

Laser Pointers – A Tool For Better Lecture Experiments

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ABSTRACT

Laser pointers enable the instructor to make the old demonstrations more attractive and more vivid. Examples are offered for demonstrations of optical properties of heterogeneous systems (suspension, emulsion, colloid, smoke, fog etc.), where the light scattering on the dispersed particles reveals the non-homogeneity of the system. Two more remarkable demonstrations are added (using a green laser pointer) covering for fluorescence and photochromism phenomena.

Key Words: *Lecture Experiments, Heterogeneous Systems, Optical Properties, Fluorescence, Photochromism.*

INTRODUCTION

Knowledge is a complex feature – it depends on many ‘variables’. Scientific knowledge is perhaps a typical example, depending on issues like individual ability to understand things; ability for abstract thinking; type and rank of education the individual has completed in her/his life; structure of curricula; quality of staff involved in the teaching process; quality of equipment used for experiments/demonstrations and etc.

Being chemists, we are principally interested in the so-called chemical knowledge (of course, there may not be a clear-cut distinction between scientific knowledge and chemical knowledge). It has been stated earlier that Chemical knowledge is learned at three levels: “sub-microscopic,” “macroscopic” and “symbolic” and the link between these levels should explicitly be taught. Also, the interactions and distinctions between them are important characteristics of chemistry learning and necessary for achievement in comprehending chemical concepts. Therefore, if students possess difficulties at one of the levels, it may influence the other. Thus, determining and overcoming these difficulties should be our primary goal (Çalık et al, 2005).

Many experiments in chemistry and physics require the use of a high intensity light source, preferably a monochromatic one. Thus, molecular light scattering in polymers has been demonstrated using collimated beam from a mercury lamp (Matthews, 1984). Tyndal

effect has successfully been demonstrated by passing a beam of light from a slide-projector through a colloid solution (Verhovskii, 1965). Recently, a fluorescence experiment has been offered using a fluorimeter (Clarke and Oprysa, 2004) – certainly not the cheapest way to perform it (nor are instruments of this kind readily available). On the other hand, there are phenomena (like demonstration of Rayleigh light scattering in optically active systems) where the authors used a laser pointer (Avalos-Pecina and Smith, 1999). The author of a General Chemistry textbook (Brady, 1990) also demonstrates the Tyndall effect using this time the older (and much more expensive) He-Ne laser.

Laser pointers are indeed devices that give an intense and monochromatic light beam. As typical high-tech devices they exhibit the same “history” as practically all devices of this kind. The common view upon their appearance on the market is that the devices are robust, of medium quality and very expensive. Their size and price decrease severally with time, while the quality increases. It is thus understandable that nowadays it is possible to buy a red diode laser pointer for some 10 \$, and this extremely low price makes it an attractive part of any science demonstration lab.

By the end of the 2nd millennium commercially available green laser pointers appeared (Edmund Scientific, 1999). In less than 10 years their price dropped by an order of magnitude. There are devices now available for ~ 50–60 \$, again making them very attractive for use in various physics and chemistry demonstrations.

Using laser pointers in teaching chemistry lab for exactly 10 years, we developed some effective lecture experiments that we offer to the readers. Originally, these were sought as physical chemistry demonstrations. However, they could be used as demonstrations in general chemistry and physics, optics, organic and analytical chemistry and so on.

AIM

The aim of this study is to introduce old science demonstrations with a new method by using laser pointers to make them more attractive and more vivid for students.

METHODOLOGY

The method is explained together with findings in the following sections for each of the experiments.

We shall first describe demonstrations that could be performed by using the very cheap red diode laser pointers. After that, we shall proceed with demonstrations that require the use of green laser pointers.

FINDINGS RELATED TO PROCEDURES AND PERFORMING EXPERIMENTS

Experiment 1: Light Scattering in Heterogeneous Systems

a) Brief Summary of Basic Terms

System is usually defined as a part of the world in which we have a special interest or a part of the Universe we happen to be studying (Atkins and de Paula, 2002). The rest of the world is simply referred to as a *surrounding*. Systems may be *homogeneous* (if the properties of the system are either identical in any of its parts, or they vary smoothly) and *heterogeneous* (if the properties vary abruptly at certain regions called *boundaries*). The homogeneous parts of the system that are divided by boundaries are called *phases*. Finally, providing no chemical reactions are possible in the system, the chemical individualities (compounds) in the system are called *components*.

