'School adopts an experiment': the photoluminescence in extra-virgin olive oil and in tonic water

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Abstract

We report a laboratory activity, carried out along with high- and secondary-school students, that can be done to increase the interest of the young in scientific studies. Groups of selected students 'adopted' experiments at physics research laboratories, under the guidance of university researchers. Subsequently, the students demonstrated the experiments to the public at large during the annual science festival organized in Palermo by the association PalermoScienza, in collaboration with the University of Palermo. Experiments on the magnetic levitation of superconductors and on the photoluminescence of several substances were proposed. We discuss the experiment on photoluminescence as a case study. The students who adopted the experiments reinforced their commitment to learning. They acquired a physics-based knowledge of the topics connected with the experiments in a much better way compared with the usual didactics in school.

Introduction

In the last decade fewer and fewer students have been attracted by scientific degree courses in physics, chemistry and mathematics. To face the problem and to increase interest in scientific studies, several actions have been put forward. Among them, an interesting activity carried out along with high-school students, as well as secondary-school students, is the so-called 'School adopts an experiment' [1–4]. In the framework of the annual science festival organized in Palermo by the association PalermoScienza[1] in collaboration with the University of Palermo, groups of students from the Liceo Scientifico 'Palmeri' (Termini Imerese, Palermo) participated by 'adopting' experiments on the magnetic levitation of superconductors [2] and on photoluminescence. Two selected groups of students adopted the above experiments. The students were trained by researchers to carry out real experiments in the laboratories of the Physics Department at the University of Palermo. Subsequently, they demonstrated the adopted experiments to visitors during the PalermoScienza event on 19–28 February 2011.

In this article, we discuss as a case study the experiment on photoluminescence of several substances, with particular attention paid to teaching aspects related to the curricular topics of light and optics.

[1] For more information on the association PalermoScienza, visit the website: www.palermoscienza.it.

Photoluminescence

The phenomenon of light emission by a substance that has absorbed electromagnetic (em) radiation is called photoluminescence. This phenomenon is also called fluorescence, from the mineral fluorite (calcium fluoride), which exhibits fluorescence under ultraviolet light (UV). From a more physical point of view, the photoluminescence phenomenon includes fluorescence and phosphorescence. They are distinguishable on the basis of the typical time of permanence of the emission of light, being of the order of 10^{-9} s for fluorescence and from 10^{-3} to 10^4 s for phosphorescence [5]. The most striking examples of photoluminescence occur when the absorbed radiation is in the UV region of the em spectrum, and thus invisible, and the emitted light is in the visible region.

For the characterization of substances (in any state of aggregation: solid, liquid or gaseous) and for the study of the dynamics of the excited electronic states in a molecule the photoluminescence spectroscopy technique can conveniently be used, which consists in illuminating a substance with em radiation with defined energy $h\nu_{ex}$ and detecting the emitted radiation at lower energies $h\nu_{em}$, where h is Planck's constant and ν the frequency of light. (The product of the frequency ν and the wavelength λ is equal to the speed of light c.) Photons that irradiate the substance bring orbital electrons of the molecules in the quantum ground state S_0 to a quantum excited state S_1 with higher energy in an absorption process,

$$\text{absorption:} \quad S_0 + h\nu_{ex} \to S_1. \qquad (1)$$

The difference in energy between S_0 and S_1 is $E_{S1} - E_{S0} = h\nu_{ex}$. Subsequently, the energy can be emitted radiatively and isotropically by photons, with energy $h\nu_{em} \leqslant h\nu_{ex}$, and/or dissipated as heat by quantum vibration or phonons with energy $h\nu_{vib}$,

$$\text{relaxation:} \quad S_1 \to S_0 + h\nu_{em} + h\nu_{vib}. \qquad (2)$$

The term $h\nu_{em}$ is responsible for the photoluminescence; the term $h\nu_{vib}$ is responsible for the sample heating. In the process the law of energy conservation must be fulfilled.

The frequencies of the exciting and emitted light depend on the particular system and on the molecular composition of the investigated substance. Photoluminescence has many practical applications, including mineralogy, gemology, chemical sensors, fluorescent labelling, dyes, biological detectors, and, most commonly, fluorescent lamps.

Figure 1. Experimental apparatus consisting of a light source in the UV spectrum (xenon lamp) and a CCD Ocean Optics detector connected through silica optical fibres and interfaced to a computer through a USB port.

