Planck's Constant and Inverse Square Law of Radiation

1 Aim

Determination of Planck's constant and to verify inverse square law of radiation using a photoelectric cell.

2 Introduction

In 1900, Planck derived the following formula for the spectral energy density of black-body radiation

$$u(\nu)d\nu = \frac{8\pi h}{c^3}\frac{\nu^3 d\nu}{e^{h\nu/kT} - 1}$$

where h is a constant given by $h = 6.626 \times 10^{-34}$ J.s This implies that the oscillators in the cavity do not have a continuous distribution of possible energies by must have specific energies

$$\epsilon_n = nh\nu, \quad n = 0, 1, 2, ...$$

An oscillator emits radiation of frequency ν when it drops from a state with higher energy to a state with lower energy and jumps to the next higher state when it absorbs radiation of frequency ν. This discrete bundle of energy is called a quantum and h determines the size of the quantum.

During his experiments on electromagnetic waves, Hertz observed that there were more sparks in his transmitter when ultraviolet light was directed at one of the metal balls in it. Others followed up this observation and discovered that electrons were emitted when frequency of light was sufficiently high. This phenomenon is known as the **photoelectric effect** and the electrons emitted are called **photoelectrons**.

Experiments showed :

1. Within the limits of experimental accuracy there is no time interval between the arrival of light at a metal surface and the emission of photoelectrons. This was unexpected because the energy in an electromagnetic wave is supposed to be spread

across the wavefronts and a period of time should elapse before the electrons accumulate enough energy to leave the metal.

2. A bright light yields more photoelectrons than a dim one of the same frequency, but the electron energies remain the same. However, the electromagnetic theory predicts that more intense the light, greater are the energies of the electrons.

3. The higher the frequency of light, the more energy the photoelectrons have. Blue light results in faster electrons than red.

In 1905, Einstein realized that the photoelectric effect can be understood if the energy in light is not spread out over wavefronts but is concentrated in photons. Each photon of light of frequency ν and energy $h\nu$, same as Planck's quantum energy. The observations listed above were explained directly by Einstein's hypothesis.

There is a minimum energy ϕ for an electron to escape from a metal. This energy is called the work function of the metal and is related to the critical frequency ν_0 by the formula

$$\phi = h\nu_0$$

If the frequency of light is such that

$$h\nu > e\phi$$

it will be possible to eject photoelectrons. In this case the excess energy appears as the kinetic energy of the electron, so that

$$h\nu = \frac{1}{2}mv^2 + e\phi$$

which the Einstein formula for photoelectric effect.

The energy of the emitted photoelectrons can be measured retarding potential techniques. The retarding potential (or the stopping potential) V_s is used to measure the kinetic energy of electrons E_e given by

$$E_e = \frac{1}{2}mv^2 = eV_s$$

which implies

$$V_s = \frac{h}{e}\nu - \phi$$

A plot of V_s as a function of ν has a slope h/e and the intercept gives the work function ϕ.

If L is the luminosity of an electric lamp and E is the luminescence (intensity of lumination) at a point at distance "r" from it,then according to the inverse law

$$E = \frac{L}{r^2}$$

Figure 1: Experimental setup.

The photoelectric current I would then be given by

$$E = \frac{L}{r^2} = K.I$$

The inverse square law can be verified by plotting I Vs $1/r^2$.

3 Apparatus in the Lab

1. **Photo sensitive device** : Vacuum photo tube.
2. **Light Source**: Halogen tungsten lamp $12V/35W$.
3. **Colour filters**: $635nm$, $570nm$, $500nm$
4. Accelerating Voltage : Regulated Voltage Power Supply

   Output : $\pm$ $15V$ continuously variable through multi turn pot

Display : $31/2$ digit 7-segment LED

Accuracy : $\pm 0.2\%$

5. Current Detecting Unit : Digital nanometer. It is high stability low current measuring instrument.

   Range: X $1\mu A$, $0.1\mu A$, $0.01\mu A$ and $0.001\mu A$ with 100 % over ranging facility

   Resolution : $1nA$ at $0.001\mu A$ range

   Display : $31/2$ digit 7-segment LED

   Accuracy : $\pm 0.2\%$

6. **Power Requirement** : $220V \pm 10\%$, $50Hz$.
7. **Optical bench** : The light source can be moved along it to adjust the distance between the light source and the phototube (scale-length is 400mm). A draw-tube is provided to install color filter; a focussing lens is fixed in the back end.

4 Procedure I

1. Insert the red filter (635 nm), set light intensity switch at strong light, voltage direction switch at "-", display mode switch at current display.
2. Adjust to de-accelerating voltage to $0V$ and set the current multiplier at X0.001. Increase the de-accelerating voltage to decrease the photocurrent to zero. Note the de-accelerating voltage V_s corresponding to zero current (for wavelength = 635nm). Repeat the exercise for other wavelengths.

5 Procedure II

To verify the inverse square law of radiation using a photoelectric cell.

1. The connection would be the same as before except that a positive voltage is applied to the anode with respect to the cathode.
2. Place a filter in front of the photoelectric cell.
3. Keeping the voltage constant and position of photocell fixed, increase the distance of the lamp from the photocell in small steps. In each case, note the position of the lamp on the optical bench "r"and the current "I".
4. Repeat the same for other filters.

6 Precautions

1. The phototube should not be exposed to direct sunlight and the room should be only dimply lit.

2. The instrument should be kept in a dust proof and moisture proof environment, if there is dust on the phototube, colour filter, lens etc., clean it by using absorbent cotton with a few drops of alcohol.

3. After finishing the experiment remember to switch off power and cover the draw-tube with the lens cover provided. Phototube is light sensitive device and its sensitivity decrease with exposure to light and due to ageing.