CHAPTER 9

DETERMINATION OF SPECIFIC ROTATION OF OLIGOMERS FROM MOLECULAR WEIGHT AND SPECIFIC ROTATION OF MONOMER
ABSTRACT

A general introduction to optical rotatory dispersion is presented. A new algebraic relation for evaluation of specific rotation of oligomers from the values of molecular weight and specific rotation of monomer is developed and is applied to determine the specific rotations of various oligomeric series. The results obtained are discussed critically in relation to earlier reported data and the advantages of the present approach are outlined briefly.
9 OPTICAL ROTATORY DISPERSION (ORD) AND CIRCULAR DICHROSIM (CD)

9.1 Introduction

The phenomenon of changes in optical activity with wavelength of a polarized beam of light has been known, since the beginning of the nineteenth century. Here, the pioneering work of Biot\(^1\), Fresnel\(^2\) and Pasteur\(^3\) may be considered as the base of modern stereochemistry. Biot\(^1\) and Fresnel\(^2\) showed that the rotatory power of an optically active medium increase with the decreasing wavelength of the incident light. Only in 1930's, the phenomenon of optical rotatory dispersion (ORD) took on a new turn due to the studies of Tschugaef\(^4\), Rupe\(^5\), Kuhn\(^6\), Lowry\(^7\), Mitchell\(^8\) and Levene and Rothen\(^9\). Later Haidinger\(^10\) observed the differences in absorption of the component of circularly polarized light. This phenomenon is known as circular dichroism (CD).

The technical difficulties on the applications of ORD and CD to organic chemical problems were overcome only in the 1950's when a photoelectric spectropolarimeter became available. The improvements in instrumentation were immediately followed by numerous applications of ORD and CD techniques to organic chemical problems. Among the dynamic and productive groups working in these field, the main are the groups of Djerassi\(^11\) and Klyne\(^12\).

Optical rotatory dispersion study of organic molecules\(^11,13-17\) has been used in determination of absolute configurations and relative positions of fundamental group, in analytical problems such as the separation of racemic mixtures; in the
detection of weak absorption bands (Magnetically allowed, electrically forbidden) or bands which are poorly resolved, in the stereochemistry of complex formation and finally, in solution problems and the study of conformational equilibria with temperature. ORD has also been developed into a powerful tool for the characterization of the conformations of bio-molecules, mainly in estimating the types and contents of secondary structure of proteins, nucleic acids and polymers\textsuperscript{18-22}. ORD is also used to determine base stacking characteristics. Recently ORD technique is used in medical field\textsuperscript{23,24} for diagnosis especially in diabetes. Finally magnetic ORD (MORD) and Magnetic Cd (MCD) open up the possibility of inducing optical activity in any molecule (Faraday effect).

ORD and CD have certain advantages even over the X-ray crystallographic studies as the former are based on solution techniques requiring absolute minimum perturbation to the system which means that experimental conditions can be chosen so that physiological relevance is ensured and further more in the solution state, desired perturbations such as change in concentration (of protein or any other component, such as substrate salt, effector, or denaturant) can be effected more readily than in the crystalline state.

9.2 THEORY

Optical rotation and circular dichroism represent two inseparable aspects of optical activity which result from the interaction of a given medium with linearly polarized light. Linear polarized light is regarded as a super position of two equal left and right circularly polarized components (Fig. 9.1). Optically active media are characterized by different indices of refraction for the two
components, \( n_L \neq n_R \), and since \( n = C/V \) (\( C \) = velocity of light in vacuum), different propagation velocities. \( V_L \neq V_R \) as well as different angular velocities of the projections of electric field vectors in Fig. 9.1 passing through a material medium of unit path length. One component gains a lead over the other and remains fixed after the light has left the optically active medium. Hence, the light continues to be linearly polarized but the plane of polarization is now rotated at angle of \( \alpha \), given by

\[
\alpha = \frac{\pi}{\lambda} \left( n_L - n_R \right) \text{ (degree)} \quad \ldots \quad (9.1)
\]

where \( \lambda \) is the wavelength of the light in vacuum.

Specific rotation, expressed as a property of materials, depends on the pathlength in decimeters and a concentration in g cm\(^3\).

It is defined as \(^\text{7,25,26}\)

\[
\left[ \alpha \right]_\lambda = \frac{\alpha}{C_l} \left[ \frac{\text{degr.cm}^3}{\text{g.dm}} \right] \quad \ldots \quad (9.2)
\]

In depends on \( \lambda \) and to a less extent on temperature (T) and concentration (c).

The term molar rotations \( [\phi]_\lambda^T \) takes into account the molecular weight \( M \) of the solute and is expressed as

\[
\left[ \phi \right]_\lambda^T = \left[ \alpha \right]_\lambda \frac{M}{100} \left[ \frac{\text{degr.cm}^3}{\text{decimole}} \right] \quad \ldots \quad (9.3)
\]
Fig. 9.1. Projection of the electric field vectors showing composition of linearly polarized light
(a) Two equal components of left and right circularly polarized light
(b) The situation after light at a wavelength which is not absorbed has left an optically active medium
For biopolymers, the data are usually expressed in terms of mean residue rotations.

\[
[m]^r = [\alpha]^r \frac{M_o}{100} \left[ \frac{\text{degr}.\text{cm}^{-1}}{\text{decimole}} \right]
\]  \hspace{1cm} (9.4)

where \(M_o\) is the mean residue molecular weight. \(M_o\) of a protein can be determined from its amino acid composition. Moffitt\(^{27}\) introduced the term reduced mean residue rotation \([m]^r\) by including Lorentz field correction.

\[
[m']^r = [m]^r \left( \frac{3}{n^2 + 2} \right) \left[ \frac{\text{degr}.\text{cm}^{-1}}{\text{decimole}} \right]
\]  \hspace{1cm} (9.5)

where 'n' is the refractive index of the solvent at the specified wavelength.

