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CRYSTAL STRUCTURE OF ENOL BENZOATE (1) OBTAINED FROM CONJUGATE ADDITION OF PHENYLMAGNESIUM BROMIDE TO BENZALACETOMESITYLENE[+] (3): (Z)-α-(2,2-DIPHENYLETHYLIDENE)-2,4,6-TRIMETHYLBENZENEMETHANOL BENZOATE (1)

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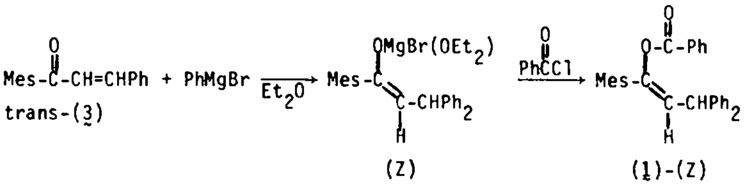
Abstract-The title compound (1) is shown to have a (Z) configuration confirming a previous assignment based on ^{1}H nmr vinyl shielding constants. Bond distances, bond angles, and selected torsion angles are reported. The benzoyl ester grouping is s-trans in accord with the usual conformation for alkyl benzoates in solution. A torsion angle of 6.6° (average) involving the ester grouping for C_8-O_2-C_7-O_1 (or C_8-O_2-C_7-C_1) was found. The cyclic mechanism of Lutz and Reveley involving reaction of an s-cis conformation of the α,β-unsaturated ketone with the Grignard reagent explains the (Z)-stereochemistry observed.

In 1935 Kohler, Tishler, and Potter[1] made the remarkable discovery that the magnesium enolates of 2,2-diphenylethyl 2,4,6-trimethylphenyl ketone (2)[++] retained their stereochemical identities since they could be converted to isomeric enol benzoates which differed in physical properties. Nesmeyanov, et al.[2] confirmed this finding and additionally characterized the isomeric magnesium enolates by elemental analysis, and differences in solubility, oxidative, and hydrolytic behavior. Neither group of workers, however, was able to assign stereochemistry to the isomers. On the basis of ^{1}H nmr vinyl substituent constants a Z configuration was assigned[3] to the enol benzoate and consequently also to the corresponding magnesium enolate obtained via conjugate addition of phenylmagnesium bromide to benzalacetomesitylene (3) (eq. 1). The E configuration was assigned to the other isomer obtained from reaction of 2,2-diphenylethyl 2,4,6-trimethylphenyl ketone (2) with ethylmagnesium bromide (eq.2)[4]. Since

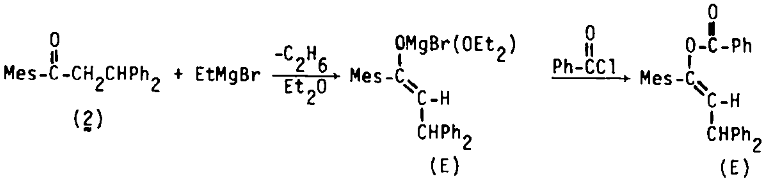


(1)

[+] Chem. Abst. index name: (E)-3-phenyl-1-(2,4,6-trimethylphenyl)-2-propen-1-one

[‡] Syracuse University; research carried out at Laboratory for the Structure of Matter, Naval Research Laboratory, Washington, DC as participant in 1983 Navy-ASEE Summer Faculty Program.

[++] Chem. Abst. index name: 3,3-diphenyl-1-(2,4,6-trimethylphenyl)-1-propanone



(2)

stereochemical assignments based on nmr data have occasionally been shown to be in error, it was important to determine the stereochemistry by an independent method in order to attempt to explain this stereospecificity. In addition, since we are unaware of any other x-ray crystal structure study of an enol ester, this could be the first such study. Well-formed crystals of the enol benzoate from the conjugate-addition reaction were available and an x-ray crystallographic study was undertaken.

