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Research on Quantum Physics Important Principles and Photoelectric Effect

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ABSTRACT: Quantum mechanics (QM; also known as quantum physics or quantum theory), including quantum field theory, is a fundamental theory in physics which describes nature at the smallest scales of energy levels of atoms and subatomic particles. Classical physics (the physics existing before quantum mechanics) is a set of fundamental theories which describes nature at ordinary (macroscopic) scale. Most theories in classical physics can be derived from quantum mechanics as an approximation valid at large (macroscopic) scale.^[3] Quantum mechanics differs from classical physics in that: energy, momentum and other quantities of a system may be restricted to discrete values (quantization), objects have characteristics of both particles and waves (wave-particle duality), and there are limits to the precision with which quantities can be known (uncertainty principle).

I. INTRODUCTION

Physics is a means to describe the world around us. It makes use of facts, theories and experiments in order to determine certain physical quantities. Physicists are always looking for knowledge, trying to understand everything. One of the basic physical ideas is that everything can be known. To know everything might be difficult. It might even be practically impossible, but theoretically it must be possible. This is the main goal of physics: to know everything. At least, it has been. For the direction of physics has been changed fundamentally in the 20th century. The world's leading physicists Heisenberg, Bohr, Einstein and many more have developed a completely new kind of physics: quantum physics. Quantum physics is not just another branch of physics, like mechanics or thermodynamics. It is physics. Quantum physics is a new way of thinking within physics, that has proven every other theory about anything to be wrong. Da Vinci was wrong, Galilei was wrong, Kepler was wrong and even Newton was wrong. In fact, all physics before quantum physics was wrong. That is why scientists distinguish two main periods in physics: Classical Physics (also called Newtonian Physics) and Quantum Physics. Classical physicists believed that everything could be known, that every quantity could be determined at any moment in time. This can be done through measurement, or through prediction. This, however, turned out to be wrong in its essence. According to quantum mechanics, the position of any particle cannot be predicted precisely. The only thing that can be known, is the probability for a particle to be at a certain position. This means - and do not be scared if you do not understand this, because no one really does - that when not measured, a particle is at all positions at the same time, while it is at no position at all. Only when measured, a particle takes a certain position. And even then, not every quantity can be known.. This seems very strange, because it is impossible for us humans to imagine. We observe everything as being where it is. But why should everything we observe be right? Experiments and mathematical theories consistently showed the rightness of this revolutionary quantum theory. Naturally there was a lot of resistance among scientists, when this theory was introduced. Even Einstein did not accept it. But eventually scientists had to accept the facts, and the facts were in favour of quantum physics.

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Vol. 6, Issue 12, December 2017

II. IMPORTANT PRINCIPLES

Planck's Constant and light quanta The founding year of quantum physics runs parallel with the start of the 20th century. In 1900 German physicist Max Planck discovered, that energy is only emitted by blackbodies (a blackbody is an idealized object that absorbs all electromagnetic radiation falling on it.¹) in discrete packets following the equation

$$E = hf$$

Where E is energy in Joules, h is the Planck's constant and f is the frequency in Hertz. These discrete packets were called 'light quanta' and later 'photons'. Planck found this while working on one of the two major problems regarding electromagnetism: the Ultraviolet Catastrophe. Scientists had predicted most of the electromagnetic radiation emitted from a blackbody to be in the ultraviolet region, while the test results showed it was somewhat in the middle of the electromagnetic spectrum

