in the acetylation of methyl ether, ions of $m/z$ 89 from reactions 1 and 2 were unreactive toward all nucleophiles added (AcOH, AcOCH$_2$, AcO, H$_2$O, CH$_3$OH).

The acylation reactions described thus far can be expressed satisfactorily by the process of eq 3 where the acylium ion complex 2 is either an intermediate or a transition state. We also wish to report related reactions whereby acyl transfer occurs between the protonated parent of one acyl compound and the neutral form of another (eq 4).

In the special case where AcX = AcY (eq 3)

$$AcX + AcYH^+ \rightarrow [AcX\cdots Ac\cdots YH] \rightarrow AcXAc^+ + HX$$

(4a)

$$AcYH^+ + AcX \rightarrow AcYAc^+ + HX$$

(4b)

The reaction is a self-acylation process that is mechanistically indistinguishable from reaction 3. However, when the acyl components are different, as in the reactions of protonated methyl acetate or thioacetate with neutral acyl derivatives, the roles of the reactants are reversed and the acyl group is transferred from the neutral to the ion rather than from the ion to the neutral (eq 4b and Table I). For example, protonated methyl acetate-d$_3$ and AcO gave (CD$_3$CO$_2$CH$_3$)Ac$^+$. Viewed in this way, any fundamental distinction between reactions 3 and 4. We wish to point out that reaction 4b is strikingly similar to gas-phase alkylation reactions of carbonyl compounds.

Sequential acyl transfers are evident in the reactions of methanol with neutral acyl derivatives, the roles of acyl transfer by reaction 3 (R = H) is the reactant ion for acyl transfer by eq 4b. These sequences are summarized in Table 1.

The key question is whether there is no fundamental distinction between reactions 3 and 4.

The development of chiral enolates which participate in highly stereoregulated aldol condensations has been a challenging undertaking. The control of both reaction diastereoselection (E$_1$ + E$_2$ vs. T$_1$ + T$_2$) and enantiomeloselection (E$_1$ vs. E$_2$ or T$_1$ vs. T$_2$) must be addressed in conjunction with this problem (eq 1).

The purpose of this communication is to report our observations on the utility of the chiral 2-oxazolidiones 1a and 2a as recyclable chiral auxiliaries, X$_2$, for carboxylic acids in highly enantioselective aldol condensations via the boron enolates, derived from the respective N-propionylimines 1b and 2b.

Oxazolidone 1a, mp 71-72°C, [a]$_D$ +14.8° (c 7.0, CHCl$_3$), was prepared from (S)-valinol and either phosgene or diethyl carbonate in high yield. In a similar fashion, the commercially available (1S,2R)-norephedrine was transformed into oxazolidinone 2a, mp 120-121°C, [a]$_D$ +167.7° (c 1.0, CHCl$_3$). The N-propionyloxazolidinones 1b and 2b were prepared in 80-90% yield by lithiation of 1a or 2b (n-BuLi, 0.3 M THF) and subsequent reaction with propionyl chloride (1.0 equiv, -78°C). The non-

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Enantioselective Aldol Condensations. 2. Erythro-Selective Chiral Aldol Condensations via Boron Enolates

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The development of chiral enolates which participate in highly stereoregulated aldol condensations has been a challenging undertaking. The control of both reaction diastereoselection (E$_1$ + E$_2$ vs. T$_1$ + T$_2$) and enantiomeloselection (E$_1$ vs. E$_2$ or T$_1$ vs. T$_2$) must be addressed in conjunction with this problem (eq 1). The


(10) RH$^+$ are acidic fragments and product ions resulting from electron impact of the neutral reactants.


crystalline adducts 1b and 2b could be conveniently purified by either molecular distillation or flash chromatography. In numerous studies carried out in this laboratory we have found that 1b and 2b undergo highly stereoselective enolization with either lithium amide bases [LiN(i-C3H7)2, -78 °C, THF] or di-n-butylboryl trifluoromethanesulfonate by either molecular distillation or flash chromatography.11,12 The unpurified reaction mixture was silylated with either of the results obtained with both imides either lithium amide bases [LiN(i-C3H7)2, -78 °C, THF] or di-n-butylboryl trifluoromethanesulfonate (T2E) to form the (Z)-enolates (ZE ≥ 100).12 The boron enolates were condensed (-78 °C) with the representative aldohydrides illustrated in Table I and the diastereoisomeric aldol adducts were isolated by oxidative workup.13 The unpurified reaction mixture was silylated (Et2NSiMe3, DMAP, CH2Cl2, 25 °C) and analyzed by capillary gas chromatography.14 The four aldol stereoisomers (E1, E2, T1, T2) in all cases reported were readily resolved by this analytical method. The analogous condensations of the corresponding lithium enolates were carried out under kinetic conditions (-78 °C, 10 min). In a representative condensation of the boron enolate derived from 1b with isobutyraldehyde, the observed diastereoisomer ratios, E:E2:T1:T2 were 99.4:0.2:0.2:0.2. The analogous aldol condensation with the lithium enolate afforded the product ratios E1:E2:T1:T2 were 99.4:0.6:0.2:0.2. The analogous condensations were found to exhibit low levels of stereoregulation.