EXPERIMENTAL

The enol benzoate, $C_{31}H_{28}O_2$,(MW = 432.56) was prepared as previously described[3] by conjugate addition of phenylmagnesium bromide to benzalacetomesitylene followed by reaction with benzoyl chloride. Single crystals, mp 162-163°C, were obtained by slow evaporation of an acetone solution. A crystal, having the approximate dimensions 0.25 x 0.35 x 0.40 mm was selected and mounted on a Nicolet P3F diffractometer equipped with graphite monochromated CuKα X-radiation (λ=1.54178 A). The dimensions of the triclinic unit-cell, a = 9.058(1), b = 11.028(1), c = 12.713(2) A, α = 104.60 (1), β = 90.92(1), γ = 93.55(1)° , were obtained from the least-squares refinement of observed 2θ values for 22 carefully centered reflections (22°C). The unit-cell volume of 1225.9 A^3, which contains two molecules, gives a calculated density of 1.171 Mg m^{-3}. A rapid preliminary scan of diffraction intensities revealed no systematic absences as required by the triclinic crystal class. The centrosymmetric space group $P\bar{1}$ was assumed which was subsequently confirmed by the successful structure solution and refinement. A diffraction data set of 4,463 unique reflections of which 3,801 were considered to be observed ($F_o>3\sigma(F_o)$) was collected using the θ/2θ variable scanning mode (2.0<2θ<129°) in which the scanning speed (3.5 to 30° min^{-1}) was dependent upon the magnitude of the diffraction intensity. Three standard reflections, well distributed in reciprocal space, were measured every 60 reflections and showed no systematic changes during the data collection. The measured intensities, after correction for background and normalization to a scanning speed of 1° 2θ min^{-1}, were reduced to structure factors, F_o, in the usual manner. Absorption corrections were deemed unnecessary because of the relatively low linear absorption coefficient of the compound (μ = 5.24 cm^{-1} (CuKα)).

The structure was solved by application of the direct-methods program SOLV of the SHELXTL, Version 3 set of programs[5] furnished for the P3F diffractometer. Twenty-nine of the thirty-three heavy atoms were located on the initial E map. A difference map calculated after isotropic least-squares refinement of these atoms revealed the remaining four heavy atoms as well as nineteen hydrogen atom positions. All remaining hydrogen atoms were located from a difference map calculated after several cycles of anisotropic least-squares refinement of all non-hydrogen atoms with coordinate refinement of the previously located hydrogen atoms. The final refinement consisted of anisotropic blocked-cascade least-squares refinement (based on F) of all non-hydrogen atoms and coordinate refinement of all hydrogen atoms whose isotropic thermal parameters were fixed at values reflecting those obtained from previous isotropic refinement cycles (382 parameters). Convergence was reached at R = 0.079 and R_w = 0.049 with w = $1/o^2(F_o)$. The highest peak in the final difference Fourier map calculated at this point was 0.21e A^{-3}. The final positional parameters and equivalent isotropic temperature factors for non-hydrogen atoms are given in Table 1.+

Table 1. Non-hydrogen atom coordinates (X 10^4) and equivalent isotropic thermal parameters (A^2 X 10^3). The estimated standard deviation in the least significant digit is given in parentheses.

atom	x	y	z	$U_{eq.}$
C(1)	2563(2)	3664(1)	9746(1)	45(1)*
C(2)	2266(2)	4868(2)	10317(1)	65(1)*
C(3)	3133(2)	5486(2)	11216(2)	77(1)*
C(4)	4277(2)	4904(2)	11570(1)	75(1)*
C(5)	4552(2)	3706(2)	11021(2)	87(1)*
C(6)	3705(2)	3086(2)	10109(2)	71(1)*
C(7)	1648(2)	3053(1)	8763(1)	44(1)*
C(8)	1538(1)	1419(1)	7144(1)	42(1)*
C(9)	793(2)	321(1)	7033(1)	46(1)*
C(10)	441(2)	-296(1)	7936(1)	46(1)*
C(11)	911(1)	-1645(1)	7691(1)	43(1)*
C(12)	165(2)	-2557(1)	8099(1)	54(1)*
C(13)	648(2)	-3760(1)	7905(2)	62(1)*
C(14)	1868(2)	-4079(1)	7297(1)	62(1)*
C(15)	2617(2)	-3193(2)	6889(1)	66(1)*
C(16)	2151(2)	-1979(1)	7082(1)	54(1)*
C(17)	-1189(2)	-174(1)	8180(1)	49(1)*
C(18)	-1621(2)	578(2)	9152(1)	71(1)*
C(19)	-3118(3)	703(3)	9345(2)	101(1)*
C(20)	-4189(3)	70(2)	8592(2)	94(1)*
C(21)	-3756(2)	-675(2)	7623(2)	80(1)*
C(22)	-2279(2)	-786(2)	7419(1)	62(1)*
C(23)	1830(1)	2098(1)	6295(1)	44(1)*
C(24)	3300(2)	2324(1)	6015(1)	50(1)*
C(25)	3578(2)	3039(1)	5279(1)	57(1)*
C(26)	2450(2)	3525(1)	4792(1)	56(1)*
C(27)	1008(2)	3252(1)	5045(1)	53(1)*
C(28)	664(2)	2550(1)	5782(1)	48(1)*
C(29)	-931(2)	2328(2)	6037(2)	64(1)*
C(30)	4566(2)	1767(2)	6478(2)	73(1)*
C(31)	2798(2)	4300(2)	3998(2)	82(1)*
O(1)	521(1)	3425(1)	8492(1)	68(1)*
O(2)	2234(1)	2002(1)	8169(1)	47(1)*

*Equivalent isotropic U defined as one third of the trace of the orthogonalised U_{ij} tensor.

