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Near-Infrared Spectropolarimetry Based on Acousto-Optical Tunable Filters

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A new approach to near-infrared (NIR) spectropolarimetry is described, in which the properties of a noncollinear acousto-optical tunable filter (AOTF) made of an anisotropic crystal of TeO_2 is employed to produce a novel instrument that precludes or reduces significantly the use of mechanical parts and simplifies the acquisition of optical rotation spectra of absorbing species in the NIR region. In essence, the instrument is based on the measurement of the relative beam intensities produced when a 45° plane polarized beam of radiation passes through a sample cell and is directed to the entrance window of the AOTF. Because of the crystal anisotropy, two planar and orthogonally polarized beams will leave the AOTF, angularly split from the nondiffracted beam, after the acousto-optical interaction has occurred. If an optically nonactive sample is present in the cell, equal intensities for both diffracted beams should be observed. On the other hand, the presence of an optically active sample will cause the polarization plane to rotate and a consequent difference in the intensities of the AOTF diffracted beams will be registered as a function of the optical activity of the sample. The instrument has been evaluated with aqueous solutions of sucrose, glucose, and fructose and for three forms of camphor (D, L, DL).

In recent decades, the interest in new instrumentation for measuring optical activity has increased. This fact comes mainly from the necessity of the pharmaceutical, sugar, and other industries to better control the quality of their products. In the case of the pharmaceutical industry, for instance, the determination of the optical purity is important because the enantiomeric forms are known to have different physiological and therapeutic effects. A classical example of this case is thalidomide, a sedative, hypnotic and anti-inflammatory medication that was chiefly prescribed during the late 1950s and early 1960s for pregnant women, as an antiemetic to combat morning sickness. Unfortunately, one of the enantiomeric forms of thalidomide shows teratogenic effects and a number of children were born with severe malformities.[1−4]

Among the current methods used to investigate optical activity are optical rotatory dispersion (ORD) and circular dichroism (CD); the latter is generally preferred because it provides direct chirooptical information on the chromophore. However, CD measurements are considered to be difficult because a small ac signal needs to be monitored on top of a large dc signal. Besides, this method is limited to reagents or analytes that absorb in the UV or visible region because most of instruments operate in these spectral regions.[2]

The near-infrared (NIR) region is promising for the investigation of optical activity because this spectral range mostly covers absorptions due to overtones and combination transitions of the C−H, N−H, and O−H bonds present in all organic molecules, even colorless ones. Additionally, NIR light can penetrate a variety of materials and usually there is no need for pretreatment of samples before the measurements. As a consequence, the NIR technique is noninvasive and nondestructive and has real-time and on-line capabilities. In spite of these advantages, instrumentation related to NIR spectropolarimetry is still poorly developed.

One of the first near-infrared CD instruments was described in 1973 by Osborne et al.[5] In this equipment, CD was measured by the standard modulation method (800−3000-nm spectral range) provided by an Infrasil quartz photoelastic modulator. In 1976, Keiderling and Stephens[6] reported overtone and combination bands (1600−2500 nm) of camphor solutions utilizing a dispersive instrument. Abbate et al.,[7] in 1989, presented CD spectra in the 800−1300-nm region, for a series of terpenes and related compounds, measured by using a Jasco model J200D spectrometer equipped with an HgCdTe detector. A spectropolarimeter (670−1030 nm) based on a solid-state titanium−sapphire laser as the light source was described by Tran and Grishko[2] in 1994. In this instrument, the required sensitivity for the CD measurements of overtones and combination transitions of saturated chiral compounds was possible using high-performance lock-in amplifiers. In 2002, Castiglioni et al.[8] described CD spectra for 12 enantiomeric pairs of molecules in the 800−1300-nm spectral region using a homemade dispersive apparatus. A modified version of this

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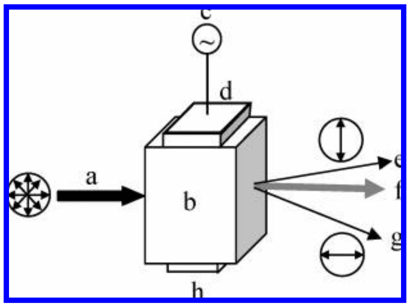

