Lecture three

- Radiation laws -

2.1 Blackbody Radiation Laws

The laws of blackbody radiation are basic to an understanding of the absorption and emission processes. A blackbody is a basic concept in physics and can be visualized by considering a cavity with a small entrance hole, as shown in **Fig. 2.1**. Most of the radiant flux entering this hole from the outside will be trapped within the cavity, regardless of the material and surface characteristics of the wall. Repeated internal reflections occur until all the fluxes are absorbed by the wall. The probability that any of the entering flux will escape back through the hole is **so small** that the interior appears dark. The term ***blackbody*** is used for a configuration of material where absorption is complete, Emission by a blackbody is the **converse of absorption**.

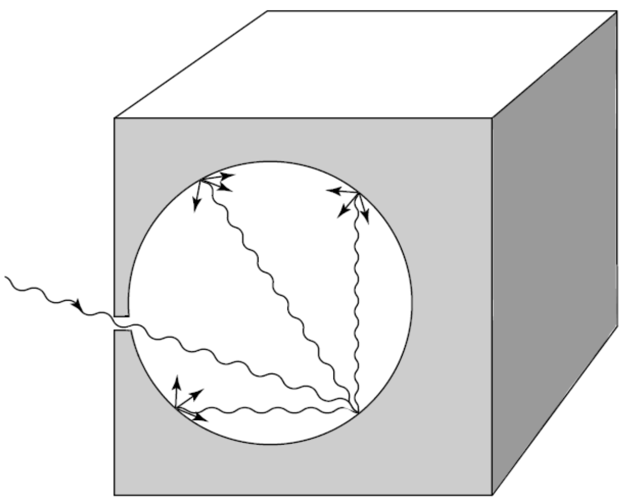


Figure 2.1 A blackbody radiation cavity to illustrate that absorption is complete.

In the following, we present **four fundamental laws** that govern blackbody radiation, beginning with **Planck's law**.

2.2 Planck's Law

Planck's Law, named after the German physicist **Max Planck**, describes the spectral distribution of the radiation emitted by a black body at a given temperature. ***This law plays a fundamental role in understanding the behavior of electromagnetic radiation and the quantization of energy in the form of photons.***

In his detection of a theoretical explanation for cavity radiation, Planck (1901) assumed that the atoms of wall behave like tiny electromagnetic oscillators. The oscillators emit energy into the cavity and absorb energy from it, Planck's law expressed as:

$$B(T,\lambda) = \frac{8\pi hc}{\lambda^5 \left(e^{\frac{hc}{KT\lambda}} - 1 \right)} \quad \text{………………………….. (2.1)}$$

$B(\lambda, T)$: is the spectral radiance of blackbody radiation at a given wavelength λ and temperature T.

h: is Planck's constant (6.626×10^{-34} J·s).

c: is the speed of light (3×10^{8}).

λ: is the wavelength.

K: is the Boltzmann constant (1.38×10^{-23} J/K).

T: is the temperature in kelvin.

Planck derived his law by assuming that energy levels in a blackbody are quantized, meaning that energy can only be emitted or absorbed in discrete units (quanta).

The Planck function relates the emitted monochromatic intensity to the frequency and the temperature of the emitting substance.

Figure 2.2 shows curves of $B_\lambda(T)$ versus wavelength for a number of emitting temperatures. It is evident that the blackbody radiant intensity increases with temperature and that the wavelength of the maximum intensity decreases with increasing temperature. The Planck function behaves very differently when $\lambda \to \infty$, referred to as the *Rayleigh–Jeans distribution,* and when $\lambda \to 0$, referred to as the *Wien distribution*.

Applications of Planck's Law:

- Determining the temperature of stars (e.g., using their spectral radiance).
- Designing devices like infrared sensors and thermal cameras.
- Studying the cosmic microwave background radiation for insights into the early universe.