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The illustrated aldol condensations were carried out according to the following general procedure. To a 0.2-0.5 M solution of...
Table I. Aldol Condensations of 1c and 1d with Representative Aldehydes (Scheme II)†

<table>
<thead>
<tr>
<th>Imide R, CHO</th>
<th>ratio 11a:12a</th>
<th>[α]D 13</th>
<th>optical purity 13:14×</th>
</tr>
</thead>
<tbody>
<tr>
<td>1d Me2CHCHO</td>
<td>98.4:1.6</td>
<td>-42.1° (1.8)</td>
<td>97.8:2.2</td>
</tr>
<tr>
<td>1d n-C4H9CHO</td>
<td>98.9:1.1</td>
<td>-27.3° (2.1)</td>
<td>99.4:0.6</td>
</tr>
<tr>
<td>1d CH3CHO</td>
<td>99.6:0.4</td>
<td>-45.8° (1.7)</td>
<td>&gt;99.9:0.1</td>
</tr>
<tr>
<td>1d C6H5CHO</td>
<td>92.4:7.6</td>
<td>-17.1° (4.1)</td>
<td>92.4:7.6</td>
</tr>
</tbody>
</table>

† Determined by GLC (ref 13). ‡ All rotations were carried out in CHCl3 except for the CH3CHO case. EOH was used instead. Inferred from the ratios of 11a and 12a after chromatographic purification. d Literature rotation: [α]D = -24.7° (c 0.98, CHCl3) (ref 19a); [α]D = -40.3° (c 4.6, CHCl3) (ref 2d). e Literature rotation: [α]D = -28° (c 2.0, CHCl3) (ref 19b). f Value is [α]D of methyl ester of 14 from methanalysis of 11a and 12a. Literature rotation for methyl ester of 14: [α]D = +33.3° (c 1.2, CHCl3) (ref 19c). g Literature rotation for antipode 14: [α]D = +18.9° (c 5.15, EOH) (ref 2g) [α]D = -18.9° (c 2.3, EOH) (ref 19d). h Products 11a and 12a, R1 = C6H5, are not stable on silica gel. The crude product from desulfurization was hydrolyzed directly to the acid.

1b in anhydrous CH2Cl2 under argon (0 °C) is added 1.1 equiv of boron triflate (7) followed by 1.2 equiv of disopropylethylamine. After allowing 30 min for complete enolization, the reaction is cooled (∼78 °C) and 1.1 equiv of freshly distilled aldehyde is added and stirred for 0.5 h at ∼78 °C and 1.5 h at room temperature. The boron aldolate complex is quenched with pH 7 phosphate buffer and oxidized with 30% hydrogen peroxide-methanol (0 °C, 1 h). The aldol adduct is then isolated by ether extraction.

It appears that these reactions will be useful for more highly functionalized substrates as well. For example, the selective enolization of 8 and its subsequent condensation with benzaldehyde afforded the diastereomerically pure adduct 9 (mp 101-102 °C, J (erythro) = 5.0 Hz) in 67% isolated yield. The absolute stereochemical assignment for 9 was carried out by a straightforward degradation to (2R)-benzylsuccinic acid (10), mp 162-163 °C, [α]D = -28.6° (c 0.9, acetone) whose optical purity was judged to be 98%.18

In view of the high levels of asymmetric induction observed in the cases cited above, it was surprising to observe that the boryl enolate derived from the N-acetyloxazolidone (1c) afforded nearly 1:1 ratios of the aldol adducts 11a and 12a with the representative aldehydes illustrated in Table II. For example, the boron enolate derived from 1c afforded a 11a:12a ratio of 52:48 with isobutyraldehyde and 72:28 with acetaldehyde. It had been hoped that 1c and 2c might function as useful chiral acetal enolate equivalents.26 A practical solution to this objective was accomplished upon examination of the aldol condensations of oxazolidone 1d which were found to be highly stereoregular in nature. Desulfurization of the aldol adducts 11b and 12b to 11a and 12a proceeded in good yield with Raney nickel20 (acetone, 60 °C, 20 min). Gas chromatographic analysis13 (Table II) indicated that asymmetric induction in the range of 92-99% could be achieved. Chromatographic purification of 11a followed by base hydrolysis, as previously described, afforded the β-hydroxy acids 13 in 80-90% yields. Since the absolute configurations of acids 13 (R1 = Ph, Me, n-C3H7, and i-C3H7) have been previously established,19,18 it follows that the sense of asymmetric induction of both 1b and 1d are the same for all aldehydes examined. One important consequence of this study pertains to the critical role of enolate substitution in aldol asymmetric induction. In related studies we have made parallel observations that unsubstituted methyl ketone boryl enolates exhibit much lower levels of asymmetric induction than the (Z)-ketene enolates.26,22

Oxazolidones 1a and 1b appear to fulfill all of the design requirements for a generally useful chiral auxiliary for the aldol process. These systems confer high stereoselection on the enolization process, provide remarkable levels of erythro-diastereofaceace selection (ΔΔG° at -78 °C ~ 3 kcal/mol), and are readily removed and recycled without attendant racemization of the substrate.

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