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Fluorescence: An Interdisciplinary Phenomenon for Different Education Levels

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Abstract
This paper shows the scientific foundations of a natural phenomenon of undoubted interest and applicability in our day, fluorescence, and its possibilities for teaching at three educational levels: primary, secondary and university. It begins by describing the nature of the phenomenon and continues by explaining how we work with students of the levels mentioned. The method of teaching starts questioning them on fluorescent tubes and fluorescent material. These questions will lead to further research into three topics: 1) fluorescent materials; 2) features of the visual system; and 3) lighting systems, types of lamps and its characteristics. The work then demonstrates its usefulness as an interdisciplinary phenomenon and as a mean of motivating students' learning.
Keywords: Fluorescence, phosphorescence, interdisciplinary, secondary education and university education.

Introduction

The phenomenon of fluorescence can be applied to different levels of education and also used to address some crosscutting themes such as, for example, ocular health and energy saving. The aim of this paper is to show how fluorescence can help students to learn about certain concepts related primarily to the physics and chemistry of materials by encouraging the study of phenomena and devices close to them, and even in their daily environment. In addition, we seek to achieve this at the three levels of primary, secondary and university education, since the phenomenon of fluorescence enables students progressively to deepen their knowledge in accordance with these levels.

Fluorescence and Phosphorescence

Most substances that absorb ultraviolet or visible radiation convert it to internal energy. However, there are others that re-emit some radiation in the form of wavelengths longer than that absorbed, for example, by absorbing ultraviolet and re-emitting blue. This phenomenon is called photoluminescence, which comprises two phenomena simultaneously: fluorescence and phosphorescence. The difference between them lies in the time between absorption and reemission. In the case of fluorescence, it is immediate (less than 10 ns) while more time elapses in phosphorescence, so that phosphorescent materials emit light in darkness. Materials with these properties are called fluorescent materials and phosphorescent materials, respectively.

Fluorescence is found in the materials of everyday life that surround students, such as detergents used for washing clothes, fluorescent lighting, synthetic fibres used in the manufacture of certain clothing, credit cards, identity cards, banknotes, theatre and cinema tickets, certain beverages such as tonics, or fluoride in toothpaste. The most usual phosphorescent materials are indoor signs, decorative objects or in certain watches. Fluorescence and phosphorescence are, as already mentioned, phenomena that have been known for at least more than four hundred years. The Spaniard Monardes Nicholas made the first reference to the former in 1565, while the Italian Vincenzo Cascariolo described phosphorescence somewhat later, in 1603. Both phenomena were studied by eminent figures in science such as Galileo Galilei and Isaac Newton. However, it was the British physicist George Stokes, who, in 1852, began to determine the nature of fluorescent emission and also gave it its name.

The nature of these phenomena is quantitatively and qualitatively different. Typically Jablonski's diagram (Figure 1) is used to explain this, but as it is somewhat complicated, we use the analogy shown in Figure 2 in Secondary Education.

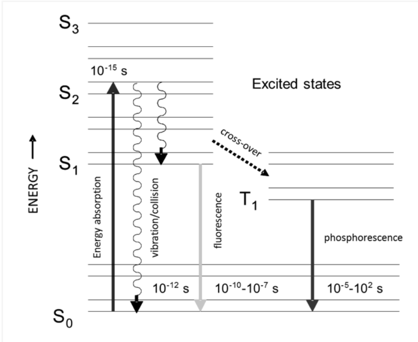

Figure 1. Jablonski's diagram: fluorescence and phosphorescence

The first step is the excitation of electrons from their base state to a higher energy state. This process is rapid, occurring in 10^{-15} s. In our analogy a helicopter lifts some people up to the roof of a skyscraper very quickly (left arrow, Figure 2). Typically, the electrons return to their starting position, swiftly losing energy through molecular vibrations and shock, but a thousand times slower than the excitation. In our analogy, the people take a lift down to the ground floor quickly (zigzag arrow). In some cases, the electrons lose energy more slowly (about one million times slower than the excitation) emitting light radiation called "fluorescence." In our analogy, the people run down the stairs (third arrow from left). The last possibility is that two excited levels (singlet-triplet) intersect where the deactivation is forbidden by the rules of quantum mechanics and this process of "phosphorescence" is about a billion times slower. In our analogy, the skyscraper is changed to a nearby cliff (right arrow); in principle it is impossible for any except expert climbers to go down, although it will take longer than descending by a staircase.