Figure 1. Acousto-optical tunable filter based on an anisotropic crystal. (a) Nonpolarized polychromatic input beam; (b) TeO$_2$ crystal; (c) radio frequency signal; (d) piezoelectric transducer; (e) ordinary polarized diffracted narrow wavelength band beam; (f) nondiffracted, zero-order beam; (g) extraordinary polarized diffracted narrow wavelength band beam; (h) acoustic absorber.

instrument was described in 2004 by Longhi et al.[9] The authors investigated CD spectra for both enantiomers of camphor and fenchone in the 850−1500-nm spectral range. More recently, the results reported in these last two papers, regarding the behavior of optically active substances in the NIR spectral region, has been corroborated by the studies of Cao et al.[10]

In the present work, we describe the construction of a new NIR spectropolarimeter based on an acousto-optical tunable filter (AOTF). An AOTF is an electro-optical device that functions as an electronically tunable excitation filter to simultaneously modulate the intensity and wavelength from a radiation source. These devices are manufactured of a specialized birefringent crystal whose optical properties vary upon interaction with an acoustic wave. Changes in the acoustic frequency alter the diffraction properties of the crystal, enabling very rapid wavelength tuning, limited only by the acoustic transit time across the crystal.[11,12]

An AOTF used for the NIR region, such as shown in Figure 1, frequently consists of a tellurium dioxide (TeO$_2$) crystal to which a piezoelectric transducer is bonded. In response to the application of an oscillating radio frequency (rf) electrical signal, the transducer generates a high-frequency mechanical (acoustic) wave that propagates through the crystal. The alternating ultrasonic acoustic wave induces a periodic redistribution of the refractive index through the crystal that acts as a transmission diffraction prism to deviate a portion of incident light into a first-order beam. Changing the frequency of the transducer signal applied to the crystal alters the period of the refractive index variation and, therefore, the wavelength of light that is diffracted. The relative intensity of the diffracted beam is determined by the amplitude (power) of the rf signal applied to the crystal.[13]

When a nonpolarized incident light beam is employed in the noncollinear configuration (Figure 1) with an anisotropic crystal, the diffracted portion of the beam comprises two spatially separated first-order beams, which are orthogonally polarized. If the input beam to the AOTF is linearly polarized at 90°, only one diffracted beam exits the device, with its polarization state rotated 90° relative to the input polarization axis. However, if the input beam to the AOTF is linearly polarized at 45° in relation to the AOTF crystal, as employed in this work, two diffracted beam (with ideally equal intensities), still orthogonally polarized, exit the device. The two beams are typically spatially separated by a few degrees (5−12°), which is a function of the device design.

The use of one of these monochromatic beams, produced by an AOTF, was the subject of a previous work describing the development of a circular dichroism spectrometer.[14] However, these authors did not exploit the full potential of the AOTF for polarimetric measurements.

The property of the anisotropic AOTF in producing two monochromatic and orthogonally polarized beams forms the basic principle utilized to develop a new approach to spectropolarimetry, based on a new use of the acousto-optic effect from birefringent crystals. The prototype of an instrument that operates under this new approach has been assembled to demonstrate its feasibility, advantages, and limitations.

EXPERIMENTAL SECTION

Instrument Prototype. In order to demonstrate the feasibility of the proposed approach to spectropolarimetry and optical rotation measurements, the instrument prototype depicted in Figure 2 has been constructed and evaluated.

The instrument employs a tungsten/halogen filament source (30 W, 12 V) whose radiation is collimated by a quartz lens and passed through a mechanical chopper set at 1 kHz. The modulated beam passes through a polarizer sheet (ColorPol IR 1300 BC5, Codixx AG) and is directed through a cylindrical sample cell with a nominal 10-cm optical path and 6 mm of inner diameter. This polarizer has recently become available and ensures a high transmittance (∼85%) and high contrast ($>5 \times 10^5$ up to 1×10^7) in the spectral range from 800 to 1600 nm. Although the AOTF could also be used to modulate the radiation (by on−off switching the rf signal), the prototype employs a mechanical chopper in order to certify that only the intensity of the polarized radiation passing the sampling cell is monitored by the detectors connected to the lock-in amplifiers. This allows the instrument to operate without a cover, under minimal influence of ambient radiation. If modulation was provided by the AOTF, spurious nonpolarized, although modulated radiation, might be detected.