Homogeneous systems with two or more components are called *solutions*. All particles in a solution are at the dimensions of individual molecules and ions. One often uses terms *solute* and *solvent*. The above are straightforward if solid (solute) is dissolved in a liquid (solvent). There are other cases (like a solution of two liquids) where it may be different to say which of the two is solvent and which one is solute.

Heterogeneous systems are often called *dispersed systems* (however, the latter term is sometimes used for both homogeneous and heterogeneous systems). In two-component heterogeneous systems one might distinguish between a *dispersed phase* (the equivalent of a solute) and a *dispersing medium* (the equivalent of a solvent).

Heterogeneous systems have different names. Thus, one speaks about *suspensions* (a solid being dispersed into a liquid), *emulsions* (a liquid dispersed into another liquid), *smoke* (microscopic solid particles dispersed in a gas), *fog* (microscopic liquid particles dispersed in a gas) and so on. *Colloids* (e.g. *colloidal suspensions*) differ from the rest of heterogeneous systems, as they are metastable (meaning, they may survive months and even years, with no precipitate to occur).

All of the above mentioned heterogeneous systems have a common *optical property*: a light beam passing through the system is *scattered*.

Students, unfortunately, very often have only vague ideas what scattering (and light scattering in particular) really means. Surely, one can give many examples to illustrate the concept. However, a much more effective and appreciative way would be to *perform a demonstration* of light scattering using diode laser (laser pointer). Providing the beam is not extremely intense (this requirement is completely fulfilled by most of the available red laser pointers), the scattering of light might be used as a criterion for non-homogeneity of the studied system as will be demonstrated.

b) Chemicals and Equipments

Suspension of BaSO_4 in water (synthesized from diluted solutions of potassium sulfate and barium chloride), colloidal suspension of $\text{Fe}(\text{OH})_3$ (or MnO_2) in water, liquid nitrogen, distilled water, mixture of ouzo and water, styrofoam cup, glass rod, 50 cm^3 rectangular glass cuvettes (if cuvettes are not available one could use ordinary beakers), 5 mW red diode laser pointer.

c) Performing the Demonstrations

a) A diluted suspension of BaSO_4 is poured in a cuvette. The liquid looks slightly milky. The light beam from a red laser pointer is directed to the liquid from the side of the cuvette. The result is given in Fig. 1 a.

b) In a cuvette half-filled with water, one adds slowly a colloidal suspension of $\text{Fe}(\text{OH})_3$ until the color is light orange-brown. The mixture is stirred with the glass rod and the laser beam is allowed to pass through it (cf. Fig. 1 b).

c) Some ouzo is poured in a cuvette half-filled with water. The mixture is stirred with a glass rod. The ouzo is added until the mixture becomes slightly opalescent. Again, a laser beam is aimed at the liquid (cf. Fig. 1 c).

d) Finally, in a cuvette with some water at the bottom one carefully adds liquid nitrogen from a styrofoam cup. Fog is immediately formed above the liquid, due to instantaneous condensation of the water in the air. The light beam from the laser pointer is this time directed from a side, but well above the foggy region and is slowly lowered until the beam is clearly evident (cf. Fig. 1 d).

