The 1H NMR spectrum of the tris(2,2'-bipyridine)osmium(II) complex in which all of the H-6 hydrogens have δ 7.6 ppm. The 13C NMR spectra of [Pt(bpy)2OH]+ (Figure 5) and cis-[Rh(bpy)2Cl2]+ (which was measured because it was readily available to us) are also very similar, and it is especially noteworthy that the four broad bands referred to in Figure 5 also appear in the kinetically inert rhodium complex. Since chemical exchange can presumably be excluded in this latter complex, these bands are probably due to intramolecular distortions in the flexible ligands.

All experimental evidence therefore points toward a configurational change from a distorted square planar structure in neutral solutions to a five- (or six-) coordinated species in alkaline solution. In the latter the two bpy ligands are in the cis position to each other. This is also supported by the 1H methyl resonance in the platinum(II) complex with 5,5'-dimethyl-substituted bipyridine which splits in basic solution just as do the H-5 and the H-5' protons of Figure 4, and we see no way to explain our data within the "covalent hydration of the ligand" hypothesis advanced by Gillard. A more detailed structure of [Pt(bpy)2OH]+ must necessarily be speculative. This could be a five-coordinate trigonal bipyramid but also could be a distorted six-coordinate complex derived from a normal square planar Pt(II) complex. Thus the structure in Figure 6 is consistent with all the NMR experiments because proton transfer enables OH− to exchange between the two sites shown as OH and OH2 in the figure with a rate which is rapid on the NMR time scale.

It is a notable feature of the so-called "Gillard pseudo base mechanism" that phen and bpy and also OH− and CN− are assumed to behave analogously. It is therefore relevant to the present work that OH− and CN− give analogous changes in the UV-visible spectrum of [Pt(phen)2I2+] and that studies of the [Pt(phen)2CN]+ cation have shown that the CN− group is directly coordinated to the platinum both in solution and in the solid state. Neither for this complex nor for [Pt(bpy)2OH]+ is it necessary to invoke new or "novel" mechanisms or structures.

The present NMR study confirms the suggestion that the hydrolysis of Pt(bpy)2OH− in basic solution occurs via attack on the metal center and therefore by the associative mechanism generally accepted for substitution reactions in Pt(II) complexes.

Acknowledgment. Thanks are due to O. Wernberg and A. Hazell for access to unpublished data and to E. Jonas Pedersen and K. Boek for help with the interpretations of the NMR spectra. The NMR spectographs are the property of the Danish Natural-Science Research Council.

References and Notes

1. The following abbreviations are used in this paper: phen, 1,10-phenanthroline; bpy, 2,2'-bipyridine.
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Received May 4, 1979

Stereoselective Aldol Condensations
via Boron Enolates

Sir:

The aldol condensation is a reaction of fundamental importance in biosynthesis. Consequently, considerable effort has been expended to develop stereoregulated variants of this process in the laboratory. It is now well appreciated that kinetic aldol stereoselection is, in part, defined by enolate geometry for those condensations wherein two new stereocenters are created in the condensation step (Scheme I). Given the reasonable postulate that the reaction proceeds via a pericyclic process, the influence of variable steric parameters may be analyzed to determine their effects upon the relative heats of formation of diastereoisomeric transition states from an enolate of defined geometry. For example, for (E)-enolates one might anticipate that transition state T2 might be destabilized relative to T1 by maximizing both R2 ≪ R1 and R2 ≪ L steric parameters. Heathcock and co-workers have recently demo-
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Table 1. Aldol Condensation of Dialkylboron Enolates with Benzaldehyde