These processes do not occur randomly, so that it is possible to know in what compounds they will occur and then use these properties to analyse substances or to prepare both organic and inorganic new compounds, which give rise to the many technological applications already mentioned, and among which fluorescent lamps are particularly important. More information can be found in Requena and Zúñiga (2003).

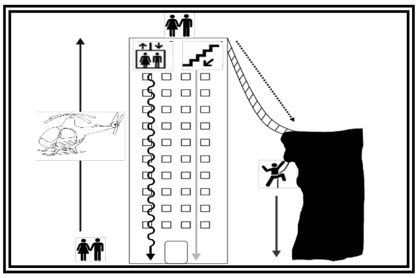

Figure 2. Analogy of Jablonski's diagram

Normal fluorescent lamps consist of a glass tube, previously 38 mm in diameter and now 26 mm, whose length varies depending on the power. The tube is coated internally with a luminophore powder and contains a noble gas at low pressure and a very small drop of pure mercury. When connected to the current a discharge is produced in the mercury vapour at low pressure which excites the mercury atoms and on their return to their base state their own lines of this element are emitted: two in the ultraviolet, 253.7 and 365,3 nm, and others in the visible, 404, 407, 435, 577 and 579 nm. The phosphor/luminescent coating of the tube is excited by 253.7 nm radiation and emits light in other parts of the visible spectrum. Figure 3 sets out a scheme of this process.

Usually a mixture of three luminophores is used, one emitting blue (e.g. barium magnesium aluminate activated with europium), another green (e.g. cesium magnesium aluminate activated with terbium) and the third emitting red (yttrium oxide activated with europium). More information about these lamps can be found in Cruz and Toledano (1992) and in Ramírez Vázquez (1993).

Fluorescence has many other applications at the scientific and technical level, among which are some related to chemical, geological and biological analysis (Ball, 1975; Fowler, 1967; Thompson, 2008).

Some activities of fluorescence have been proposed for use at different educational levels. For example, Hall (2008) suggests observation of the phenomenon of fluorescence by simple experiments that can be performed by secondary school students with readily accessible reagents and materials. Other authors, such as Herreman and Tieghem (1992), use it to make the invisible visible and Kamata and Matsunaga (2007) to develop an optical experiment using small torches light the three primary colours.

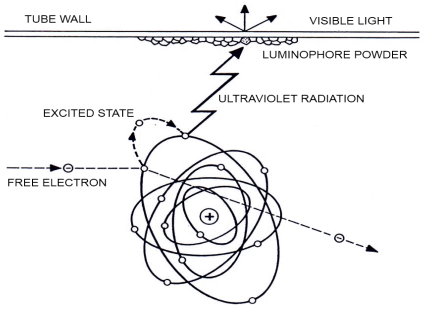

Figure 3. Diagram of a fluorescent lamp

Procedure

Our starting point will be fluorescent tubes, commonly used in lighting and that probably illuminate the classroom. This start enables us to encourage our students on a topic:

Why are these lamps called fluorescent tubes? What key elements are they made of?

The answers provided give us early indications for further work, which will lead to new questions:

What is a fluorescent material? Can any material be fluorescent? Are we sensitive to any electromagnetic wave (radiation)? What are the features of our visual system? What should a lamp be like for us to get the maximum benefit from the energy and visual point of view?

These questions will lead to further research into three topics:

1) Fluorescent Materials
2) Features of the visual system
3)Lighting systems. Types of lamps. Characteristics.

The depth with which each of these issues is treated and the follow-up questions will depend, of course, on the educational level of the students and the teacher's interest. For example, at primary education level we can only try to address the concept of fluorescent material and its potential applications close to our students, such as its use to prevent counterfeiting (our students can provide documents and / or banknotes and look at them under white light and ultraviolet light), their use in decoration, and so on. However, it can be treated with greater depth and scientific rigor at other educational levels.

