gave (±)-**2b** (7.31 g, 38% from the acid): bp 129-136 °C (17 mm). Anal. ($C_8H_9NCl_2$) C, H, N.

(*S*)-α-(3,5-Dichlorophenyl)ethylamine [(*S*)-2b]. Racemic **2b** (6.95 g, 36.6 mmol) and (+)-10-camphorsulfonic acid (8.49 g, 36.6 mmol) were dissolved in hot methanol (50 mL). The methanol was removed at reduced pressure. Recrystallization (4×) of the residue from 30-50% ethanol in water gave the pure salt (1.26 g, 16%): $[\alpha]^{25}_D$ +6.8° (*c* 1.38, NaOH-CH_3OH[34]). Decomposition of the salt gave (*S*)-**2b**: $[\alpha]^{26}_D$ -24° (*c* 1.45, CH_3OH); >95% ee.[35]

(*S*)-α-Benzylethylamine [(*R*)-3a] had $[\alpha]^{22}_D$ +33.1° (neat, d^{20}_4 0.949, 0.5 dm) [lit.[15] $[\alpha]^{15}_D$ +35.6° (neat)].

(*S*)-α-Benzylethylamine hydrochloride [(*S*)-3a·HCl] had $[\alpha]^{25}_D$ +21.6° (*c* 9.0, H_2O) [lit.[15] $[\alpha]^{15}_D$ +24.8° (*c* 9.00, H_2O)].

(*S*)-α-(*p*-Chlorobenzyl)ethylamine hydrochloride [(*S*)-3b·HCl] had $[\alpha]^{25}_D$ +22° (*c* 2.10, H_2O) [lit.[16] $[\alpha]^{25}_D$ +22° (*c* 2.10, H_2O)]; >95% ee.[35]

(*R*)-α-(*p*-(Trifluoromethyl)benzyl)ethylamine [(*R*)-3c]. Racemic **3c**·HCl,[20] mp 202-204 °C (lit.[19] mp 195-197 °C) (4.83 g, 20.2 mmol), in 95% ethanol (25 mL) was mixed with 20% NaOH (4.1 g, 20 mmol). To the mixture was then added L-*N*-acetylleucine[38] (3.55 g, 20.5 mmol) in 95% ethanol (25 mL), and the mixture was heated to boiling and filtered. The solvent was evaporated, and the residue was recrystallized from methanol. A second recrystallization from methanol gave the salt (1.12 g, 29%): $[\alpha]^{26}_D$ -15° (*c* 1.47, CH_3OH). Decomposition of the salt gave (*R*)-**3c**: $[\alpha]^{26}_D$ -19° (*c* 1.76, CH_3OH); >95% ee.[35] The hydrochloride salt [(*R*)-**3c**·HCl] formed by the addition of concentrated HCl to an ether solution of the amine had mp 170-172 °C and $[\alpha]^{26}_D$ -7° (*c* 1.23, CH_3OH).

(*R*)-*N*,*N*-Dimethyl-α-benzylethylamine [(*R*)-4a]. A mixture of formic acid (2.4 g of 97%, 51 mmol) and formaldehyde (2.0 mL of 36%) was added with cooling to (*R*)-α-benzylethylamine [(*R*)-**9a**], $[\alpha]^{22}_D$ -35.0° (neat, d^{20}_4 0.949) (1.35 g, 10.0 mmol). The mixture was boiled for 15 h, acidified with 6 N hydrochloric acid (2.0 mL), and concentrated at reduced pressure. The concentrate was made basic with 10% sodium hydroxide (10 mL) and then extracted with ether (2 × 10 mL). The ether solution was dried (KOH) and evaporated. Distillation of the residue gave (*R*)-**4a** (0.828 g, 51%): bp 116-120 °C (32 mm) [lit.[41] bp 115-118 °C (20 mm) for (±)-**4a**]; $[\alpha]^{26}_D$ +7.8° (*c* 1.96, CH_3OH) [lit.[17] $[\alpha]_D$ +7.8° (*c* 2.6, CH_3OH)].