Figure 2. The optical fibre used to direct light onto the samples and also to detect the emitted radiation.

Experimental details

The proposed experiment consists in the detection of the photoluminescence emission by solutions containing different molecules: fluorescein (green light), Alexa647 (red light), quinine chlorhydrate in tonic water (blue light) and chlorophyll in extra-virgin olive oil (red light). To perform the experiment we use the apparatus shown in figure 1. It consists of a light source (xenon lamp) in the UV region of the em spectrum, a CCD Ocean Optics detector and silica optical fibres (figure 2). The acquisition of spectra is carried out by the detector that automatically analyses the intensity of the light as a function of frequency. The spectral distribution is acquired by a computer through a USB port, allowing one to record and visualize the collected spectra. A torch equipped with

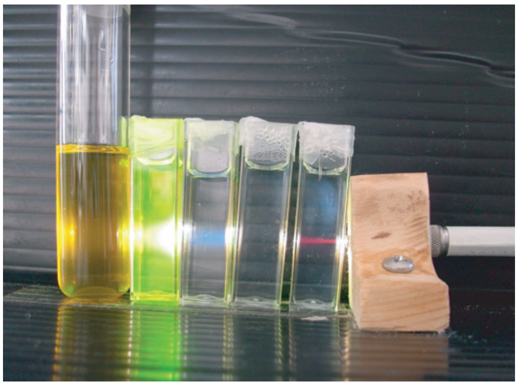

Figure 3. Fluorescent substances under UV irradiation. From left to right: extra-virgin olive oil, fluorescein, tonic water, distilled water and Alexa647.

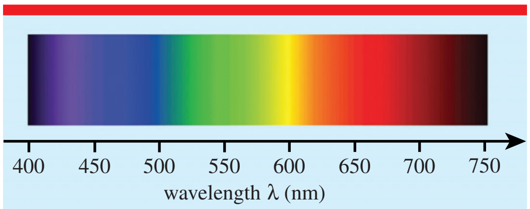

Figure 4. The electromagnetic spectrum in the visible region, in which is shown the correspondence between colour and wavelength in nm.

a light emitting diode (LED) in the UV region can also be used to see by the naked eye the photoluminescence of the substances.

Results and discussion

Figure 3 shows the photoluminescence effect in different substances when irradiated by the UV light of the xenon lamp: extra-virgin olive oil, fluorescein, tonic water, distilled water and Alexa647. For the sake of clarity, we show in figure 4 the visible region of the em spectrum, in which is indicated the correspondence between colour and wavelength.

Fluorescein is a synthetic organic compound soluble in water and alcohol (basic molecular formula $C_{20}H_{12}O_5$), which is widely used as a fluorescent tracer for many applications. It has an absorption maximum at $\lambda = 494$ nm and emission maximum at $\lambda = 521$ nm, in the green region of the em spectrum [6]. In figure 3, one can see the green light emitted by the fluorescein solution.

Figure 5. Blue light emitted by the quinine in commercial tonic water when illuminated with UV light produced by a portable LED torch.

The fluorescent dyes of the Alexa family are[2] typically used as cell and tissue labels in photoluminescence microscopy and cell biology. The excitation and emission spectra of the Alexa fluorescent probe series cover the visible spectrum and extend into the infrared region. The individual members of the family are numbered roughly according to their excitation maxima (in nanometres). For the experiment we have used a solution of Alexa647, which emits red light. In figure 3, one can see the red light emitted by the Alexa647 molecules in solution.

Tonic water is a soft drink in which quinine chlorhydrate (basic molecular formula $C_{20}H_{24}N_2O_2$) is dissolved. Quinine was originally used as a prophylactic against malaria; now, commercial tonic water has significantly lower quinine content and is consumed for its distinctively bitter taste. Tonic water shows photoluminescence owing to the presence of quinine, which emits em radiation of blue colour ($\lambda = 450$–480 nm) when irradiated by UV light [6, 7]. In figure 3 one can see the blue light emitted by the quinine in commercial tonic water, whereas figure 5 shows the emitted light of tonic water when irradiated by a portable UV LED torch. As a comparison, we also irradiate a sample of distilled water with UV. In this case, no photoluminescence is observed, as can be seen in figure 3.

