History of Science for Science Courses: "Spin" Example from Physics

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Abstract

In this study, we aim to provide the story of spin concept in historical manner to help students' construction the idea of spin. Historical discussion of physics provides students both information about content and its nature and methods. For this aim, "Stern- Gerlach Experiment", and its earlier and later ideas about spin were mentioned. Stern- Gerlach Experiment is the one of the most important experiments which indicates "spin" and "measurement" concepts in quantum mechanics. The controversial ideas about determination of "spin of bounded electrons" and "spin of unbounded electrons" by introducing the analysis of scientific debates in history of physics could provide Physics Educators integrating history of physics into physics lectures.

Keywords: History of Physics, Spin, Stern- Gerlach Experiment.

Resumen

En este estudio, tenemos como objetivo proporcionar la historia del concepto de espín de una forma histórica para ayudar a los estudiantes en la construcción de la idea de espín. El debate histórico de la física proporciona a los estudiantes información sobre su contenido, naturaleza y métodos. Para este propósito, se mencionan el "Stern-Gerlach Experimento" y sus ideas más tempranas sobre el espín. El experimento de Stern-Gerlach, es uno de los experimentos más importantes que indica los conceptos de "espín" y "medición" en mecánica cuántica. Las ideas polémicas sobre la determinación de la "rotación de los electrones confinados" y del "espín de los electrones no confinados" al introducir el análisis de debates científicos en la historia de la física se podría proporcionar a los maestros la integración de la historia de la física con la enseñanza de Física en las clases de física.

Palabras clave: Historia de la Física, Espín, Experimento de Stern- Gerlach.

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I. HISTORY OF SCIENCE IN SCIENCE CLASSES

Science develops gradually with its all domains. During this development, many concepts and theories may inspire the construction of different concepts and theories at different times. The teaching of concepts with their historical context may prevent students' thinking of science courses as a set of concepts. It provides students connecting the concepts with previous concepts, scientists and their lives, social, religious and economical factors which affect the development of concepts. More specifically, history of science is important for science education because it "motivates students", "allows connections between topics and disciplines of science", "connects the development of individual thinking and the development of scientific ideas", "humanizes the subject matter", "promotes comprehension of scientific concepts by tracing their development and refinement", "demonstrates that the science is changeable and mutable", "allows to students a richer understanding of scientific method" [1, 2]. In addition, sequencing approach to a scientific concept provides students' progress viewpoints, masters students' interim conceptions, and shows being overthrown of ideas by another [2], in other words it provides a "psychological validation" [2].

In last three decades, a group of European physicists pointed out that physics has a history, and this history might be useful in physics education as a new perspective [3]. In addition, history and philosophy of science courses have taken part in science teacher education [4]. Heilbron (1983) explained that the historical discussion of physics could provide information both the content of physics and its nature and methods [as cited in 3].

In this study, it is aimed to use history of spin concept in physics courses with the debates in its history. Spin is a concept of quantum theory. It is one of the fundamental concepts of quantum mechanics course at departments of physics, in the universities' physics curricula. The explanations about spin include mathematical calculations, because mathematics is the only way to express the physical ideas of quantum theory [5]. For this reason, both nature and expression of spin cause it becomes an abstract and counter-intuitive concept for many students. This abstractness may be dismissed partially with analogy of spin as a turning ball in its axis. Although this analogy is a good explanation in many ways, quantum theory says that spin of some particles (i.e. electrons) not result of this type of motion [6]. Also, analogy is type of model and models do not show all characteristics of the physical reality. For this reason, some missing explanations about abstract concepts on the mathematical expressions may result students' understanding of the analogy as total physical reality and concluding "spin is motion of electron in its axis". The explanations of two teacher candidates about spin as follows:

One of the (male) 4th grade pre-service physics teachers who completed quantum mechanics course defines "spin" is "motion of particles around the atom, moving ahead by turning, repeating this motion in a continuous way". Another (female) 4th grade pre-service physics teacher says "when I think of spin, electron is the first thing comes to my mind, it is turning of electron in its axis". The explanations of the physics teacher candidates show us students need more conceptual explanations about this concept.

Spin caused debates among scientists both its nature and due to this its possibility for unbounded electrons. In the years 1920s, in the period of old quantum mechanics, spin was studied by many scientists. In addition to mathematical and analogical explanations of spin concept, it should be mentioned about its contextual development, the ideas of other scientists, experiment results in order to provide meaningful learning of the concept. This also may provide different point of views to students about the concept.

There are some methods, which were defined by the different researchers, for teachers to introduce history into science classrooms such as reproduction of historical experiments, role plays of historical debates and episodes, writing pen portraits of major characters, essays, individual and group projects, reading and interpretation of original papers [1].

Many writers and science educators recommended "story line" approach to teach science. Story line approach was developed by Lühl, a science teacher, to teach "atomic theory" at middle schools, Kieran Egan also developed story from approach, and Wandersee's historical vignettes are some examples for use of history of science [7]. Also, in order to help teaching of a narrow topic, a historical experiment can be chosen [8]. In this study, the essay about history of spin concept was presented by considering the historical experiment which is "Stern-Gerlach Experiment" (SGE) in the story form.

Stinner and Williams [7] mentioned some features of story line approach. These are mainly: mapping out the unifying central ideas, providing students with experiment related to their everyday world, inventing a story line for highlighting the main idea, ensuring the major ideas, concepts and problems, showing that the concepts are diversely.

By considering the aforementioned reasons, the historical essay below in a story form may be used in physics lectures for students. This is a case for the spin concept including debates in its history.