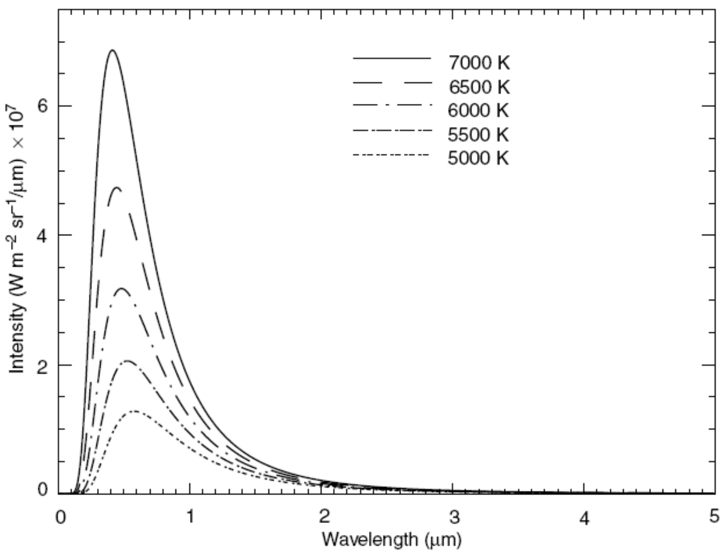


Figure 2.2 Blackbody intensity (Planck function) as a function of wavelength for a number of emitting temperatures.

2.3 Stefan–Boltzmann Law

The total radiant intensity of a blackbody can be derived by integrating the Planck Function over the entire wavelength domain from 0 to ∞. Hence,

$$B(T) = \int_0^\infty B_\lambda(T)d\lambda = \int_0^\infty \left(\frac{2hc^2\lambda^{-5}}{(e^{\frac{hc}{kT\lambda}} - 1)} \right) d\lambda \quad \ldots\ldots\ldots.(2.4)$$

On introducing a new variable $x = hc/k\lambda T$, Eq. (2.4) becomes

$$B(T) = \frac{2k^4T^4}{h^3c^2} \int_0^\infty \frac{x^3dx}{(e^x - 1)}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

The integral term in Eq. (2.5) is equal to $\pi^4/15$. Thus, defining

$$b = \frac{2\pi^4 K^4}{(15c^2h^3)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.6)$$

We then have:

$$B(T) = bT^4 \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.7)$$

Since blackbody radiation is **isotropic**, the flux density emitted by a blackbody is Therefore:

$$\boldsymbol{F = \pi b(T^4) = \sigma T^4} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.8)$$

Where $\boldsymbol{\sigma}$ is the Stefan–Boltzmann constant and is equal to 5.67×10^{-8} J m^{-2} sec^{-1} deg^{-4}. Equation (2.8) states that the flux density emitted by a blackbody is proportional to the fourth power of the *absolute* temperature. This is the **Stefan– Boltzmann law**, fundamental to the analysis of broadband infrared radiative transfer.

2.4 Wien's Displacement Law

Wien's displacement law states that the **wavelength** of the maximum intensity of blackbody radiation is inversely proportional to the **temperature**. Wien's Displacement Law is an empirical law that relates the temperature of an ideal blackbody radiator to the wavelength at which it emits the most radiation. It states that:

λ_{max} * T = constant

Here:

- λ_{max} is the peak wavelength of radiation.
- T is the absolute temperature of the blackbody in kelvin.

The constant of proportionality is approximately 2.898x10^-3m·K.

There are many steps to Determine Wien's law:

1. Find the wavelength at which the spectral radiance is maximized, you need to find the wavelength, λ_{max}, that maximizes B(λ,T) eq. 2.3.
2. Simply, consider finding the maximum of the function $f(\lambda) = \frac{1}{[exp(\frac{hc}{\lambda kT}) - 1]}$, which occurs when its denominator is minimized.
3. Condition for the denominator to be minimized is when the exponent, $\frac{hc}{\lambda kT}$ is equal to 1:

$$\frac{hc}{\lambda_{max}\, kT} = 1$$

- Solve for λ_{max}:

Commented [af1]: المقام

$$\lambda max = \frac{hc}{kT} .$$

- Recognize that $\frac{hc}{k}$ is a constant, which we'll call b:
  $b = \frac{hc}{k}$.
- Now, you have:
  λ_{max} = b / T.
  This equation is essentially Wien's Displacement Law. It shows that the product of the peak wavelength (λ_{max}) and the absolute temperature (T) of a blackbody is a constant (b). As the temperature increases, the peak wavelength decreases, **which means that higher-temperature objects emit radiation with shorter wavelengths.** Where ***b*** **= 2.897 × 10^{-3} m deg.** From this relationship, we can determine the temperature of a blackbody from the measurement of the **maximum monochromatic intensity**. The dependence of the position of the maximum intensity on temperature is evident from the blackbody curves displayed in Fig. 2.2.