The polarized beam impinges onto an AOTF (Brimrose TEAF_0.8−1.6, spectral range 800 to 1600 nm, nominal resolution between 2 and 6 nm) made of TeO$_2$. The radio frequency signal necessary to drive the AOTF was produced by an rf signal generator (TGR 1040, Turlby Thandar Instruments) whose output signal was amplified by an rf amplifier (RFGA 0101-05, RF Gain). The rf signal frequency and amplitude are computer controlled through a RS-232 serial interface. The intensities of the two diffracted beams produced by the AOTF were monitored by twin InGaAs detectors (Hamamatsu, G8605-22), and the preamplified signals were sent to two miniature lock-in amplifiers (LIA-MV-150, Femto). From the lock-in amplifiers, the signals are directed to two of the analog inputs of a parallel interface (PCL-711S) to be digitalized with 12-bit resolution. A program written in Visual

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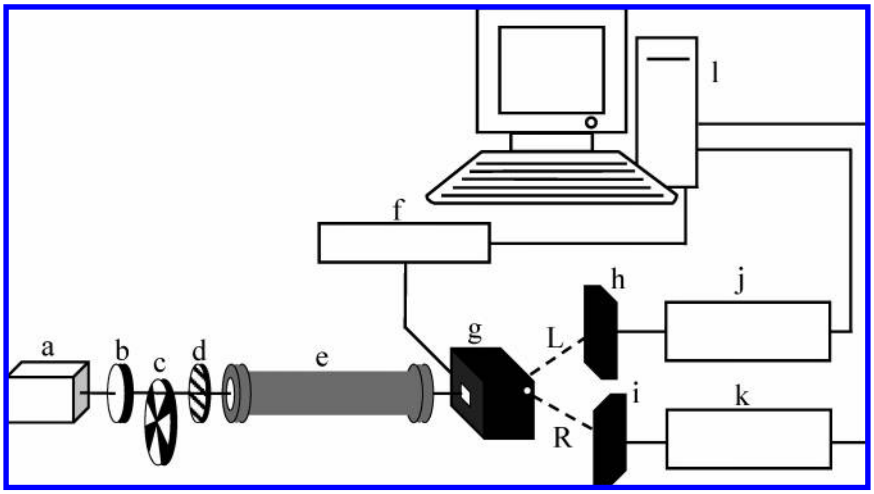

Figure 2. Schematic diagram of the spectropolarimeter based on AOTF. (a) tungsten/halogen radiation source; (b) collimating lens; (c) mechanical chopper; (d) polarizer sheet; (e) sample cell; (f) rf generator; (g) acousto-optical tunable filter; (h) and (i) InGaAs detectors; (j) and (k) miniature lock-in amplifiers, and (l) controlling microcomputer. R and L, right and left beams, considering the intensity increase caused by a dextro- and levorotatory optically active substance, respectively.

Basic 5.0 was employed to control the rf generator, for signal acquisition and storage, and for data treatment.

Instrument Setup and Calibration. The proposed approach to spectropolarimetric measurements based on AOTF requires that the two diffracted beams produced by the device ideally present the same wavelength and intensity when an optically nonactive substance is present in the sample cell and the polarizer is set at 45° in relation to the AOTF crystal. The two diffracted beams produced by the AOTF will be denominated right (R) and left (L) beam according to the increase of intensity observed when a dextro- or levorotatory species is placed in the sample cell. In this way, the R beam will have its intensity increased in relation to the L beam when a solution of a dextrorotatory species (such as sucrose) is introduced into the cell.

It is well-known that the two beams refracted by an AOTF are not identical, at least in terms of wavelength, and that they show a exponential relationship with the rf signal frequency.[13] Therefore, to implement the proposed NIR spectropolarimeter, it is important to match the beams in terms of the instantaneously monitored wavelength.