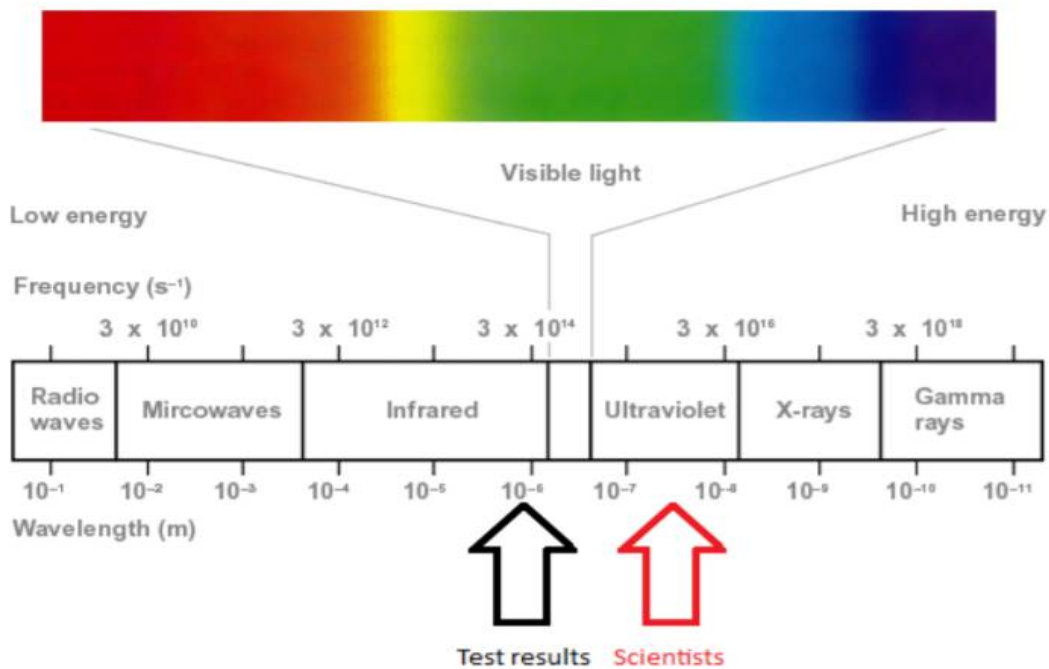


Figure 1: The electromagnetic spectrum

Unlike most physicists at that time, Planck tried to find a theory to fit the results, instead of claiming the results of the experiments were incorrect. That is how he eventually found the 'simple' $E = hf$ equation. At the time, Planck's idea was radical. Planck's theory was mathematical and although it solved the Ultraviolet Catastrophe, it was not known why light would only be released in these quanta.² At first, not even Planck himself believed light was only emitted in these small packets.

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Vol. 6, Issue 12, December 2017

III. PHOTOELECTRIC EFFECT

It was Einstein in 1905 who took away the doubt by applying Planck’s theory to the second major problem regarding electromagnetism: the problem of the Photoelectric Effect. When light shines on a metal surface, it frees electrons from the metal. This happens because light carries energy and if it has enough energy, it will free electrons. This is called the photoelectric effect. @ These electrons can be coming out at different velocities and with different amounts, depending on the nature of the light shined upon it. The problem of the photoelectric effect was the following: if light consisted of continuous waves, which was the commonly accepted theory at that time, an increase in the intensity of the light beam would imply a higher velocity of the beam of electrons. For a higher intensity means the wave contains more energy. This, however, did not turn out to be true. Experiments on the photoelectric effect showed different results (see table).

Results	Higher intensity of light	More electrons, same velocity
Results	Higher frequency of light	Higher velocity of the electrons, same amount
Prediction according to wave theory	Higher intensity of light	Higher velocity of the electrons, same amount
Prediction according to wave theory	Higher frequency of light	No difference at all

When Einstein applied Planck’s theory to this problem, he found a solution that matched all test results: light consists of small packets. If light consists of small packets, an increase in the intensity of the light would just mean that more ‘light packets’ are emitted. Naturally, more emitted light packets imply more freed electrons. Additionally, when the frequency of the light is raised, the number of emitted light quanta, and thus of freed electrons, remains the same. A higher frequency of the light also causes the wavelength to be shorter, which then causes the freed electrons to have more velocity (energy).

