Advance in Electronic and Electric Engineering.
ISSN 2231-1297, Volume 4, Number 4 (2014), pp. 361-366

http://www.ripublication.com/aeee.htm

Quantum Mechanics and Applications

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Abstract

All the matters in the world are made up of small kinds of particle known as atoms etc. The study of such small and minute particles falls under the field of physics. The major part of the physics is mainly based on the light. The study of the characteristics of light and its interior matters is known as quantum mechanics or quantum theory or quantum physics. The aim of the paper is to provide the sufficient knowledge about the quantum mechanics and the laws derived based on the quantum theory.

Note: Atoms are made up of small kinds of particles known as electrons, protons, neutrons.

1. Introduction

1.1 Physics

The branch of science concerned with the nature and properties of matter and energy. The definition of physics can be given as "the study of matter, energy, and the interaction between them".

1.2 Classification of physics

Physics is then divided into two major category based upon some of the characteristics. They are

- Classical theory
- Quantum theory

1.2.1 Classical theory

The classical theory successfully explained the motion of an object that is visible to our eyes or observed by the microscope. It failed to explain the behavior of atomic particles such as electron and also about the hydrogen spectrum, stability of atoms, extra nuclear space.

1.2.2 Quantum theory

In order to overcome the failures of classical theory a new theory was proposed which is mainly based on the concept of photons. This theory is known as quantum theory.

2. Quantum Theory

2.1 Quantum theory

The quantum theory was proposed by Max Planck in 1900. This theory deals with the body of science principles that explains the behavior of matter and its interaction with energy on the scale of atoms and subatomic particles, mainly with the photons.

This theory overcome all the failures of the classical theory and also give rise to new theories such a s black body radiations, photoelectric effect, Zeeman effect, Compton effect, absorption and emission of light.it deals with the physical phenomena at microscopic scales, which is in order of Planck constant.

The quantum theory is otherwise known as quantum mechanics, or quantum physics. The theories that comes under the concept of quantum theory are

- Black body radiation
  - Stefan-Boltzmann law
  - Kirchhoff's law
  - Wien's displacement law
  - Rayleigh-jeans' law
- Planck quantum theory
- Compton effect
- Time dependent equation & time independent equation
- Schrodinger wave equation
- De Broglie wavelength

3. Black Body Radiation

3.1 Black body

Ablack body is defined as an object that appears black and emits all kinds of radiation when it's heated. It absorbs all radiations of any frequency.

Spectrum of black body radiation:

- Emits radiations from shorter to longer wavelength
- Energy density is directly proportional to the wavelength
- Energy density is directly proportional to the temperature

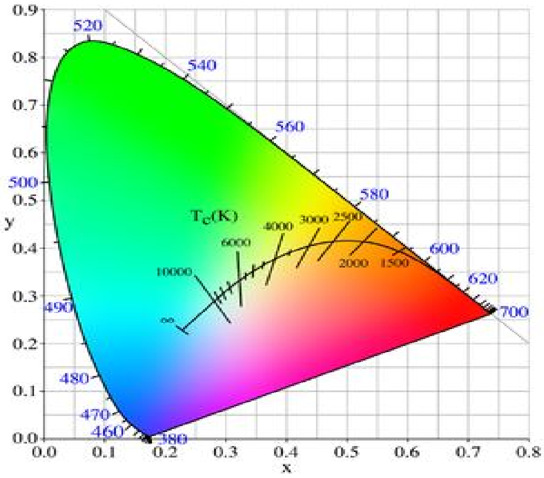


Fig. 1: Black body spectra.