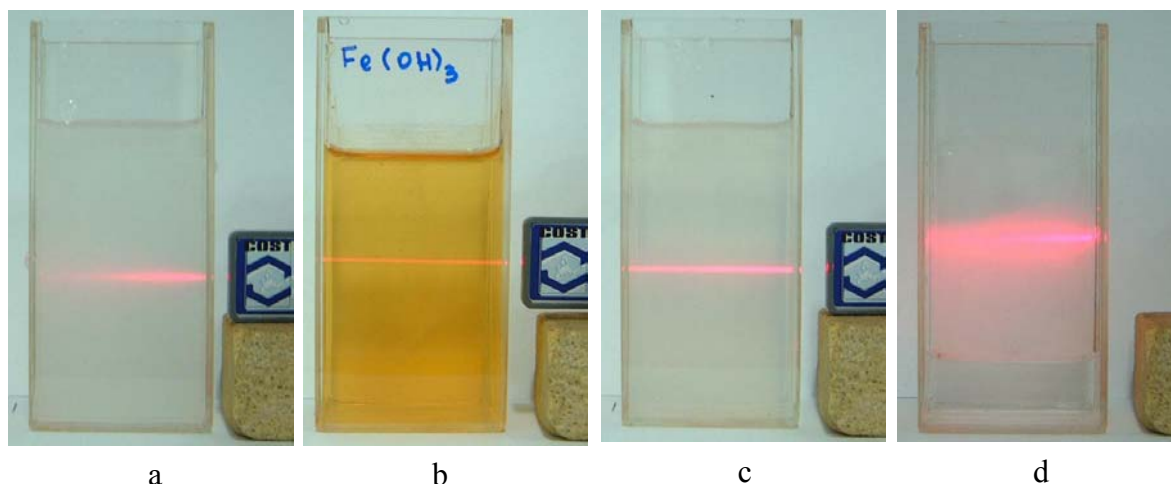


Figure 1: Light scattering of a red laser beam in suspension (a), colloid (b), emulsion (c), and fog (d).

The ‘trace’ of the beam is clearly visible in all of the above demonstrations. Explanation is given that the beam is scattered on the dispersed microscopic particles (the dispersed phase). These are microscopic solid particles in demonstrations a and b, and microscopic liquid drops in demonstrations c and d. Instead of water and ouzo, one could use a mixture of water and ethanol whilst amyl alcohol (or benzene, chloroform etc.) should be added to it. From the point of view of environmental protection, the recommended variant is the safest one. After the lecture experiment is performed, and theoretical explanations are given, it is *obvious* what light scattering really means. The vague students’ ideas have grown into knowledge, with probably a deep understanding of the phenomenon.

As an extension or supplement to the above, one can successfully demonstrate the light scattering on cigarette smoke or on ammonium chloride aerosol (the latter is easily generated if the bottles containing concentrated aqueous solutions of hydrogen chloride and ammonia are opened and their necks are approached).

Experiment 2: Fluorescence

a) Brief Summary of the Phenomenon and the Basic Terms

If a light beam passes through a system (typically a solution of some dye), it may happen that photons are absorbed by the medium, transferring the dye from the *ground energy state* to *electronically excited state*. If this *electronic transition* (or, more precisely, *vibronic transition*) is accompanied by another instantaneous transition to the ground electronic, but *vibrationally excited* state, the system radiates back *lower energy* photons than those used to excite it. The phenomenon is known as *fluorescence* or *luminescence*.

Fluorescence exhibits similarity with Stokes scattering in Raman spectroscopy. The important difference is that in fluorescence phenomena the molecule is indeed excited to a real electronic level, while in Raman scattering it is virtual energy levels that take part in the scattering process (URL-1, 2005). The difference is a sharp one: in Stokes Raman scattering it is the Raman shift that is constant and independent of the excitation frequency of the used beam, while in fluorescence it is the response of the system (the fluorescence radiation) that is in a wide range independent of the excitation light beam. Also, the Raman scattering process is on the picosecond, while fluorescence process is on the nanosecond scale.

