IMPROVING THE STUDENTS' LEARNING OF OPTICS AND ATOMIC AND MOLECULAR PHYSICS BY COMPUTER-ASSISTED SCHOOL EXPERIMENTS

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Abstract

In the present work, we investigate the possibility to improve the students' understanding of the spectral properties of different light sources and the transmission/absorption of different media by means of a partially computer-based school experiment in physics. Numerous studies have identified certain difficulties in understanding and applying atomic models, and more specifically, atomic spectra. Some examples of students' misconceptions are: they do not take into account the quantization of atomic energy levels; assume that the atom can absorb a photon with arbitrary energy; do not differentiate between the quantities intensity and frequency or assume them to be directly proportional; often assume violation of the energy conservation law with respect to the emission of a photon; do not consider the possibility of an atom to decay into an excited state with lower energy, etc.

The experiment includes data acquisition and analysis of the spectra of different light sources, as well as the transmission spectra of different media. The numerical data are then used to calculate and visualize the absorption spectra of the media, with an analysis of the energy level structure of the absorber. A detailed description of the experiments will be provided, together with results from a survey performed among 10-grade students before and after the experimental work. Our hypothesis is that the proposed combined practical work on physics and information technology will improve the students' understanding of optics and atomic and molecular physics, as well as their data analysis skills..

Keywords: computer-assisted experiment; spectroscopy practical education.

INTRODUCTION

High-school atomic physics covers several multifaceted concepts, the comprehension (and application) of which requires students to develop appropriate mental models. This process takes time and there is recent evidence [1] that diversifying instructional approaches helps students acquire knowledge about the microscopic world.

Generally, high-school students may form misconceptions related to the understanding and application of atomic models [2, 3], and more specifically, atomic spectra [4, 5]. Savall-Alemany [4] identify the following students' misconceptions: not taking into account the quantization of atomic energy levels; assuming that the atom can absorb a photon with arbitrary energy; not differentiating between the quantities *intensity* and *frequency* or assuming them to be directly proportional; violating energy conservation with respect to the emission of a photon; not considering the possibility of an atom decaying to an excited state of lower energy (i.e. not necessarily the ground state) etc.

The above mentioned study [1] suggests that, specifically in relation to understanding atomic transitions and spectra, 10th grade students may require more than one instructional approach - preferably experimental. The development, implementation and discussion of such a practical setup is presented below.

HYPOTHESIS TESTING

The hypothesis we check with the present work is that computer-based school experiment will lead to an increased interest and better understanding of the studied material. This is realized by comparing the results from testing of students' knowledge of atomic physics before and after working on the laboratory setup constructed specifically for this purpose.

In the Bulgarian textbooks for 10-th grade students there is a plan for a laboratory exercise on making a DIY spectroscope, in which the diffraction grating is replaced by a CD or a DVD [6]. This idea is very appropriate and interesting but it allows for only a qualitative analysis of the spectra observed. On the other hand, the setup proposed by us includes a spectroscope with a CCD matrix allowing for acquisition of quantitative data with a good resolution. Thus, here the computer is used in this laboratory exercise for data acquisition, processing and visualization. We suppose that the students will benefit from this in two ways – first, this will improve their understanding of the basic concepts of atomic physics and second, it will improve their skills to work with certain computer programs. In this sense, the proposed laboratory work is interdisciplinary, since it involves areas such as physics, computer and information technology and mathematics. Moreover, such exercise will give the students a better idea of real scientific experiments.

To validate the hypothesis, we developed a test with seven multiple-choice questions targeting levels of remembering, understanding and application according to the Bloom's taxonomy [7]. More specifically, the questions included are: identification of atomic gas emission spectrum; knowing the definition of thermal emission, photoelectric effect, dispersion and fluorescence; absorption-emission of atoms in ground state; identification of hydrogen spectral line series; relationship between frequency and wavelength of light waves; calculation of emission photon energy from energy level diagram; understanding and application of energy conservation law through the relationship of absorption and fluorescence light colour and its relation to its energy.

Unfortunately, the student sample group was very small (only 12 students), so in the analysis of the preliminary (control) tests and the tests made after laboratory work we will not apply statistics but rather a case study approach.

Description of the laboratory setup

The laboratory setup was designed for registration of emission, transmission and fluorescence spectra, with subsequent calculation of absorbance spectra (see Fig.1).

