The Photoelectric – X Ray Experiment and Possible Proof of De-Broglie Bohm Theory

Ajinkya J. Naik;

Residential Address:- A-16, Shivnagri Society, Jijai Nagar, Pune-411038, Maharashtra India.

Contact :- najinkya1313@gmail.com

+91-9423974007

Position :- 12^{th} std Science student

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1.Abstract

Photoelectric effect and the production of X-Rays in Cathode Ray Tube are two correlated phenomena. It is quite surprising to note that there has been no substantial attention given to this correlation. It is possible to bridge these two separate processes, enabling us to study the quantum interactions which occur naturally. A modified version of Photoelectric setup can be used, in which the ejected photoelectrons with high energies travel to the anode. A heavy metal viz. Tungsten is used as anode, which produces X-Rays due to photoelectronic collisions with anode. The photoelectrons are assumed to be non-relativistic and a relation is obtained between the De-Broglie Wavelength of the photoelectrons ($\boldsymbol{\lambda}_{\mathrm{e}}$*) and the wavelength of X-Rays (*$\boldsymbol{\lambda_x}$*) such that* $\boldsymbol{\lambda_x} = \boldsymbol{\Psi\lambda}_{\mathrm{e}}{}^2$*.*

The connection of results with a possible proof of De-Broglie Bohm Hypothesis is then discussed in Final Discussion.

2. Background and Introduction

The Photoelectric Effect – first discovered in 1887 by Heinrich Rudolf Hertz and then later associated with Planck's results of blackbody radiation by Albert Einstein in 1905 is an important phenomenon involving particle interactions on a quantum level. A corresponding discovery was made in 1895 by Wilhelm Conrad Roentgen, when he observed X-Rays in Cathode Ray Tubes. In 1913, William Coolidge invented the Coolidge Tube[1] which was used for continuous production of X-Rays. These two phenomena found remarkable applications in the field of applied science and engineering. The Photoelectric effect and X-Ray production is being employed in an array of everyday tasks ranging from Solar Cells to Medical Diagnostics and Treatment.

Both processes form a closed chain of quantum interactions which can be studied closely with least artificial hindrance. In the photoelectric effect, a photon's energy is completely utilized to free an electron from the binding nuclear forces. Photons are completely annihilated in this process and we are obliged to think about the Quantum Information carried by the photons i.e. its Maxwell Wave Function[2]. The information must be imprinted either on the ejected photoelectron or must be propagated somewhere else. Since quantum information of a state is indirectly attributed to its wavefunction, a relation can be obtained between the De-Broglie wavelength of an electron and the electromagnetic wavelength of a *photon at the event of a photoelectric interaction. There must exist a transforming equation which relates the De-Broglie wavelengths of two quantum particles during an interaction in which one particle is annihilated or absorbed.*

The prime reason for bridging Photoelectric Effect and X-Ray Generation Process into a Photoelectric X-Ray setup is the setup acts as an input-output machine, receiving an input (a photon of suitable frequency or an energetic electron), passing it through two quantum interactions and finally an output which is a particle of same nature as that of input. The significance of such nature of this setup is that the output particle can be analyzed and compared with input particle to obtain any resemblance or simple relation regarding their quantum characteristics such as wavelengths, wavefunctions, etc. If one finds any resemblance in these characteristics, then it is plausible to deduce that the quantum information of input particle which was initially absorbed completely at the first quantum interaction is imprinted on the next particle. The particle on the second interaction delivers this information completely or partially on the output particle. Thus, this experiment is a potential way to interpret the nature of quantum interactions between a pair of particles involving absorption of one particle.

3.Photoelectric X-ray Setup

The setup will consist of a simple connection between a standard Photoelectric setup and an X- Ray generation setup. The experiment can be set in an alternate way (Phase 2) where the X-Ray generation will be followed by the Photoelectric effect.

An artificial source of electromagnetic radiation, preferably X-Rays are made incident on a photosensitive surface. The frequency of incident radiation is so chosen that the ejected photoelectrons possess maximum kinetic energy. Ejected photoelectrons are then accelerated through a vacuum tube through an electric potential towards the anode. A heavy metal like Tungsten is used as anode. The X-Rays generated at anode are then sent to the analyzer, to map their characteristics like Polarization, Wavelength, Amplitude, Phase, etc.