In order to confirm the appropriateness of the topic for our students and to see in practice how it can be tackled, we employed it at the different levels of primary, secondary and university education and considered their experience of it. We then comment on it as well as the results derived from it.

Application to different educational levels

Primary Education

On various occasions, and with increasing frequency, primary schools ask to visit our laboratories in the Faculty of the University of Granada. Recently, at different times, four groups came to our laboratories for Optics and Inorganic Chemistry. We mentioned to their teachers, that among other things, we were going to experiment using different fluorescent and phosphorescent materials, requesting them to deal with it later in class and to let us have their comments.

The students came to our laboratory highly motivated by the simple fact of being in a university laboratory, but, even so, we sought to initiate an activity that would have the maximum possible interest for them. On the other hand, for us, accustomed to working with university students, it was a real challenge; their teacher's help and looking for questions close to their daily life was very useful to us. This aspect of motivation, involving their experience was the first phase of the activity, which also led us to reflect on the subject as we now explain.

1) Questions to stimulate the students about their experience:
- Why do you think these lamps are called fluorescent tubes?
- Have you noticed that when you go shopping with your parents, when you go to pay the cashier she puts the banknote through a machine to see if it is false?

2) We discuss briefly what is in the tubes and what a fluorescent material is.

3) Applications of fluorescent and phosphorescent materials. Some examples are given:

- To avoid fakes, to examine banknotes, documents (identity card, driving licence...) illuminating them with visible light and rich ultraviolet light.
- Other materials in daily use having fluorescent dyes: pens, paper, balloons, detergents, antifreeze, drinking straws...
4) Introduce phosphorescent materials.
- What is the fundamental difference between fluorescent and phosphorescent materials?
- Look around you to see where phosphorescent materials are used.

Figure 4: Cabin used. Left: illuminated with white light. Right: illuminated with ultraviolet-rich light

5) New questions were raised and left open for the group-class to solve, the group being divided into subgroups to tackle them. Thus, for example:

The use of a cabin that enables us to illuminate objects in white light and / or rich in ultraviolet light (Fig. 4) will illustrate the various steps and examples that we are making. We may also propose a number of issues that make the students participate or we leave issues open, so that the teacher can treat them in subsequent work in the classroom. An example of this would be:
- How can fluorescent materials be used?
- What do you think you have to do with a fluorescent tube if it "peels" a little?

Then we wish to emphasize the environmental aspects, we explain:
- The use of these lamps saves energy.
- You must not break them when they stop working; they contain mercury, which is a major pollutant. Take them to a collection point.

When we want to emphasize health education, we ask:
- Is ultraviolet radiation dangerous?

6) Idea-Sharing Sessions and Conclusions
As mentioned above, we undertook this experience with four groups of three primary schools in the province of Granada of varying socio-economic status. Each group consisted of between 20 and 25 pupils, aged between 9 and
12. The main observations were:
- Students are very motivated to carry out the visit.
- They happily participated in "breaking the ice".
- They showed great curiosity.
- Their participation is easily gained

We propose that in the early stages the work is done with the whole group. It should then be divided into small groups to work on one of the aspects (environment, health, visual system, other applications of fluorescent materials, etc.). The issues raised are primarily concerned with the need for mercury recycling and energy conservation involving these lights. Finally, we address idea-sharing, discussion and conclusions.

The teachers also reported themselves pleased with the visit and said they would work on many aspects of the experience in future lessons. After we had been in contact with them over a period of time, they told us that they had referred to the visit at various times in their teaching and that when they did so, the students remembered it well and considered it very interesting for them.

Secondary Education

For two consecutive years, 2009 and 2010, we have carried out interdisciplinary activity on fluorescence in the departments of Inorganic Chemistry and Optics, in "Science Week" which takes place every year in November at the Faculty of Science in the University of Granada.

