The Kerr effect in nitrobenzene—a student experiment

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In any method for quantitatively determining the Kerr constant of nitrobenzene, the question of the purity of the material cannot be ignored. In the method described, account is explicitly taken of the effect of impurity ions in the dielectric on the optical performance of the Kerr cell. Thus, although nitrobenzene of less than the highest attainable purity is employed, results comparable in accuracy to expert determinations of the Kerr constant are obtained. The method, therefore, offers possibilities for a student experiment. Details of cell construction, nitrobenzene purification, optical procedures, and data reduction are given. Also included is a general discussion of electrical effects and the electro-optical effects in Kerr cells having dielectrics that are less-than-perfect electrical insulators.

I. INTRODUCTION

The primal position of the *Kerr effect*[1] in the burgeoning science of electro-optics, as well as its intimate connection with the subjects of birefringence and polarized light, make this effect an increasingly attractive choice for a student experiment in the undergraduate physics laboratory. A likely choice for the Kerr cell dielectric is the organic liquid nitrobenzene. Its very large Kerr constant and its almost universal use in commercial and experimental Kerr cells are strong points favoring its choice. While a qualitative lecture-type demonstration of the Kerr effect with a nitrobenzene-filled Kerr cell is not at all difficult, anything of a more quantitative nature, such as would suit the more advanced type of undergraduate laboratory, is likely to lead the average lab demonstrator to frustration and disappointment. This is because the behavior of a nitrobenzene-filled Kerr cell is seldom quite as clean cut and neat as the textbooks in optics would suggest. Complications arising from the less-than-perfect nature of the nitrobenzene dielectric create an optical nonuniformity in the cell which renders the usual methods of optical retardance measurement ineffective. However, another technique of retardance measurement, which differs only slightly from the usual, proves to be well suited to the job. It has been found to lead to excellent results for a quantitative measurement of the Kerr constant of nitrobenzene, and opens the way to a very interesting and instructive student experiment.

II. THE KERR EFFECT (IDEALIZED CONDITIONS)

Expositions of the Kerr effect can be found in several places.[2] Briefly, the electro-optical Kerr effect is the production within a substance of a state of birefringence (i.e., double refraction), by electrical means. The substance is placed between two plane parallel electrodes in what is called a Kerr cell. When voltage is applied to the plates of the cell, the electric field in the dielectric material between the plates causes distortion (i.e., induced polarization) and/or alignment of the constituent molecules, with the result that the substance becomes birefringent. Thus, in the ideal case, the excited Kerr cell assumes the aspect of a uniaxial birefringent optical crystal such as quartz, or calcite. Plane-polarized light passing through the space between the plates in a direction parallel to their planes is then subjected to optical retardance, and emerges (in general) as elliptically polarized light. This retardance behavior is summarized in Kerr's law[3]:

$$\Delta = 2\pi BLE^2, \tag{1}$$

where Δ is the phase shift or optical retarding power of the cell, L is the cell length, E is the electric field in the cell gap, and B is the Kerr constant of the cell medium. For a determination of B, then, it would suffice to know the electric field in the cell, the cell length, and to measure by a suitable optical technique the phase shift or retardance introduced by the cell.

III. THE KERR EFFECT FOR REAL DIELECTRICS

Implicit in the foregoing procedure for Kerr constant determination is the assumption that there is *uniformity* of retardance (Δ) within the optical gap of the cell. The standard techniques for retardance measurement, particularly any technique making use of a half-shade device, require uniformity of the optical sample. Unfortunately, no Kerr cell dielectric is a perfect insulator. Thus, besides the electric charges which reside on the Kerr cell *plates* (due to an applied voltage), there may also be conduction charges in the space between the plates, that is in the bulk of the dielectric. Such charges tend to distort or modify the electric field within the cell gap, imparting to the field a character which is significantly different from that to be expected solely on the basis of the geometry of the naked electrode structure. The result is an optical nonuniformity that is voltage dependent (Kerr's law suggests that this dependence should be as the square of the voltage). This can prove to be a real deception because at the lower voltages experimental results are often fairly good, but they become vague and confusing as higher voltages are applied to the Kerr cell.

The imperfection of the insulation of Kerr cell dielectrics is often due to the existence, in the dielectric, of ionically dissociated impurities. One way out of the difficulty is to work with a sufficiently pure dielectric. This was the way chosen by Gabler and Sokob for their determination of the Kerr constant of nitrobenzene.[4] Their ef-