(*S*)-*N*,*N*-Dimethyl-α-(p-chlorobenzyl)ethylamine hydrochloride [(*S*)-4b·HCl] had $[\alpha]^{25}_D$ +11° (*c* 2.09, H_2O) [lit.[16] $[\alpha]^{25}_D$ +11° (*c* 2.09, H_2O)].

(*S*)-*O*-Methylmandelic acid was prepared as described previously[22,42] and had mp 63-66 °C $[\alpha]^{26}_D$ +161° (*c* 1.20, H_2O) [lit.[22] mp 65-67 °C and $[\alpha]^{23}_D$ -161.9° (*c* 1.66, H_2O) for the *R* isomer].

Registry No. (*S*)-**1a**, 2627-86-3; (*S*)-**1a**·HCl, 17279-30-0; (±)-**1b**, 42070-98-4; (*S*)-**1b**, 27298-98-2; (*S*)-**1b**·HCl, 84499-72-9; (±)-**1c**, 35588-60-4; (*R*)-**1c**, 27298-99-3; (*S*)-**1c**, 4187-56-8; (*S*)-**1c**·HCl, 56782-68-4; (*S*)-**1d**, 27298-97-1; (*S*)-**1d**·HCl, 84499-77-4; (*S*)-**1e**, 36244-70-9; (±)-**1f**, 84580-06-3; (*S*)-**1f**, 84499-73-0; (*S*)-**1f**·L-*N*-acetylleucine, 84499-82-1; (*S*)-**1f**·HCl, 84499-78-5; (±)-**2a**, 84580-07-4; (*S*)-**2a**, 84499-76-3; (*S*)-**2a**·L-*O*,*O*'-dibenzoyltartrate, 84520-44-5; (*R*)-**2a**·HCl, 84499-74-1; (*S*)-**2a** (*N*-5-bromosalicylidene derivative), 84499-81-0; (±)-**2b**, 84499-83-2; (*S*)-**2b**, 84499-75-2; (*S*)-**2b**·(+)-10-camphorsulfonic acid, 84580-08-5; (*S*)-**2b**·HCl, 84499-79-6; (*S*)-**3a**, 51-64-9; (*S*)-**3a**·HCl, 1462-73-3; (*S*)-**3b**, 405-46-9; (*S*)-**3b**·HCl, 16064-30-5; (*R*)-**3c**, 84580-99-4; (*R*)-**3c**·HCl, 84580-09-6; (*R*)-**3c**·L-*N*-acetylleucine, 84620-15-5; (*S*)-**3c**, 84580-04-1; (*S*)-**3c**·HCl, 84580-05-2; (*R*)-**4a**, 52691-87-9; (*S*)-**4a**·HCl, 36913-04-9; (*S*)-**4a**, 17279-39-9; (*S*)-**4b**, 84499-80-9; (*S*)-**4b**·HCl, 16064-30-5; (*R*)-**9a**, 156-34-3; *p*-methylacetophenone, 122-00-9; *p*-chloroacetophenone, 99-91-2; *p*-(trifluoromethyl)-acetophenone, 709-63-7; 3,5-dimethylacetophenone, 5379-16-8; methyllithium, 917-54-4; 3,5-dichlorobenzoic acid, 51-36-5; 3,5-dichloroacetophenone, 14401-72-0; 2-(3,5-dichlorophenyl)-2-propanol, 68575-35-9.

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(42) Reeve, W.; Christoffel, I. *J. Am. Chem. Soc.* **1950**, *72*, 1480-1483.

