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Portable, Inexpensive Polarimeter

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Abstract. A simple, portable and inexpensive polarimeter for the low budget undergraduate laboratory is described. The instrument enables students to get acquainted with the phenomenon of optical activity.

Resumen. Se describe un polarímetro simple, portátil y barato para un laboratorio de licenciatura con bajo presupuesto. El instrumento permite a los estudiantes familiarizarse con el fenómeno de actividad óptica.

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1. Introduction

During undergraduate optics lectures students are introduced to topics such as optical activity.

We have found that a most satisfactory way to demonstrate this phenomenon is by using a polarimeter. Students can then actually measure the amount of rotation of plane polarized light in optically active substances.

In this paper we shall describe a very inexpensive polarimeter for the low budget laboratory. The device outlined here enables students to measure the rotatory power for various substances using visible light of different wavelengths. In addition the instrument may be easily constructed by the students themselves being this fact a complementary pedagogical advantage.

The theory of rotation of plane polarized light in optically active substances is due mainly to Born and his collaborators. Excellent reviews and text books on the topic are available [1]. Therefore we shall restrict ourselves to a brief description on how the instrument works and the way it has been constructed. Besides, we shall compare obtained results on few standard substances with literature data and with those obtained in a commercial polarimeter in order to confront the accuracy of our instrument. Finally we shall give some suggestions on the tasks the students may perform.

2. Principle of the Device and Characteristics of the Phenomenon

A polarimeter is an instrument with a fixed polarizing device at one end of a tube and a rotatable polarizer at the other (observer's end) as shown in Fig. 1. If the two polarizers are adjusted to exclude the passage of light and an optically active substance is placed in between them, some amount of light will be observed. The angle through which the movable polarizer must be rotated in order once more to extinguish the passage of light gives an indication of the degree of optical activity of the sample. This angle is known as the observed rotation α. An adequate measure for the activity of the sample is the quantity known as specific rotation or rotatory power $[\alpha]_\lambda^T$. For a sample solution of an optically active substance this is defined as

$$[\alpha]_\lambda^T = \frac{\alpha}{l\rho},$$

where l is the length in decimeters of the light path and ρ the concentration expressed in grams of active substance per 100 ml of solution. Rotatory power is also function of temperature T and of the wavelength λ of light used. The dependence upon wavelength is approximately proportional to its inverse square.

An interesting characteristic of optically active substances is that some of them rotate the plane of vibration to the right and others to the left. Substances which rotate to the right are know as dextrorotatory and those which rotate to the left, levorotatory. This rotation effect presented is due to unsymmetrical properties within the molecular or crystal structure of the optically active

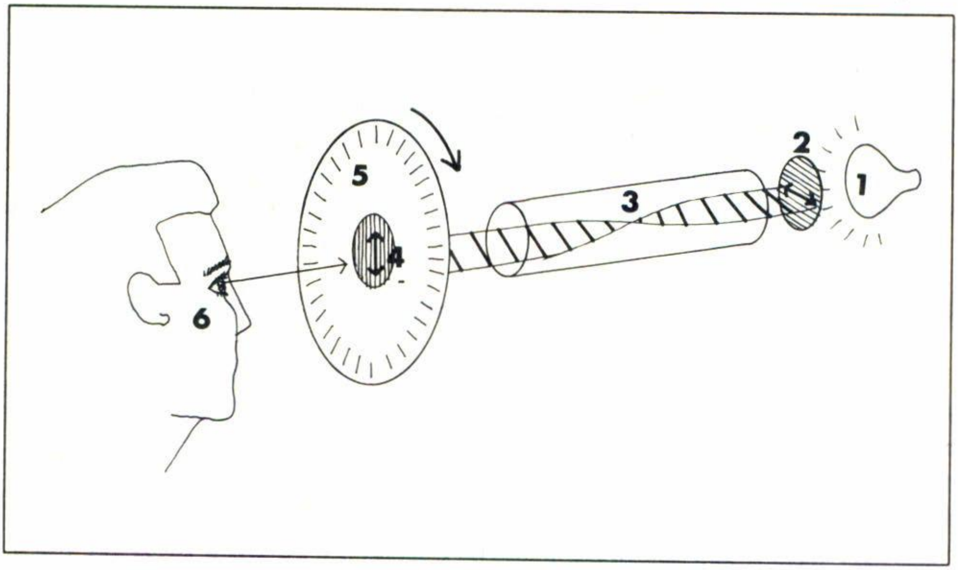

FIGURE 1. Simplified diagram of a polarimeter. 1) Light source; 2) polarizer; 3)sample cell; 4) rotatable analyzer; 5) angular scale attached to the analyzer; 6) observer.

substances. A full discussion of these matters is found in the existing literature [1,2].