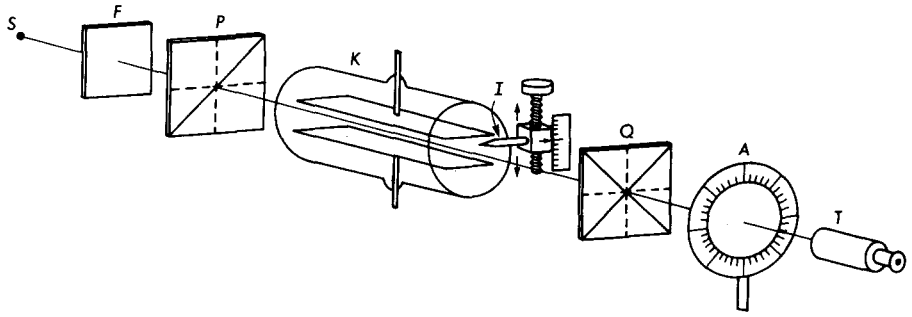

Fig. 1. Schematic of optical system for Kerr constant determinations. S = light source; P = polarizer with polarizing direction at 45° to horizontal and vertical; K = Kerr cell with plates horizontal; I = movable index pointer; Q = quarter-wave plate (compensator plate) with principal axes (fast/slow) at 45° to horizontal and vertical; A = analyzer (a polarizing filter) mounted in a divided-circle mount; T = small viewing telescope.

forts toward purification, however, were of almost heroic proportions and are not likely to appeal to the average lab demonstrator. An approach which recognizes the existence of impurities and makes a rational attempt to deal with their consequences seems more realistic and is probably more reliable. In addition, from a teaching point of view, there are certain pedagogic advantages, for the method provides an introduction to the timely subject of space charge effects in condensed media.

IV. BASIC METHOD AND PROCEDURE

Our basic method of determining the Kerr constant of nitrobenzene is illustrated in Fig. 1. Light from the source S, made monochromatic by filter F, passes through the polarizer P, emerging as a linear vibration inclined at an angle of 45°. It then enters the Kerr cell K whose plates are horizontal, that is, at 45° to the plane of vibration of the incident light. Passing through the energized Kerr cell where it undergoes a change from plane polarization to elliptical, the light meets the quarter-wave plate Q whose principal axes, fast and slow, are inclined at 45°. The light, whatever may have been its degree of ellipticity on entering plate Q, is restored to a linear vibration on leaving it. However, the *azimuth* of the restored vibration is a function of the initial ellipticity (Sénarmont compensator principle). Being linear, the vibration is capable of being crossed and blocked by means of the analyzing element A, which is capable of controlled and measured rotation in its mount. A telescope T, focused on a plane near the output end of the Kerr cell, accepts any light which passes through the analyzer. A movable pointer I, also near the output end of the Kerr cell, is seen in the field of view of the telescope. So also are seen, in profile, the Kerr cell plates.

With a perfect dielectric in the Kerr cell, the field of view of the telescope would show perfect uniformity. In actuality, with sufficient voltage, a pair of horizontal dark *bands* are seen (see Fig. 2). These bands can be moved toward or away from the Kerr cell plates by changing either the applied voltage on the Kerr cell, or the azimuth of the analyzer. The bands are very distinct, especially when they are close to the plates. Thus, by means of the calibrated pointer, their position in the cell gap can be quite accurately determined.

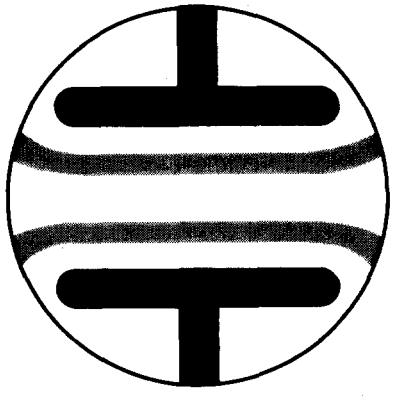

Fig. 2. Pictorial diagram showing Kerr cell plates (end view) and dark bands as seen through viewing telescope (T, Fig. 1).

The experimental procedure is to move the bands systematically across the gap by varying the analyzer azimuth (cell voltage kept constant), while noting band position and corresponding analyzer azimuth. Thus, in effect, we *scan* the cell gap. We then make a plot of the square root of the Kerr cell retardance (retardance data obtained from analyzer azimuth readings) vs band position within the gap. In effect, such a plot, according to Kerr's law, provides an indication of the way the E field varies along a line extending across the gap from one cell plate to the other. It is then possible, using the graph, to find an effective or average E and a corresponding retardance Δ. The length L of the optical path through the retarding part of the cell is known, and, knowing E and Δ, we calculate B using Eq. (1).

The technique here described has been used to obtain a value for the Kerr constant of nitrobenzene. Within experimental error, the agreement with the current best value found in Landolt–Börnstein has been virtually perfect. The method is an adaptation of a technique employed by Möller.[5] Prior to Möller's classical investigation, reported values for the Kerr constant of nitrobenzene varied over almost a factor of 2. Unfortunately, some of the early, highly erroneous values persist in optical texts still in use today.

V. THE KERR CELL: CONSTRUCTIONAL DETAILS

The Kerr cell assembly is shown in Fig. 3. The main enclosure consists of the heavy-walled Pyrex-glass "body tube" a, which is 25 mm o.d., 17.5 mm i.d., and 140 mm long. The two end faces of this tube are first cut off square and are then ground to a moderate degree of smoothness. Care should be taken to have the end faces fairly accurately perpendicular to the tube axis, for, if this is not the case and the end faces are not parallel, the cell when filled with liquid will act like a large refracting prism, producing an appreciable refraction of any light beam sent through it. This can make trouble in attempting to align the cell with other elements on an optical bench.