There are, in principle, two ways to attain such matching. The first one is to calibrate both beams as functions of the same rf signal applied to the AOTF. That will produce two equations relating the selected wavelength to the signal frequency. However, the data collected will present a distinct set of wavelengths, one for the ordinary and the other for the extraordinary beam. Because in the present study the ratio of the two intensities will be correlated with the optical activity, this approach will require further data processing to match the wavelengths of the two signals. The second approach, adopted in this work, includes the independent calibration of the two beams in order to produce two distinct tables of frequency values to be applied to the AOTF in order to produce two beams of matched wavelength. In this way, the same wavelength will be sequentially produced by the R and L beams after the corresponding rf signals are successively applied to the device. This, of course, introduces a small delay (~100 ms) between the acquisition of the intensities of the two beams as it require the rf generator to apply two successive signals with slightly different frequencies to the AOTF. On the other hand, the signals obtained are ready to be processed by calculating the ratios at each wavelength.

Equations 1 and 2, relating the frequency of the rf signal (y) with the selected wavelength (x), were determined after calibration of the R and L beams employing 10 absorption peaks of chloroform in carbon tetrachloride (20% v/v) occurring in the range from 800 to 1600 nm.[15] During beam calibration, the polarizer was removed from the optical path of the instrument. These equations apply only to the AOTF employed in the present polarimetric instrument, and their coefficients will need to be determined for each acousto-optic device.

$$\text{right beam (R) } y = 64.26 + \frac{585.86}{1 + e^{(x-172.18)/437.97}} \qquad (1)$$

$$\text{left beam (L) } y = 64.35 + \frac{590.37}{1 + e^{(x-168.09)/438.69}} \qquad (2)$$

Once the beams had been calibrated for wavelength, the arrangement was aligned in order to attain equal intensities for the R and L beams, still in the absence of the polarizer. When the intensities were matched, the polarizer was introduced into the optical path. The cell was filled with optically inactive carbon tetrachloride which also does not absorb in the spectral region 800−1600 nm. The polarizer is held in a rotating support. The support was rotated and the beam intensities were monitored during complete scans from 800 to 1600 nm. The operation was stopped when the two beam intensities matched as much as possible. The objective of this procedure is to present to the AOTF a 45° linearly polarized beam, which ensures that when an optically nonactive species is present in the cell, the ratio between the beam intensities will approach unity, the ideal value. For measurements of aqueous solution of sugars, water was employed during this initial setup calibration of the instrument.

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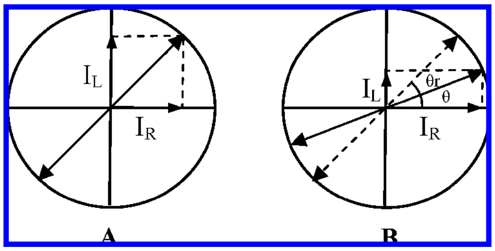

Figure 3. Determination of the rotation angle (θ_r). (A) Initial situation for an optically inactive substance present in the sample cell. (B) Situation with a dextrorotatory substance present in the cell. I_L and I_R, intensities of the left and right beam, respectively. $\cot(\theta) = I_L/I_R$.

Conversion of Intensity Ratio to Rotation Angle. The measurement of optical rotation is based on the ratio of the intensities of the R and L beams, I_R/I_L. This ratio was adopted because it allows for corrections for fluctuations common to the beam intensities due to alterations in the radiation source or absorption by nonactive substances present in the sample matrix. Also, the use of the ratio allows for prompt identification of the direction of angle displacement. When the ratio is greater than *1*, the substance is dextrorotatory; a levorotatory species will produce a ratio lower than *1*. On the other hand, this ratio do not present a linear relationship with the real angle shift expressed in degrees. Figure 3 shows a trigonometric circle where it is possible to identify the intensities of the R and L beams. The ratio I_R/I_L, the parameter accessed by the proposed instrument, is equal to the cotangent of θ. For a dextrorotatory or levorotatory substance,

$$\theta_r = (45 - \theta) \tag{3}$$

where θ_r is the angle with which the polarized beam has been rotated, either to the right or to the left, by the active substance present in the cell. The angle θ_r assume positive (+) or negative (−) values for dextro- or levorotatory substances, respectively. There is no simple relationship between the $\cot(\theta)$, obtained through the beam intensities ratio, and θ. For convenience, in this work an equation has been fitted to relate θ to $\cot\theta$ employing the values of θ and $\cot(\theta)$ extracted from compiled tables, for θ varying from 5° to 85°. This relationship is approximately given by

$$\theta = 78.67\mathrm{e}(-\cot(\theta)/1.15) + 12.46 \tag{4}$$

Equation 4 is employed to convert the ratio of intensities [$\cot(\theta)$] to the angle θ expressed in degrees with reasonable accuracy for angles between 5 and 85° (which means for θ_r varying from −40 to +40°). It should be observed that eq 4 was produced without use of any experimental data. Therefore, it is not a calibration of the instrument but a way to determine the rotation angle directly from the experimentally measured ratio I_R/I_L. The conversion of $\cot(\theta)$ to θ could be made using more accurate procedures, such as interpolation in a cotangent table, or by using locally adjusted equations estimated for a narrower ranges of angles.