3. Description and Operation of the Polarimeter

The instrument described in this work is quite simple and can be assembled very easily using mainly cast offs from the laboratory or home workshop. Construction of the sample container might however require some assistance from the glass shop.

A self explanatory assembly drawing is given in Fig. 2 where the reader will find no difficulties in understanding the use and interconnections between different parts of the polarimeter.

The devise, as the illustration shows, includes a light source which is an all of the same color array of 7 light emitting diodes (LEDS) either red (TIL 220), green (TIL 236) or yellow (TIL 234)

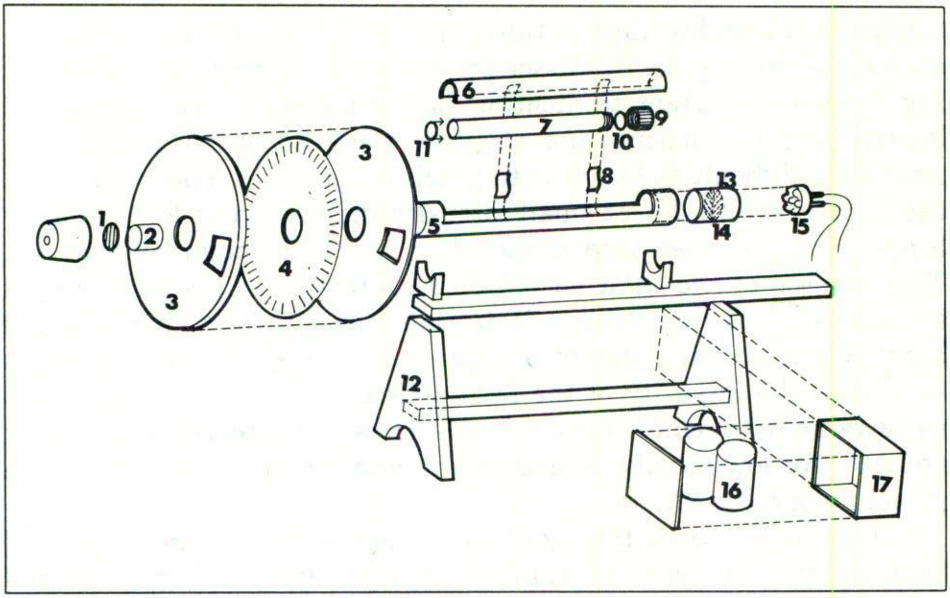

FIGURE 2. **Assembly drawing of the instrument. 1) Analyzer; 2) support; 3) case; 4) protractor; 5) sample cell holder; 6) lid; 7) sample cell body; 8) hinges; 9) cap; 10) and 11) sealing glass disc; 12) support; 13) polarizer's holder; 14) divided field polarizer; 15) light source; 16) battery set; 17) battery housing.**

whose lead terminals are inserted into 14 small mounting holes in a cylindrical plastic base that fits snugly into the sample cell support. In this way the observer may change the wavelength of the light source by interchanging arrays of different colors. Since the array requires only small amounts of input power it may be operated by two D size dry batteries. It must be noted that although light radiated from LEDS cannot be considered by the standards of spectral lines monochromatic, the band width emitted from them is narrow enough for this undergraduate laboratory instrument [3]. In addition, an important feature of the LEDS source is its negligible operation temperature rise, preventing, in consequence, a temperature increase in the sample. This is a valuable characteristic since some substances change considerably their rotatory power with temperature fluctuations. Returning to the description of the polarimeter shown in Fig. 2, it is important to mention that if a single polarizing device is used both in polarizer and analyzer, the position of complete extinction is difficult to locate with precision due to the poor ability of the human eye to detect small intensity differences at low intensity levels. The polarizer used is therefore of a more complex type [4]. This consists of two adjacent polarizing filters glued together in such a way that their respective polarization planes make a small angle β between them. The value of β depends on the quality of polarizers as well as the intensity of the light source. The rule of thumb is to use a value between 5° (for good polarizers and intense light source) and 10° (for low quality polarizers and weak light source) [4]. In the present work $\beta = 8°$.