The end closures on the cell consist of two glass disks w, about 32 mm in diameter and about 6 mm thick. Disks cut from a piece of good quality plate glass should serve. Our disks were cut with a water-lubricated diamond-studded tubular cutter, run at a moderate speed

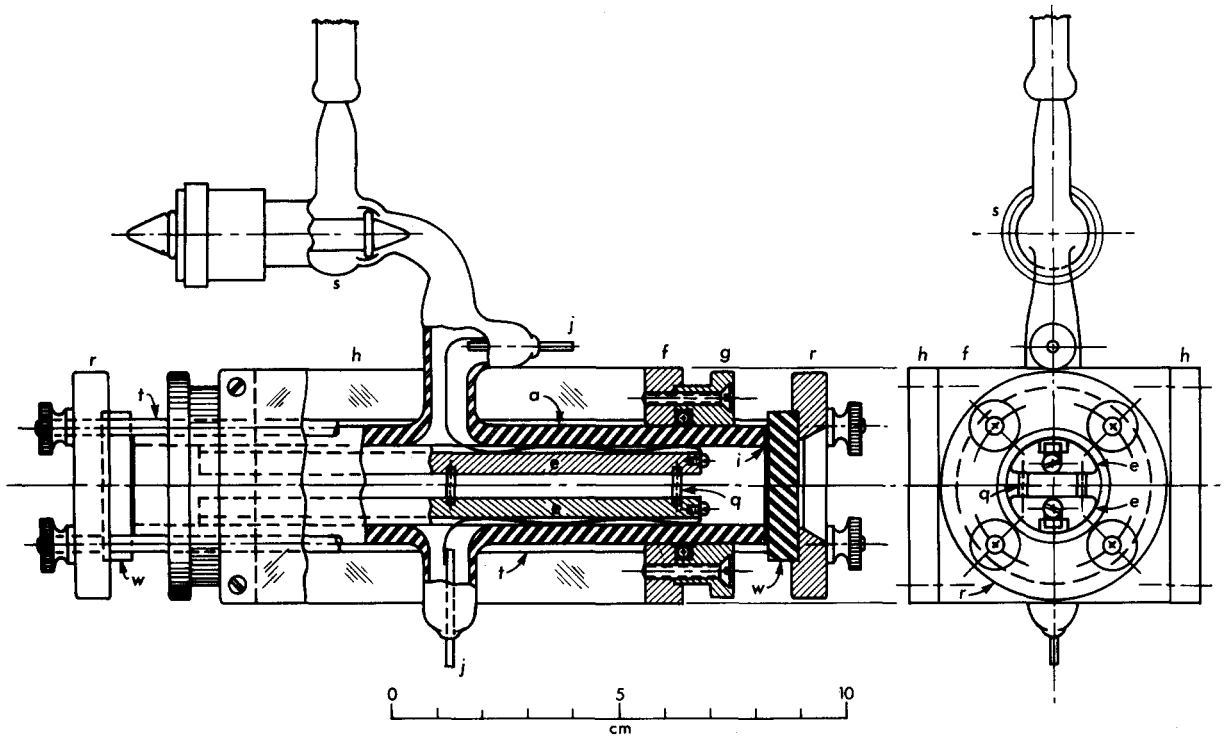

Fig. 3. Side elevation (partially in section) and end elevation of Kerr cell. The glass body tube is at a. The stainless steel plates e,e are held apart by quartz spacers, q. The flat windows, w, are sealed to the body tube by means of thin indium metal washers, i. The electrical leads come out through glass–metal seals at j.

in a drill press. To keep the edges of the disk from chipping, the glass plate can be sandwiched between two other glass plates during the cutting operation, double-sided sticking tape being used to hold all plates together.

Excessive residual birefringence in the end windows should be avoided. If the glass plate from which the windows are to be cut is examined by placing it between a pair of crossed polarizers, and if there is little or no brightening of the otherwise dark field, the disk cut from such a plate should be usable in a Kerr cell.

The strong solvent action of nitrobenzene complicates the problem of providing a suitable seal for the windows. Making the tube ends and windows optically flat, and pressing and holding them in optical contact have been successfully tried. However, we found it simpler to work the two ends of the Kerr cell body tube to a moderate degree of smoothness, and then to provide a gasket consisting of a 0.010-in.-thick foil ring of indium metal[6] between the tube and window. All parts are first carefully cleaned with absolute ethyl alcohol, dried, and then assembled. The thumb nuts and longitudinal tie rods (t, Fig. 3) hold the whole assembly together, providing a hermetic seal for the windows.