Equation 4 could also be replaced by a calibration made using standard substances for which the specific rotations are well-known, taking the intensity ratios and determining a mathematical expression that adequately fits the experimental data.

Throughout this work, eq 4 will be employed to produce the rotation angle for active substances.

Signal Processing, Treatment, and Acquisition. The ideal situation for the spectropolarimetric measurements proposed here would be obtained when any optically inactive substance, such as water or CCl_4, present in the cell, results in a flat signal set at 0° ($I_R/I_L = 1$), whether or not it produces absorption bands in the monitored spectral region. However, the nonidealities of the AOTF, detectors and instrument geometry and alignment can cause a deviation of actual signals from ideality. Thus, some signal preprocessing needs to be employed in order to correct for these sources of signal mismatching.

The procedure adopted in this work is based on the acquisition of a reference signal employing only the sample solvent. The beam intensity ratios are calculated and converted to rotation angle shifts throughout the spectral range and stored to be subtracted from the signal obtained for the sample. This correction procedure assumes that there is a perfect match between the two spectrometric channels of the instrument in terms of wavelength and spectral resolution and that any eventual difference between the beams caused by instrumental mismatch will remain the same for the solvent and for the samples.

All signals were obtained as averages of 10 scans in the spectral range of interest at a nominal resolution of 2 nm. After correction for beam mismatch, made as described above, the signals were smoothed by using a Savitz-Golay filter (15 points, second-order polynomial).

Reagents and Solutions. The reagents utilized in this work were as follows: (D)-sucrose (Synth), (D)-glucose (Synth), (L)-fructose (Synth), (DL)-camphor (Acros), (D)-camphor (Acros), (L)-camphor (Acros), carbon tetrachloride (Merck), and chloroform (Synth). All reagents were of analytical grade and were used without further purification. Deionized water was employed throughout.

RESULTS AND DISCUSSION

Measurements of Optical Rotation. A preliminary validation of the proposed method for optical rotation measurement was evaluated by rotating the instrument polarizer by known angles to the right and left positions in relation to the instrument setup (made with the polarizer at 45°) and with carbon tetrachloride present in the measurement cell. This procedure simulates the rotation imposed by an optically active substance present in the cell. The ratio of the R and L beams were obtained along the spectral range covered by the AOTF and the rotation angles were determined by using eq 4. On average, the results agree with the polarizer rotation angle within ±0.08°, which validates the proposed procedure.

The proposed method for optical rotation measurement was applied to aqueous sucrose, glucose, and fructose solutions in order to observe the wavelength dependence of the optical rotation of these optically active substances.

Deionized water was employed as reference, and solutions containing the sugars in the concentration range from 5 to 25% (w/v) were measured in the spectral range from 800 to 1200 nm. The very strong water absorption impedes the work above this wavelength. Even for the spectral region investigated, water