When light passes through this arrangement of filters it emerges from the two halves as a beam consisting of two kinds of polarized waves whose polarization planes differ by β. In this form the field of view is divided into two halves in which the directions of polarization differ slightly.

When performing a measurement, the analyzer (1 in Fig. 2) is set for equality of brightness in the two halves of the field, rather than for a complete extinction on either half.

The advantage of using this method over that of ordinary extinction point lays in the better ability of the human eye to detect contrast rather than very small intensity differences at low intensity levels.

Immediately adjacent to the polarizer is the sample cell containing the optically active substance (7 in Fig. 2). The sample cell has been constructed using a screw top pyrex test tube (No. 9825, length 150 mm O.D. 16 mm, GCMI thread size 15–415) with a black bakelite cap.

The rounded end of the tube was cut off perpendicularly to the tube axis and then reclosed by sealing to the opening a microscope slide disc (11 in Fig. 2). The other end was ground and polished to insure leak free contact with a sealing glass disc made of another microscope slide (10 in Fig. 2).

A hole was drilled in the top of the bakelite tube cap (9 in Fig. 2) with its cemented in rubber liner and the glass disc seal (10 in Fig. 2) placed inside between the polished tube end and the rubber liner before screwing shut.

The sample cell holder (5 in Fig. 2) consists of a hollow copper tube of an appropriate internal diameter into which the cell is snugly fit.

A side section of the tube (6 in Fig. 2) was removed to allow the insertion of the sample cell, the removed segment fitted into position as the lid cover of the sample cell holder and hinged with two pieces of black tape (8 in Fig. 2).

The inner wall of the cell was painted black to avoid reflexions and the holder mounted on a wood support (12 in Fig. 2).

A two size D battery cell holder (17 in Fig. 2) was attached to one of the legs of the support making the instrument portable.

The analyzer (1 in Fig. 2) consists merely of a single polaroid film mounted in the center of a rotable full circle plastic protractor, graduated from 0° to 360° in half degree intervals; its diameter being 152 mm. (4 in Fig. 2).

The protractor is enclosed in a cardboard case (3 in Fig. 2): Scale reading is made through a small window opening fitted with a thin marker for precise measurements.

A comparison of the angular orientation of the analyzer as measured on the protractor's scale both with the sample cell empty and filled with a bubble free solution serves to measure the angle of rotation produced by the sample on the polarized light. As we have already mentioned, this comparison is made by matching the intensity of the two adjacent fields. Figure 3 shows the finished instrument.

4. Discussion

The experiments required to be performed are simple.