Molecular Structure of Acetylacetone. A Crystallographic Determination

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Abstract: A drug complex crystallized from acetylacetone (2,4-pentanedione) was found by X-ray crystal structure determination to contain one molecule of acetylacetone per asymmetric unit in the crystal lattice. The acetylacetone does not interact with the other molecules in the crystal but displays a keto-enol configuration stabilized by an intramolecular hydrogen bond. In contrast to electron diffraction studies of acetylacetone and crystal structure studies of other β-diketones, bond distances, including the hydrogen bond, are not symmetric but are indicative of localized single and double bonds throughout the molecule. Past estimates of acetylacetone diketo/keto-enol ratios in the liquid and gas phases may be in error if they assume complete bond length symmetry for the enol form.

The β-diketones have been among the most widely studied chelating compounds because of their strong hydrogen-bonding property and their ability to form coordination complexes with almost every metal in the periodic table. Although scores of such metal chelates have been investigated crystallographically,[2] only limited structural data have been collected on β-diketones themselves. The questions of whether the diketo or enol form predominates for these molecules and whether or not the enol intramolecular hydrogen bond is symmetrical have been examined in the crystal structure determinations of bis(*m*-bromobenzoyl)-methane,[3] bis(*m*-chlorobenzoyl)methane,[4] dibenzoylmethane,[5] and tetraacetylethane.[6] All of these compounds were found to be in the enol configuration in the crystalline state and all except dibenzoylmethane are characterized by equidimensional C-O distances and a symmetric intramolecular hydrogen bond. The latter

Table I. Acetylacetone Intermolecular Contacts Less Than 3.2 Å

O(2)- - -H(C), A[a]	2.56	O(2)- - -H(C), D	2.76
O(2)- - -C, A	3.15	O(2)- - -H(C), D	3.11
O(2)- - -H(N), A	2.80	O(4)- - -H(N), A	2.95
O(4)- - -H(C), D[a]	2.91	O(4)- - -N, A	3.18

[a] A, 9-ethyladenine; D, diphenylhydantoin.

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(2) For a review, see: Mehrotra, R. C.; Bohra, R.; Gaur, D. P. "Metal β-Diketonates and Allied Derivatives"; Academic Press: London, 1978.
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Table II. Acetylacetone Fractional Coordinates

atom	x	y	z	atom	x	y	z
C(1)	0.33316	0.23193	0.21553	H(4)	0.29120	0.12245	0.40162
C(2)	0.29359	0.17827	0.28212	H(3)	0.12853	0.18204	0.24414
O(2)	0.36466	0.14964	0.32240	H(1a)	0.33169	0.19336	0.15168
C(3)	0.17876	0.15790	0.29863	H(1b)[a]	0.2767	0.2758	0.2096
C(4)	0.13991	0.10369	0.35445	H(1c)[a]	0.4285	0.2971	0.2580
O(4)	0.20748	0.06785	0.40078	H(5a)	0.03709	0.05951	0.43582
C(5)	0.01389	0.07521	0.37188	H(5b)[a]	−0.0078	0.1488	0.3918
				H(5c)[a]	−0.0612	−0.0020	0.3066

[a] Calculated positions.

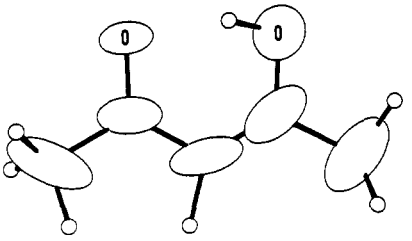

Figure 1. Perspective drawing of acetylacetone. Thermal ellipsoids are drawn at the 40% probability level.

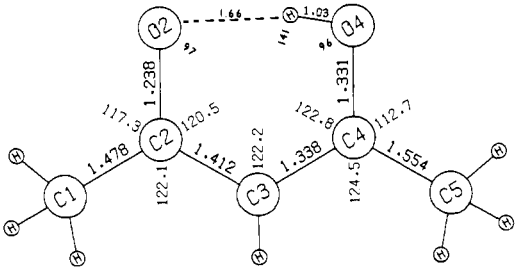

Figure 2. Bond distances and angles for acetylacetone. Errors in the heavy atom distances and angles are 0.01 Å and 0.9°, respectively. The H atom distances range between 0.89 and 1.15 Å, with errors of 0.09 Å; angles range between 96 and 132°, with errors of 5°. The O(2)–O(4) distance is 2.535 Å.

compound deviates slightly from this symmetry, but differences between related C–O, O–H, and C–C bond lengths are only barely outside experimental error.