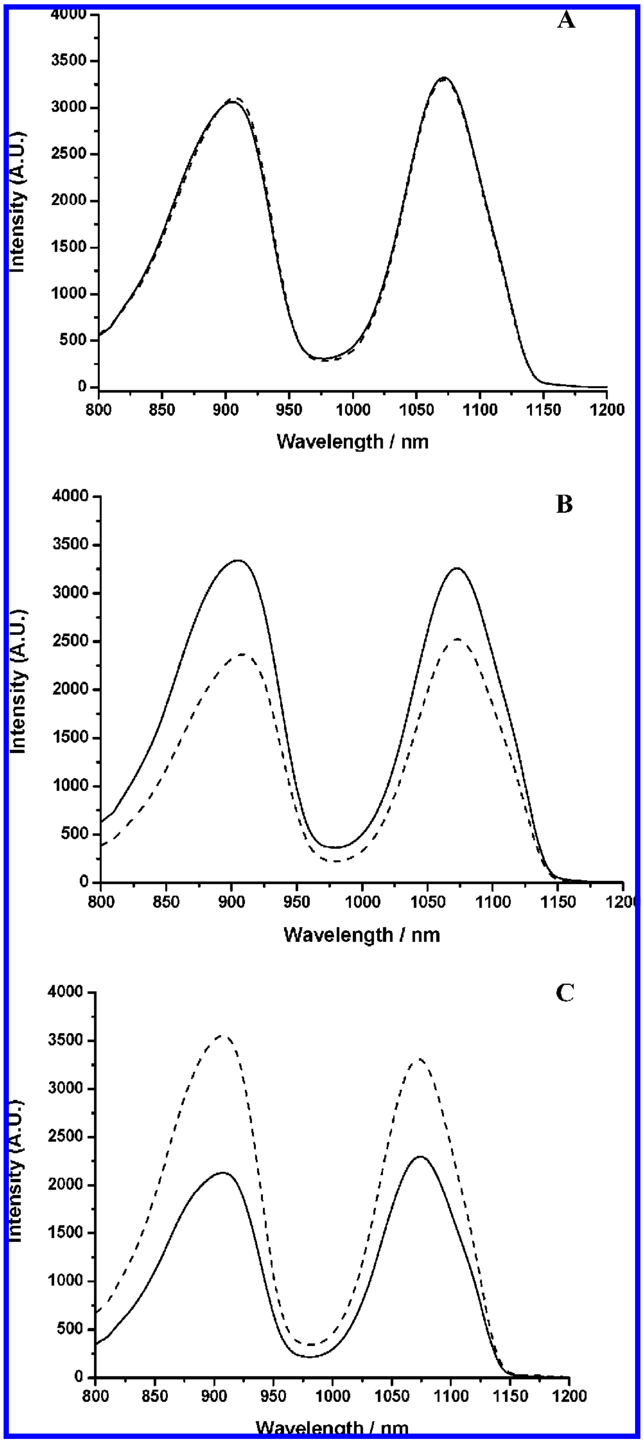

Figure 4. Intensity spectra registered for the L (---) and R (—) beams by the spectropolarimeter prototype for (A) deionized water, (B) sucrose aqueous solution (20% w/v), and (C) aqueous fructose solution (20% w/v).

presents a strong absorbance in the region 930−1060 nm due the second overtone of vibrational modes of the water O−H bond.

Figure 4 shows the original intensity spectra obtained for pure water, for a solution containing sucrose (dextrorotatory), and for a solution containing fructose (levorotatory). Figure 5 shows the optical rotation spectra resulting after converting the I_R/I_L ratio to rotation angle expressed in degrees for both solutions at various concentrations. The behavior of the optical rotation spectra agrees with the Fresnel relationship,[16] which predicts that the absolute optical rotation tends to decrease as the wavelength increases. Biot's law,[17] which predicts a linear relationship between the rotation angle and the concentration of the optically active substance, was also verified. The relationship between the optical rotation and the concentration was then evaluated at 840, 880, and 1080 nm for sucrose, glucose and fructose solutions. Table 1 shows the parameters of the linear equations found by least-squares for the relationships of concentration with the optical rotation and the related correlation coefficients. A very good linearity was observed at the selected wavelengths, which demonstrates the feasibility of the proposed method for quantitative measurements.

The optical rotation spectra shown in Figure 5 indicate that the region from 930 to 1020 nm is highly affected by the strong absorption of water. Figure 4a shows that there is a significant decrease in the intensity of both the R and L beams in this region. This drastic decrease of intensity appears to invalidate the observation of the optical rotation spectra in this region (marked in the spectra of Figure 5). A nonsystematic behavior of the optical rotation signal, uncorrelated with the concentration of the optically active species, is observed. It should be noted that the water absorption should be reduced as the concentration of the sugars increases to higher values, as employed in this study (up to 25% w/v). Furthermore, the sugars absorb in the same region but with a lower intensity. Apparently, the sum of all these effects reduces the capability of rotational spectrum correction by using of the apparent optical rotation spectrum of pure water. On the other hand, it should be of interest to investigate in detail this spectral region because the interaction of water and sugar molecules can reveal some important information for the conformational studies of these optically active substances. In order to achieve such a goal, instrument performance must be improved by, for example, decreasing the optical path, increasing the radiation source power, and optimizing the experimental conditions to that region. Experiments with this goal are programmed.

