A teaching-learning sequence about introductory quantum mechanics using an integrated physics-chemistry approach for high school students

Umberto Scotti di Uccio, Italo TESTA

Department of Physics "E. Pancini", Complesso M.S.Angelo, Via Cintia, 80126 Napoli, Italy

Abstract. We present a teaching learnng sequence (TLS) for high schools about introductory quantum mechanics. Building on the measurement of *h* with LEDs, we first introduce the concept of mechanical action from which we derive the Heisenberg inequality, and then the ψ-function building on students' knowledge about orbitals in chemistry. The pilot testing of the TLS has involved about 100 high schools leading to a revision of some theoretical aspects. Results of the subsequent implementation with 20 students will be discussed at the conference.

1 Introduction and aims

Teaching of introductory Quantum Mechanics (QM) is increasingly present in high schools in several countries. This circumstance raises a tremendous interest for introducing research-based teaching-learning sequences (QM-TLSs) and suitable experiments and simulations designed to support teachers in their practice [1-2]. In this paper, we propose to resort to a simple introductory experiment on which to build a complex path. To this aim, we use the well known LED experiment to measure the Planck constant *h* [3]. On this basis, we introduce the QM without any reference to its historic development. Instead, we first insist on the universality of the so-found constant. Then, we propose as a general principle for QM the idea that the Mechanical Action *A* can only be varied by discrete amounts. On this basis, we first introduce the Heisenberg inequalities, and soon after the ψ-function. In doing that, we strongly resort on information that students previously got from classes of Chemistry, such as the notion of orbital. The proposed QM-TLS was validated by involving a selected sample of high school students, with the aim of answering the research question: *to what extent the proposed TLS is effective in helping students understand basic quantum mechanics concepts?*

2 Methods

2.1 Design of the integrated TLS

The TLS features a preliminary laboratory activity and a theoretical activity.

The lab activity is designed in such a way to be easily realized with the help of very standard electronics. The students mount a simple circuit constituted by a variable fem generator, a limitation resistance R and a LED. After performing the measurement with diodes of different known wavelengths, the students are asked to plot the values of the threshold diode voltage V_{th} times electron charge *vs.* emitted light frequency ν. From the slope of the linear plot, the students are guided to determine the Planck constant.

The main steps of the theoretical part are briefly described below:

– The students are familiarized with the concept of universality of *h* as derived from the experiment. From simple dimensional considerations, the Mechanical Action *A* for a particle is introduced, provisionally defined as A = Et, or alternatively as A = px, insisting that a precise definition is not necessary at this level. After comparison with a macroscopic system, the students are guided to understand that *h* is “a very small action”.

- The basic Principle of QM is then postulated in the form “Action can never change by less than *h*”, insisting on the concept that factors such as 2π, etc. will not be considered for sake of simplicity. Hence, the Heisenberg inequalities are derived using simple algebra and qualitatively interpreted.
- The ψ function is introduced with tight reference to the familiar notion of atomic orbital. By describing realistic models of atoms and of solids, students are guided to the comprehension of the quantum mechanism of electric conduction and of emission and absorption of photons. Hence, the constitutive relation $E = h\nu$ is deduced.
- The last step is the description of semiconductors and LED physics.

The proposed introductory QM-TLS includes some didactical choices that mark in our view a meaningful difference from more traditional approaches.

- the whole theoretical activity is designed to drive deep consequences from *one* feasible measurement procedure; correspondingly, the core of the QM-TLS is *one* simple principle (action quantization), as far emphasized as the classical three Newton Principles are; the De Broglie relations are considered as an advanced issue, to pursue *after* the introductory level of this QM-TL. The same holds for the Schrödinger equation.
- the historic path is *firmly avoided*. No mention is made, e.g., of “Bohr atom”, while black body radiation is only introduced in contrast to the easier process of single line emission. Instead, *very recent experiments* and applications are described;
- the QM-TLS is designed to appear as the natural evolution of previous courses in chemistry, thus pointing to an *interdisciplinary approach*; moreover, it also develops issues of classical mechanics and electromagnetism, by providing insight in the basic *properties of matter*, such as electric and thermal conduction; finally, it includes *technological applications* (i.e., semiconductor physics);

2.2 Validation of the TLS

We piloted the QM-TLS activity with 106 high school students attending a 15-hour extra-curricular course at our department to assess feasibility of the activities and revise some of the theoretical aspects of the proposed path. Then, we implemented the revised TLS with 20 high school students in curricular hours. A pre-posttest design using a 7-question probe was adopted to assess students’ understanding. The preliminary analysis is in progress.

3 Conclusion and implications

Analysis of the pilot implementation shows that the developed QM-TLS can be effective in improving students’ understanding of basic quantum mechanics concepts. At the conference we will discuss results obtained during the curricular implementation.

4 References

[1] Zollman D. A., Rebello N. S. and & Hogg K. Quantum physics for everyone: hands-on activities integrated with technology. Am. J. Phys., **70**, 252–259 (2002)

[2] Kohnle , A. , Bozhinova , I. , Browne , D. , Everitt , M. , Fomins , A. , Kok , P. , Kulaitis , G. , Prokopas , Raine, M., D. & Swinbank, E. (2014) A new introductory quantum mechanics curriculum. Eur. J. Phys., **35** 015001.

[3] Indelicato V. La Rocca P., Riggi F., Santagati G. & Zappalà G. Eur. J. Phys. **34** 819 (2013)