During the first year, the activity was undertaken by 12 groups from secondary schools in the province of Granada. As a result of the many applications received, during the second year the schedule was expanded, allowing the number of groups to climb to 20. The way to perform this type of activity for students starts from the same point as mentioned above but treated at a deeper level and incorporating new experiments. We highlight in particular how a joint venture of the various branches of science, aided by technology, promotes the general advancement of the society. Thus, for instance, it is often quite enlightening for them to see how chemical compounds that have been used in the manufacture of fluorescent tubes from its invention to the present time have evolved, sometimes when looking to improve certain properties (e.g. stability or efficiency), others when seeking the appropriate wavelength to improve aspects of lighting, or greater corporate profitability.

Following the completion of the visit, the centres were asked to fill out a survey of satisfaction. In it, (as well as organizational aspects that are not relevant here), they were asked about each experiment, to indicate whether they considered it interesting, if they believed their students had learned and their overall assessment. With regard to the fluorescence experiment, the responses received indicated that they had seemed very interesting (80%) or interesting (20%), that their students had learned a great deal (close to 90%), and 85% evaluated it as very good overall and 15% as good.

At this educational level, as well as the chemical and optical implications of the activity, various aspects of electricity can also be dealt with, such as the installation of these lamps and the role each of the constituent elements plays, showing again the interdisciplinarity that the phenomenon presents. In addition, social issues such as energy saving or ocular health continue to be of special interest at this level of education.

University Education

The implementation of the new European educational system (European Higher Educational Area) brings with it highly significant changes in the methodology of university education. The aim of teaching skills takes on a greater importance, we must not only "know", but also "know how". Working in small groups has been a commonly used tool, but if not planned properly, it may have unintended results. The proposal to work on this subject with our university students has shown it to be well suited to this level.

With undergraduate students we cannot restrict ourselves to a mere description of the experiment. In particular we worked with students of the Degree in Chemistry, enrolled in the course of Fundamentals of Optics (optional 2nd year) and students of the Degree in Optics and Optometry, enrolled in the Physics course (compulsory first year). In both cases the students prepared and/or characterized (Esposti and Bizzocchi 2008) by emission spectroscopy several phosphors such as activated ZnS, Y_2O_3: Eu (III), $SrAl_2O_4$: Eu:Dy and rare earth complexes (Mikus 1963, Sib 1984, Bolstad 2002, Filhol et al 2009, Workman, 1971, Esposti and Bizzocchi 2008, respectively) carrying out the experiment in a much less supervised way, as we sought to enhance the students' initiative and interest. A historical review of the luminophores that have been used in the manufacture of fluorescent tubes introduces students into how research has improved the luminophore used to obtain greater stability, the emission of the appropriate wavelength or the optimization of any other parameter. The introduction of research topics is usually also a motivating aspect for students who are starting a degree course.

The fact that the activity is interdisciplinary has interesting advantages in higher education. For the future chemist it is stimulating since it shows how research in chemistry is useful for other disciplines. In addition, students often feel proud of the degree they are studying and of themselves, which undoubtedly contributes to their academic performance. Since this work is presented in a first cycle course, the benefits are even greater, because then the students are still not aware of what the science is that they are studying and the impact it may have, or even why they to have to study other subjects that are not purely chemistry. For Optics students the conclusions on the activity are very similar to those discussed for chemistry students, but from a different perspective.

Conclusion

In this paper we have shown how certain scientific questions can be the subject of an ongoing study at different educational levels. Specifically, we chose to study the phenomena of fluorescence and phosphorescence as they allow explanations of the same subject to suit the conditions of primary, secondary and university education. Furthermore, these phenomena are close to the daily lives of students, making it easier to motivate them, since fluorescent or phosphorescent materials are common in the students' environment, and now, even seem to be fashionable.

Another advantage of studying these phenomena is that they meet the requirement of interdisciplinary, often needed in the study areas of the different educational levels analysed. We have shown how not only physics and chemistry are involved, as expected, but other disciplines such as the science of materials, Optics or studies related to environmental sciences.

To support our thesis, we have shown the experience of working with students from primary, secondary and university education, doing experiments and explaining them in the field of fluorescence and phosphorescence. The results supported our original hypothesis as they have shown the efficacy of the study of these phenomena in the students' attitude towards learning them.

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