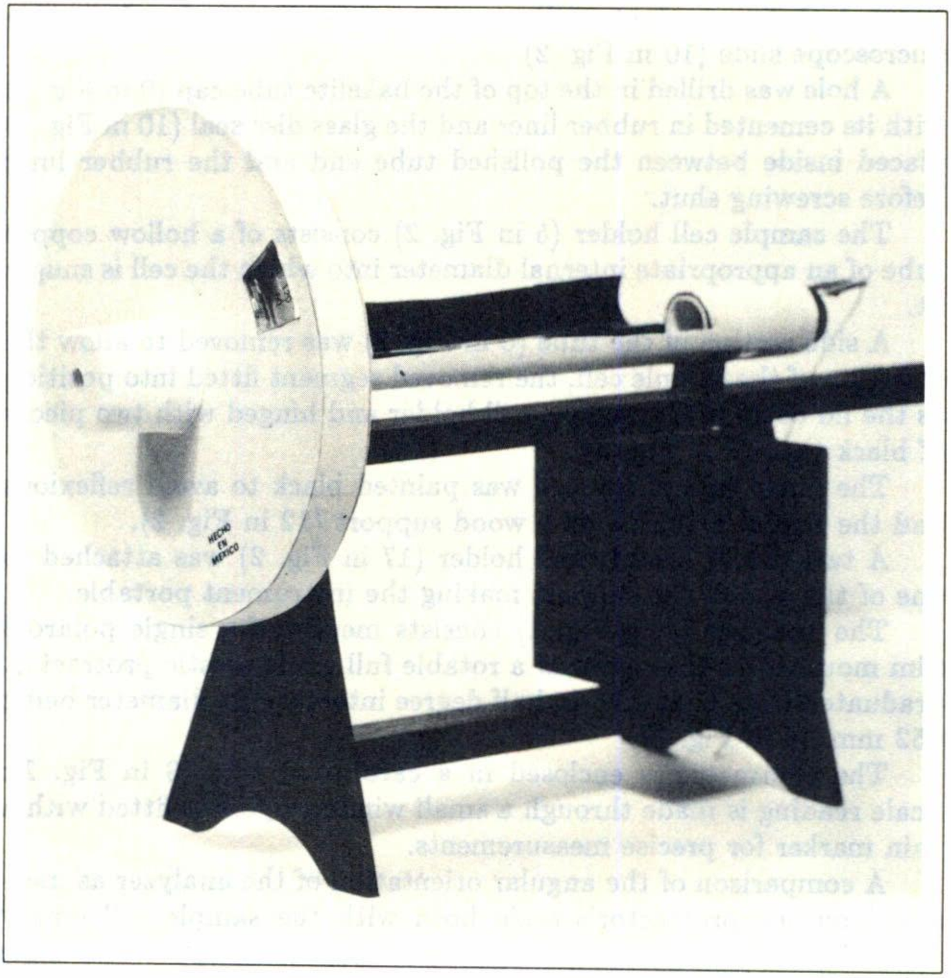

FIGURE 3. Polarimeter.

Initially students are provided with various cells filled with sugar solutions of known concentration from which they are to obtain the specific rotations and compare them with established literature data. Table I list typical results obtained using the instrument here described, those obtained using a commercial polarimeter and those reported in the literature [5]. From these it is readily seen that good agreement exists between the performance of the polarimeter, the commercial instrument and the results established in the literature. Small departures may be explained as due to measurements obtained at room temperature (around 20°C) and at a fixed temperature of 25°C for reported data.

TABLE I

Specific rotation $[\alpha]_\lambda^T$ for various sugars

Substance[a]	this work[b] ±0.5	commercial[c] polarimeter ±0.1	literature[d] data
glucose	+52.5	+52.2	+50.9
maltose	+129.0	+129.3	+127.7
Sucrose	+66.5	+66.1	+64.7
Lactose	+52.5	+52.7	+51.2

[a] Concentration of 10 gr/100 ml.
[b] Room temperature, yellow LED, band centred at 580 n.m.
[c] Room temperature, yellow gelatin filter (No. 22 Wratten) ERMA optical works, model 1198, Japan.
[d] Ref. 5. 25°C, Sodium D Line $\lambda_{D_1} = 589.0$ n.m. and $\lambda_{D_2} = 589.6$ n.m.

Students are next asked to investigate the dependence of the observed rotations as a function of wavelength and substance concentration. Fig. 4 shows some obtained results.

Finally students are encouraged to build the polarimeter and to measure samples of their own interest [6].

5. Conclusions

The instrument described besides being quickly assembled at a modest expenditure is compact and portable.