The repeatability of rotation measurements made by the proposed method was evaluated obtaining the rotation angle for 10 consecutive measurements that simulated the complete measurement cycle (including the operations of removing, emptying, filling, and replacing the sample cell) for a 15% (w/v) sucrose solution at 880 nm. The standard deviation obtained was 0.11°. The instrumental precision is 0.05°, for the same sucrose solution and with the cell kept in its support during 10 uninterrupted measurements.

Preliminary Evaluation of the Proposed Prototype for Cotton Effect (ORD) Measurement. It would be highly interesting if the proposed method of optical rotation measurement and the prototype instrument could be used for acquisition of ORD data from absorbing substances in the NIR spectral region and, therefore, for observation of the Cotton effect.[16] As mentioned before, the high absorption of water hindered this type of study for sugars, which absorb in the same region where water shows a very intense absorption band. On the other hand, the two enantiomeric forms and the racemic mixture of the optically active substance camphor (D, L, DL) present a relatively sharp absorption

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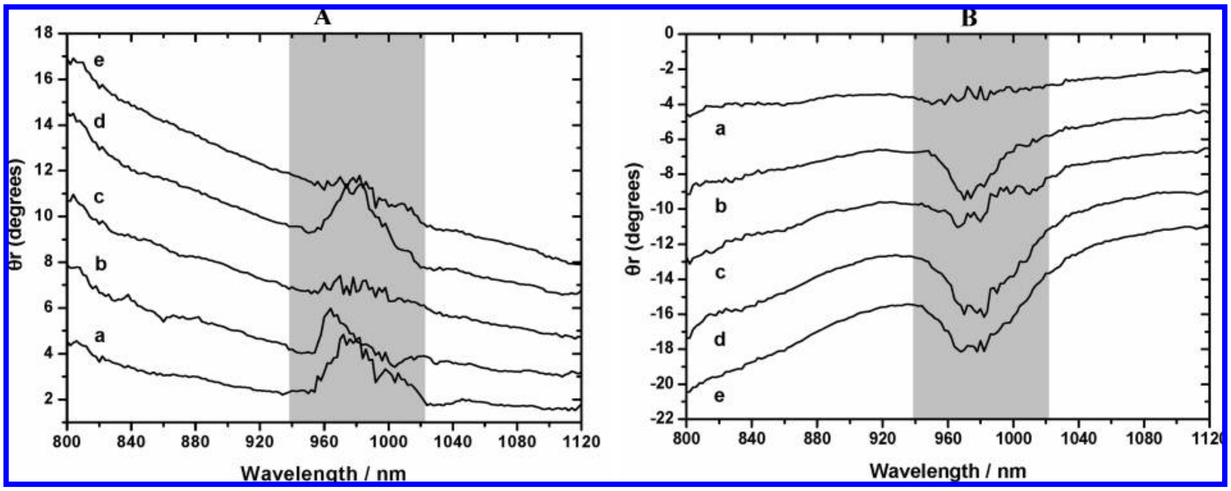

Figure 5. Optical rotation spectra for sucrose (A) and fructose (B) aqueous solutions after correction for water reference spectra. (a−e) 5−25% (w/v), in steps of 5% of each sugar's concentration. The region of high water absorption is shaded.

Table 1. Regression Equation Parameters Obtained by Least-Squares Fitting of the Rotation Angle vs Concentration for Several Sugars[a]

	θ_r (840 nm)			θ_r (880 nm)			θ_r (1080 nm)		
	a	b	r	a	b	r	a	b	r
sucrose	0.553	0.572	0.99997	0.295	0.533	0.99967	−0.196	0.358	0.99918
glucose	0.457	0.441	0.99929	0.599	0.415	0.99989	0.166	0.269	0.99948
fructose	−0.439	−0.741	0.99969	−0.454	−0.665	0.99975	−0.149	−0.453	0.99936

[a] Data refer to the equation $\theta_r = a + bc$, where θ_r is the rotation angle in degrees (at the indicated wavelength) and *c* is the sugar Concentration (% w/v). *r*, regression coefficient. Sugar concentrations: 5, 10, 15, 20, and 25% (w/v).