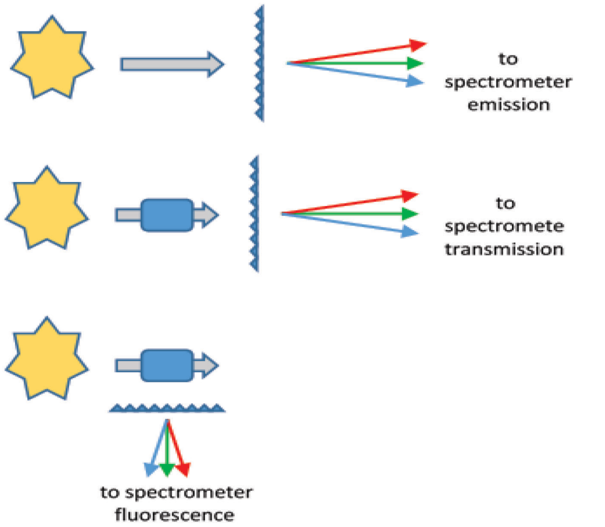

Fig.1. *Schematic representation of the registration of emission, transmission and fluorescence spectra*

The setup includes a ThunderOptics SMA-E spectrometer with an optical fiber and an optional collimator input. The spectrometer has a USB output to a computer with an appropriate software for spectra visualization and data export. The following emission sources were used: solar light, tungsten white source, luminescence light tubes, several LEDs (with wavelength from 380 to 630 nm), He-Ne laser generating at 632.8 nm. The absorbers for the transmission measurement were red wine and an ethanol solution of fluorescein. They were prepared and placed in plastic cuvettes. The materials used for fluorescence measurement were fluorescein, olive oil, rum and tonic (the last three were randomly purchased from food market). They were also contained in cuvettes, held either freely or in a cuvette holder with four fiber outpurts. The free standing cuvettes were used when the collimator was required to collect weaker signals, while strong signals were collected by means of fiber attached to the cuvette holder.

Laboratory exercise reports

In this section we will briefly illustrate some of the obtained spectral results used for discussion, analysis and comparison of the different processes involved.

Fig.2 presents emission spectra, where (a) is a comparison of a tungsten lamp with a luminescence tube (intensities normalized), and (b) presents the difference in the spectra of an LED and a laser with practically the same central wavelength.

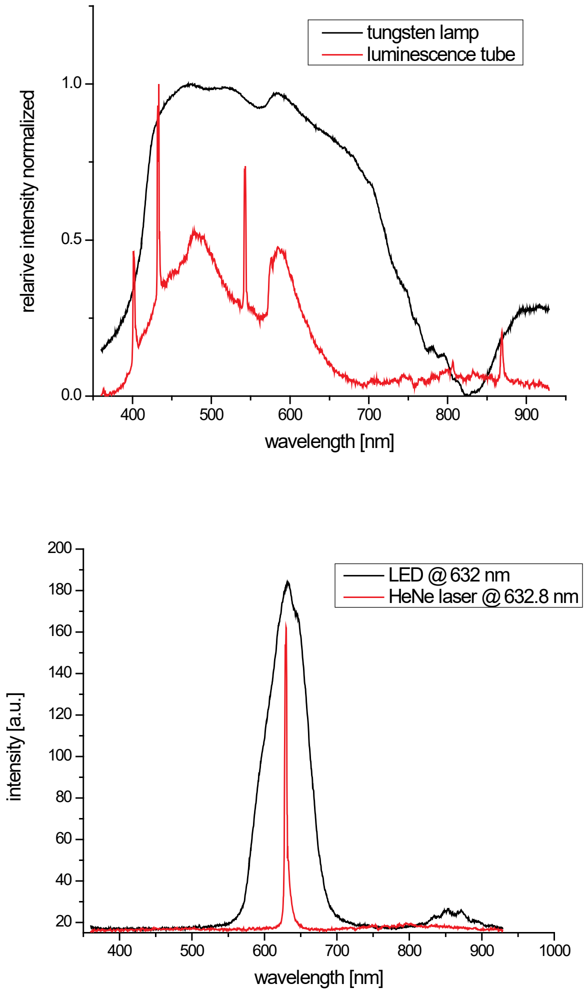

Fig.2. Emission spectra recorded. (a) tungsten lamp and luminescence tube (intensities normalized), and (b) LED and laser.

It can be seen that this quantitative visualization is very useful and illustrative for the different kinds of spectral light sources, both in terms of linewidth and structure (spectral shape).

Next, transmission spectra were recorded and absorption spectra were calculated and analyzed. The example of fluorescein is illustrated in Fig.3 (the same was also performed with red wine). The figure shows the tungsten white broadband emission spectrum (purple line) registered when the input (light source) fiber and the output (to the spectrometer) fiber are connected to the empty cuvette holder. Placing an empty cuvette in the cuvette holder gives us the transmission spectrum of the cuvette itself (black line). When the fluorescein solution is added to the cuvette, the transmission again changes (red line in the figure). In general, when the spectrometer is calibrated not only for wavelength but also for intensity and when it is not saturated, the difference between the cuvette transmission and the fluorescein plus cuvette transmission signals should correspond to the absorption spectrum.