2.5 Kirchhoff's Law

The preceding three fundamental laws are concerned with the radiant intensity emitted by a blackbody, which is dependent on the **emitting wavelength** and the **temperature** of the medium. A medium may absorb radiation of a particular wavelength, and at the same time also emit radiation of the same wavelength. This is the fundamental property of a medium under the condition of ***thermodynamic equilibrium***. The physical statement regarding absorption and emission was first proposed by **Kirchhoff (1860)**.
To understand the physical meaning of Kirchhoff's law, we consider a perfectly insulated enclosure having black walls. Assume that this system has reached the state of thermodynamic equilibrium characterized by uniform temperature and isotropic radiation. Since the blackbody absorbs the maximum possible radiation, it has to emit that same amount of radiation.

On the basis of the preceding discussion, the emissivity of a given wavelength, ***ε_λ*** ***(defined as the ratio of the emitting intensity to the Planck function), of a medium is equal to the absorptivity, A_λ (defined as the ratio of the absorbed intensity to the Planck function), of that medium under thermodynamic equilibrium.*** Hence, we may write

$$\varepsilon_\lambda = A_\lambda \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

A medium with an absorptivity A_λ absorbs only A_λ times the blackbody radiant intensity $B_\lambda(T)$ and therefore emits ε_λ times the blackbody radiant intensity.

For a blackbody, absorption is a maximum and so is emission. Thus, we have

$$A_\lambda = \varepsilon_\lambda = 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.15$$

For all wavelengths.

A *gray body* is characterized by incomplete absorption and emission and may be described by

$$A_\lambda = \varepsilon_\lambda < 1. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.16$$

Kirchhoff's law requires the condition of thermodynamic equilibrium, such that uniform temperature and isotropic radiation are achieved.

Obviously, the radiation field of the earth's atmosphere as a whole is not isotropic and its temperatures are not uniform. **However, in a localized volume below about 60–70 km, there is a good approximation, that may be considered to be isotropic with a uniform temperature in which energy transitions are governed by molecular collisions.**

It is in the context of this local thermodynamic equilibrium (LTE) that Kirchhoff's law is applicable to the atmosphere.

2.4 Vertical Profile of Absorption of trace gases (lower atmosphere):

The atmosphere interacts with both incoming solar radiation and outgoing terrestrial radiation. The strength of the interaction as a function of wavelength responsible for heating of the lower atmosphere.

2.4.1 Shortwave Radiation

Blackbody curves for emitters at 5777 K and 280 K are shown in figure 3, above it Also shown is the fraction of light entering the top of the earth's atmosphere that is absorbed before reaching 10 km (middle panel) and sea level.
At 10 km (top of the troposphere) virtually all radiation below **290 nm** has been absorbed. All radiation below **100 nm** is absorbed in the thermosphere above **100 km.**