A further place where the solvent action of nitrobenzene (or its tendency to leak out) can cause trouble is in the filling stopcock s (Fig. 3). At first a stopcock having a Teflon plug was tried, but this leaked. A stopcock or valve of the type shown in Fig. 3 was substituted. The seal on this device, also of Teflon, has more the form of a needle valve, and, in the closing of the valve, it can apparently be subjected to considerable pressure. In any case, no difficulty with leakage has been experienced.

For convenience in mounting on a optical bench, the Kerr cell is provided with a kind of chassis assembly, also shown in Fig. 3. This consists of two brass clamping blocks f,g, held in position by a pair of longitudinal chassis bars h,h, made of Lucite. Part g of each block is round. It carries an O-ring and fits into a round recess in f. The "fit" of f and g on a is loose, but the O-ring holds to a quite securely, simply by friction. The outer part of g forms with f an annular channel. These channels are for fitting into V-groove brackets (not shown) for the optical bench mounting of the Kerr cell. The V-groove support permits rotation of the cell and chassis assembly about the main optical axis of the total assembly, and this feature is valuable in providing the initial azimuthal alignment of the Kerr cell in the optical system.

The electrode structure of the Kerr cell is based on a design described by Le Fèvre and Le Fèvre.[7] The electrodes themselves (e, Fig. 3) consist of two identical bars of stainless steel which are flat and smooth on one side, and cylindrically curved on the opposite side to match, with a little clearance, the curvature of the inner wall of the body tube. The length of the electrodes is 11 cm. Following the Le Fèvre design, the electrode pieces are kept at a fixed distance of separation by means of six small round cylindrical spacers of fused quartz, 2 mm in diameter. Each electrode has six socket holes, each about 2 mm deep, into which the quartz spacer rods fit with a small amount of diametral clearance.

The cylindrical side of each electrode is milled lengthwise with a channel groove 0.25 in. wide and about 0.0625 in. deep, as shown in the end-view illustration in Fig. 3. These grooves provide space for the flexible stainless ribbon-shaped leads which at one end are spot welded to the tungsten feed-through terminals j, and at the other end are fastened under the heads of small stainless steel screws which screw into tapped holes provided

for them at the ends of the electrode bars.

Stainless steel seems to be an acceptable material for the cell electrodes. Pure nickel and gold-plated brass have also been successfully used. Plain brass, however, has been reported as unsatisfactory.

The electrodes should be carefully constructed and should be given a smooth, bright finish. All sharp edges should be slightly rounded and smoothed to avoid excessive electric field gradients. All cell parts should be thoroughly cleaned with reagent grade acetone, followed by absolute ethyl alcohol. After drying, the parts can be assembled.

VI. THE KERR CELL LIQUID: NITROBENZENE

Apart from its unusually large Kerr constant, not very many good things can be said about nitrobenzene. It is toxic to breathe, toxic in contact with skin, inflammable, hygroscopic, and a distressingly powerful organic solvent. In its pure state it is a slightly yellow-green tinged liquid somewhat resembling corn oil in appearance. Its wetting contact with glass tends to be somewhat spotty. Its odor is rather penetrating and suggests shoe polish. It freezes at +5.7°C. Its trade name is oil of mirbane. Even in quite pure form (reagent grade) it is relatively inexpensive, costing only a few dollars for 500 g.

The hygroscopic nature of nitrobenzene means that all serious Kerr cell work with it must be carried out in a sealed system to keep out moisture.

Normal safety precautions in handling nitrobenzene appear to be adequate. Work is best carried out in a fume hood, and contact with the skin should be avoided. Nitrobenzene does not seem to be given to violent boiling if, at room temperature, a vacuum is pumped over it with a good mechanical pump. (For any such pumping, the pump output should of course be vented to a hood.)

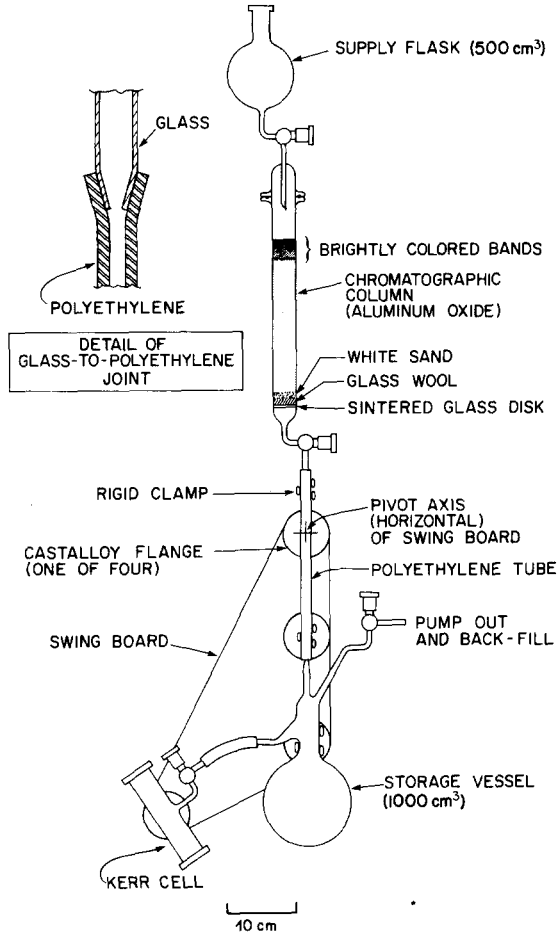

Fig. 4. Diagram of system (mostly glass) for purifying the nitrobenzene and filling the Kerr cell. Inset shows a typical glass-to-polyethylene tubing joint.

