A new teaching-learning sequence of quantum physics via Michelson interferometer using the Dirac notation

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Abstract. There are many ways to introduce quantum mechanics to secondary school students. In the last decades two-state approaches became popular. These may have the disadvantage of being less compatible with traditional approaches (wave-particle duality) and thus not overlapping with the school curriculum. In this presentation we show a new way based on the single photon interpretation of Michelson interferometer that provides the possibility to give a two-state description that fits perfectly to the wave-particle duality, using the Dirac notation, trickily bypassing the complex phases.

Introduction

It is very difficult to faithfully describe quantum phenomena without mathematical formalism. In fact, research has already shown that some students believe that limited visual models are an exact representation of the phenomena (Gestalt thinking), so they often imagine photons like hard balls following certain trajectories [1-2]. Prior research has indicated quantum formalism can help students' understanding [3], so we provide secondary school students with a representation of reduced quantum theory based on mathematics and formal arguments in order to support the students' transition to a functional understanding of the photon model.

The teaching-learning sequence

We build on a wave optics experiment, the Michelson interferometer [4-5], which allows students to observe and analyse a wave optic interference phenomenon. Based on the observations, students reinterpret the phenomenon using a single photon source via an interactive screen experiment (see *Figure 1*) that explores some of the laws of quantum physics. While the experiments offer the wave-particle duality interpretation, we focus on *a simplified two-state description using the Dirac notation*. We avoid complex numbers: the complex phase e^{ix} is replaced by a visualisation of phase as an arrow φ_x on a phase circle. After a one-lesson repetition on optics, our teaching-learning sequence comprises of 5 lessons (45 minutes each) as shown in *Table 1*. The developed *Geogebra* animations, worksheets and the used interactive screen experiment [6] can be accessed via the website [7].

Conclusions

The result of our research is a new secondary school teaching-learning sequence using the Dirac notation and two-state formalism avoiding complex numbers. This fits well with the traditional learning path and could even be a way to introduce quantum mechanics, and later quantum computation because a two-state description is used.

Fig. 1. A low-cost Michelson interferometer is shown in (a) [8]. The students can observe the interference pattern (b), then interpret via an animation of *GeoGebra* (c) [7]. Then using a single photon source, the beam splitter (d) and Michelson (e) experiments are reinterpreted via a real screen experiment made [6].

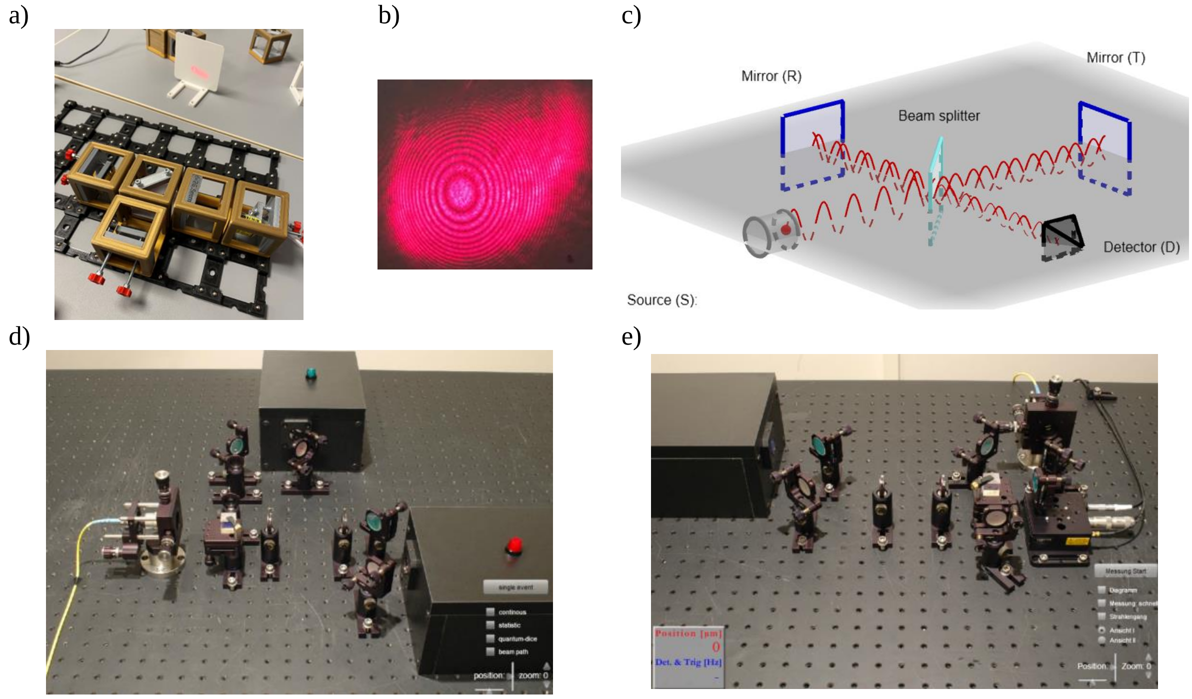

Table 1. The structure of the learning path. Through the website [7], our materials can be reached.

Lessons.	Topic
0) Repetition.	Students observe the interference pattern on a Michelson interferometer and then they interpret it via the GeoGebra animations using wave interference.
1-2) A single photon at a beam splitter.	Students explore the indivisibility of photons and the probability law using "Worksheets 1-2". We introduce the superposition principle.
3-5) A single photon in a Michelson interferometer.	Students explore the quantum interference and the lack of trajectory via "Worksheets 3-4", while they can explain the results via the reduced Dirac formalism.

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