<table>
<thead>
<tr>
<th>Entry</th>
<th>RCOCH₂CH₃ (1)</th>
<th>L₂BOTf (2)</th>
<th>Conditions</th>
<th>Enolate Ratio</th>
<th>Aldol Ratio</th>
<th>Yield, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td>-78°C, 30 min</td>
<td>&gt;99:1</td>
<td>&gt;97:3</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>L = n-C₄H₉ (2a)</td>
<td>L = n-C₄H₉ (2a)</td>
<td>0°C, 30 min</td>
<td>82:18</td>
<td>84:16</td>
<td>86</td>
</tr>
<tr>
<td>B</td>
<td>Ph</td>
<td>L = n-C₄H₉ (2a)</td>
<td>-78°C, 30 min</td>
<td>&gt;99:1</td>
<td>&gt;97:3</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L = n-C₄H₉ (2a)</td>
<td>25°C, 1 h</td>
<td>&lt;5:95</td>
<td>&lt;5:95</td>
<td>90</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>L = n-C₄H₉ (2a)</td>
<td>-78°C, 30 min</td>
<td>&gt;99:1</td>
<td>&gt;97:3</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>L = n-C₄H₉ (2a)</td>
<td>L = n-C₄H₉ (2a)</td>
<td>0°C, 1 h</td>
<td>45:55</td>
<td>44:56</td>
<td>(92)</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>L = n-C₄H₉ (2a)</td>
<td>0°C, 30 min</td>
<td>82:18</td>
<td>84:16</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>L = n-C₄H₉ (2b)</td>
<td>L = n-C₄H₉ (2b)</td>
<td>0°C, 2 h</td>
<td>&gt;99:1</td>
<td>&gt;97:1</td>
<td>65</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td>L = n-C₄H₉ (2a)</td>
<td>-78°C, 1 h</td>
<td>--</td>
<td>33:67</td>
<td>(71)</td>
</tr>
<tr>
<td></td>
<td>L = n-C₄H₉ (2b)</td>
<td>L = n-C₄H₉ (2a)</td>
<td>0°C, 1 h</td>
<td>32:68</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>L = n-C₄H₉ (2a)</td>
<td>0°C, 30 min</td>
<td>≤5:95</td>
<td>10:90</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>L = n-C₄H₉ (2b)</td>
<td>L = n-C₄H₉ (2b)</td>
<td>0°C, 30 min</td>
<td>≤5:95</td>
<td>5:95</td>
<td>90</td>
</tr>
</tbody>
</table>

* Except where noted, diisopropylethylamine was employed as the enolization base. * Enolate ratios were determined by conversion of 3Z-3E mixtures to the corresponding (trimethylsilyl) enol ethers via successive treatment with methylolithium (3 equiv) and chlorotrimethylsilane and subsequent comparison with authentic samples by GLC. * Aldol ratios were determined by 'H NMR. * Values reported are isolated yields. Values in parentheses refer to yields determined by 'H NMR relative to internal standard.

Onstrated that, for specified (Z)- and (E)-lithium enolates (R₁ sterically demanding), excellent diastereoselection could be attained in the formation of erythro- and threo-aldol adducts respectively; however, for less bulky enolate substituents (Rᵀ = C₄H₉, i-C₃H₇, C₆H₅, OMe, N(i-C₃H₇)₂), diastereoselection has been generally observed to be greatly diminished. 1-4 Owing to the fact that metal-oxygen bond lengths for these and related metal enolates (M = Li, Mg₂, Zn₂, Al₂), are relatively long (~ 1.9-2.2 Å), as are the M-L bond lengths (M-C ~ 2-2.2 Å), the origin of the observed stereoselection could be largely due to R₁ ≈ R₂ interactions. 6

In an effort to confer greater stereostereochemical control in kinetically controlled aldol processes, we have studied the steric effects conferred upon these reactions by the metal center. Accordingly, maximal pseudo-1,3-diaxial R₂ ≈ L interactions in the transition states T₁ and T₂ might be achieved by minimizing M-O and M-L bond lengths (D) and maximizing the bulk of the metal ligands. 6 Dialkylboron enolates (M = BL₂), which may be readily prepared under mild conditions from ketones and dialkylboron triflates (2), 7,8 satisfy the above criteria (D₉.0 = 1.36-1.47, D₉.0 = 1.5-1.6 Å), and one case, 3Z and 3E (R₁ = Ph), has been reported to undergo conden-

sation with propionaldehyde (R₂ = Et) to give 4a and 5a, respectively (cf. Scheme II). 7b

