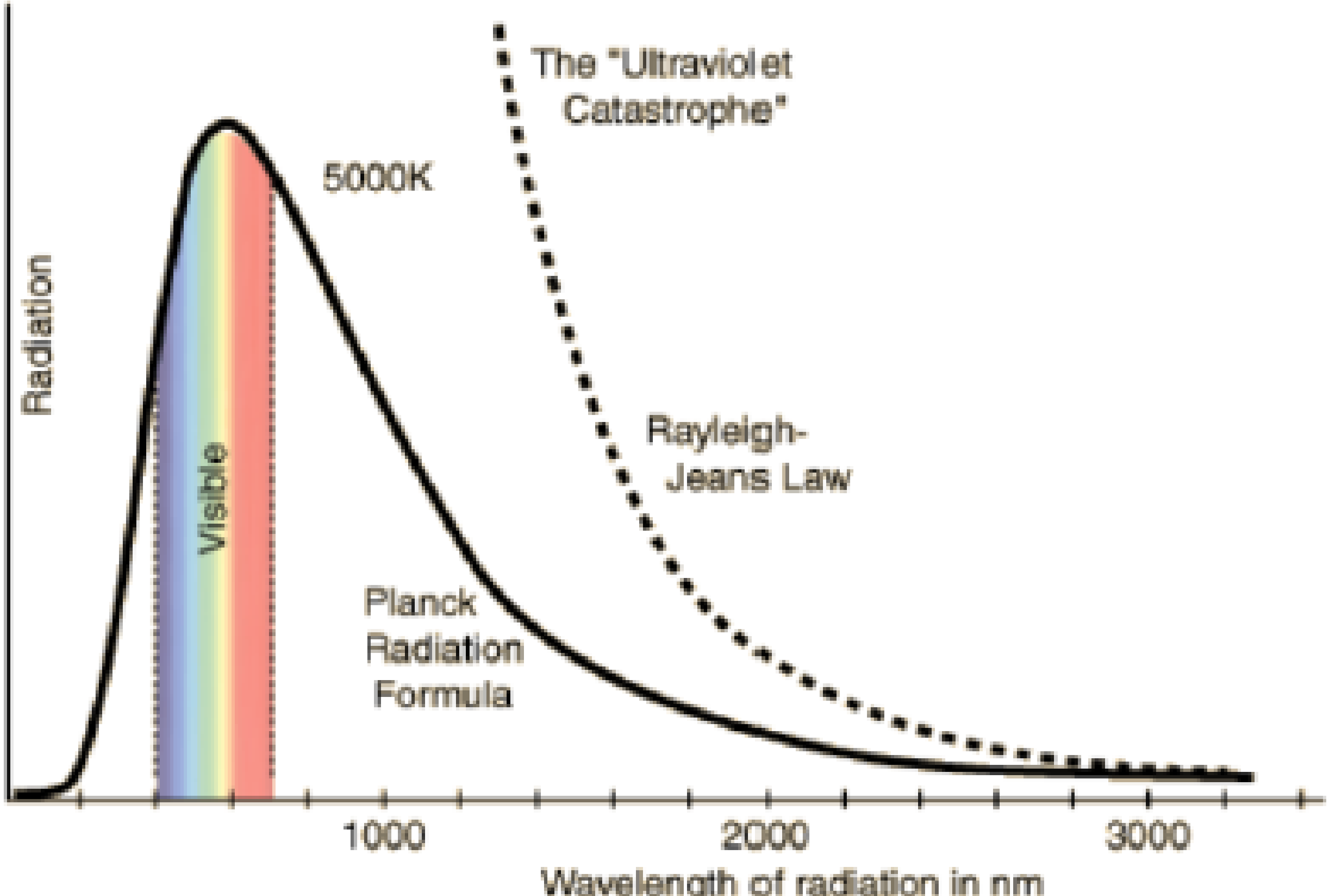
- The hole acts as a perfect absorber

- The nature of the radiation leaving the cavity through the hole depends only on the temperature of the cavity

Black body spectrum



As the temperature decreases, the peak of the black-body radiation curve moves to lower intensities and longer wavelengths. The black-body radiation graph is also compared with the classical model