Fluorescence phenomena are usually demonstrated using UV or 'white' light (e.g. by direct exposure of the fluorescent material, e.g. the solutions to sunlight). It is a common students' misconception that fluorescence phenomena are necessarily related to a UV source as a *'conditio sine qua non'*, and that is simply wrong! Again, lots of verbal arguments could be offered to iron-out this misconception. In addition, a time saving alternative would be to select a proper lecture experiment that could serve the purpose. In the lecture demonstration that we offer, a green (532 nm) laser pointer was used, thus assuring an excellent visibility of the phenomenon.

b) Chemicals and Equipments

Diluted water solutions of fluorescein, eosin blue, eosin yellow, and rhodamin B (dilute until the laser beam passes the entire length of the cuvette), concentrated water solution of fructose, $\text{Fe}(\text{OH})_3$ colloid, 50 cm³ glass cuvettes (or glass beakers), 3–5 mW green laser pointer, cuvette stand.

c) Performing the Demonstration

The cuvettes are one by one placed on the stand. The laser beam is directed through the solution. The results are shown in Fig. 2 (a–f).

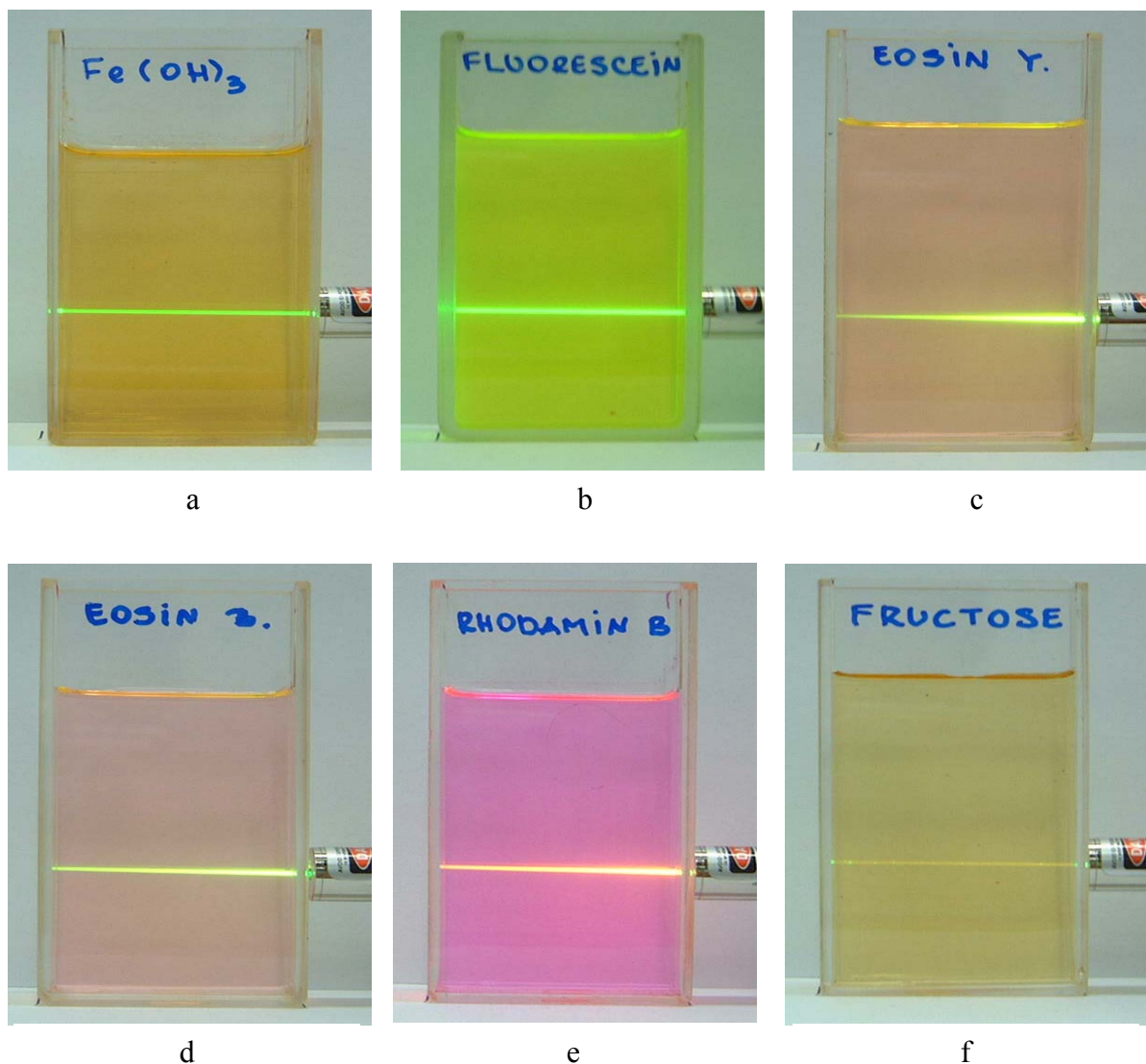


Figure 2: The original color of the green laser light scattered in $\text{Fe}(\text{OH})_3$ colloid (a) and fluorescence light from water solutions of fluorescein (b), yellow eosin (c), blue eosin (d), rhodamin B (e), and fructose (f).

It is obvious that the color of the light beam changes on passing through the solutions. The original green beam (cf. Fig. 2 a) looks yellowish-green in the solution of fluorescein (cf. Fig. 2 b), greenish-yellow in both eosin solutions (Fig. 2 c,d), orange in the rhodamin solution (Fig. 2 e), and yellow-orange in the fructose solution (Fig. 2 f). One could use only part of the above fluorescent materials (those that are at disposal). Other compounds could also be used.

The demonstration performed in this way, apart from being original has some obvious advantages: a) It does not depend on whether the day is sunny or not; b) It does not require robust equipment; c) It is possible to compare the colors (visually) of the fluorescent light with the original laser light (i.e. with the laser light scattered on colloid particles), and to make qualitative conclusions; d) there is no doubt that the phenomenon does not require UV radiation.

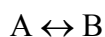
The latter demonstration is really an attractive one. Students are often fascinated by the fact that the color changes are sometimes unexpected. A simple variation of the experimental conditions, e.g. placing the cuvette with rhodamin B solution between two cuvettes containing $\text{Fe}(\text{OH})_3$ colloid sol, and then passing the laser beam through all 3 in the same time, might further strengthen the effect: the beam color is green in the first and third cuvette containing colloid sol, but is bright orange in the second one containing rodhamin B solution!