The present study demonstrates the generality of employing boron enolates in stereoselective aldol condensations and the utility of boron triflates 2 in the selective enolization of ketones and thio esters. The representative aldol condensations summarized in Table I were carried out according to the following general procedure. Enolate equilibration may be achieved. The resultant enolate solution is cooled to -78 °C and subsequent heating at reflux (1-3 h), enol equilibration may be achieved. The resultant enolate solution is cooled to -78 °C, 1 equiv of aldehyde is added, and the solution is stirred for 30 min at -78 °C followed by 1-2 h at 0 °C. The resultant boron chelates 4a are most efficiently oxidized to the ketols 4b by the addition of 1.5 equiv of MoO₃py-HMPA, MoOPH₉ (30 min, 0 °C; 45 min, 25 °C),
followed by the addition of 1 N aqueous sodium hydroxide solution. In our hands this oxidant is superior to the classical hydrogen peroxide procedure.7a For boron triflate 2b,10 enolization at 0 °C rather than −78 °C appears to be necessary. Control experiments were carried out to ensure that the product ratios were a result of complete kinetic stereoselection. In all cases examined it was found that the primary aldol products 4a and 5a were quite stable (34 °C, 3 h, Et2O) and that subsequent conversion of these boron chelates into the hydroxy ketones 4b and 5b proceeded without loss of stereochemistry.

A number of conclusions may be drawn from the data in Table I. Entry A underlines two important points which have influenced subsequent studies. First, in the reaction of diethyl ketone with boron triflate 2a (L = n-Bu), the kinetic enolate ratio is a function of the base employed in the enolization process (Et3N(i-Prop)2, 3Z:3E ≥ 99:1; lutidine, 3Z:3E = 69:31). Second, with a given amine base (Et3N(i-Prop)2) the boron ligand (L) in the trivalent reagent 2 exerts a pronounced effect upon the kinetic enolate ratio (L = n-Bu, 3Z:3E = 99:1; L = CsHg, 3Z:3E = 84:16). We surmise that the consequence of boron ligand effects on the kinetic enolization process may well be generalizable (cf. entry D). With the exception of entry E, the conditions reported in the table reflect apparent kinetic control during the enolization process. Under kinetic conditions (−78 °C to 0 °C), tert-butylethyl ketone afforded, in low conversion, an enolate ratio of Z:E ~ 25:75; however, in refluxing ether, enolization and attendant enolate equilibration resulted in the production of the pure (Z)-enolate (entry E).

Given the illustrated dialkylboron enolates of defined structure, the resultant aldol diastereoselection observed with benzaldehyde is excellent. It is readily apparent that, for a given aldehyde, enolate steric parameters, R1 (Scheme I), can be varied without loss of aldol diastereoselection. These results are in marked contrast to those of Heathcock and co-workers in their investigations with lithium enolates.3 These comparative observations between boron and lithium enolates support our hypothesis that metal center steric effects are important in conferring enhanced diastereoselection to the condensation process. In general, we have found that (Z)-boron enolates exhibit higher levels of diastereoselection (erythro/threo ≥ 30) than (E)-boron enolates (threo/erythro = 2:19). Corresponding trends have been noted with lithium enolates.1c,2

The modest levels of diastereoselection observed with cyclohexanone (entry F) were surprising. Accordingly, this system was chosen to study the interplay between boron ligand structure and the role of solvent effects on kinetic aldol stereoselection (Table II). For a given boron ligand (entries A, B) there appears to be a small but consistent solvent effect (c.f. entries C, D). Nonpolar solvents, in general, may affect compression of the diastereoisomeric transition states and confer greater reaction stereoselectivity. In a given solvent little enhancement in stereoselectivity was observed in changing the boron ligand from n-buty1 to cyclopentyl (entries B, D); however, with the cyclopentyl theryl enolate, prepared from boron triflate 2e,2 a significant improvement in reaction stereoselectivity was observed. Modestly increased aldol diastereoselection induced via boron ligand structural changes was also noted with tert-buty1 thioisopropionate (entry G, Table I).

Table III summarizes the results of three kinetic enolate condensations with benzaldehyde where a direct comparison can be made upon the influence of the metal upon the degree of diastereoselection. It is evident that the boron enolates are superior to the corresponding lithium enolates in stereoselective bond construction.