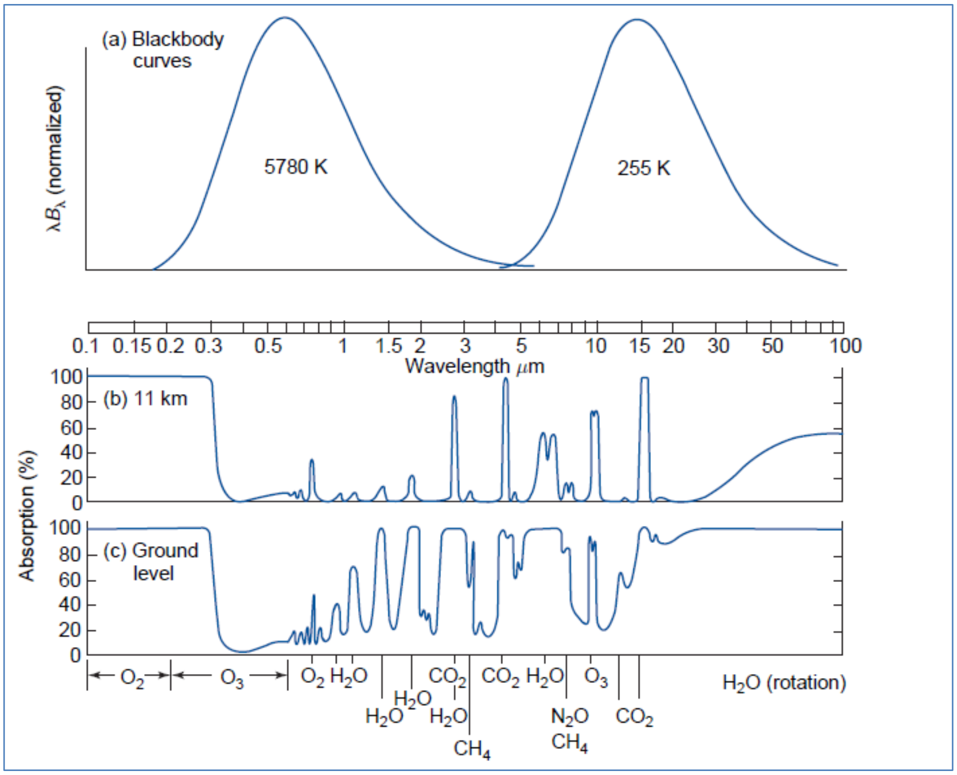


Figure 3: Absorptivity of solar radiation according to wavelength

There is little tropospheric absorption below 0.6um or 600 nm ($1m=10^9nm$) but H_2O and CO_2, at high tropospheric concentrations, deplete the (near IR part) of the incoming solar flux appreciably.

2.4.2 Long wave Radiation (outgoing radiation or Terrestrial Radiation):

1. Much of the outgoing radiation is absorbed in the lowest 10 km where several different molecules are efficient absorbers of upwelling IR radiation much of the outgoing radiation of wavelengths less than ***7 µm*** is absorbed by **water vapor**, with some contribution from ***methane and nitrous oxide, N_2O***.

2. Light of wavelengths longer than **13 µm** is efficiently absorbed by **CO_2**. This band, center at **15 µm**, is important as it lies close to the maximum of the longwave irradiance spectrum. At longer wavelengths **water vapour** is excited into many rotational states that effectively form an absorption continuum beyond **25 µm**.

3. The only fraction of the outgoing radiation that is transmitted through the troposphere without undergoing appreciable absorption lies in the so-called **atmospheric window between 7 and 13 µm.**

The only significant absorptions of infra-red radiation in the stratosphere are due to **ozone**. The **9.6 µm band** of ozone happens to lie in the middle of the atmospheric window and as a result means that stratospheric ozone plays a significant role in the outgoing longwave radiation budget of the Earth.(why?).

2.5. Absorption by Stratospheric (upper Temperature atmosphere)

1. The main layer of ozone in the atmosphere is situated between 15 and 30 km and reaches a maximum concentration of around ***5×10^{12} molecules cm^{-3}*** at 22 km.
2. Zone is a very efficient absorber of solar radiation between ***200*** ***and*** ***300*** ***nm***.
3. The maximum temperature at the top of the stratosphere occurs at around 50 km, well above the main *ozone layer*.
4. To understand the effect of stratospheric ozone on the temperature profile we need to understand the way ozone is created and destroyed in the mesosphere and stratosphere.
   The absorption of UV radiation by both oxygen and ozone leads to their photolysis and the energy involved in these sunlight-induced reactions produces local warming. *The temperature at a particular altitude will then be a combination of the rates of photolysis of the two oxygen species, in particular ozone, and the air density.* The rates of photolysis will depend on the local incidence of radiation and thus on the optical density of the atmosphere in the column above at a given wavelength. Although the temperature profile is

strongly linked to that of ozone its maximum occurs not at the maximum ozone concentration, but above it and close to the region where the photolytic formation and loss processes of ozone are most.

