Improvements of theoretical background and experiment on atomic spectra for high school and university students

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Abstract. The study of atomic spectra is one of the key subjects in teaching physics. It represents a combination of topics such as wave physics, atomic physics, particle physics, etc. Because of its complexity, it takes a well-prepared student and a very creative and resourceful teacher for this subject to be adequately understood and comprehended. This article presents theoretical background with key points in physics that help teachers to better organize their preparation for students and different experimental sets for this specific experiment, such as Nikola Tesla's transformer or some other high-voltage transformers. Another point of view for this experiment is a variety of subexperiment possibilities to choose from in the execution of this practical exercise. This article also brings some difficulties that both teachers and students experience while preparing or doing this experiment, such as lack of more profound quantum physics knowledge since the conventional approach in teaching this specific topic in high schools and universities focuses on an introductory course in the history of this topic-oriented towards early years of the 20th century.

1. Introduction
Teaching any physics' topic requires both – theoretical introduction and (if it is possible) experimental demonstration. However, it is not always feasible to provide an experimental demonstration due to various obstacles such as finding and adapting teaching material [1], money [2], practical realization of high-maintance experiments etc. Therefore, additional efforts should be invested in the preparation of a theoretical introduction. This might as well be a valuable starting point for experimental demonstration. The lack of resources and possibilities for practical presentation of some physical phenomenon could be intuitively introduced through different subexperiments.

We will start by presenting a theoretical background in teaching atomic spectra since there is an excellent potential for improving how students perceive and understand basic concepts for further studying atomic spectra.

Afterward, we will present the usual methods of practical realization of this topic. There is a difference in how this is presented to high school students in comparison with university students. Either way, the essential equipment set for an experiment on atomic spectra can be improved with some modifications that we will also present here.

Nonetheless, it is the teacher that organizes its classes and moderates the course of a specific topic. Often, teachers encounter difficulties in teaching atomic spectra that go far beyond the problem of the
lack of financial resources. It is the lack of interactive materials that poses a problem for teachers, especially in a field of spectra formation for gases and other sources of light [3]. Some other problems that we tackle here are related to teachers’ difficulties with understanding some key concepts in quantum mechanics [4].

Besides previously mentioned difficulties for teachers, there is also a difficulty in a lack of students' preknowledge on the topic. There has been conducted a thorough research in this field [4] that brings very similar results with what we have experienced in our 10-year practice in class with students (both high school and university students).

2. Theoretical background for studying atomic spectra
Classical physics is studied in elementary school, revised in high school and fortified in university once again. Hence classical physics is something where both teachers and students have a solid theoretical background. Quantum physics as a set of modern physics topics is vaguely presented in high school, and there are not enough classes in the physics curriculum allocated for quantum physics topics [5].

2.1. Current theoretical background for studying atomic spectra
Atomic spectra are studied in the final year in high school, while it is studied as a part of some practice courses at the university level. Either way, it is studied in a field of Atomic Physics, where topics are introduced as it follows: different models of the atom through history, Bohr's model of an atom with an emphasis on a hydrogen atom, and afterward emission spectra with a final point – line spectra where atomic spectra are studied on an experimental level.

Prior knowledge that is assumed is wave optics, where concepts of wave nature of light, namely diffraction and interference, have been studied in detail. In addition to this are also quantum concepts such as energy packages, photoelectric effect, photon energy, etc.

2.2. Proposal for broader theoretical background for studying atomic spectra
One of the most important concepts for students to understand here is the structure of an atom. This involves electron configuration, quantum perspective on the nucleus, energy levels distributed by shells and subshells, energy quantization, and specifics for each element. Students' misunderstanding of atomic spectra comes firstly from vague knowledge of these elements. Hence it is crucial to dedicate more time and effort to explain these quantum concepts.

Although Bohr has explained hydrogen spectral lines frequencies quite well, the teacher should have in mind that for students, this model should be explained more thoroughly as it is already stated in detail in some previous research [4].

Since it is left no more than class or two on this, it is vital to organize class efficiently and concisely. We propose the following form of topics to be revised in preparation for the experimental demonstration of atomic spectra:

- current model of an atom with terms of energy levels by shells and subshells
- electron configuration
- energy quantization with the notion of photon energy
- photoelectric effect
- interference and diffraction with an emphasis on mathematics, namely trigonometry, in order to provide a clear understanding of the sine of an angle by which the light wave is being diffracted.

A topic that is almost never mentioned and explained is the role of high voltage. Part of the apparatus for this experiment is inevitably a glass tube filled with a specific gas. In order to have excited states, there must be something to trig this effect. This specific detail is being omitted as something that is assumed, but it plays an important role in students' understanding of an experiment's build-up. This is why we propose for students to have a list of instruments used in this experiment as well as a questionnaire on why and where is each of them used. They could answer this prior to performing an experiment and once again afterward and to compare their answers in order to strengthen what they have learned during the experimental demonstration.
3. Equipment used for studying atomic spectra

We present here two cases: equipment used for high school students and form of a class with learning points and modification and improvement for university students with learning points specified for university level.