3.2 Laws of black body radiation

3.2.1 Kirchhoff's law

The ratio between the emissive power and the absorption coefficient at a particular wavelength and constant temperature is equal to the emissive power of that black body at that particular temperature and wavelength.

$$B_\lambda(T) = B_\nu(T)\left|\frac{d\nu}{d\lambda}\right|.$$

3.2.2 Stefan-Boltzmann law

The quantity of energy radiated per unit area of cross section of black body is directly proportional to the fourth power of the absolute temperature.

$$E^* = \sigma T^4$$

where σ (sigma) = $5.67 \times 10^{-8}\ Wm^{-2}\ K^{-4}$

and T is the temperature in Kelvin

3.2.3 Wien's displacement law

The wavelength corresponding to maximum energy density of a black body is inversely proportional to its absolute temperature.

$$\lambda_m T = 2897.8[\mu m \cdot K]$$

3.2.4 Rayleigh-jeans 'law

The energy radiated by a black body per second per unit area of cross section in a frequency range of v and v+dv is given by.

$$N = \frac{8\pi L^3}{3\lambda^3}$$

4. Planck Quantum Theory

The Planck law describes the electromagnetic radiation emitted by a black body in thermal equilibrium at a definite temperature.

Postulates

- The oscillators vibrate at all frequencies
- The frequency of radiation emitted by a oscillator is equal to the frequency of vibration of the oscillator
- The oscillator emits discrete energy
- The oscillators emit or absorb radiation in the order of hv

Derivation

The total number of oscillators present in a black body is given by:

N = N0 + N1 + N3 + (1)

N=N0 exp (-nE/kT) (2)

Where n=0, 1, 2, 3, 4, 5

N = N0 [1 + exp (-E/kT) + exp (-2E/kT) + exp (-3E/kT) +] (3)

Average energy of the oscillator is given by the ratio of the total energy to the total number of oscillators.

Average energy = E/N ….. (4)

By substituting the value of the average energy of equation (4) in equation (3)

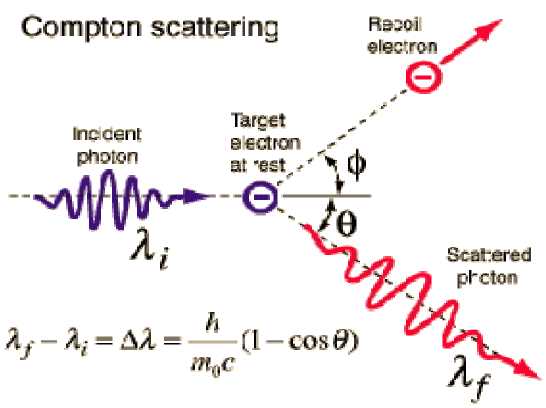
$$I(\nu) = \left(\frac{8\pi h\nu^3}{c^3}\right)\frac{1}{e^{h\nu/k_BT}-1} \qquad (5)$$

Energy density = number of oscillators per unit volume x average energy of the oscillators

Equation (5) is known as Planck equation for black body radiation

5. Compton Effect

When a monochromatic beam of X-rays is made to incident on a scatterer with low atomic weight such as carbon, two scattered beams are observed, one with same frequency and another one with reduced frequency. This phenomenon is known as Compton effect.



6. Schrodinger Wave Equation

The Schrodinger equation describes the state and evolution of quantum mechanical systems. It's centrality to quantum mechanics can be compared to the importance of Newton's laws of motion. This equation can be given in to two forms. They are:

- Time dependent wave equation
- Time independent wave equation

$$H\Psi = i\hbar \frac{\partial \Psi}{\partial t} \qquad \frac{-\hbar^2}{2m}\frac{\partial^2 \Psi(x)}{\partial x^2} + U(x)\Psi(x) = E\Psi(x)$$

Time evolution   Time independent equation

7. DE-Broglie Wave Equation

The wavelength of the wave associated with any material particle was calculated by analogy with photons. According to Planck quantum theory it is assumed to have wave character, and according to Einstein equation it is assumed to have particle character.

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

Where P is the momentum of the particle

De-Broglie equation connects the wave nature with the particle nature of the matter.

8. Applications

- Pivotal experiments in quantum physics - The hydrogen atom
- Interaction of radiation and matter - Atomic clocks
- Photo-electric effect - Franck-Hertz experiment
- It explains the spectral series of hydrogen atom
- It is used in Davisson and Germer experiment
- Used to determine the wave nature and particle nature of matter
- Used for the measurement of photon momentum and intensity of light
- With the application of quantum physics the characteristics of light can be studied.

9. Conclusion

Photons exists all over the universe in the form of light. It has a wide range of applications and a lot of different characteristics. Quantum theory and the laws related to it gives us a brief idea about the application of light and photons in various fields.

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