Common vegetable oils, including olive oil, show photoluminescence spectra when irradiated by UV light [8, 9]. In particular, they exhibit photoluminescence in the blue region ($\lambda = 430$–450 nm). Extra-virgin olive oil shows a photoluminescence spectrum composed of three

[2] For more information on the Alexa fluorescent probe series, visit the website: www.invitrogen.com.

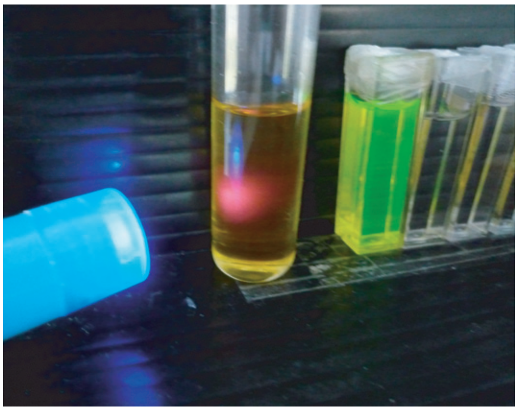

Figure 6. Red light emitted by the extra-virgin olive oil when illuminated with UV light produced by a portable LED torch.

bands: one low-intensity doublet at $\lambda = 440$ nm and 455 nm (blue region), one of strong intensity at $\lambda = 525$ nm (green light), and one of medium intensity at $\lambda = 680$ nm (red light). The band at $\lambda = 680$ nm (red light) is due to the photoluminescence of chlorophyll (basic molecular formula $C_{55}H_{72}O_5N_4Mg$), which is contained in the extra-virgin olive oil. The band at 525 nm (green light) is due to the vitamin E.

In refined olive oils, the chlorophyll content is considerably reduced and consequently the red-light emission disappears. This result could possibly be used for authentication of extra-virgin olive oil, unless chlorophyll is added to the refined oil. In any case, the absence of red-light photoluminescence is an indication of the lack of chlorophyll. In figure 3, one can see the red light emitted by the chlorophyll in extra-virgin olive oil produced in the Palermo area. Figure 6 shows the emitted light of extra-virgin olive oil when irradiated by a portable UV LED torch.

Educational benefits

Because of competition among students and classmates, the students who adopted the experiments reinforced their commitment to learning; they acquired knowledge of the physics arguments connected with the experiments in a much better way compared with the usual didactics in school. They studied in order to understand better the physics concepts behind the experiments and to be competitive with other students during the demonstrations. This has increased their awareness of what they have learned in lessons at school. In order to extend the benefit to other schools, the students have prepared posters and leaflets, in which they describe and discuss the experiments on the photoluminescence phenomenon in relation to curricular topics of optics and light.

Usually, research institutions organize one-day events addressed to the public at large. It would be very fruitful for these institutions to address such events also to school students, allowing them to participate actively in the event by adopting an experiment. It would give students the opportunity to visit the research laboratories and, at the same time, it would give more visibility to the research institutions. If the event were planned at the beginning of the academic year, it would be feasible for schools to include the subject of the experiments in the curricular teaching activity. This would be useful, for example, in Italian schools since they plan extra-curricular activities at the beginning of the academic year. It allows schoolteachers to prepare students to adopt an experiment in the planned event in collaboration with researchers, stimulating the students' curiosity and giving them the opportunity to consider scientific research.

Conclusion

We have described how cutting-edge research in physics can helpfully reach high-school students, focusing on the teaching aspects of physics and on the related educational benefits. A different approach has been developed to explain the physics concepts connected with the adopted experiments, exploiting the potentialities of laboratory activities as a key to success in stimulating students to learn and to be interested in scientific topics. Groups of selected students adopted experiments on the magnetic levitation of superconductors and the photoluminescence of several substances. We have discussed the experiment on photoluminescence as a case study. The students illustrated the experiments to the public at large during the science festival organized in Palermo by the association PalermoScienza, in collaboration with the University of Palermo. The experience was that the students adopted the experiments with enthusiasm. They learned the topics connected with the experiments more deeply in comparison with the didactics in school. Furthermore, competition among students and classmates during the exposition stimulated them to learn to the best of their capabilities.

Acknowledgments

This work was carried out in the framework of the Italian National Plan 'Lauree Scientifiche' under the financial support of the Italian Ministry of Education, University and Research. The authors thank V Vetri for kindly providing the fluorescent dyes and the association PalermoScienza for inviting them to participate in the science festival.

Received 20 May 2011, in final form 29 June 2011
doi:10.1088/0031-9120/46/5/015

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