Misconceptions in Quantum Mechanics through Double Slit Experiment

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Abstract

The best-known early experiments in quantum theory include a double slit experiment. *This experiment points to the wave-corpuscular dualism of microparticles, their wave and particle properties. For its simplicity and unexpected behavior, it is mentioned in many introductory quantum physics courses as well as in the curricula of some technical secondary schools. Despite the frugality of this experiment, many students have difficulty understanding certain parts of the behavior of micro-objects, resulting in many misunderstandings and misconceptions. For this reason, our work aims to reveal some misconceptions regarding the behavior of objects in microworld in connection with the use of a double slit experiment and its modifications. Misconceptions that we focus on will be primarily concerned with the state of the physical system in quantum mechanics. To achieve the goal, the research method was chosen in the form of a test, which consisted of a set of nine test questions focused towards the behavior of particles – electrons – in* double slit experiment*. Testing of students took place over a more extended period from a professional interpretation of a double slit experiment. A random group of university students was selected as a test sample. The collected data from the tests were analyzed and evaluated by the analytical-synthetic method, out of wrong answers there were set up misconceptions, created by misunderstanding or incorrect understanding of behavior in the world of microparticles when explaining double slit experiment. Identification of misconceptions and their subsequent analysis is of great importance in the educational process itself, as such findings can be the subject of further lectures to remove misconceptions from student awareness and subsequent correct understanding of the theory of microparticles.*

Keywords: *Double slit experiment, wave-particle duality, misconception;*

1. Introduction

The teaching of quantum mechanics theory comes along with some paradoxes. One of them is also a well-known fact in the pedagogical practice that despite the enormous effort of pedagogues using the most current methods and forms of teaching, there is a misunderstanding of the presented topics and concepts. This knowledge, based on pedagogical practice has been and continues to be the subject of several studies. As per findings, this is caused by the students' attempt to understand and explain the elements of surrounding objective reality, using the theoretical knowledge, tools, and experience gained from previous studies of classical physics, creating their misconceptions and informal theories that we can name by a term of preconception. Early non-identification and subsequent non-removal of the preconceptions thus formed with students later the misconceptions of the world of behavioral microparticles in quantum physics, resulting in various misconceptions. Misconceptions manifest themselves as unrelated or mistaken knowledge, so we can simply define them as deformed thought structures that lead to incorrect predictions, interpretations, explanations, or solutions to science issues [1]. Based on this simplified definition there is a definite negative impact of misconceptions not only on science and research but also on the quantum physics teaching process. As discussed above to eliminate misconceptions, it is essential to identify these and define their nature. The aim of our work was, therefore, to discover some misconceptions concerning the behavior of objects in microworld in connection with the use of a double-slit experiment and its modifications, since this experiment belongs among the basic experiments of the introductory courses in quantum mechanics, to be found for example in [2]. More about double-slit experiments can be found in [3].

2. Theory

As a core of our research aimed at identifying and defining the misconceptions arising from the study of the world of microparticles, double slit experiment was used as a tool that was divided conceptually in three different ways into research questions. By double-slit, we sent not only bunches of electrons, but also electrons one after another - individual, when the electron interfered with itself. The first variant was a standard double-slit experiment, consisting of a particle source, in our case, electrons, double-slit, and a detection device. In the second experiment variant, one of the slits was covered in the experimental apparatus. This variation of the double-slit experiment is often cited as an example in quantum physics introductory textbooks to compare the results with classical particles and classical wave [2]. In the third variation of the double-slit experiment, a modification was made in when a detection device was located for one slot of the apparatus to allow us to identify which slot the particle went through (the so called "which way experiment"). The electron passage is only registered by the connected recording device. Registering the electron passage by the slot breaks the resultant interference pattern. In this case, the electron behaves as a classical particle. Such a modification of the double-slit experimentation apparatus is not so popularized and published in textbooks, and it is, therefore, possible to expect the most frequent occurrence of misconceptions in the theory of electron comprehension behavioral theory in this type of experiment.

3. Data and methods

The research itself was carried out on a sample of 54 students of the first year of the Technical University without a previous university course in quantum mechanics. The knowledge gained by students was exclusively from their previous studies at secondary or high schools. To achieve the goal, the research method was chosen in the form of a test which consisted of a set of nine test questions focusing on the behavior of particles – electrons in the double-slit experiment. The data were collected by the questionnaire method. The questionnaire consisted of nine closed questions with the choice of one correct answer. The respondent was presented with a variant of the double-slit experiment and its two different modifications in the questionnaire, with the respondent choosing one of the five options offered. In the first part of the questionnaire, the respondent was provided with the description of the device for the study of the electron passage through two parallel narrow slits at a small distance - a double-slit with a backlight in the background. In case I. the two slits are open, in case II. the right slit is closed, and in case III. both slits are open, but close to the right slit there is a sensor that registers when the electron passes through this slit. Subsequently, the types of shapes or figures were presented to the respondent that could, in given cases, create a trace of electron impact, i.e., five possibilities of determining the correct resultant interference pattern marked by letters A through E. (Fig. 1)

A B C D E

Figure 1 Possibilities of interference patterns from which the student should choose the right option as per the question

The test questions were divided into three interrelated parts according to the type of apparatus described above, i.e., a conventional double-slit with a detector, an apparatus with a right slit covered, and an apparatus with a path sensor. Each part consisted of three questions, the answer being the correct interference pattern from the choice of options, if the electron passes through the apparatus, a large number of electrons in the form of one after another electron, and the flow of many electrons. The respondent should have realized the fact that, if we have information about which slit was crossed by microworld object, the interference pattern disappears. More about conceptual testing can be found in [4] and [5].