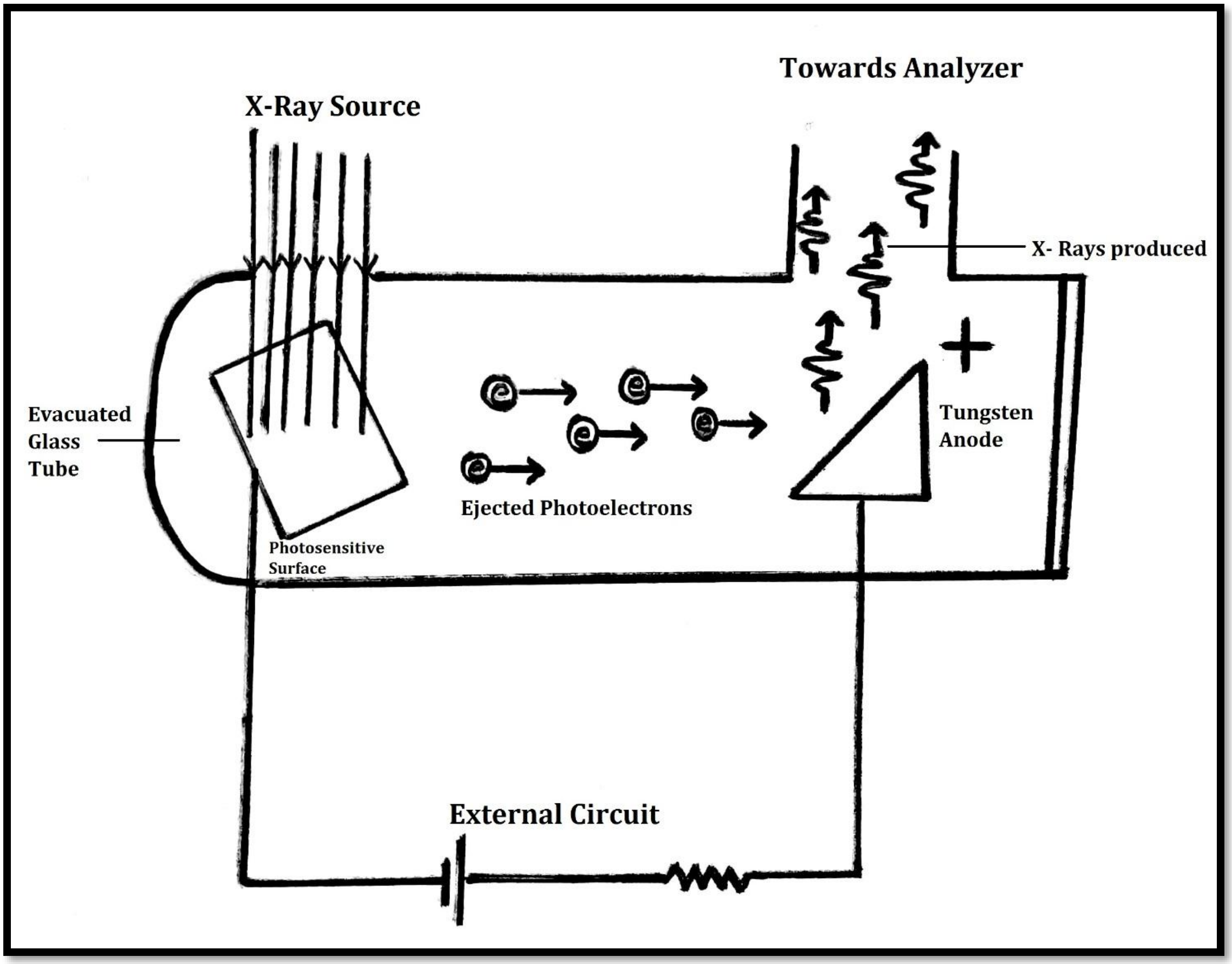

Fig 1 :- A Simplified Diagram of the Photoelectric- X-Ray Setup

For Phase 2, a standard Coolidge Tube is used to generate X-Rays, which are then made incident upon a photosensitive surface. The ejected photoelectrons are then analyzed to determine their quantum properties.

4.Photoelectric X-ray Equation

A Photoelectric X-ray equation is derived which relates the De-Broglie wavelength of ejected photoelectrons with the wavelength of X-Rays generated. A constant with dimensions $[\mathrm{L^{-1}M^{0}T^{0}}]$ *is also obtained in the process. The photoelectrons are assumed to be non-relativistic and it is assumed that the entirety of X-Rays is consisting of Bremsstrahlung radiations, neglecting the other spectrum.*

Consider a photoelectron ejected from the surface of a photosensitive metal of certain Threshold frequency. The electron is ejected from the surface with an energy ***eV*** *and is accelerated towards the tungsten anode through a potential difference. Therefore, the maximum kinetic energy of electron with non-relativistic velocity* ***v*** *when it reaches the anode is given by :-*

$$\mathrm{eV} = \frac{1}{2}\mathrm{mv}^2$$

which can also be written as,

$$\mathrm{eV} = \frac{\mathrm{pv}}{2}$$

Rearranging this equation, we get,

$$\mathrm{p} = \frac{2\mathrm{eV}}{\mathrm{v}} \qquad -\,(\mathrm{a})$$

Now, according to De-Broglie's Equation

$$\lambda_{\mathrm{e}} = \frac{\mathrm{h}}{\mathrm{p}}$$

where $\boldsymbol{\lambda}_{\mathbf{e}}$ *is the De-Broglie wavelength of photoelectron.*