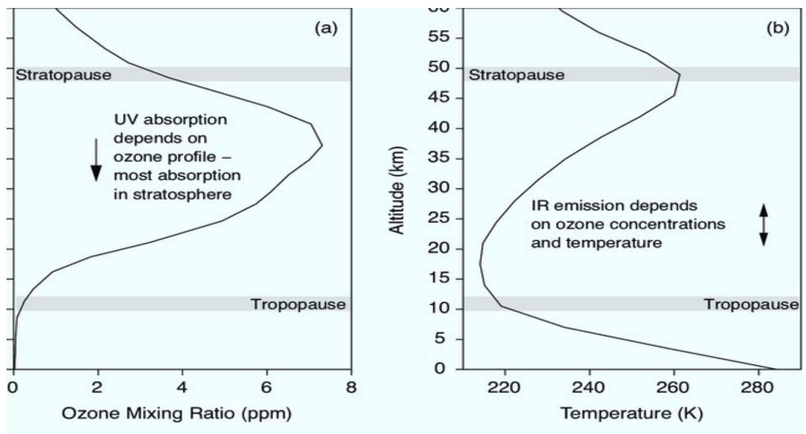


Figure 4: Vertical profiles of ozone-related quantities. (a) Typical mid-latitude ozone mixing ratio profile, (b) atmospheric temperature profile, based on Fleming et al. (1990), showing the stratosphere bounded by the tropopause below and the stratopause above;

Question and Answer Based on Blackbody Radiation

Q1: What is a blackbody in physics?
A1: A blackbody is an idealized physical concept that describes a material or configuration that completely absorbs all radiant flux (electromagnetic radiation) incident upon it, regardless of the wavelength or direction of the radiation.

Q2: How is a blackbody visualized in physical terms?
A2: A blackbody can be visualized as a cavity with a small entrance hole. Any radiant flux entering the hole is trapped within the cavity due to repeated internal reflections, ultimately being absorbed by the cavity walls. The probability of radiation escaping back through the hole is negligible.

Q3: Why does the interior of a blackbody appear dark?
A3: The interior of a blackbody appears dark because most of the radiant flux entering the cavity is absorbed, leaving minimal radiation to escape back through the entrance hole.

Q4: What is the relationship between absorption and emission in a blackbody?
A4: In a blackbody, emission is the converse of absorption. A perfect blackbody not only absorbs all incident radiation but also emits radiation efficiently according to its temperature, as described by Planck's law of blackbody radiation.

Mathematical example

1-Heated body body emitted radiation power 600watt/m^2, calculate the following :

1-Tempeature of that body.

2-Kinetic heat flux of this radiation.

3-Wavelength of this radiation energy.

example :-

Heated body emitted Radiation power 600 $\frac{watt}{m^2}$, calculate The following :

1- Temperature of That body

2- Kinematic heat flux of This Radiation

3- wavelength of This Radiant energy.

used The constants $\sigma = 5.67 * 10^{-8} \frac{watt}{m^2 \cdot K^4}$

$\rho_{air} = 1.2 \frac{kg}{m^2}$, specific heat capacity $= 1000 \frac{J}{kg \cdot K}$

$\rho C_p = 1231 \frac{watt}{m^2} / \frac{K}{(m/s)}$

The answer

① $E = \sigma T^4 \Rightarrow 600 \frac{watt}{m^2} = 5.67 * 10^{8} \frac{watt}{m^2 \cdot K^4} * T^4$

$T^4 = \frac{600}{5.67 * 10^{8} \frac{1}{K^4}} = 1.058 * 10^{+6} K^4$

$\boxed{T = 0.03207 K} = 32,0716 K$

② $E = 600 \frac{watt}{m^2} \longrightarrow \frac{600 \frac{watt}{m^2}}{1231 \frac{watt}{m^2} / \frac{K}{(m/s)}}$

$E = 0.4874 (m/s) \cdot K$

③ $\lambda_{max} = \frac{0.2898 * 10^{-2} m \cdot K}{32.0716 K} = 0.009036 * 10^{-2} m$

$\lambda_{max} = 10^6 * 10^{-2} * 0.009036 = 0.009036 * 10$

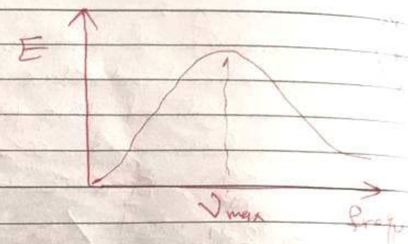
$\boxed{\lambda_{max} = 90,36 \mu m}$

2-Block body have temperature 1500k, calculate its maximum wavelength and frequency at this temperature.