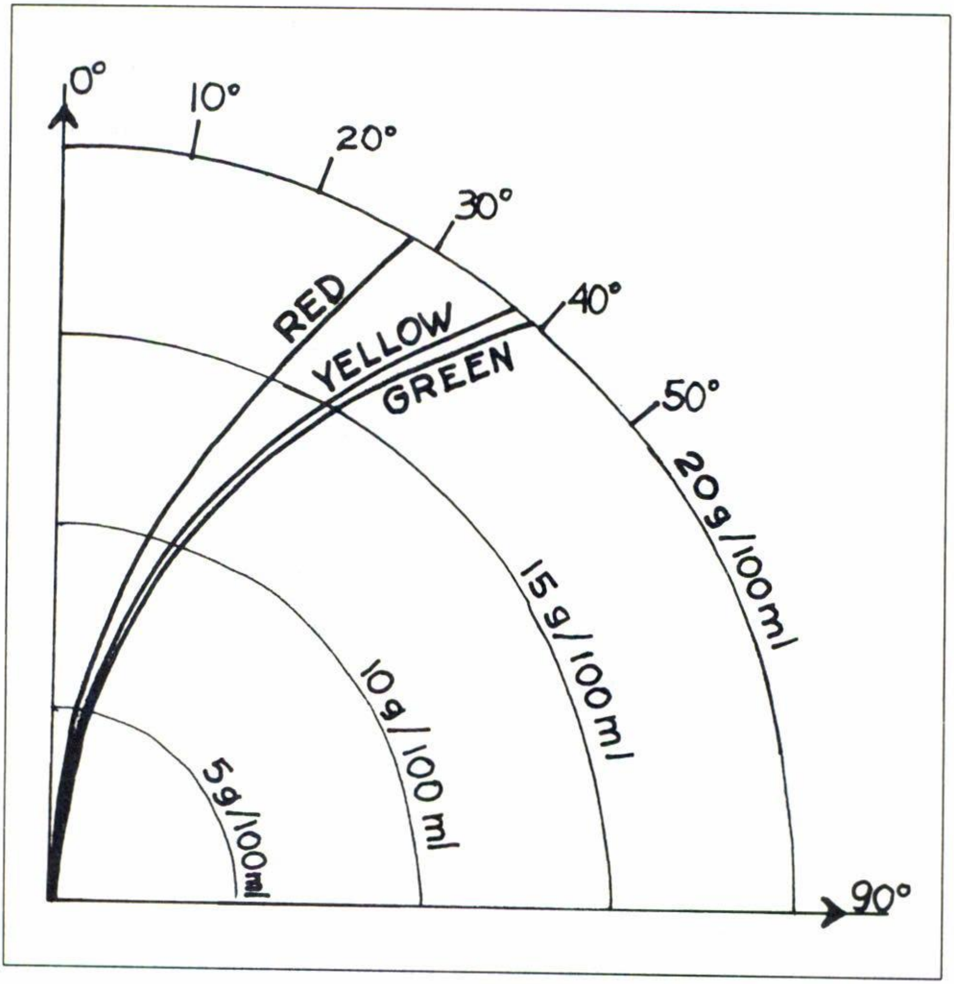

FIGURE 4. Polygraph illustrating observed rotation for increasing concentrations of sucrose in water using light sources of different colors. Red = 650 n.m., yellow = 580 n.m., green = 560 n.m.

Furthermore, it can be constructed by the students themselves being this fact a valuable pedagogical feature.

Commercial equipment available, although more accurate, is far more expensive [7]. It has also generally the disadvantage, as some noncommercial polarimeters, of operating either with vapor arc lamps, ordinary light bulbs, or else of not providing a way of changing the wavelength of the source [8].

The experiments that can be performed by students with the instrument described, are simple and can serve as an introduction to discussions on molecular symmetry.

According to our experience most students find in these experiments a stimulating introduction to a field of physics previously unfamiliar to them.

References

1. F.A. Jenkins and H.E. White, *Fundamentals of Optics* 3d ed. (Mc Graw-Hill, New York, 1957) Chap. 28, pp. 572–587, and references therein.

2. R.P. Feynman, R.B. Leighton and M. Sands, *The Feynman Lectures on Physics* Vol. 1, Addison-Wesley, Reading, Massachusetts (1965), Chap. 33–5.

3. For a comparison between LED spectra and Transmission of ideal color filters as well as bandpass filters see J. Pucilowki, R. Schuman, and J. Velázquez, *Appl. Opt.* **13** (1974) 2248.

4. See for example problems 7, 8 of Chapter 28 "Optical Activity" of Ref. 1 or W. A. Surcliff and S. S. Ballard, "Luz Polarizada" (Momentum Books No. 7, Ed. Revertè Mexicana, S.A. 1968), spanish translation of "Polarized light" (Van Nostrand Momentum Books No. 7 (1964) pp. 122*ff*.

5. R.C. Weast ed., *Handbook of Chemistry and Physics* 49 ed (The Chemical Rubber Co. Ohio 1968) p. C–707.

6. In our case one student has investigated the purity of commercial *pure* honey from his local store. For this purpose the honey has to be prepared in order to transform it into a colorless and transparent liquid (AOAC method (1980) 31.107). Pure honey contains glucose which is dextrorotatory and is often adulterated with sucrose which is also dextrorotatory. By adding a small quantity of sodium hydroxide to the sample sucrose breaks to give dextrose and levulose the latter being levorotatory. Therefore if there is a decrement of rotatory power

in the sample after this process, one might conclude that the honey has been artificially sweetened.

7. For example, a Polarimeter, Sargent Welch catalog 130 No. 5-70541 with a Vernier accuracy of o.1° costs 2000 US$.
8. See, for example, recently presented polarimeter by S. Epstein published in "The amateur scientist" column edited by Jearl Walker (*Sci. Amer.* **254** No. 1, p. 98, 1986). Epstein's polarimeter operates on light from a 60 Watt bulb and uses a potassium dichromate solution as filter and a series o lenses for collimation. An additional disadvantage is the cost about 8 US$ of the sample cell there reported.