VII. FILLING THE KERR CELL

Successful quantitative work with a nitrobenzene-filled Kerr cell requires that a high level of purity of the filling liquid be achieved, and that care be taken in the transfer of the purified liquid into the cell to maintain purity.

The purifying and transferring system is shown in Fig. 4. The system can be divided into two parts: an upper section consisting of the 500-cm³ supply flask and a chromatographic purifying column, and a lower section consisting of a 1000-cm³ storage vessel and the Kerr cell. The two sections are connected together by a length of flexible polyethylene tubing. The upper section remains stationary with respect to its laboratory surroundings, but the lower section, all parts of which are mounted on a plywood "swing board," pivots on a fixed horizontal pivot rod and can swing to left or right, somewhat like a pendulum. When the lower section is swung to the left, the nitrobenzene descending from the purifying column goes directly into the storage reservoir. When the section is swung to the right, the nitrobenzene from the column goes into the Kerr cell.

The "floor" or base of the purifying column is formed of a sintered glass disk fused into the glass column tube. Above the disk there is a section of clean glass wool, about 0.5 in. thick, and above this a layer of clean white sand. Finally, there is the main purifying section consisting of finely powdered aluminum oxide.[8] In building up the column, the aluminum oxide is slowly poured in, and at the same time the column is tapped on its side with a rubber hammer consisting of a somewhat large rubber stopper attached to a wooden dowel handle. By this means the oxide is suitably packed in the tube.

With the help of a heat gun, the polyethylene tubes are sealed onto the glass tubes to which they connect. A typical joint is illustrated in the inset of Fig. 4. Both the glass tube and the polyethylene tube are warmed with the gun, and when the polyethylene tube has become sufficiently soft, it is carefully pushed onto the glass and then allowed to cool. The result is a hermetically tight joint.

In using the purifying and filling system, one proceeds as follows. With the stopcock under the supply reservoir closed and all the other stopcocks open, the entire system is pumped for about 30 min with a good mechanical vacuum pump, for example, Cenco Hyvac. Möller[5] cautions against the use of a Tesla sparker in Kerr cell systems where nitrobenzene is to be used, because of possible contamination, but our occasional brief use of a sparker for roughly monitoring pressure did not seem to produce any ill effects. When the system is well pumped, the pumpout stopcock is closed and the stock (unpurified) nitrobenzene[9] is poured into the supply reservoir. The lower section is swung to the left, and the supply reservoir stopcock is cautiously opened, allowing the nitrobenzene to enter the column. The flow rate should not be more than a few cubic centimeters per minute. The first 40 or

50 cm^3 of purified liquid is sent directly into the storage reservoir, after which the lower section is swung so as to admit liquid to the Kerr cell. If desired, some of this initial Kerr cell liquid can be sloshed around in the Kerr cell and then flushed out into the storage flask, following which the Kerr cell is filled almost full with nitrobenzene from the column. A little "expansion space" should be allowed for nitrobenzene vapor in the stopcock tube connecting to the Kerr cell; that is, the cell should not be totally filled, up to the stopcock, with liquid. The remainder of the nitrobenzene (except for the last few cubic centimeters) can be run down into the storage reservoir to be kept for future use.

The stopcock below the reservoir is now closed, and dry nitrogen at a slight pressure over atmospheric is admitted to the storage reservoir. The stopcock at the Kerr cell is opened momentarily to admit this nitrogen backfill, and then it is tightly closed. The Kerr cell can then be detached from the system by heating the connecting polyethylene tube to softness and pinching it closed with a pair of pliers. The tube can then be cut right through at the pinch with cutoff pliers or a knife. This completes the cell filling.

The appearance of several colored bands in the aluminum oxide column gives evidence of its purifying action. Uppermost is a zone having the color of mustard. It is darkest on top and light yellow on the bottom. Below is a narrow band that is very light brown, and under this is a thick zone of faint oranges and brown. Also, the color of the purified nitrobenzene is different from the unpurified. The latter is golden yellow—about the color of a light beer—but the purified liquid as already noted is pale yellow or yellow-green, that is, less golden in color than the unpurified liquid. As a possible indication of the purity of the nitrobenzene used in our Kerr cell, it may be noted that typical currents carried by the cell, measured some 30 min or so after application of a potential of 4000–5000 V, were found to be in the range of 5–6 μA.