Although the aforementioned studies were carried out with
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Received May 9, 1979

Annnulated Pyranosides as Chiral Synthons for Carbocyclic Systems. Enantiospecific Routes to Both (+)- and (−)-Chrysanthemumdicarboxylic Acids from a Single Progenitor

Sir:  
There is currently considerable interest in the use of carbodiyate derivatives as chiral synthons as may be judged from the annihilation in recent years. These accomplishments fall largely into two categories for which we have suggested the terms (a) acyclic transfer and (b) cyclic transfer to denote the manner in which the carbodiyate moiety has been employed. A third category, (c) transcription, may be recognized which is particularly applicable to carbocyclic compounds, and, in this context, it is noteworthy that Stork's synthesis of the prostaglandins is the only instance, to our knowledge, where a carbocyclic natural product has been synthesized from a sugar.

In this communication, we introduce the novel concept of annulated pyranosides as chiral synthons for carbocyclic systems, and exemplify the potential of this methodology by outlining the enantiospecific syntheses of (+)- and (−)-chrysanthemumdicarboxylic acids (I) from a single precursor, whereby all stereochemical centers of the target are of known, predetermined configuration by "transcription" from the carbohydrate template. A significant aspect of this work is that it makes provision for preparing chrysanthemates with isotopic labels at a variety of specific sites.

In the context of this project, the key structural feature is the gem-dimethylcyclopropane ring, and, of the many routes which we and others have developed to cyclopentane-pyranosides, the one chosen for initial study is that summarized in Scheme I. Thus, the photoinduced alkylation of enone 2 with methanol gave the ketol 3a which was converted into 4a in excellent yield. For the synthesis of 4b, the tert-secry alcohol 3b was obtained in 87% yield by alkylation of 2 with 2-propanol. However, all attempts to bring about cyclization 3b → 4b met with abject failure.

We next turned our attention to the carboethoxy cyclopropane 7a, first prepared by Meyer zu Reckendorf and studied further by us. Attempts to α-methylate 7a were unsuccessful. We therefore examined the reaction of 5 with the

A common aldehyde, benzaldehyde, to minimize the changes in reaction variables, we have found our observations to be general. For example, the (Z)-dibutylboron enolate derived from 3-pentanone affords cleanly the erythro-aldo adducts with n-butyaldehyde, isobutyaldehyde, crotonaldehyde, and methacrolein. The generality of these reactions and the application of chiral boron enolates to enantioselective aldol condensations will be reported in due course.

Acknowledgment. This work has been supported by the National Science Foundation.

References and Notes

1. J. E. Dubois and M. Dubois, Tetrahedron Lett., 4215 (1967); for a common aldehyde, benzaldehyde, to minimize the changes in the stereochemical course of a reaction, we have found our observations to be general. For example, the (Z)-dibutylboron enolate derived from 3-pentanone affords cleanly the erythro-aldo adducts with n-butyaldehyde, isobutyaldehyde, crotonaldehyde, and methacrolein. The generality of these reactions and the application of chiral boron enolates to enantioselective aldol condensations will be reported in due course.


8. (a) T. Mukaiyama and T. Inoue, Chem. Lett., 559 (1976); (b) W. Fenzl and R. Köster, Justus Liebigs Ann. Chem., 1322 (1975); the (Z)- and (E)-enolates (R1 = Ph) were reported to undergo stereospecific condensation with C6H4CHO to give 4a and 5a, respectively.


11. To tricyclo[2.2.2]octanone (H. C. Brown and B. C. Subbaro, J. Am. Chem. Soc., 81, 6425 (1959); (1 equiv) was added with cooling 1 equiv of trifluoromethanesulfonic acid. Short-path distillation afforded 2b in 90% yield, bp 70-72 °C (1.0 mm Hg).

12. Satisfactory spectral and analytical data were obtained on all new compounds.

13. Boron triflate 2b was generated in situ in the following manner. A mixture of 1 equiv each of hexylborane and cyclopentene in THF (1.0 M) was stirred at -20 °C (1 h), cooled to -78 °C, and quenched with 1 equiv of trifluoromethanesulfonic acid (dropwise).

14. Treatment of tert-butylicloropropionate with LDA (Et2O, -78 °C) affords ≥95% enolate corresponding to 5 in direct analogy to the observation of Ireland.


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