Q1) Block body have Temperature 1500K, calculate ~~its~~ maximum Wavelength and frequency ~~at~~ this Temperature.

$\boxed{\text{The answer}}$

$$T_{max} \lambda_{max} = \frac{2.899*10^{-3}\, m.\cancel{K}}{1500\cancel{K}}$$



$$T_{max} = \frac{2.899*10^{-3}\, m}{1500}$$

$$T_{max} = \frac{2899}{1500} = 1.9326\, \mu m$$

from the law of waves $c = \lambda_m * f_m$

$$\boxed{\lambda_m = \frac{c}{f_m}}$$

$$T_{max} \cdot \lambda_{max} = 2.899*10^{-3}\, m.K$$

$$T \cdot \frac{c}{f} = 2.899*10^{-3}\, m.K \Rightarrow 1500 * \frac{3*10^{8}\, m/s}{f_{max}} = 2.899*10^{-3}$$

$$f_{max} = \frac{1500\cancel{K} * 3*10^{8}\, \frac{m}{s}}{2.899*10^{-3}\, \cancel{m.K}}$$

$$= \frac{4,500*10^{8}\, \frac{1}{s}}{2.899*10^{-3}} = 1002,259*10^{11}\ \text{hertz}$$

Questions and Answers about Blackbody Radiation Laws

Q1: What is a blackbody?

A1: A blackbody is an idealized physical object or configuration of material where absorption of radiation is complete. It absorbs all incident radiant flux and emits radiation because of its temperature.

Q2: How can a blackbody be imagined?

A2: A blackbody can be pictured as a cavity with a small entrance hole. Radiant flux entering the hole is trapped inside the cavity due to repeated internal reflections, ensuring that almost all the radiation is absorbed by the cavity walls. The interior appears dark because the probability of flux escaping back through the hole is negligible.

Q3: What is the consequence of the equilibrium condition in a blackbody within the cavity?

A3: After repeated reflections and interactions within the cavity, absorption and emission of radiation reach an equilibrium state. At this point, the emission depends solely on the temperature of the walls of the blackbody.

Q4: What is the relationship between absorption and emission in a blackbody?

A4: In a blackbody, emission is the converse of absorption. Since a blackbody absorbs all incident radiation, its emission characteristics are determined by its temperature, independent of material or surface properties.

Q5: What are the fundamental laws that govern blackbody radiation?

A5: The fundamental laws governing blackbody radiation include:

1. **Planck's Law** - Describes the spectral distribution of radiation emitted by a blackbody as a function of its temperature.
2. **Wien's Displacement Law** - Relates the wavelength at which the emission is maximum to the temperature of the blackbody.
3. **Stefan-Boltzmann Law** - States that the total energy radiated per unit surface area of a blackbody is proportional to the fourth power of its temperature.

4. **Kirchhoff's Law of Radiation** - States that the emissivity of a body is equal to its absorptivity in thermal equilibrium.

Q6: Why is the interior of the cavity in the blackbody set up dark?

A: The interior appears dark because the radiant flux entering the cavity is trapped due to repeated reflections, and the probability of escaping through the entrance hole is extremely small.

Multiple Select Questions (MSQ) on Planck's Law

Question 1:

Which of the following are key parameters in the expression of Planck's Law?

- Gravitational constant (G)
- Planck's constant (h)
- Wavelength (λ)
- Temperature (T)
- Speed of light (c)
- Electric charge (e)

Answer: Planck's constant (h), Wavelength (λ), Temperature (T), Speed of light (c)

Question 2:

What assumptions did Planck make when deriving his law?

- Energy is emitted or absorbed continuously.
- Energy levels in a blackbody are quantized.
- Atoms of the wall behave like tiny electromagnetic oscillators.
- Blackbody radiation is independent of temperature.