I. (HI)STORY OF THE SPIN CONCEPT

A. Gaining Attention and Motivation

Eddington (1928) stated about his electron concept in his mind with these words: "When I think of an electron there rises to my mind a hard, red, tiny ball" [as cited in 9]. This statement actually says something about abstract and counter intuitive nature of quantum mechanics. In addition, some students think that quantum mechanical concepts are strange, and it is difficult to imagine them [10]. Although, we have no chance to see the structure of an electron in our daily life, successful experiments and mathematical calculations explain its nature in detail. One of the most important experiments in quantum mechanics about the nature of electron was performed in 1922, by Otto Stern and Walter Gerlach.

The "spin" concept for an electron which has great importance in the explanation of atomic spectra [11] was developed mostly by Pauli, Dirac and Heisenberg between the years 1925-1928 [12]. It is firstly proposed by Uhlenbeck and Goudsmit [13]. Pauli explained that spin was a quantum mechanical property and it could not be described classically [as cited in 14].

Many particles which have spin produce a magnetic field in space due to their spin direction. These particles may be thought as small magnets. When these particles are passed in a magnetic field, they scatter in the magnetic field due to their spin direction [6]. The SGE is a successful experiment which shows the scattering of electrons only in two directions, and it is a proof for quantum theory by indication of electrons had only two possible spin states. In SGE, silver atoms were used. The silver atoms were vaporized and they were sent from the pinhole of the oven. The un-polarized beam of silver atoms was collimated before entering the inhomogeneous magnetic field produced by the magnets shown in Figure 1. While the beam of silver atoms passing through the magnetic field, it undergoes splitting, in other words two polarized beam of silver atoms appeared [15]. Stern and Gerlach received the two lines on the plate. Silver atom (Z=47) has single electron in its outer shell and this electron is in an "s" orbital. Its intrinsic spin angular momentum makes the dominant contribution to the atomic magnetic moment, by this way orbital and spin magnetic moments of all the other electrons cancel [16].

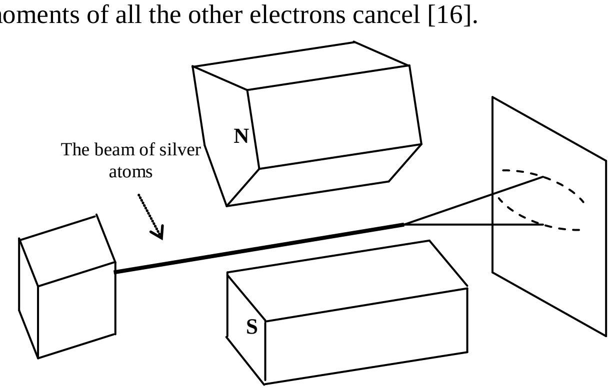

FIGURE 1. Stern-Gerlach Experiment setup.

B. A Debate in the Historical Development of the Concept

Bohr, Pauli and Mott say, in principle, it is impossible to measure the spin components of free electron [11]. This was because of "the spin degree of freedom characterized the electron only when it is bound in an atom" [17]. Mott and Bohr showed that the magnet used in SGE did not work with electron beams because of "the combined effect of Lorentz Force and Heisenberg uncertainty principle" [as cited in 18]. Pauli had also same idea with Bohr and Mott and he also thought there were not any device based on the classical particle trajectories, and also no magnetic fields in the separation of an electron beam by spin, in other words, there was nothing which measures the electron's magnetic moment [as cited in 18]. In conclusion of these three physicists (Mott, Bohr and Pauli) agreed "the charge of an electron relates to its magnetic moment in such a manner that the separation of the spin components by the magnetic interaction is counteracted by the effect of the Lorentz force on the moving particle" [11].

1928 is the crucial period for Bohr, because the ideas about measurability of free electron spin appeared in minds [17]. An alternative experiment to SGE was put forward by Brillouin in these years. He suggested that electrons could be separated by spin "using magnetic gradient forces acting along the direction of motion, instead of transversely to it" [as cited in 19]. However, Pauli, by the support of Bohr, rejected Brillouin's proposal in the sixth Solvay Conference [as cited in 19].

Gallup, Batelaan, and Gay [18], in their study which is originated the idea of Brillouin, they showed possibility of observing spin splitting of the electron beams by "using longitudinal magnetic field configuration". Batelaan [15] explained the longitudinal configuration as: "magnetic field gradient is aligned with the electron beam and spin 'forward' and 'backward' electrons passing through the magnet are separated along the direction of propagation". In Batelaan's [15] study, quantization axis was selected along the symmetry axis of the magnet.

C. Discussion

The possibility or impossibility of using electron beam instead of atomic beam in SGE is a debate in history of quantum theory. After the SGE in 1922 with beam of silver atoms, experiment was tried by different beams of atoms. Later, SGE was conducted by many physicists using the atoms which have single electron in outer shell potassium, sodium [20]. In 1927, Phipps and Taylor conducted the SGE by using "hydrogen" atomic beam instead of silver atomic beam. They also observed the splitting of beam.

D. Connection of the Concept with Daily Life

Electron spin is important for daily life, especially for the technological applications, for the magnetic devices such as computer hard drives [12].

III. CONCLUSION

The SGE established the quantization of intrinsic spin [16, 21] of electron. In historical context, SGE is a subject of many analyses and discussions, and it exists in physics curricula, in the atomic physics, modern physics, and quantum physics courses [22]. This study presented a debate about measurability of free electron spin in the early years of quantum theory. Explanation of controversial ideas in history of physics may provide students different point of views about concept. This essay may be used in the physics courses (at college/ university level) with different aims such as to motivate students before teaching spin concept, to construct conceptual understanding of spin concept on mathematical expressions or asking the possibility of spin for free electrons to create discussion environment for inquiry in physics lectures.

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