3.1. Equipment used in high school for studying atomic spectra

The focus and primary goal with high school students are to teach them quantum concepts, revise and establish topics studied previously, such as wave optics and atomic physics. Hence the necessities are glass tubes and high voltage for demonstration of excitation states of each element in a tube and diffraction pattern. Looking through diffraction pattern, students observe by themselves different patterns for each element and get the basic idea of atomic spectra. With a further extension of the apparatus, it can be organized for students to measure specific distances, plot the graph, find wavelengths for different colors for each element, etc. However, at this level, it is a success if students solidify their previously acknowledged concepts with experimental observation.

Instead of using an ordinary high-voltage transformer as in figure 1, we propose to use Tesla's transformer that can be made in class as a part of practical classes or bought as a replica of the original one.

![Figure 1. Scanfysik electronic power source.](image)

We have been using a very compact and simple Tesla's transformer - Blue over 700K Mini Coil Tube Neon Glow Coil with Clear Plate Power Supply for Tesla – shown in figure 2.
Figure 2. Blue over 700K Mini Coil Tube Neon Glow Coil with Clear Plate Power Supply for Tesla.

It is very simple and practical for high school students, without any wires, making it easier to move from one student to another. Figure 3 presents the practical demonstration for students for different gases (helium, neon, etc.) and in a series of figures 4-7 using diffraction pattern Paton Hawksley with 300 lines per mm.

Figure 3. Visible excitation for Neon with Tesla’s transformer.

Figure 4. Neon. Figure 5. Argon. Figure 6. Neon. Figure 7. Krypton.
3.2. Equipment used in university for studying atomic spectra

University students have a higher level of knowledge of mathematics. Therefore, a different concept of experiment should be used. Besides the visual observation, students are asked to perform a calculation and produce a graph.

The apparatus consists of a source of light, a slit, small optical bench with a slider to provide the different positions for diffraction pattern. In this apparatus, we use SP200V Spectrum Tube Power Supply (230V) with 5000 V and 10 mA output, Electro-Technic Products, Inc, Chicago, IL 60640 USA, as a transformer – figure 8.

![SP200V Spectrum Tube Power Supply](image)

Figure 8. SP200V Spectrum Tube Power Supply (230V) with 5000 V and 10 mA output, Electro-Technic Products, Inc, Chicago, IL 60640 USA.

Since students are asked to measure spectral line position in reference to the position of a slit and the position of the diffraction pattern from the slit, they are given the scales and optical benches from where the result can be read (figure 9).

![Scale for reading spectral line position](image)

Figure 9. Scale for reading spectral line position.

![Optical bench](image)

Figure 10. Optical bench.
For students at the university level it is more practical to use a spectrum tube power supply since it is specifically designed for glass tubes. Without a methodically designed apparatus for glass tubes, it would be impossible to perform all the measurements using only Tesla's transformer.

4. Difficulties encountered both by teachers and students
Atomic spectra are complex topic since it represents the sublimation of various 20\textsuperscript{th}-century physics phenomena such as energy quantization, radiation intensity, etc. Key concepts in understanding this topic can be categorized in three categories: atomic model, light model, and emission and absorption model concepts [4].

Wave optics, as a physics phenomenon before the 20\textsuperscript{th} century, still presents some difficulties in understanding the dual nature of light (particle and a wave) [6].

Atomic spectra are taught in different schools by different teachers (chemistry graduates, physics graduates, and engineers), and, depending on their background, they experience different difficulties. Nevertheless, these could be underlined as a lack of a more profound understanding of the quantum model and the connection between the model of radiation and the quantum concept of the atomic model.

5. Conclusion
There are several categorizations of the fields of physics, but most widely, we can divide it into classical and quantum physics. Atomic spectra are topic that merges these two while inclining toward quantum concepts. Although students have a certain knowledge of classical physics, quantum physics concepts are not fully understood, and problems in understanding and performing emerge when the two are combined.

Therefore, it is necessary to recognize the atomic spectra topic as an opportunity to revise previously acquired terms and notions in classical physics in order to introduce quantum concepts more widely. Important terms to be thoroughly revised in the theoretical background introduction for atomic spectra are: atom, energy (quantization), light (diffraction, interference, dual nature), and emission/absorption.

An experimental demonstration could be performed at different levels for high school and university students. We have shown how Tesla's transformer could be used in teaching electromagnetism as an introduction to the quantum model of emission and absorption of electromagnetic radiation. With a broader theoretical background in introductory classes for atomic spectra experiment, as well as dissection of difficulty level in the experiment itself, students would have the opportunity for a deeper understanding of quantum concepts along with acquisition of different models and their interaction – quantum model and radiation model.

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