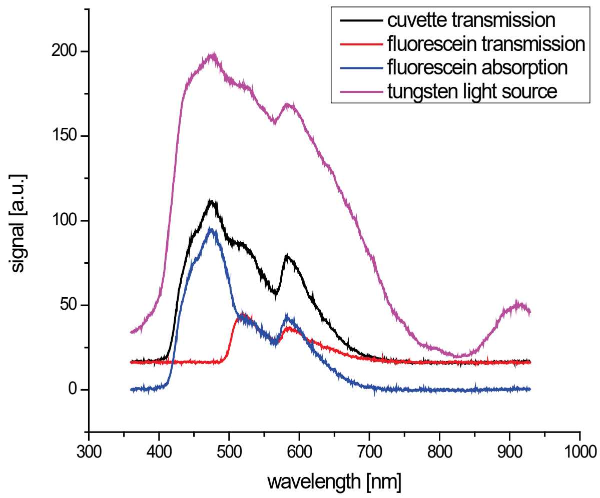

Fig.3. Transmission and absorption spectra of fluorescein

In our case this is not so for the intensity calibration. This is mostly seen in the region around 550-560 nm, where there is an artefact dip in the signal due to a hardware related decrease in the sensitivity of the sspectrometer, according to information given by the producers. Work is in progress for a software correction which would make possible to perform more correct relative intensity measurements.

Finally, we recorded several fluorescence spectra by using the collimator, since the signals are weaker and undetectable without it. Four spectra are illustrated on a single plot in Fig.4. The excitation with a 400 nm LED source is seen at the low-wavelength side of the plot. It is indeed very useful from a didactic point of view to see the colour of fluorescence by eye and then see the plot – the greenish of fluorescein, the orange-reddish of olive oil, and the bluish of tonic and rum.

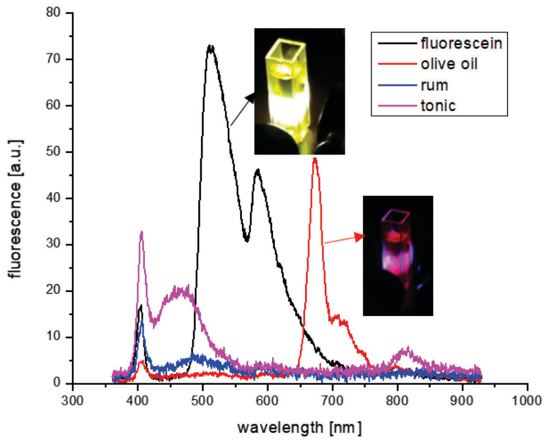

***Fig.4**. Fluorescence spectra registered*

Analysis of the test results and hypothesis check

The laboratory exercise being completed, with the spectra recorded, data extracted and processed, an active discussion followed, which showed that the students were very much interested and excited by the laboratory work, especially the fluorescence part. Shortly afterwards the testing was repeated and the results were compared with the results from the control testing.

Generally, the results, taken as a case study, were positive. Surprisingly, a slightly increased number of wrong answers were obtained on the final compared to the control test for the first question, where more students identified an emission spectrum as absorption one. One possible explanation for this effect is that during the laboratory exercise naturally more attention was paid to absorption, as related to transmission, absorption and fluorescence.

There were no wrong answers after laboratory work on the questions related to the definition of thermal emission, photoelectric effect, dispersion and fluorescence (3 wrong on the control); absorption-emission of atoms in ground state (4 wrong on the control); relationship between frequency and wavelength of light waves (7 wrong on the control); understanding and application of energy conservation law through the relationship of absorption and fluorescence light colour (2 wrong on the control).

For the question about identification of hydrogen spectral line series the correct answers increased, but still four of the students did not demonstrate improvement in understanding. The same applies for the question about calculation of emission photon energy from energy level diagram. We suppose (and this was confirmed by an interview with three of the students) that the reason for this is that students are confused by the negative energy values for the levels. Although they have mentioned at school that a negative value for the energy means that energy must be supplied to the system for the electron to overcome the attractive force of the nucleus, still this is not a notion fully comprehended by the students.

CONCLUSIONS

We have shown that diversifying the teaching approaches is helpful for the students to gain and deepen their knowledge in the field of atomic physics. Unlike areas like mechanics and thermal effects studied at school, in this area students have no background knowledge and real-life experience on which they could rely. The microscopic world and its description therefore require more effort on the side of teachers to compensate for that.

Laboratory work is one of the most powerful tools in the hands of physics teachers. With our study we have shown that the performing computer-assisted laboratory exercise may further contribute to the students' involvement and thus, understanding of the material studied. We propose a laboratory setup based on a very user-friendly and affordable spectrometer connected to a computer for quantitative study of emission, transmission/absorption and fluorescence spectra and the processes lying behind them.

From the tests we made before and after laboratory work with a small number of 10-th grade students it can be seen that the number of correct answers clearly increases. Moreover, not only the test results in general, but also the feedback from the students showed that the laboratory exercise, combined with visually attractive tasks and with computer work, proved useful both for the understanding of the phenomena and for raising the students' interest in atomic physics and optics.

Acknowledgements:
The work is financially supported by the Fund for Scientific Research at the University of Sofia "St. Kliment Ohridski", grant №80-10-42/10.05.2022 г.

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