The prototype β-diketone, acetylacetone (2,4-pentanedione), is a liquid at room temperature (mp −23 °C) and has not been until now subjected to crystallographic examination. An NMR study[7] concluded that liquid acetylacetone at 25 °C is approximately 80% enol and 20% ketone, while two electron diffraction experiments have suggested that in the gas phase the ratios are 97% enol at 27 °C[8] and 67% enol at 105 °C.[9] Although they differ on bond-length estimates, both electron diffraction studies conclude that the enol form of acetylacetone, like the substituted β-diketones, possesses aromatic character and a symmetric intramolecular hydrogen bond.

As part of a research project on antiepileptic drugs we have recently crystallized a complex of diphenylhydantoin and 9-ethyladenine, using acetylacetone as solvent.[10] Elucidation of the three-dimensional structure of the crystals revealed that one molecule of acetylacetone per asymmetric unit is present in the crystal lattice. The acetylacetone does not interact in any way with the other molecules in the crystal; thus we are able to observe its molecular structure in a rather isolated environment. This environment is illustrated quantitatively in Table I, which lists all contacts less than 3.2 Å between acetylacetone atoms and those of diphenylhydantoin and ethyladenine. No contacts shorter than van der Waal's distances are observed. We now report that acetylacetone in the solid state is in the enol configuration with bond lengths that indicate nonequivalence of related atoms (no aromatic character) and a definitively asymmetric intramolecular hydrogen bond.

The complex of diphenylhydantoin and 9-ethyladenine with acetylacetone included in the lattice crystallized in space group $P\bar{1}$ with cell constants a = 12.256 (2) Å, b = 13.691 (2) Å, c = 14.835 (2) Å, α = 112.04 (1)°; β = 98.72 (1)°, γ = 110.99 (1)°, Z = 2. The structure was solved by direct methods and refined by least-squares methods to a final discrepancy index $R = (\sum||F_o| - |F_c||)/\sum F_o = 0.054$. Positions of most of the acetylacetone hydrogen atoms including H(4) were located in difference electron-density maps. The exceptions were two hydrogens of each of the methyl groups whose positions were calculated. Hydrogen atom coordinates were refined in the final least-squares cycle, but their thermal parameters were kept equal to those of the heavy atoms to which they are bonded. Final acetylacetone fractional coordinates are listed in Table II.

Table III. Selected Bond Distances (Å) in Acetylacetone and Related Compounds

bond	BrBM[a]	ClBM[b]	BM[c]	TAE[d]	AcAc[e]	AcAc[f]	AcAc[g]
C–O	1.306	1.299	1.292	1.295	1.315	1.287	1.238
		1.318	1.317	1.310			1.331
C–C	1.393	1.397	1.385	1.395	1.416	1.405	1.338
		1.402	1.413	1.411			1.412
O–H	1.23		1.18		1.19	1.26	1.03
			1.34				1.66
O–O	2.464	2.475	2.468	2.424	2.38	2.52	2.535

[a] Bis(*m*-bromobenzoyl)methane.[3] Space-group symmetry requires equivalence of the two C–O bonds and of the two C–C bonds in this molecule. [b] Bis(*m*-chlorobenzoyl)methane.[4] [c] Dibenzoylmethane.[5] [d] Tetraacetylethane.[6] [e] Acetylacetone, electron diffraction.[8] [f] Acetylacetone, electron diffraction.[9] [g] Acetylacetone, X-ray crystallography (this work).