Representing momentum in terms of De-Broglie wavelength,

$$\mathrm{p} = \frac{\mathrm{h}}{\lambda_{\mathrm{e}}} \qquad - (\mathrm{b})$$

Substituting this in result (a) we get,

$$\frac{\mathrm{h}}{\lambda_{\mathrm{e}}} = \frac{2\mathrm{eV}}{\mathrm{v}}$$

Rearranging,

$$\lambda_{\mathrm{e}} = \frac{\mathrm{hv}}{2\mathrm{eV}} \qquad - (\mathrm{c})$$

Now, the minimum wavelength of X-Rays generated - $\boldsymbol{\lambda}_{\mathbf{x}}$ *by an electron of energy* ***eV*** *incident on the anode is given by,*

$$\lambda_{\mathrm{x}} = \frac{\mathrm{hc}}{\mathrm{eV}} \qquad - (\mathrm{d})$$

From result (c) and [d] we get,

$$\boldsymbol{\lambda}_{\mathbf{e}} = \frac{\mathbf{v}}{\mathbf{2c}} \boldsymbol{\lambda}_{\mathbf{x}} \qquad - (\mathrm{e})$$

To eliminate the variable ***v****, some simplifications are performed on result (e),*

$$\frac{\lambda_e}{v} = \frac{\lambda_x}{2c}$$

*Dividing both sides by the rest mass of electron **m**,*

$$\frac{\lambda_e}{mv} = \frac{\lambda_x}{2mc}$$

$$\frac{\lambda_e}{p} = \frac{\lambda_x}{2mc}$$

From result (b),

$$\frac{\lambda_e^2}{h} = \frac{\lambda_x}{2mc}$$

Therefore,

$$\boldsymbol{\lambda_e^2 = \frac{h}{2mc}\lambda_x}$$

Since h, m and c are constant for any non-relativistic electron,

$$\boldsymbol{\lambda_x = \Psi\lambda}_{\mathrm{e}}{}^2 \qquad -\ (\mathrm{f})$$

where, $\boldsymbol{\Psi = \frac{2mc}{h}}$

Result (f) is the Photoelectric- XRay Equation (non- relativistic version)

The approximate value of Ψ *is calculated to be* $8.2403 \times 10^{-57}\ \mathrm{m}^{-1}$.

5.Final Discussion

The derived Photoelectric X-ray equation is found to be a simple transforming equation for quantum interactions between a non-relativistic electron and a photon. The equation involves a constant $\boldsymbol{\Psi}$ *relating the wavelength of photon and square of De-Broglie wavelength of electron. In other words, when a photon is completely converted into an electron(in the sense of energy and quantum information) or vice versa, the wavelength of photon is directly proportional to the square of De-Broglie wavelength of electron.*

The value of constant $\boldsymbol{\Psi}$ *=* $8.2403 \times 10^{-57}\ \mathrm{m}^{-1}$ *is found to be a fraction. Thus, it can be deduced from result (f) that when an electron is transformed into a photon (as in X-Ray generation), the resulting wavelength of photon is shorter than the electron's De-Broglie wavelength. Opposite is the situation when a photon's energy is delivered to an electron (Photoelectric effect). The constant which is -* $\frac{\mathbf{1}}{\boldsymbol{\Psi}}$ *, now becomes non-fractional. Hence, it can be inferred that when a photon is transformed into an electron, the resulting De-Broglie wavelength of electron is greater than the photon's wavelength.*

*By considering results (c) and [d] of the mathematical workings, it is observed that the two are analogous. The numerator of both results involves Planck's Constant and velocity (**c** can be regarded as velocity of photon and not of the electromagnetic wave), while the denominator involves energy in **eV**. Both expressions represent the wavelength of a wave but, one is physical while the other is abstract. The Electromagnetic wave is established as a physical wave* *propagating through space. On the contrary, the statistical interpretation debates De-Broglie wavelength, or the wave described by wavefunction as a probability wave through abstract space devoid of any physical meaning. However, the close similarity between results (c) and [d] strongly suggest a different picture. If the wavelength given by result [d] can be a real wave, then one must consider the physical nature of De-Broglie wavelength given by result (c) which is quite similar to [d]. The results can thus be extended as a potential proof of Louis De-Broglie's initial vision of the matter waves being physical. It can also be used in favour of the De-Broglie Bohm Theory*[3] *where the non-local hidden variables might be related to the constant of proportionality –* $\boldsymbol{\Psi}$ *used in Photoelectric X-ray Equation.*

This paper proposes the Photoelectric X-ray experiment in the form of a thought experiment. However, this does not limit it from conducting an actual experiment with proper apparatus and setup. The concept however has certain loopholes such as assuming non-relativistic electrons and considering only Bremsstrahlung radiations. Further work and research on the thought can open new perspectives to look at some of the foundational aspects of Quantum Theory.

6.References and Sources

I would like to thank Anna V- an active user of the Stack Exchange Physics forum for providing a different insight into the electric and magnetic fields of photon being embedded in its wave-function. I would also like to acknowledge my little sister – Janhavi for aiding me with the diagram. Some other sources and references are listed below :-

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