VIII. THE OPTICAL SYSTEM

The optical system used for Kerr constant determination is shown schematically in Fig. 5. A sturdy optical bench of the lathe-bed (double-track) type, equipped with saddles having both up-and-down and sidewise motion, is recommended, especially if the Kerr cell exhibits any appreciable amount of refraction due to lack of parallelism of the windows (see Sec. V). The light source S is a low-pressure mercury discharge lamp whose discharge region is imaged by lens L_1 (focal length = 40 mm) at the horizontal slit B having dimensions 0.0625 in. high by about 0.4375 in. long. Lens L_2 (focal length $\approx$ 50 cm) is placed at its focal distance away from B. Thus, the light emerging from L_2 is parallel. An interference filter F (λ5461 Å) renders the light monochromatic. The polarizer is at P. This is of the film (Polaroid) type, and is held in a rotatable mount, which is readable in azimuth to 0.1°. The Kerr cell K mounts on two of the doubly adjustable saddle mounts mentioned above, one at each end. Also mounted on the Kerr cell assembly is the movable pointer mechanism I. This was conveniently made from a microscope mechanical *X-Y* stage unit.[10] The pointer itself consists simply of a piece of stiff fine wire. The position of the pointer is readable on a vernier to 0.1 mm. At Q we have the compensator plate.[11] This, in our instrument, is accurately of quarter-wave retardance at λ5461 Å, the wavelength chosen for our Kerr constant determinations. The mounting for this plate is similar to the mounting for P. Following Q, we have the analyzer A, a unit identical to P. Finally, T is a small telescope which is focused at the output end of the Kerr cell.

The alignment procedure for setting up the various elements in the system is detailed but straightforward and will not be given here. It is important that the polarizer be placed at 45° to the Kerr cell plates, and that one of the principal axes of the compensator plate shall align with the polarizer. The "zero" azimuth of the analyzer can be established by crossing the analyzer with the polarizer when the Kerr cell is unenergized. By focusing the telescope first on the near end of the Kerr cell and then on the far end, the alignment of the cell with the telescope optical axis (i.e., the line of sighting through the system) can be checked.

The Kerr effect is temperature dependent.[12] A thermometer should therefore be placed in contact with the cell when measurements are being taken.

For precise Kerr constant determinations making use of Eq. (1), it is necessary to use, in place of the actual or geometrical length l of the Kerr cell plates, an effective length L. Owing to fringing effects at plate ends the effective length (L) is greater than the geometrical length (l). The relationship between L and l is given by the following formula, due to Chaumont[13]:

$$L = l + (d/\pi)[1 + (h/d)\ln(1 + d/h)]$$
$$= l + (2d/\pi)[1 - \tfrac{1}{4}(d/h) + \tfrac{1}{6}(d/h)^2 - \cdots].$$

Here, d is the interelectrode spacing and h is the electrode plate thickness. In laboratory Kerr cells intended for quantitative work, the relative increase of L over l may amount to several percent.

IX. DATA, PLOTS, RESULTS

The curves shown in Fig. 6 have been plotted from actual Kerr-effect measurements. The procedure for taking data is essentially that given in Sec. IV. In obtaining band position data, more accurate results seem to be obtained if the pointer is set to a known position in the cell gap, and the band centered upon the pointer by adjusting the analyzer, than by adjusting the band to a given posi-

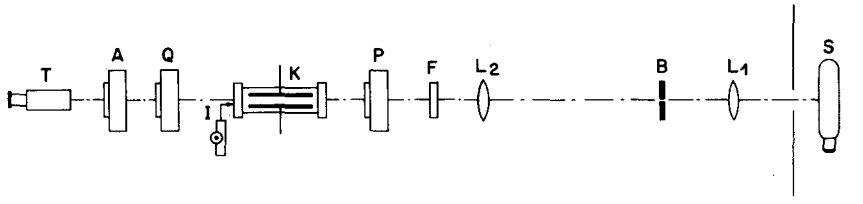

Fig. 5. Schematic of optical system as used for actual Kerr-effect measurements. Symbols S, F, P, K, I, Q, A, and T are as in Fig. 1. B is a slit with jaws horizontal, that is, parallel to Kerr cell plates. Lens L_1 images source S at B; the distance from B to L_2 is equal to the focal length of L_2, so light beyond L_2 is parallel. The source has been placed in a light-shield chimney.