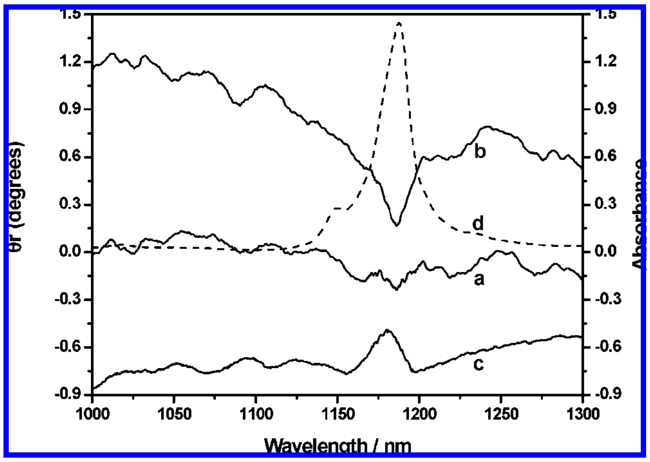

Figure 6. Optical rotation spectra for camphor solutions (7.5%, w/v) in CCl_4. (a) racemic mixture (DL), (b) Dextrorotarory camphor (D), (c) Levorotatory camphor (L). (d) Absorption spectrum of a 15% (w/v) solution of DL-camphor in CCl_4 using a 10-cm light path.

band in the 1100−1300-nm range, as depicted in Figure 6 (line d). Furthermore, the three species are soluble in carbon tetrachloride, which does not absorb in the NIR spectral region.

The prototype spectropolarimeter was optimized for operation using CCl_4 as reference and for the region from 1000 to 1300 nm. Three solutions containing 7.5% (w/v) of the three camphor species were prepared and measured. Figure 6 shows the ORD spectra obtained for the three substances. It is possible to observe an inverse tendency of the ORD spectra of the (D) and (L) camphor while the (DL) camphor, as expected, did not show any notable feature in the spectral region that encompasses the absorption peak (line d in Figure 6). This last observation allows confirming that the spectral features observed in the (D) and (L) camphor spectra are not artifacts but real alterations in the optical rotation of the molecules as a function of the radiation wavelength.

There is a complete absence of data in the literature regarding the ORD spectrum of the camphor species in the NIR spectral region. A recent work reports the CD spectra for the same three species employed in this work and in the same spectral region.[9] These results also show an inverse behavior of the CD spectra for the (D) and (L) camphor species.

CONCLUSION

The proposed scheme for optical rotation measurement of optically active substances made by employing two diffracted beams of an anisotropic AOTF has been demonstrated. The proposed system is simple and shows the feasibility of ORD measurement in the near-infrared spectral region, which can contribute to studies of many interesting compounds.

The instrument allows for simultaneous acquisition of the absorption spectra of optically active and inactive species. For optically active species the intensities of the R and L beams must be added for the reference (background) and for the sample scans. Thus, the usual calculations of transmittance can be employed. This facility of attaining complementary information for optically active substances (absorbance and ORD spectra) can be useful to increase the analytical information for these types of substances and can provide, in the near future, a way to improve the selectivity and sensitivity of analytical methods based on the NIR spectral region using chemometric multivariate data treatments.

The proposed instrument is simple, robust, and versatile and makes use of the high energy throughput of the AOTF in order to improve the signal-to-noise ratio of spectropolarimetric measurements. Because the prototype employs a double-beam system, the optical rotation measurement is less prone to fluctuations in the radiation source. For instance, it has been observed that a ±15% change in source intensity (deliberately induced by lowering or increasing its supply voltage) results in alterations in the measured rotation angle that are within the precision of the present instrument (±0.11°).

Of course, the results obtained in this work could still be improved in order to increase the analytical sensitivity and the precision of the rotation angle measurement that, at the moment, is far from the best results that are obtained in the UV−vis spectral region, where precisions of 0.01° can be easily achieved. This can be achieved, in future prototypes, by better alignment of the optical devices and better matching and stabilization of the twin detectors employed in the proposed spectropolarimeter.

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