Educación Química (2017) **28**, 120–126

educación Química
www.educacionquimica.info

DIDACTIC

Photoprocesses in chemical education. Key experiments for core concepts

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Received 20 January 2017; accepted 15 March 2017
Available online 17 April 2017

KEYWORDS
Fluorescence;
Phosphorescence;
Ground states and excited states;
Energy level model;
Stokes shift;
Down conversion;
Photochromism;
Solvatochromism;
Aggregation Induced Emission (AIE)

Abstract Due to the ''big five'' challenges in the 21st Century related to the terms of energy, food, water, mobility and climate, mankind has to replace energy from fossil fuels step by step by renewable energies. Between them, solar energy is definitely the most abundant and clean. This is a major, but not the only reason for the inclusion of photoprocesses into chemical education. In this article we present an experimental approach to the basic concept suitable for teaching all phenomena involving light in a reasonable approximation. Updated experiments demonstrating the down conversion of light by fluorescence and room-temperature phosphorescence as well as aggregation induced emission and rigidification induced luminescence are described. In order to use these experiments for teaching basic concepts in photochemistry, a simple version of an energy level model, and an extended version, containing vibrational states, are proposed.

PALABRAS CLAVE
Fluorescencia;
Fosforescencia;
Estados base y estados de excitación;
Modelo de nivel de energía;

Fotoprocesos en la enseñanza de la química. Experimentos clave para conceptos básicos

Resumen Debido a los «cinco grandes» retos del siglo XXI en relación con los términos de energía, alimentos, agua, movilidad y clima, la humanidad tiene que sustituir la energía de combustibles fósiles por las energías renovables paso a paso. Entre ellas, la energía solar es, sin ninguna duda, la más abundante y limpia. Esta es una razón importante, pero no la única, para

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Peer Review under the responsibility of Universidad Nacional Autónoma de México.

http://dx.doi.org/10.1016/j.eq.2017.03.003
0187-893X/

Desplazamiento de Stokes;
Conversión descendente;
Efecto fotocromático;
Solvatocromismo;
Emisión inducida por agregación (AIE)

la inclusión de los fotoprocesos en la enseñanza de la química. En este artículo se presenta un enfoque experimental del concepto básico adecuado para la enseñanza de todos los fenómenos relacionados con la luz en una aproximación razonable. Se describen experimentos actualizados que muestran la conversión descendente de la luz por fluorescencia y fosforescencia a temperatura ambiente, así como la emisión inducida por la agregación y la luminiscencia inducida por la rigidificación. Con el fin de utilizar estos experimentos en la enseñanza de conceptos básicos en fotoquímica, se proponen una versión sencilla de un modelo de nivel de energía y una versión extendida, que contienen los estados vibracionales.

Introduction

Light-involving phenomena are most suitable for the communication of core concepts in natural sciences in close combination with everyday experiences of students as well as with innovative technological applications. In this sense a series of teaching materials have been developed. Several of them are available *online* in English for free on our website (http://www.chemiedidaktik.uni-wuppertal.de; Chemie und ihre Didaktik, 2016a, 2016b) by clicking ''Flash Animations'' or ''Teaching Photochemistry'' respectively, further have been published in this Journal and others (Tausch, 2005; Tausch, Banerji, Scherf, 2013; Tausch & Bohrmann, 2003; Tausch, Bohrmann-Linde, Ibanez, et al., 2013; Tausch & Korn, 2001). Recent and good introductory texts regarding the importance of photochemistry, basic concepts and actual topics have been published by Bach (2015), Balzani, Bergamini, and Ceroni (2015), and Bléger and Hecht (2015).

According to N. J. Turro's paradigm of the ''*excited states of molecules*'' as ''*the heart of all photoprocesses*'' and the interpretation of the excited state as ''*an electronic isomer of the ground state*'' (Turro, 1978), it should be emphasized that the excited state A* of a molecule A is not necessarily generated by light irradiation. It can also emerge from an exergonic chemical reaction or by supplying electrical energy (Fig. 1).

Actually, the excited state A* can deactivate or react in very different ways as well. Therefore a veritable zoo of photoprocesses results from the different deactivation routes of A* (Fig. 1). Traditionally some of them are allocated mainly to physics (i.e. photo- and electroluminescence). However, if one agrees with Turro that A* is an electronic isomer of A, all photoprocesses have to be considered as photochemistry.

Due to the fact that fluorescence and phosphorescence phenomena nowadays count among everyday experiences of everyone, these should be used for teaching the core concepts of ground state and excited states in molecules.

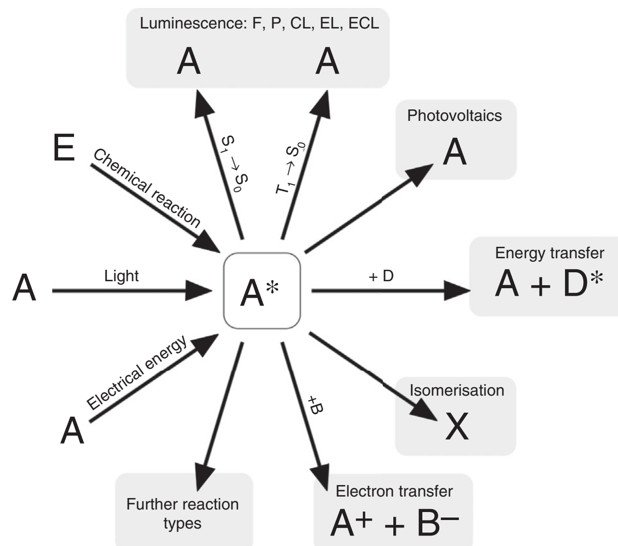

Figure 1 Generation and deactivation paths of the electronically excited state A* (**F**: Fluorescence, **P**: Phosphorescence, **CL**: Chemiluminescence, **EL**: Electroluminescence, **ECL**: Electrochemoluminescence, **S_1**: 1st electronically excited singlet state, **S_0**: singlet ground state, **T_1**: 1st excited triplet state, **D**: Molecule of a compound D involved in energy transfer, **B**: Molecule of a compound B, involved in electron transfer, **E**: molecule of a starting compound E in a chemiluminescent reaction).

Experiments

Phosphorescence at room temperature

Melt about 4 g of tartric acid in a large test tube over the flame of a Bunsen burner. Heat gently to obtain a clear, molten fluid (it does not need to be colorless). Remove the heat and add about 5 mg of esculin to the molten substance. Shake slightly to dissolve the white powder in the tartric acid and then spread the mixture on a large area of the test tube by tilting and rotating it (see video on http://www.chemiedidaktik.uni-wuppertal.de/lehre/photo-mol/en/index.html).

The fluorescence and phosphorescence effects can be explained by the model in Fig. 2, shown using common laboratory UV-light sources (λ = 366 nm) or even a low cost (approx. 10$) ''UV-Flashlight'' Ultrafire WF-501B, λ = 400 nm, FWHM = 40 nm.

The fluorescence and phosphorescence spectra (Fig. 3) in this article have been recorded using a Varian Cary Eclipse Fluorescence Spectrometer by pouring the molten solution on a glass slide before rigidification.