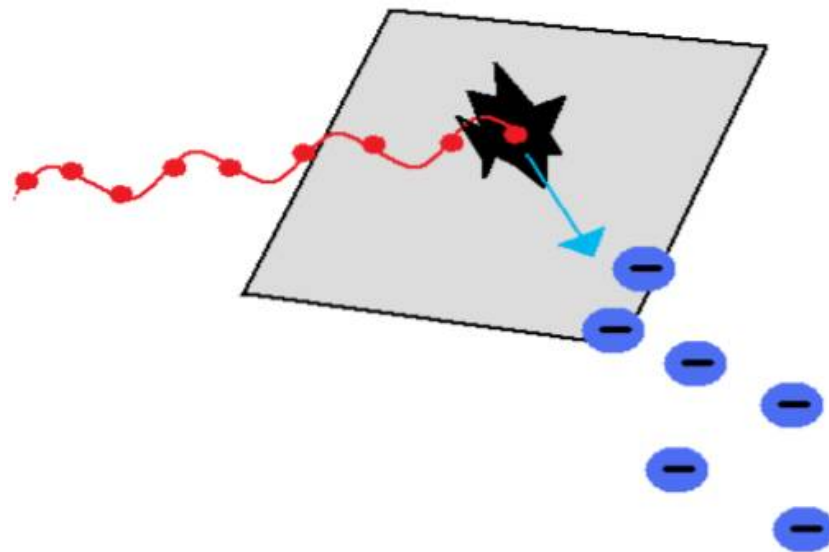


Figure 2: The photoelectric effect. Photons (red) hit the metal (grey) knocking out electrons (blue).

So Einstein showed Planck’s theory was multi-applicable, because it had already solved two major scientific problems of that time. From this moment on, physicists began to accept Planck’s revolutionary theory; quantum physics was born.

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The Compton Effect:- All doubts and uncertainties about the particle nature of light when it interacts with matter were taken away by Arthur Compton. In 1923 he thought of an experiment to confirm the photon (a photon is a discrete light quantum) interpretation of light. This was later called the Compton Effect or the Compton Scattering. The experiment is very simple: shoot a beam of light at free electrons and measure the quantities of both particles afterwards. This is what classical physics had predicted: Light (also called electromagnetic radiation) is a wave in the electric and magnetic field. The oscillation of the light wave in the electric field would cause the electron to oscillate as well, and with the same frequency as the incident light ray. Subsequently, the oscillation of the electron would cause electromagnetic radiation to be emitted in all directions – again with the same frequency.

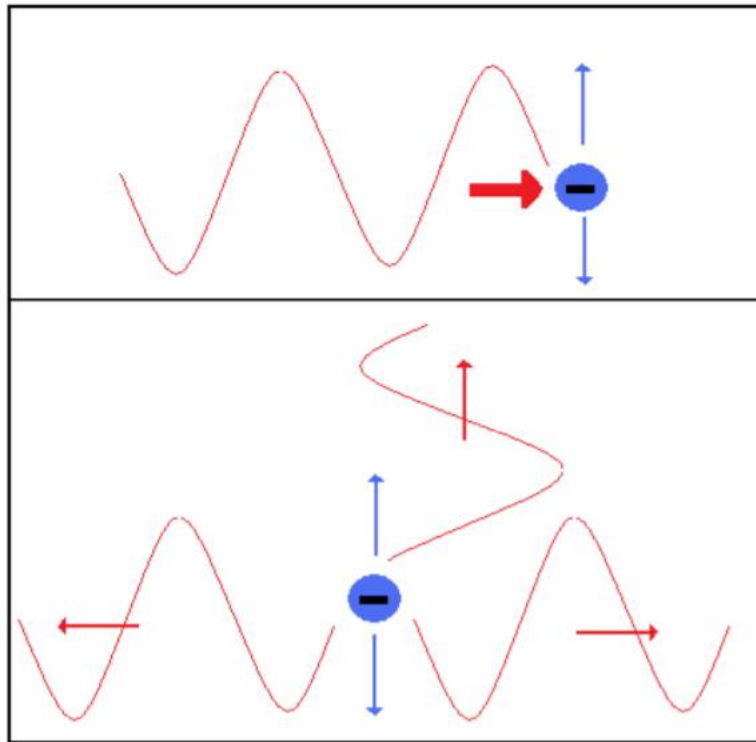


Figure 3: The Classical prediction of the Compton Effect. A (red) electromagnetic wave makes the (blue) electron oscillate (1). The oscillating electron emits electromagnetic radiation in all directions and with the same frequency (2).

Compton used the photon's properties and the laws of conservation of energy and momentum to derive his Compton Equation

$$\lambda' - \lambda = \frac{h}{m_e c} (1 - \cos \phi)$$

Where λ' is the wavelength of the outgoing photon, λ is the wavelength of the incoming photon, h is Planck's constant, m_e is the electron's mass, c is the speed of light and ϕ is the photon's angle.