Answer: Energy levels in a blackbody are quantized, Atoms of the wall behave like tiny electromagnetic oscillators.

Question 3:

Which of the following statements about Planck's Law are true?

- It describes the spectral distribution of blackbody radiation.
- It assumes energy is emitted or absorbed in discrete units (quanta).
- It applies only to visible wavelengths.
- It shows that blackbody intensity increases with temperature.

Answer: It describes the spectral distribution of blackbody radiation, It assumes energy is emitted or absorbed in discrete units (quanta), It shows that blackbody intensity increases with temperature.

Question 4:

What are some applications of Planck's Law?

- Determining the temperature of stars.
- Measuring gravitational waves.
- Designing infrared sensors and thermal cameras.
- Studying the cosmic microwave background radiation.
- Calculating the speed of sound.

Answer: Determining the temperature of stars, Designing infrared sensors and thermal cameras, Studying the cosmic microwave background radiation.

Question 5:

What happens to the Planck function at extreme wavelengths?

- At $\lambda \to \infty$, it approaches the Rayleigh–Jeans distribution.
- At $\lambda \to 0$, it approaches the Wien distribution.
- At $\lambda \to 0$, intensity becomes constant.
- At $\lambda \to \infty$, intensity is infinite.

Answer: At $\lambda \to \infty$, it approaches the Rayleigh–Jeans distribution, At $\lambda \to 0$, it approaches the Wien distribution.

Multiple Select Questions (MSQ) on Stefan–Boltzmann Law

Question 1:

Which of the following are true about the Stefan–Boltzmann Law?

- It states that the flux density emitted by a blackbody is proportional to the fourth power of its absolute temperature.
- It states that the flux density emitted by a blackbody is independent of temperature.
- It applies to blackbody radiation across all wavelengths.
- It applies only to visible wavelengths.

Answer: It states that the flux density emitted by a blackbody is proportional to the fourth power of its absolute temperature, It applies to blackbody radiation across all wavelengths.

Question 2:

What is the expression for the total flux density emitted by a blackbody as per the Stefan–Boltzmann Law?

- ☐ $F = \pi b(T^2)$
- ☑ $F = \sigma T^4$
- ☐ $F = bT^5$
- ☑ $F = \pi b(T^4)$

Answer: F=σT4, F=πb(T4)

Question 3:

What does the Stefan–Boltzmann constant (σ\sigma) represent, and what is its value?

- ☑ It is the proportionality constant in the Stefan–Boltzmann Law.
- ☑ Its value is $5.67 \times 10^{-8}\,\mathrm{J\,m^{-2}\,s^{-1}\,K^{-4}}$.
- ☐ It is a measure of the speed of light in vacuum.
- ☐ Its value is $6.626 \times 10^{-34}\,\mathrm{J\,s}$.

Answer: It is the proportionality constant in the Stefan–Boltzmann Law, Its value is 5.67×10^{-8} J m^{-2} s^{-1} K^{-4}

Question 4:

What is the relationship between the total radiant intensity (B(T)B(T)) and temperature (TT) in the Stefan–Boltzmann Law?

- ☑ $B(T) \propto T^4$
- ☐ $B(T) \propto T^2$
- ☑ $B(T) = bT^4$, where b is a constant derived from Planck's function.
- ☐ $B(T)$ is independent of temperature.

Answer: B(T)∝T4, where b is a constant derived from Planck's function.

Question 5:

Which of the following are steps involved in deriving the Stefan–Boltzmann Law?

- ☑ Integrating the Planck function over all wavelengths.
- ☑ Introducing a new variable $x = \frac{hc}{k\lambda T}$.
- ☐ Subtracting the Wien distribution from the Rayleigh–Jeans distribution.
- ☑ Using the result $\int_0^\infty x^3/(e^x - 1)dx = \pi^4/15$.

Questions and Answers on Wien's Displacement Law

Q1: What does Wien's Displacement Law state?

