

**Topics:**

- Central features of quantum theory in physics education
- Teaching the heart of quantum theory
- Approaching the theory of quantum mechanics: the first steps towards a coherent synthesized interpretation with a supporting formalism
- Worksheets for pupils involvement in learning quantum mechanics

DWB TITLE:**CENTRAL FEATURES OF QUANTUM THEORY IN PHYSICS EDUCATION**

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CENTRAL FEATURES OF QUANTUM THEORY IN PHYSICS EDUCATION

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1 INTRODUCTION TO THE DISCUSSION WORKSHOP

Quantum theory was since its invention in the beginning of the 20th century a heavily discussed theory exciting many people interested in implications of physics. It turned out to be the most fundamental physical theory because it explains many physical phenomena of the most basic nature such as e.g. magnetism and stability of matter. Furthermore it is of relevance for many technologies based on e.g. solid state physics, laser devices, and atomic physics. Soon it became obvious that the physical interpretation of its mathematical structure would have deep influence on world view. Accordingly, many people are fascinated by the fundamental differences of quantum phenomena to classical physics. So, there is a high public interest in understanding quantum theory that can be seen in the resonance in media, the wide-spread popular literature on quantum physics and related subjects. Besides, the rising of quantum theory provides insight into the process how unexpected results are coped with in scientific research. It illustrates in which way more and more exact experiments

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force the physicists into a new type of theory abandoning the familiar classical arguments. Several incompatible opinions emerged, strong adherence towards some aspects of quantum theory versus strong refutation. Up to now the interpretation of quantum physics is not yet settled in the sense that the relation between the framework of classical physics and that of quantum physics is still a topic of discussion. Only recently with realization of former thought experiments there arose something like "experimental philosophy" that could help in deciding which interpretations would explain best the experimental results within a unified conceptual context.

2 CONTRIBUTIONS

Because of these aspects quantum physics has to have its place in the school curriculum. However, for most teachers quantum physics seems to be quite abstract and hence difficult to understand from the perspective of their pupils. So, although quantum physics is more than 100 years old it still struggles about its place in school. The workshop should suggest some proposals and discuss their appropriateness. A unified concept for teaching quantum physics in the light of new results was presented by Micheleni (s. below). It may be important to show that the astonishing features have a solid empirical background in order to prevent misunderstanding of the consequences. Students can learn the interplay between surprising experimental results, ideas about physical processes, their mathematical description and the resulting interpretation. In this direction the contribution of Micheleni, Stefanel and Santi (s. below) shows a way to implement in school lessons the proposed concept with worksheets, experimental explorations and testing hypotheses. Besides the overwhelming physical relevance of quantum theory it is especially well suited to show physics as part of culture.

3 RESULTS OF FINAL DISCUSSION

After the presentation of contributions and active work with the presented material the participants discussed several questions and arrived at the following conclusions.

Reasons for teaching quantum physics: Quantum physics is conceptually completely different from Newtonian physics. This is a main reason for teaching it. Students should learn to know that there is a necessity to introduce in some sense strange concepts and to use them in explaining nature. So it also provides an opportunity to build the theoretical-physical thinking e.g. in analyzing thought experiments. The connected discussions show the cultural importance as well as the technological applications or implication of quantum physics.

Preferable approaches: The choice of approach depends on classes interest of teacher and available time. But there was a consensus that a course should be started with crucial experiments (e.g. photoelectric effect) showing the necessity of the new concepts. In some respect the historical approach via photoelectric effect

or atomic physics as the original way was regarded as a possible way. Some participants proposed to use applications of quantum theory as main focus.

But in all approaches - which ever would be chosen - and taking into account the restricted time available at school it was strongly recommended rather to leave some aspects out than to rush through. There ought to be "*a nucleus of understanding*" ensuring that the students have had a glimpse onto quantum physics and reached a certain degree of understanding depending on the level of class.

Concepts: It has been agreed that an approach using 2-state systems as proposed by Micheli (ex.: polarization states, possibly enriched by other examples) would be a very suitable way to infer the concepts of superposition and uncertainty which most participants agreed to be the main concepts. The wave property of matter was regarded as an additional important concept.

Role of quantum physics in view of teaching the „Nature of Science“ In a general physics course designed for teacher education the course should include the treatment of 2-state-systems to have a basic example for the fundamental concepts. Much time should be spend on the understanding of concepts and visualization techniques. Concerning the debate on interpretation the students should be offered one clear interpretation they could use in teaching. The well known phenomenon of Schrödinger's cat and the questions concerning the measuring process should be treated as well as they are often found in popular literature.

Concerning courses at high school it would be best to convey **one** concept clearly in order to reach the "nucleus of understanding". Additional concepts should be covered.

A furthering question was whether quantum physics could be taught to all, e.g. as soon as in grade 10. In Germany there are first curricula to introduce the phenomenology of quantum physics in this grade. In this connection there arose the question whether quantum physics was really more difficult than Newtonian mechanics, presuming that Newtonian mechanics also is far from everyday experience.

Concluding remark Overall it seemed that now there are big possibilities to introduce central features into the teaching of quantum physics besides the traditional way stressing the photoeffect the matter wave dualism.