Heisenberg's Uncertainty Principle:-

Another famous fundament of quantum physics is the uncertainty principle. It says that the position and the momentum and the energy and time of a particle can never be determined simultaneously. Werner Heisenberg published this idea

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in 1927. Heisenberg noticed that in order to define the position of a particle, you (or some measuring device) will have to see the particle.³¹ But the definition of seeing something, is that light has to hit the particle. Otherwise it would be invisible. In Classical Physics, the hitting of this particle can theoretically be done as delicate as you like. However, one of the definitions of quantum physics is that there is a limit to this: a photon. So in order to see a particle, it must be hit by a photon first. Now we want a very accurate measurement of the position of the particle. To do this, we need to hit it with photons that have a very small wavelength, say γ -rays, because photons with a large wavelength would cause a bigger uncertainty in the measurement of the position. But now a problem arises: photons with a small wavelength have a lot of energy ($E=hc/\lambda$). This means the high energy photon will give the particle a relatively big kick, making it impossible to accurately measure the speed (thus momentum, for $p=mv$) of the particle at that same time.=: A consequence of this is that the position and momentum of a particle can never be measured accurately at the same time; the more accurate the measurement of position, the less accurate the measurement of the momentum and visa versa. This is the core of Heisenberg's uncertainty principle.

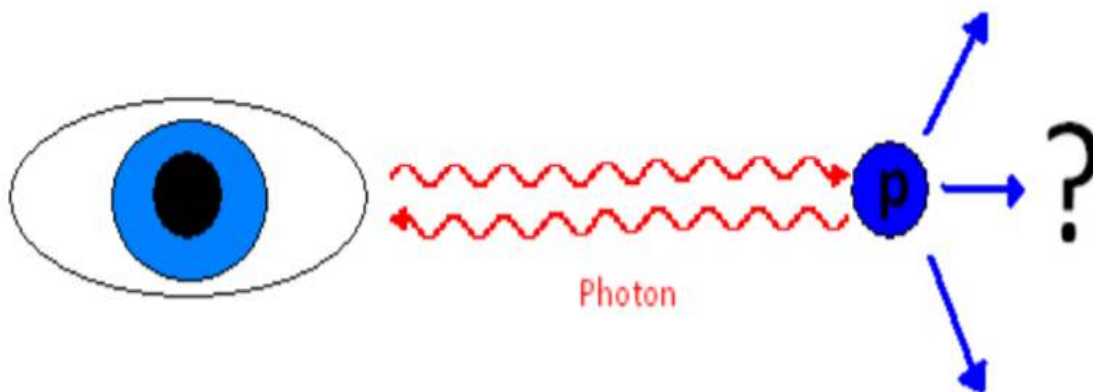


Figure 4: The theory behind Heisenberg's Uncertainty Principle. A photon with a small wavelength hits a particle, giving it a random kick and thus changing the momentum, and the eye observes the reflected photon, seeing the particle's position quite accurate.

In Classical Physics, the act of measuring does not affect the outcome of the measurement itself, because the measurement can be done as delicate as you like. In order to measure for example the position of a marble, you (or a measuring device) will have to see the position of that marble. To see the marble, light bouncing off the marble has to enter your eyes. The same goes for a device: in order to measure the marble, light has to hit it first. Of course, the position of the marble will not change after it has been hit by some light. But an electron is much smaller than a marble and therefore it can be affected by the light. But when the amount of light (energy) hitting the electron is made so ridiculously small compared to the electron itself, the impact of it is negligible. In Quantum Physics, however, this is impossible. Because of the quantization of light, there is a limit to the amount of light hitting the electron: one photon. When the photon hits the electron, it gives it a random kick and thus it changes the electron's position.

IV. CONCLUSION

To this, Heisenberg's uncertainty principle and the concept of probability can be added, albeit that the uncertainty principle can best be explained in the 'photon giving particle a random kick' way and probability by avoiding the wave function. Also, it is best to use the model of the atom as the core and a 'problemtheory approach', possibly in a loose historical context, is ideal. The text type should be normal, but inserting dialogues some way (debate or cartoon for example) is important too. So the very act of measurement or observation changes the result of the measurement itself to a certain degree. This is what causes the outcome of the double-slit experiment to change when an observer is added and it is also a fundament for the uncertainty principle.

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Vol. 6, Issue 12, December 2017

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