A perspective drawing of the molecule is shown in Figure 1. The seven non-hydrogen atoms define a plane from which the maximum deviation is 0.038 Å and the average deviation is 0.018 Å. The hydrogen atom attached to O(4) lies 0.36 Å out of the plane. Bond distances and angles are listed in Figure 2. These values present a clear indication that acetylacetone, in the solid-state isolated environment at least, does not exhibit aromatic ring characteristics with a symmetric intramolecular hydrogen bond, but rather adopts a discrete keto–enol configuration with an O–H···O hydrogen bond that is asymmetric and nonlinear. Differences between the C–C distances (0.074 Å), C–O distances (0.093 Å), and O–H distances (0.63 Å) are far greater than the standard deviations of the bond lengths and clearly distinguish between single and double bonds joining the respective atoms.

Comparisons of bond lengths found for acetylacetone in the solid state, those postulated for the molecule from the electron diffraction radial distribution curves, and those found in substituted β-diketones in other crystallographic investigations are shown in Table III. These comparisons suggest that the apparent acetylacetone keto–enol ratios in the liquid and gas phase may be in error if they include an assumption of symmetry of bond lengths for the enol form. They also suggest that either a trend toward aromatic character in the intramolecular hydrogen-bond ring system of the β-diketones increases with increasing substitution

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or alternatively the symmetry observed in some β-diketone structures is the result of statistical disorder.

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Registry No. Acetylacetone, 123-54-6.

Supplementary Material Available: Table of anisotropic thermal parameters (1 page). Ordering information is given on any current masthead page.

A New Approach to Asymmetric Synthesis of Polycycles on the Basis of *o*-Quinodimethane Generation

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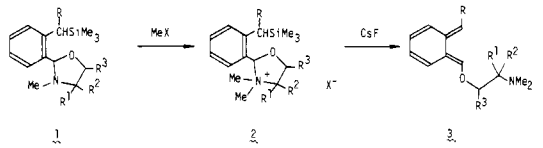
Abstract: The fluoride anion induced 1,4 elimination of 2-[*o*-[1-(trimethylsilyl)alkyl]phenyl]-3,3-dimethyloxazolidinium salts generates (*E*,*E*)-α-alkyl-α′-[2-(dimethylamino)alkyl]-*o*-quinodimethane intermediates, which are trapped stereoselectively with dienophiles to give polycycles. Intramolecular cyclization of 2-[*o*-[1-(trimethylsilyl)hept-6-enyl]phenyl]-3,3-dimethyl-4-(*R*)-methyl-5(*R*)-phenyloxazolidinium triflate at 0 °C produces a 3:1 diastereoisomeric mixture of 6-[2(*R*)-(dimethylamino)-1(*R*)-phenylpropoxyl]-*trans*-octahydrophenanthrene, which is converted by hydrogenolysis on Pd/C to *trans*-octahydrophenanthrene with $[\alpha]_D$ +46.6° (50% ee). Similarly, intramolecular cyclization of 2-[*o*-[1-(trimethylsilyl)hept-6-enyl]phenyl]-3,3-dimethyl-4(*S*)-methoxymethyl-5(*S*)-phenyloxazolidinium triflate produces, after hydrogenolysis on Pd/C, *trans*-octahydrophenanthrene with $[\alpha]_D$ −51.1° (55% ee). The enantioselection in the cycloaddition with *o*-quinodimethane intermediate may be accounted for on the basis of π-stacking interaction in the Diels–Alder transition state.

