Kirchhoff’s Law of Thermal Radiation

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1. Introduction

Thermal radiation plays a crucial role in **statistical mechanics**, **thermodynamics**, and **quantum theory**. Every body at a temperature above absolute zero emits electromagnetic radiation. The nature of this radiation depends on the temperature and the surface properties of the body.

To relate **emission** and **absorption** of radiation, **Kirchhoff formulated a fundamental law**, known as **Kirchhoff's Law of Thermal Radiation**.

Kirchhoff's Law states:

> At a given temperature and wavelength, the ratio of the emissive power of a body to its absorptive power is the same for all bodies and is equal to the emissive power of a perfectly black body at that temperature and wavelength.

Mathematically,

where:

- = emissive power of the body
- = absorptive power of the body
- $E_\lambda(T)$ = emissive power of a black body at temperature T

3. Important Definitions

- **Emissive Power (e_λ)**:
  Energy radiated per unit area per unit time per unit wavelength.
- **Absorptive Power (a_λ)**:
  Fraction of incident radiation absorbed by a body.
- **Black Body**:
  An ideal body which absorbs **all incident radiation** and emits maximum possible radiation.

4. Derivation of Kirchhoff’s Law

Consider an enclosure maintained at uniform temperature T.

Let:

- Body **A** have emissive power e_λ and absorptive power .
- Body **B** be a black body with emissive power E_λ and absorptive power $a_\lambda = 1$.

Thermal Equilibrium Condition

In thermal equilibrium:

$$\text{Energy absorbed} = \text{Energy emitted}$$

For body **A**:

$$a_\lambda E_\lambda = e_\lambda$$

Rearranging,

$$\frac{e_\lambda}{a_\lambda} = E_\lambda$$

Since E_λ depends only on **temperature and wavelength**, the ratio $\frac{e_\lambda}{a_\lambda}$ is **universal**, independent of the nature of the body.

✅ **Hence proved — Kirchhoff's Law of Thermal Radiation.**

5. Physical Explanation

- Good absorbers are **good emitters**.
- Poor absorbers are **poor emitters**.
- Black bodies absorb all radiation and emit maximum radiation.

This law explains why:

- Black surfaces cool faster.
- Polished metals reflect heat efficiently.
- Cavity radiation behaves like black-body radiation.

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6. Significance of Kirchhoff’s Law

1. Forms the **foundation of black-body radiation theory**
2. Leads to **Planck’s radiation law**
3. Explains **thermal equilibrium radiation**
4. Important in **statistical mechanics & quantum physics**
5. Applications in:
   - Astrophysics
   - Thermal engineering
   - Climate science

7. Limitations

- Applicable only in **thermal equilibrium**
- Does not explain radiation distribution (explained later by Planck)

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8. Conclusion

Kirchhoff’s Law establishes a fundamental relationship between **emission and absorption** of radiation. It bridges **classical thermodynamics** and **statistical mechanics**, and serves as a stepping stone toward **quantum theory of radiation**.

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