The application of Moffitt's expression for the secondary structure studies on proteins and poly peptides in particular and on biopoly polymers in general depends on the measurement of specific rotation very accurately. An accurate determination of the same needs the help of a sophisticated equipment called as spectropolarimeter, the availability of which is limited to very few institutions because of high cost of the unit. In such a case where the data on specific rotation is needed but the equipment is not available readily, an alternate approach is suggested for the low molecular weight polymers, i.e. oligomers. This is first step in the approach which enables the evaluation of specific rotation for a given oligomer from a knowledge of specific rotation of the monomer and the corresponding molecular weight of monomer. The details of the approach and its applications to a few oligomeric systems are discussed in Section 9.3.
9.3 RELATION

A new algebraic relation between molecular weight of oligomer and its specific rotation $\alpha$ is proposed, which reads as

\[
\left( \frac{3}{n^2 + 2} \right)^{-0.05} \frac{1}{M_o^{0.77-0.001P} M_p^{0.23+0.001P}} \ln \left[ \frac{M e^{0.0045P}}{\ln(3^{\frac{1}{p}} \alpha)} \right] = \Delta, \text{ a constant} \quad \ldots \quad (9.6)
\]

where $M_o$ and $M$ refer to the molecular weight of monomer and oligomer, $p$ is the degree of polymerization and '$n'$ is the refractive index of the solvent and $\alpha$ is the specific rotation of the oligomer; $\frac{3}{(n^2 + 2)}$ provides Lorentzian correction.

$+$ refers to the decrease in specific rotation with increase in the degree of polymerization

$-$ refers to the increase in specific rotation with increase in the degree of polymerization.

For a monomer, the equation (9.6) reduces to

\[
\left( \frac{3}{n^2 + 2} \right)^{-0.05} \ln \left[ \frac{M e^{0.0045P}}{\ln \alpha} \right] = \Delta \quad \ldots \quad (9.7)
\]

The value of constant $\Delta$ can be evaluated for the monomer from Eqn.(9.7) by substituting values of $M_o$ and $\alpha$ of monomer and refractive index '$n'$ of the solvent.

The same value of $\Delta$ is used to evaluate specific rotations of oligomer for different '$p$' values.
This expression has been applied to calculate \( \alpha \) of oligomers of the following systems.

They are

1. Malto oligooses in \( \text{H}_2\text{O} \)
2. Cello-oligooses in \( \text{H}_2\text{O} \)
3. Oligo (\( \beta \)-xylopyranoses) in \( \text{H}_2\text{O} \)
4. Iso-Malto oligooses in \( \text{H}_2\text{O} \)
5. Cello oligoose acetates in CHCL\(_3\)

The required values of molecular weights of oligomers with respect to 'p' values and specific rotation of the monomer for above oligomers are taken from reference 28 and are given in Table 9.1. Table 9.1 presents the results of the work with \( \Delta \), the constant of the equation, and values of specific rotations of oligomers calculated and standard values from reference 28.

It is however to be borne in mind that the above formula holds good when the specific rotation changes in one sens alone. If the rotation changes its sign suddenly at one degree of polymerization (p), the difference of the rotation obtained for that p and that corresponding to previous state of p values are to be taken.

9.4 RESULTS AND DISCUSSION

A reference to Table 9.1 brings forth the following conclusions.
### TABLE 9.1
Specific rotations of oligomers

<table>
<thead>
<tr>
<th>Compound</th>
<th>p</th>
<th>W</th>
<th>Δ</th>
<th>α° in H₂O (cal)</th>
<th>α° in H₂O (std)</th>
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<td>198.54</td>
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Table 9.1 (continued)

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<th>Compound</th>
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<th>Δ</th>
<th>( \alpha^0 ) in CHCl(_3) (cal)</th>
<th>( \alpha^0 ) in CHCl(_3) (std)</th>
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The agreement between the calculated and standard value of specific rotation is fairly satisfactory. However, at larger values of \( p \) the difference is found to be marked. Thus this method enables any stereochemist to obtain the specific rotation rather formally but not exactly. This is due to the fact that an accurate determination of \( \alpha \) is not readily available and any small variation in specific rotation of monomer is likely to influence largely \( \alpha \), since the expression involved natural logarithm of \( \alpha \).

This method is useful for a qualitative discussion of secondary structures since the final information to be obtained from optical rotatory dispersion is only qualitative and not quantitative. The application of this method to the evaluation of specific rotation of polymers (with any modification of the expression 9.6 if necessary) is being taken up in these laboratories at present.
REFERENCES