4. Results and discussion

On the first test question, what pattern appears when the electron passes through a double slit experiment when both slits are open, 62.5 percent of respondents answered correctly. The achieved result shows that more than half of the students have a clear idea of the behavior of alone electron passing through a double slit experiment. However, students are already facing issues when we start asking questions when the electron beam is sent through the apparatus individually or in the group, parallel. Despite the high success rate of answers to the first question, up to 37.5 percent of students are unaware of the composite of partial interference structure of points. The most common failure was the occurrence of an interfering pattern of options B and C, indicating the existence of misconception that already one particle that has passed through the double slit creates a complete interference pattern. In the second question, we asked what kind of interference pattern occurs when the two-slit apparatus is passed by a large number of electrons, but one electron sequentially, so that at one point only one electron was in the apparatus. Only 12.5% of the students answered correctly. A third of students in the second question assumed that the detector would have a single stripe (option B) of an interference pattern, by that they did not realize that the particular electrons interfere together and with interference pattern is created, as shown in option D. In this question, there is a misconceptual assumption that, if we do not know the information where the electron passed (the two slits are open), there is no interference pattern. Students do not realize the superposition principle at all with this question. In the third question, the flow of electrons passed through both slits, with 51.97 percent of respondents correctly answering. An incorrect answer to the C pattern was noted in 37.5 percent of students. A high degree of failure results in students not realizing an interference pattern. Interestingly, none of the respondents indicated a correct answer for a spotted image, that is, the possibility of a final option of A. In the fourth and fifth question there was a modification that one slit was closed. Even though this is a classic textbook example in the fourth question, half of the respondents answered incorrectly. In the group of 26.79 percent of the students predominated in the idea that a figure of A would be created, therefore a single point on the detector. This fact suggests that while the student is aware of the disappearance of the superposition of quantum states, they do not realize that a scatter pattern arises from the points of multiple points of hit electrons, resulting in a misconception that supposes that the disappearance of the particle scattering is also extinguished by the disappearance of superposition of quantum states. To the fifth question, half of the students answered correctly. The most common misconception when sending the electrons through one slit was the E response, in which 23.21 percent of the students considered an interference pattern other than the one right one. In the questions six to nine we consider the apparatus when we connect a detection device to one of the slits. This device gives us information about where the electron has passed. In the sixth question, we send one large number of electrons one by one, and it should be realized that the registration device has been connected, hence switched on. Quantum theory also states in this case that there is interference created. The correct answer to the sixth question was provided by only 10.71 percent of the respondents. A group of 35.71 percent of respondents assumed the appearance of a double interference pattern C. On the seventh question, the regulation of the registration device is the same as in the question six, but the only difference is that we sent electrons as a flow. Only 12.50 percent of respondents correctly answered question 7. This is the same misconception as in the sixth question that if we have information about where the electron passes through the slit, a double interference pattern is created. The origin of the double interference pattern was chosen by half the respondents. Questions 8 and 9 are an analogy of questions 6 and 7; however, the student was aware of the fact that the detection device is disconnected. Question 8, in which the electrons were sent one by one, was answered correctly by 14.29 percent of the students. The most common answer was an E option, therefore a different pattern creation. The students did not realize that if the device is disconnected, i. e. we do not know through which slit the electrons have passed, the interference pattern given in option D is created. In this case, it does not matter if the electrons are emitted one by one or in one as electron flow. The answer to the 9th question was provided correctly by 28.57 respondents. The answers were unambiguous because also 28.57 respondents replied that after the electron beam crossing, the interference pattern would be different from any of to be selected from the above. Table 1 shows the success rate of individual respondents' answers.

Table 1 Percent evaluation of questions

No. of question	Percentage success rate of correct responses
1	62.50%
2	12.50%
3	51.79%
4	48.21%
5	51.79%
6	10.71%
7	12.50%
8	14.29%
9	28.57%

5. Conclusion

Evaluating the results of our research to identify misconceptions in understanding the behavior of the world of microparticles in quantum physics students, which we made using a double slit experiment on a sample of students, we concluded that the understanding of the fundamental questions of quantum physics theory provides some misconceptions and opinions, leading later to more severe problems in understanding the essence of the functioning of the world of quantum physics. The origin of misconceptions is conditioned by a non-complete understanding of basic theoretical models, or by preconceptions acquired during the previous secondary education, which was also confirmed by this research. Percentage of respondents to individual questions is in Table 1. By evaluating the incorrect answers (including correlations), we were able to identify the resulting misconceptions associated with the state of the physical system and the particle-wave dualism using an example of a double slit experiment. The most common misconceptions that occurred among the respondents of the research sample can be briefly summarized in the following misconceptions:

- Electrons entering individually behave like regular particles.
- The macroscopic flow of electrons acts as a classic wave.
- Path sensor does not affect interference pattern.

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