+Lists of structure factors, anisotropic temperature factors for non-hydrogen atoms and hydrogen atom coordinates and isotopic temperature factors have been deposited with the Cambridge Crystallographic Data Centre and are available on request from the Director of the Cambridge Crystallographic Data Centre, University Chemical Laboratory, Lensfield Road, Cambridge CB2 1EW. Any request should be accompanied by the full literature citation for this communication.

RESULTS AND DISCUSSION

Structure. The configuration of the enol benzoate obtained from the conjugate addition reaction of phenylmagnesium bromide and benzalacetomesitylene is shown in the stereoscopic drawing of figure 1 and is Z. The previous assignment reported from a ^1H nmr study[3] is thus confirmed.

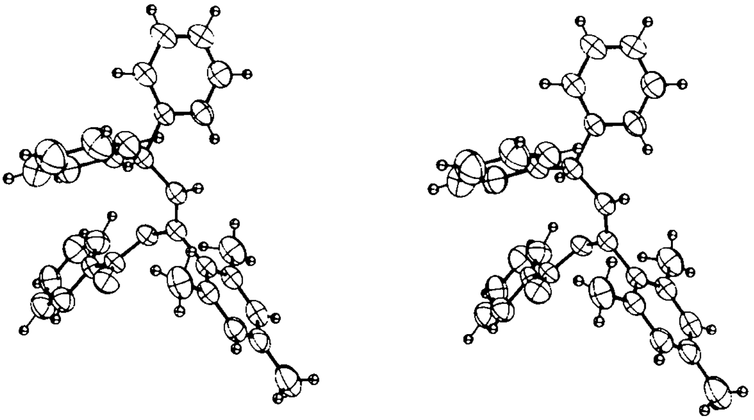


Figure 1. A stereoscopic drawing of (Z)-(1-mesityl-2-phenylmethyl)vinyl benzoate. Non-hydrogen atom thermal ellipsoids are drawn at 50% probability. Hydrogen atoms are represented by small spheres of arbitrary size.

The intermolecular bond distances and angles, along with their estimated standard deviations, are in Figs. 2 and 3 from which the atom numbering scheme can also be deduced. All bond distances and angles are seen to be completely normal, agreeing very well with expected and accepted values.

The sterically crowded nature of the molecule is evident in the stereoscopic view (Fig. 1). The conformation of the molecule is that which minimizes repulsive interactions between phenyl groups as well as the benzoyl phenyl group. These intramolecular interactions are dominant in determining its molecular conformation as no intermolecular contacts were found which were shorter than normal van der Waals distances. The benzoyl ester grouping is s-trans which is the usual conformation[6] for alkyl benzoates. In simple alkyl benzoates (methyl and ethyl)[6] in solution as well as in the solid state[7] (diethyl terephthalate)[7] the carbonyl groups are in the same plane as the benzene ring. This low energy conformation results because of optimum overlap between phenyl and carbonyl pi orbitals. In esters with larger alkyl groups (t-butyl benzoate)[6] in solution, a deviation as high as 37° has been determined for this "angle of twist". In the present ester this angle (O_1-C_7-C_1-C_2) is 11.64° which reflects the effect of other large grouping in the molecule in causing some deviation from coplanarity.

Considering the torsion angle involving deviation of the alkyl group of esters from planarity with the carbonyl group, values for alkyl esters in solution generally[6] range from 25 to 30° (31 to 45° for alkyl acetates). For the crystalline ester (diethyl terephthalate), the C-O-C=O atoms are reported[7] to be in the same plane. Possible reasons for this conformation and related torsion angles have been previously discussed[6]. The torsion angle for the ester grouping in the enol benzoate reported here (C_8-O_2-C_7-O_1, or C_8-O_2-C_7-C_1) was found to be 6.6° (average).