A variety of methodologies[1] have so far been developed to generate in situ *o*-quinodimethane and applied to synthesize polycycles including steroidal structures by their cycloaddition reactions. However, a generation of *o*-quinodimethanes with electron-donating heteroatom substituents[2] at the α position, which may be expected to exert higher regioselectivity and higher reactivity in Diels–Alder cycloaddition, has been scarcely known. In the preceding papers[3], we reported a mild and efficient generation of *o*-quinodimethanes by the fluoride anion induced 1,4-elimination of *o*-[1-(trimethylsilyl)alkyl]benzyltrimethylammonium halides. The methodology for the generation of *o*-quinodimethanes has been successfully extended to 2-[*o*-[1-(trimethylsilyl)alkyl]phenyl]-3,3-dimethyloxazolidinium salts (**2**),

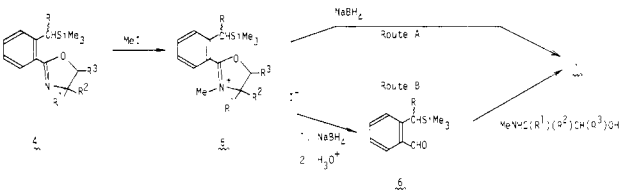


a, R = H; R^1 = R^2 = Me; R^3 = H
b, R = R^1 = R^2 = H; R^3 = Me
c, R = $-(CH_2)_4CH{=}CH_2$; R^1 = R^2 = H; R^3 = Me
d, R = $-(CH_2)_4CH{=}CH_2$; R^1 = R^2 = H; R^3 = (*R*)-Ph
e, R = $-(CH_2)_4CH{=}CH_2$; R^1 = (*S*)-Me; R^2 = H; R^3 = (*R*)-Ph
f, R = $-(CH_2)_4CH{=}CH_2$; R^1 = (*R*)-Me; R^2 = H; R^3 = (*R*)-Ph
g, R = $-(CH_2)_4CH{=}CH_2$; R^1 = (*S*)-CH_2OMe; R^2 = H; R^3 = (*S*)-Ph
h, R = $-(CH_2)_4CH{=}CH_2$; R^1 = (*R*)-Ph; R^2 = R^3 = H
i, R = $-(CH_2)_4CH{=}CH_2$; R^1 = (*S*)-CH_2Ph; R^2 = R^3 = H
j, R = H; R^1 = (*S*)-Me; R^2 = H; R^3 = (*R*)-Ph

leading to the formation of (*E*,*E*)-α-alkyl-α′-[2-(dimethylamino)alkoxy]-*o*-quinodimethane intermediates (**3**).

In this paper, we describe a synthesis of polycycles by the inter- and intramolecular cycloadditions of **3**. Of special interest is that

Scheme I



a, R = H; R^1 = R^2 = Me; R^3 = H
b, R = R^1 = R^2 = H; R^3 = Me
c, R = $-(CH_2)_4CH{=}CH_2$; R^1 = R^2 = Me; R^3 = H
d, R = $-(CH_2)_4CH{=}CH_2$; R^1 = R^2 = H; R^3 = Me

some 2-[*o*-[1-(trimethylsilyl)alkyl]phenyl]-3,3-dimethyloxazolidinium salts (**2**) with a phenyl substituent at the C-5 on the oxazolidinium ring were cyclized enantioselectively via the corresponding *o*-quinodimethanes to afford polycycles. This reaction, which is the first use of *o*-quinodimethane in asymmetric synthesis, may present a new approach to asymmetric synthesis of polycycles. The 2-(dimethylamino)alkoxy substituent of **3**, which conferred high reactivity in reactions with dienophiles and brought about the asymmetric induction, was easily removed after the reactions.

Results and Discussions

Preparation of the requisite oxazolidines **1**[4] for the generation of *o*-quinodimethanes **3** could be carried out via quaternization and reduction of the corresponding 2-[*o*-[(trimethylsilyl)-methyl]phenyl]oxazolines (**4**) and 2-[*o*-[1-(trimethylsilyl)alkyl]phenyl]oxazolines (**4**, R = alkyl), which were accessible from alkylations at the silicon-stabilized carbanion of **4** R = H[4a] (route A in Scheme I). Thus, 2-[*o*-[(trimethylsilyl)methyl]phenyl]-3,4,4-trimethyloxazolidine (**1a**) and 2-[*o*-[1-(trimethylsilyl)-hept-6-enyl]phenyl]-3,5-dimethyloxazolidine (**1c**) were prepared

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