It might also be a good teachers' practice to mention that fluorescein (and similar materials) are widely used in tracing water flows (geology), in the rescue-packages (the intense yellow-green fluorescence has many times helped in locating and rescuing the pilot of a crashed plane), in art installations etc.

Experiments 3: Photochromism

a) Brief Summary of the Phenomenon

There are materials that upon illumination change the color. Such materials are called *photochromic* materials, and the phenomenon is known as *photochromism*. Usually, upon irradiation, the molecules of the photochromic compound (A) are subject to *isomerisation reaction*, and transform to a chemically different form (B), i.e.:



Both A and B absorb light, but the absorption properties are different, resulting in different colors (photochromism). If compound B is left in a dark, it transforms back to A. In principle, the process can be infinitely repeated.

Students do have some prior knowledge about the phenomenon, particularly if they are reminded that there exist pieces of equipment that were designed for that purpose. An example could be offered in terms of the well-known photo-grey sunglasses (their color is dark when sunny, and light when cloudy). However, a 'more chemical', faster and sharper demonstration might be desirable during the teaching process: a demonstration of the very essence of the phenomenon. Since dithizonates of various (as a rule heavy) metals exhibit the property to be photochromic, it might be a good idea to use a solution of some metal dithizonate. One of the cheapest and convenient compounds to synthesize is mercury(II) dithizonate.

b) Chemicals and Equipment

Mercury(II) dithizonate (it may be synthesized according to Hutton, 1986), benzene, 20 cm³ glass cuvette (or a large test-tube), 3–5 mW green laser pointer, cuvette stand.

c) Performing the Demonstration

Diluted solution of mercury(II) dithizonate in benzene is prepared and is poured in the cuvette. (We recommend the solution to be prepared prior to demonstration, by slowly adding benzene to the salt, until the green laser light beam is seen through the entire cuvette. The color of the solution has to be light orange.) The cuvette is placed on the stand. The laser beam is directed to the solution from a side and is allowed to pass it for some 5 seconds (cf. Fig. 3 a). When the laser is switched off, one notices a dark segment stretching along the cuvette (Fig. 3 b). In few seconds the color of the segment fades (Fig. 3 c) and soon the original orange color is retrieved (Fig. 3 d).