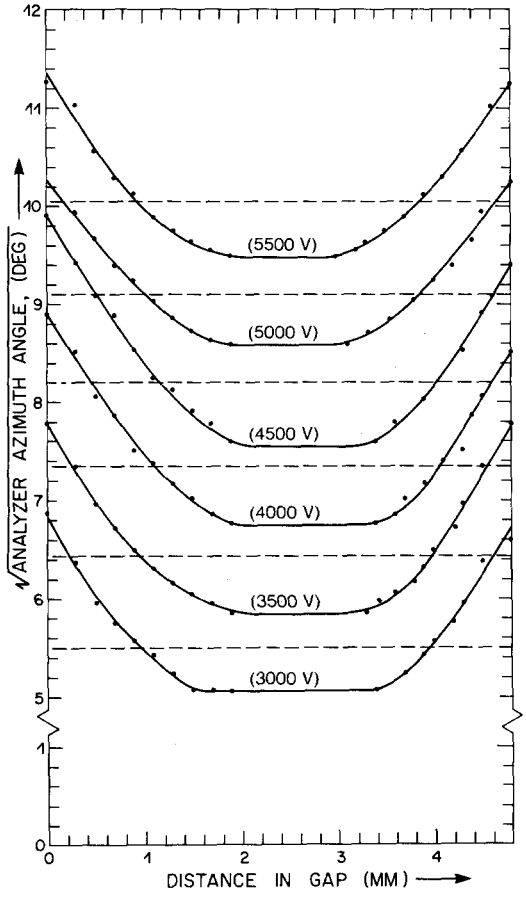

Fig. 6. Plots of experimental data showing gap scans for six different cell voltages. The abscissa of each point indicates the position of a dark band. The ordinate is the square root of the analyzer azimuth setting. This quantity is proportional to the square root of the cell retardance [see Eq. (2)]. The horizontal dashed line for each curve was found by trial and error and divides the curve into three areas as explained under Fig. 7.

tion with the analyzer, and then attempting to fix accurately upon the band with the pointer.

Each curve was taken at a known, fixed value of the Kerr cell voltage. (Note that from a safety point of view these Kerr cell voltages can be dangerous.)

Plotted in Fig. 6, effectively, is the square root of the optical retardance of the Kerr cell in that part of the gap where a dark band appears, against the position of the band in the gap. At a given voltage on the Kerr cell, it has taken a definite rotation α of the analyzer from its initially crossed position (at zero cell voltage) with the polarizer to locate the band at its present position. In accordance with the basic principle of operation of the Sénarmont compensator, the azimuth angle α of the analyzer bears a simple relationship to the retardance Δ of that part of an optical element transmitting light which is blocked (crossed) by the analyzer. The relationship[14] is

$$\Delta = 2\alpha; \qquad (2)$$

that is, retardance of an optical element which is passing light that is subsequently blocked equals twice the analyzer azimuth, where the "zero" analyzer azimuth is at that position at which the analyzer crossed with the

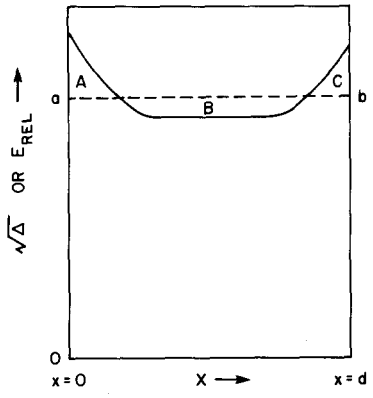

Fig. 7. Typical hammock-shaped scan curve. The horizontal line ab sets off an area B equal to the sum of the areas A and C. It corresponds to the average value of E_{rel}, which equals V/d (see text), and intercepts a particular numerical value of $\Delta^{1/2}$ on the vertical axis.

polarizer when the Kerr cell is unenergized. What is plotted vertically in Fig. 6 is simply $\alpha^{1/2}$, where α is the analyzer azimuth.

Each curve yields an independent determination of the Kerr constant B. For each plot, a horizontal line has to be drawn through the hammock-shaped curve so as to set off two side areas (A and C, Fig. 7), and one central area (B, Fig. 7). This line must be located so that area B equals the sum of areas A and C. Such a line intercepts a certain value of $\Delta^{1/2}$, and therefore of Δ, on the vertical axis of the plot. As explained in the Appendix, this value of Δ, together with a value of E obtained simply by dividing the known voltage on the cell by the known plate separation, along with the known path length L, allows a calculation of B. The value of B obtained as an average from the six separate curves shown in Fig. 6 is, along with its rms deviation,

$$(3.86 \pm 0.04) \times 10^{-5} \text{ esu},$$

which agrees exactly with the value considered as best in Landolt–Börnstein.[15] This value of the Kerr constant of nitrobenzene is for light of wavelength 5461 Å and for a temperature of 20°C.

X. CONCLUSION

The practically unavoidable optical nonuniformity found in a nitrobenzene-filled Kerr cell need not rule out this device as the basis of a versatile and illuminating quantitative undergraduate experiment in polarized light.

Detailed information on the design and construction of a nitrobenzene-filled Kerr cell suitable for use in an advanced undergraduate teaching laboratory has been given. Also included are easily followed directions for adequately purifying the nitrobenzene and for transferring the liquid, without additional contamination, into the cell.

A theoretical discussion reveals the origin of the optical nonuniformities. It then explains how these can be dealt with to yield a value of the Kerr constant of nitrobenzene which agrees with the best currently accepted value.

Information on the optical setup is given, including experimentally obtained optical retardance curves for an actual Kerr cell.

