DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB101J-Electromagnetic Theory, Quantum Mechanics, Waves and Optics

Module 3- Lecture-II

Blackbody Radiation, concept of photon, Qualitative explanations -Photoelectric effect & Compton effect

Topics of Lecture 2:- Blackbody Radiation, concept of photon
Qualitative explanations -Photoelectric effect & Compton effect

Blackbody Radiation

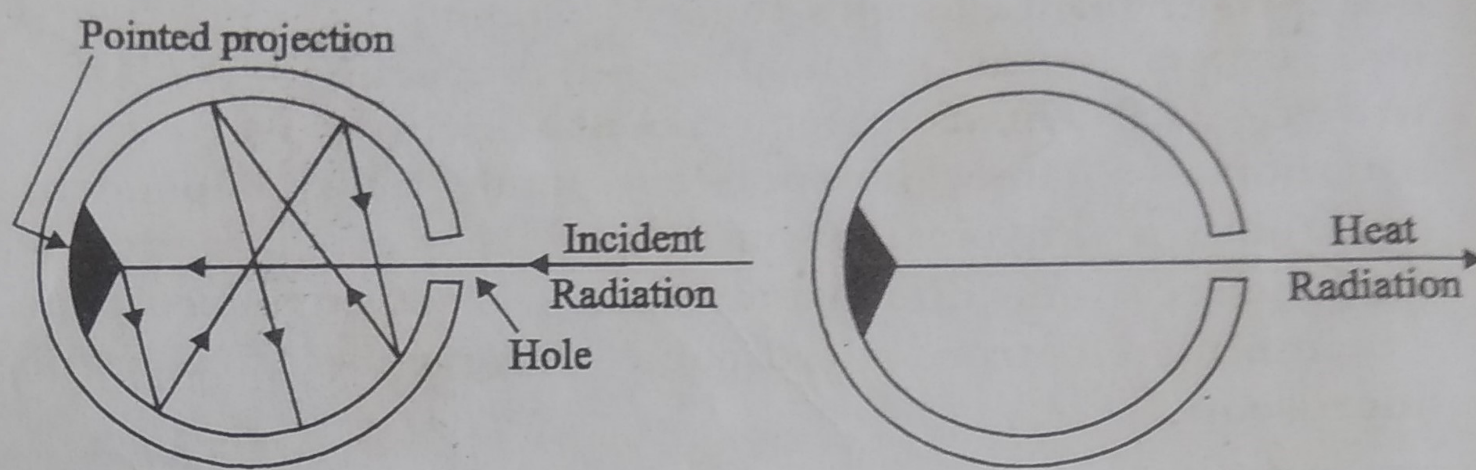
Black Body

In practice, a perfect black body is not available. The body showing close approximation to a perfect black body can be constructed.

A hollow copper spherical shell is coated with lamp black on its inner surface. In this, a fine hole is made and a pointed projection is provided just in front of the hole. (Fig. 4.1(a)).

When the heat radiations enter into this spherical shell through the hole, the heat radiations suffer multiple reflections and they are completely absorbed. **Now, this body acts as an absorber**.

When this body is placed in a constant temperature bath at high temperature, the heat radiations comes out from the hole (Fig. 4.1(b)). **Now, this hole acts as a radiator**. It is to be noted that only the hole and not the walls of the body acts as the radiator.



(a) Absorber **(b) Radiator**

Fig. 4.1 Black body

Perfect black body

A perfect black body is one which absorbs all the heat radiations (all the wavelengths) incident on it. Further, when such a body is placed at constant high temperature, it emits radiation of all the wavelengths.

Black body radiation

The heat radiation emitted from a black body is known as black body radiation.

The wavelength at which the maximum energy of radiation emitted depends only on temperature of the black body and it does not depend on the nature of the material.

> Any object coated with a dull black pigment is a good approximation to a perfect black body.

Concept of Photon:

- A photon is an elementary particle. It is a quantum of light.
- Energy of a photon is given by $E=h\nu$. Its momentum is $p=h\nu/c$ and speed is c, which is the speed of light.
- Irrespective of the intensity of radiation, every photon of a frequency ν has the same momentum $p=h\nu/c$ and energy $E=h\nu$.
- The increase in the intensity of light only increases the number of photons crossing an area per unit time. It does not affect the energy of the radiation.
- A photon remains unaffected by electric and magnetic fields. It is electrically neutral.
- A photon has a zero mass, i.e. it is massless.
- It is a stable particle.

Concept of Photon:

- Photons can be created or destroyed when radiation is emitted or absorbed.
- The total energy and momentum are conserved during a photon-electron collision.
- A photon cannot decay on its own.
- The energy of a photon can be transferred during an interaction with other particles.
- A photon is a spin-1 particle, unlike electrons which are ½ spin. It's spin axis is parallel to the direction of travel.

4.6 COMPTON EFFECT

Compton effect refers to the change in the wavelength of scattered X - rays by a material.

Statement

When a beam of X - rays is scattered by a substance of low atomic number, the scattered X - ray radiation consists of two components, one component has the same wavelength λ as the incident ray and the other component has a slightly longer wavelength λ'.

This change in the wavelength of scattered X - rays is known as Compton shift. The phenomenon is called Compton effect.

The radiations of unchanged wavelength in the scattered radiations are called **unmodified radiations**. The radiations of longer wavelength are known as **modified radiations**.

The change of wavelength is due to loss of energy of the incident X - rays.