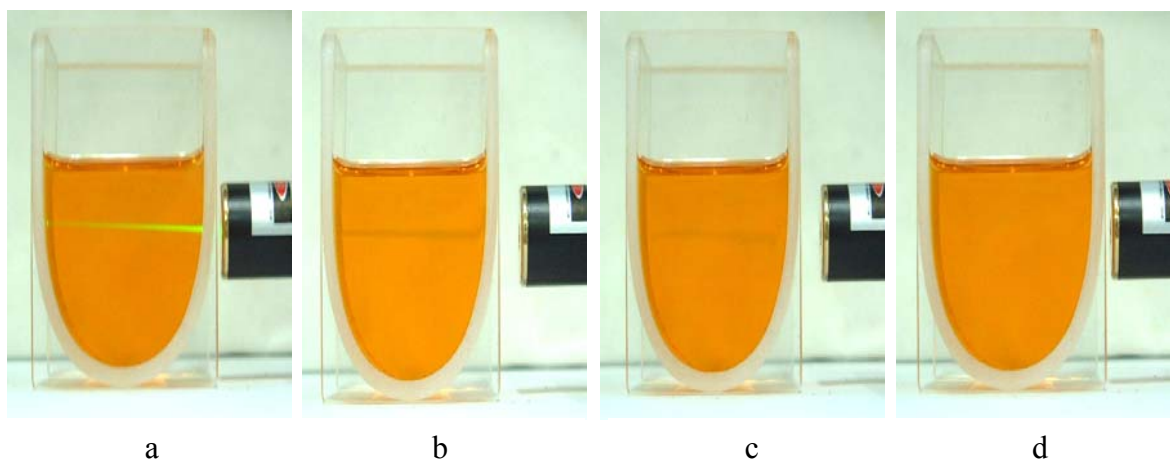


Figure 3: Photochromism of a benzene solution of mercury(II) dithizonate. Green laser beam is used to activate the transition (a), giving segment of the dark blue isomer (b), which fades after few seconds (c), and finally disappears (d).

This is again an elegant way of demonstrating the phenomenon that does not depend on weather conditions neither calls for use of robust equipment (like reflector light-bulbs etc.). Apart from its toxicity, mercury(II) dithizonate is both cheap, easily synthesizable and the relaxation time in benzene solution is very short (few seconds). As to the chemical structure of the A and B forms, one might check the literature data (Hutton, 1986). If the demonstration is performed in the above way, it is exceedingly fast (on the scale of few seconds), and all students could get the idea what are we talking about. Only for comparison, if photo-grey sunglasses are being used, the phenomenon is much slower (on the scale of several minutes), so it is much less efficient, since a student should necessarily *remember* the exact color and intensity in the beginning.

It is a good practice that (if possible) the cuvette with the benzene solution of the photochromic compound (covered) be kept in a refrigerator (not in the freezer!) before the demonstration. Experience showed that the demonstration is much more effective in this way (the colored segment is stable for few more seconds at low temperatures of the solution).

CONCLUSIONS

The above demonstrations are (with one exception – the demonstration of the optical properties of colloid systems) original and very effective. They require the use of red and green laser pointers that are nowadays available at more than reasonable prices. The demonstrations (or lecture experiments, if they are organized in that way) can

strengthen the knowledge acquired and motivate the students to widen their science horizons.

Safety Tips and Disposal

Always wear safety goggles when performing chemistry demonstrations.

Liquid nitrogen can cause skin burns. Wear protective gloves when using it.

Laser light is dangerous to the eyes! Never aim the laser beam to your or other peoples' faces, due to a risk of permanent eye damage.

All mercury salts are extremely toxic. Benzene and its derivatives are toxic and are suspected carcinogens. Avoid swallowing and inhaling. In case of poisoning, call for physician immediately. Dispose the waste according to local safety regulations.

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