ACKNOWLEDGMENTS

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formation and encouragement—is gratefully acknowledged. The high order of craftsmanship of H. W. Klassen in Kerr cell construction has contributed greatly to the success of this project. The assistance of C. J. Williams in several aspects of the work deserves grateful mention.

APPENDIX: ELECTROSTATICS OF FIELD DISTORTION IN KERR CELLS

The electric charges which cause optical nonuniformity in Kerr cells are thought to be free ions resulting from the dissociation of impurities in the Kerr cell liquid.[5] When the cell is under voltage, these ions exist as space charge clouds near the cell electrodes. The ions form what is called a heterocharge[16] distribution: positive charges near the negative electrode and negative charge near the positive electrode. Thus, in the region extending from each charge distribution to the adjacent electrode plate, the electric field is stronger than its normal (unmodified) value, while in the space between the two distributions (i.e., in the mid region of the cell gap) the electric field is weaker than its unmodified value. The result is a hammock-shaped E field distribution, such as is shown in Figs. 6 and 7. On first inspection, this grossly distorted pattern of the E field might appear to create a virtually hopeless situation for determining the Kerr constant because, according to Eq. (1), such a determination requires a knowledge of the value of the electric field E. Further examination, however, reveals a way out of the difficulty. All we need to assume is that the distribution of the disturbing space charges is *uniform* over any surface that is parallel to the plane of the electrodes.[17] Such uniformity has the important consequence that, in the cell gap, the E lines are straight or totally X directed, where by X we understand a coordinate line that is perpendicular to the plane of the plates. Let us take the line integral of $\mathbf{E}$ across the cell gap. The vectorial (i.e., general) expression for this integral would be $\int_0^d \mathbf{E} \cdot d\mathbf{x}$, where d is the gap length. However, since the field is X directed only, we can write instead the simpler expression $\int_0^d E\,dx$. However, we already know the value of this integral: it is simply the voltage V applied to the Kerr cell. However, so also is the value of the same integral when a voltage V is applied but space charges are *absent*. This means that, whatever may be the spacial details of the distortions of E caused by space charges in the cell, the distorted E field must still be such that its integral along the X direction from one cell plate to the other shall equal the voltage applied to the plates. But this is just another way of saying that the *average value* of the distorted E field (averaged across the cell gap) must be the same as the value of the undistorted (i.e., uniform) E in the gap, which is simply V/d.

Now, from experimentally obtained gap-scanning data (retardance Δ vs position X, with V constant, as explained in Secs. IV and IX) we can make a plot like the one shown in Fig. 6, where $\Delta^{1/2}$ is plotted against X. By Kerr's law, Eq. (1), such a plot is equivalent to a plot of E vs X, where the scale of E is relative only because we do not yet know the Kerr constant B. Let us call the relative field strength E_{rel}, as in Fig. 7. But again, even this relative field, when averaged over the gap length d, must have the value V/d. Thus, if we find the *average value* of E_{rel} from our experimental plot (Figs. 6 and 7), we can say that this equals V/d. At the same time this average value of E_{rel} corresponds to a definite value of $\Delta^{1/2}$, and therefore of Δ. We now know Δ, L, and an "equivalent E." By using Eq. (1), we get the Kerr constant B.

That the line ab (Fig. 7) intercepts areas A, B, C such that A + C = B can be verified by measuring the respective areas with the help of a planimeter, or by the familiar technique of counting small squares on graph paper.

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[8]The complete manufacturer's designation for this material is aluminum oxide, Woelm, Neutral, Activity Grade I. Obtained from Alupharm Chemicals, 610–612 Commercial Place, P. O. Box 30628, New Orleans, LA 70130.

[9]Nitrobenzene, Fisher Certified. It is more golden in color than the column-purified liquid.

[10]Obtainable from Edmund Scientific Co., Barrington, NJ 08007.

[11]Complete compensator units (e.g., Sénarmont compensator with Chauvin half-shade) are obtainable from Precision Tool and Instrument Co., Hillbrow, East Liss, Hampshire, England; also, precision rotatable mounts. Retardation plates are obtainable from Optical Industries, Inc., P.O. Box 2444, 1218 East Pomona Ave., Santa Ana, CA 92707. (An accurate retardation plate has its precise value of retardation at one wavelength only, e.g., 5461 Å.)

[12]The Kerr effect decreases with increase of temperature. We have used Szivessy's value of 1.65% decrease/°C to reduce our experimental results to 20°C. Szivessy's value holds between 6.3 and 25.5°C. See G. Szivessy, Z. Phys. **2,** 30 (1920).

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[15]Landolt–Börnstein, *Zahlenwerte und Funktionen* (Springer, Berlin, 1962), 6th ed., II. Band, 8. Teil, p. 5-855.

[16]See Z. Croitoru, in *Progress in Dielectrics* (Academic, New York, 1965), Vol. 6, p. 103.

[17]This assumption is supported by the experimental fact that the dark (extinction) bands as seen in the telescope run parallel to the electrode plates in the Kerr cell.