Explanation

The compton effect was explained on the basis of quantum theory of radiation. The X - radiation consists of quanta or photons each having an energy of $h\nu$. These photons move with velocity of light (c). They obey the laws of conservation of energy and momentum when they undergo collision.

The whole process is treated as a particle - particle collision between X - ray photon and a loosely bound electron of the atom in the scattering substance.

When a photon of energy $h\nu$ collides with a free electron of the scattering substance initially at rest, the photon transfers some of its energy to the electron (fig. 4.3).

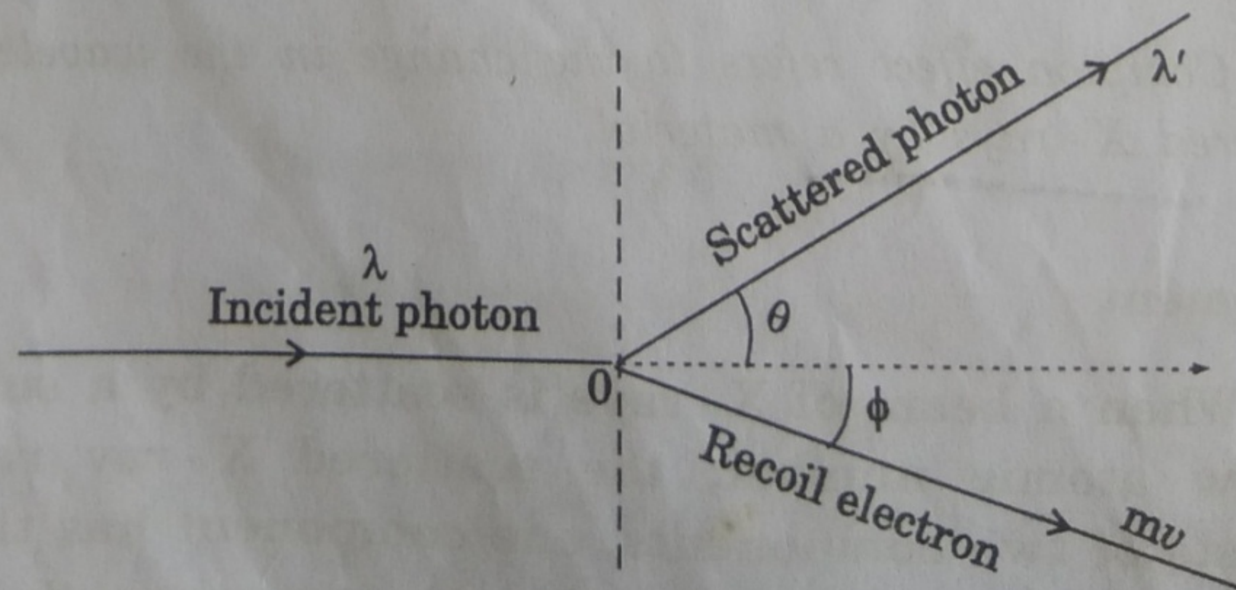


Fig. 4.3 Compton effect

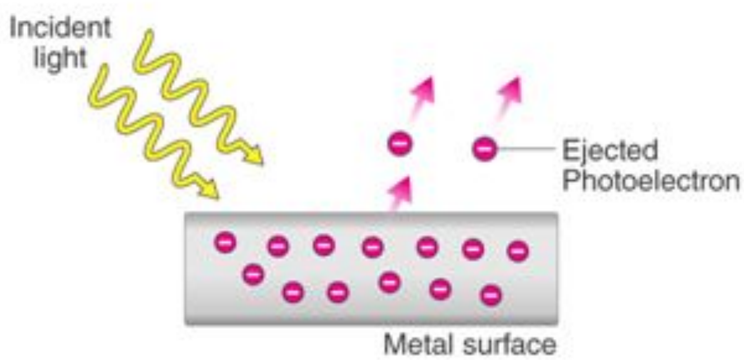
The electron gains kinetic energy and it recoils with velocity v. Therefore, the scattered photon has lower energy, (lower frequency and longer wavelength) than that of the incident one.

Photoelectric effect

The photoelectric effect is a phenomenon in which electrons are ejected from the surface of a metal when light is incident on it. These ejected electrons are called **photoelectrons**. It is important to note that the emission of photoelectrons and the kinetic energy of the ejected photoelectrons is dependent on the frequency of the light that is incident on the metal's surface. The process through which photoelectrons are ejected from the surface of the metal due to the action of light is commonly referred to as **photoemission**.

The photoelectric effect occurs because the electrons at the surface of the metal tend to absorb energy from the incident light and use it to overcome the attractive forces that bind them to the metallic nuclei. An illustration detailing the emission of photoelectrons as a result of the photoelectric effect is provided below.

Photoelectric effect



Explaining the Photoelectric Effect: The Concept of Photons

The photoelectric effect cannot be explained by considering light as a wave. However, this phenomenon can be explained by the particle nature of light, in which light can be visualized as a stream of particles of electromagnetic energy. These ‘particles’ of light are called **photons**. The energy held by a photon is related to the frequency of the light via Planck’s equation:

$$\mathbf{E = h\nu = hc/\lambda}$$

Photoelectric effect

Where,

E denotes the energy of the photon

h is Planck's constant

ν denotes the frequency of the light

c is the speed of light (in a vacuum)

λ is the wavelength of the light

Thus, it can be understood that different frequencies of light carry photons of varying energies. For example, the frequency of blue light is greater than that of red light (the wavelength of blue light is much shorter than the wavelength of red light). Therefore, the energy held by a photon of blue light will be greater than the energy held by a photon of red light.