The "Ultraviolet
Catastrophe"
5000K
Radiation
Visible
Rayleigh-
Jeans Law
Planck
Radiation
Formula
1000
2000
3000
Wavelength of radiation in nm

Classical approach of explaining black body radiation-1

Wien's displacement law

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

λ_{max} is the wavelength at which the curve peaks

T is the absolute temperature

The wavelength is inversely proportional to the absolute temperature

As the temperature increases, the peak is "displaced" to shorter wavelengths

Wien's law works well only for short wavelengths

Classical approach of explaining black body radiation-2

Rayleigh jeans law

An early classical attempt to explain blackbody radiation was the **Rayleigh-Jeans law**

At long wavelengths, the law matched experimental results fairly well

At short wavelengths, there was a major disagreement between the Rayleigh-Jeans law and experiment

This mismatch known as the *ultraviolet catastrophe;* You would have infinite energy as the wavelength approaches zero

It is explained by considering the radiation inside a cavity of absolute temperature T whose walls are perfect reflectors to be a series of standing em waves.
This is a three-dimensional generalization of standing waves in a stretched string.

The number of independent standing waves $G(\nu)d\nu$
In the frequency interval between ν and dν per unit volume in the cavity turned out to be density of standing waves in cavity

$$G(\nu)d\nu = \frac{8\pi\upsilon^2 d\upsilon}{c^3}$$

According to the theorem of equipartition of energy, the average energy per degree of freedom of an entity

$$\frac{1}{2}K_B T$$

Classical average energy per standing wave

$$\bar{\varepsilon} = K_B T$$

The total energy $U(\nu)d\nu$ per unit volume in the cavity in the frequency interval from ν to ν+d ν is therefore

$$U(\nu)d\nu = \bar{\varepsilon}G(\nu)d\nu$$

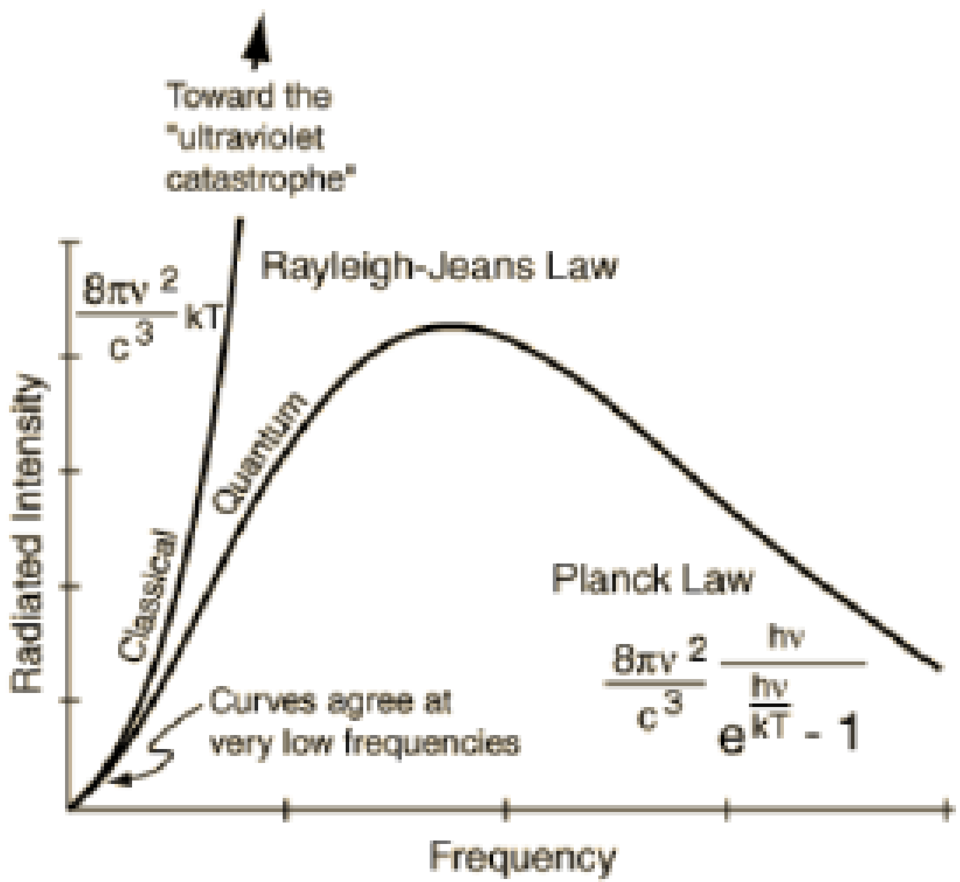
$$\boxed{U(\nu)d\nu = \frac{8\pi kT}{c^3}\upsilon^2 d\nu}$$