A1: Wien's Displacement Law states that the wavelength of maximum intensity (λmax\lambda_{\text{max}}) of blackbody radiation is inversely proportional to the absolute temperature (TT) of the blackbody. Mathematically:

$$\lambda_{\max} \cdot T = \text{constant}$$

The constant is approximately $2.898 \times 10^{-3}\,\mathrm{m}\backslash\mathrm{cdotpK}$.

Q2: What is the constant in Wien's Displacement Law, and what is its value?

A2: The constant in Wien's Displacement Law is denoted as b and is equal to $2.898 \times 10^{-3}\,\mathrm{m}\backslash\mathrm{cdotpK}$.

Q3: What is the significance of Wien's Displacement Law?

A3: The law helps determine the temperature of a blackbody by measuring the wavelength of its maximum radiation intensity. It also shows that higher-temperature objects emit radiation at shorter wavelengths.

Q4: How is the peak wavelength (λ_{max}) determined?

A4: The peak wavelength is determined by maximizing the Planck function B(λ,T). The condition for the maximum occurs when the exponent in the Planck function, hc/(λkT), equals 1. Solving for λmax, we get:

$\lambda_{\max}$, we get:

$$\lambda_{\max} = \frac{b}{T}$$

where $b = \frac{hc}{k}$ is a constant.

Q5: What happens to the peak wavelength as the temperature of a blackbody increases?

A5: As the temperature of a blackbody increases, the peak wavelength (λmax) decreases. This means that hotter objects emit radiation at shorter wavelengths, shifting toward the blue or ultraviolet part of the spectrum.

Q6: What physical constant values are used in deriving Wien's Displacement Law?

A6: The constants used in deriving Wien's Displacement Law include:

- Planck's constant (h) = 6.626×10^{-34} J\cdotps
- Speed of light (c) = $3 \times 10^{8}\ \mathrm{m/s}$
- Boltzmann constant (k) = $1.38 \times 10^{-23}\ \mathrm{J/K}$

Q7: How does Wien's Displacement Law relate to blackbody curves?

A7: Wien's Displacement Law explains the dependence of the peak intensity position on temperature. In blackbody radiation curves, as temperature increases, the peak of the curve shifts to shorter wavelengths, demonstrating the inverse relationship between (λmax) and T.

Multiple Select Questions (MSQ) on Kirchhoff's Law

Q1: What does Kirchhoff's Law state under thermodynamic equilibrium?

- ☑ The emissivity (ϵ_λ) of a medium is equal to its absorptivity (A_λ).
- ☐ The emissivity (ϵ_λ) is always greater than the absorptivity (A_λ).
- ☐ The absorptivity (A_λ) of a blackbody is less than 1.
- ☑ A blackbody has maximum absorption and emission, with $A_\lambda = \epsilon_\lambda = 1$.

Q2: What is the value of emissivity (ϵλ) and absorptivity (Aλ) for a blackbody?

(Select all that apply)

- ☑ $\epsilon_\lambda = 1$
- ☑ $A_\lambda = 1$
- ☐ $\epsilon_\lambda = 0$
- ☐ $A_\lambda = 0.5$

Q3: What are the characteristics of a gray body as described by Kirchhoff's Law?

(Select all that apply)

- ☐ $A_\lambda = \epsilon_\lambda = 1$
- ☑ $A_\lambda = \epsilon_\lambda < 1$
- ☑ It exhibits incomplete absorption and emission.
- ☐ Its radiation is isotropic under all conditions.

Q4: Under which conditions is Kirchhoff's Law applicable to the Earth's atmosphere?

- When the atmosphere is in a state of local thermodynamic equilibrium (LTE).
- When the atmospheric radiation field is always isotropic.
- In localized volumes below about 60–70 km.
- At altitudes where molecular collisions do not occur.

Answer: When the atmosphere is in a state of local thermodynamic equilibrium (LTE), In localized volumes below about 60–70 km.

Q5: Which of the following statements about thermodynamic equilibrium and Kirchhoff's Law are true?

- Uniform temperature and isotropic radiation are required for thermodynamic equilibrium.
- A medium in thermodynamic equilibrium emits and absorbs radiation proportionally.
- Kirchhoff's Law does not apply to blackbodies.

- Earth’s entire atmosphere satisfies thermodynamic equilibrium conditions.