This is called Rayleigh Jeans formula.

It contains everything that classical physics can say about the spectrum of black body Radiation

Energy density is proportional to υ^2; at high frequencies $U(\nu)d\nu \longrightarrow \infty$

In the black body spectrum $U(\nu)d\nu \longrightarrow$ 0 and $\nu \longrightarrow$ 0



The Rayleigh-Jeans curve agrees with the Planck radiation formula for long wavelengths, low frequencies

Planck's Hypothesis

Molecules can only have discrete values of energy *En*, given by:
$E_n = nh\nu$
where *n* is a positive integer called a quantum number and ν is the natural frequency of oscillation of the molecules.

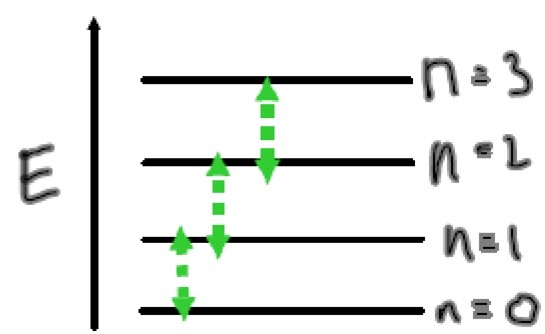
This is quite different from the classical model of the harmonic oscillator, in which energy of identical oscillators is related to the amplitude of the motion and unrelated to the frequency.

Because the energy of a molecule can only have discrete values, we say the energy is *quantized*. Each discrete energy level represents a specific quantum state.

The molecules emit or absorb energy in discrete packets that later became known as photons. The molecules emit or absorb photons by 'jumping' from one quantum state to another.

If the jump is downward from state to an adjacent lower state, the amount of energy radiated by the molecule in a single photon is ***hv***. A molecule emits or absorbs energy only when it changes quantum states.

The RayleighJeans curve agrees with the Planck radiation formula for longer wavelengths, (low frequencies)
Planck's constant h = 6.626×10^{-34} J *s*



Average energy of an oscillator whose frequency of vibration is υ.

$$\overline{E} = \frac{h\upsilon}{(e^{h\upsilon/kT} - 1)}$$

Energy radiated per unit volume in the frequency interval υ and υ+dυ

$$U(v)dv = \frac{8\pi h v^3}{c^3} \frac{dv}{e^{hv/k_B T} - 1}$$

This is called Planck's radiation formula.

h –Planck's constant

c –velocity of light

k_B – Boltzmann constant 1.38 x 10^{-23} J/K

T- Absolute temperature

At high frequencies $h\upsilon >> kT$ and $e^{h\upsilon/kT} \longrightarrow \infty$

Which means that $U(\nu)d\nu \longrightarrow 0$ as observed.

At low frequencies

$$\frac{h\upsilon}{kT} << 1$$

$$e^x = 1 + x + \frac{x^2}{2!} + ...$$

If x is small

$$e^x = 1 + x$$

$$\frac{1}{e^{h\upsilon/kT} - 1} = \frac{1}{1 + \frac{h\upsilon}{kT} - 1} = \frac{kT}{h\upsilon}$$

At low frequencies Planck's formula becomes

$$U(v)dv = \frac{8\pi h v^3}{c^3} dv\left(\frac{kT}{h\upsilon}\right)$$

$$= \frac{8\pi kT v^2}{c^3} dv$$

which is Rayleigh Jeans formula.