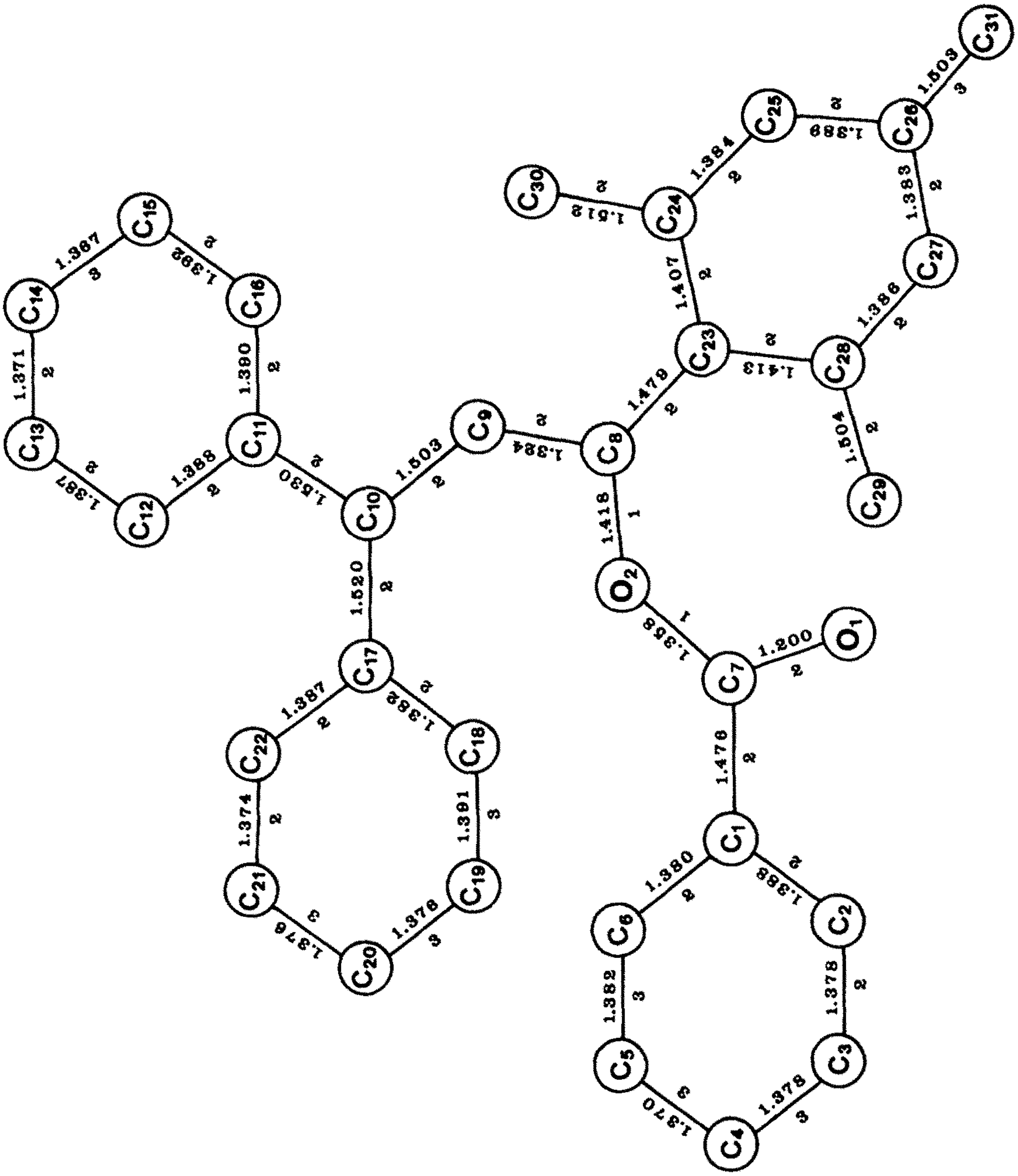


Figure 2. Intramolecular bond distances (A) with the esd of the least significant digit given below each value.

The torsion angle involving restriction of the C_8-O_2 bond between ortho-methyl groups of mesityl is 58.6° which reflects somewhat greater flexibility in this bond rotation as compared with a reported[8] mesityl to O=C-Bu^t torsion angle of 89.9°. The pertinent torsion angles are summarized in Table 2.

Mechanism

Formation of the Z configuration of the molecule is explicable on the basis of the cyclic mechanism (eq.3) originally proposed by Lutz and Reveley[9] and favored by Kharasch and Reinmuth[10].

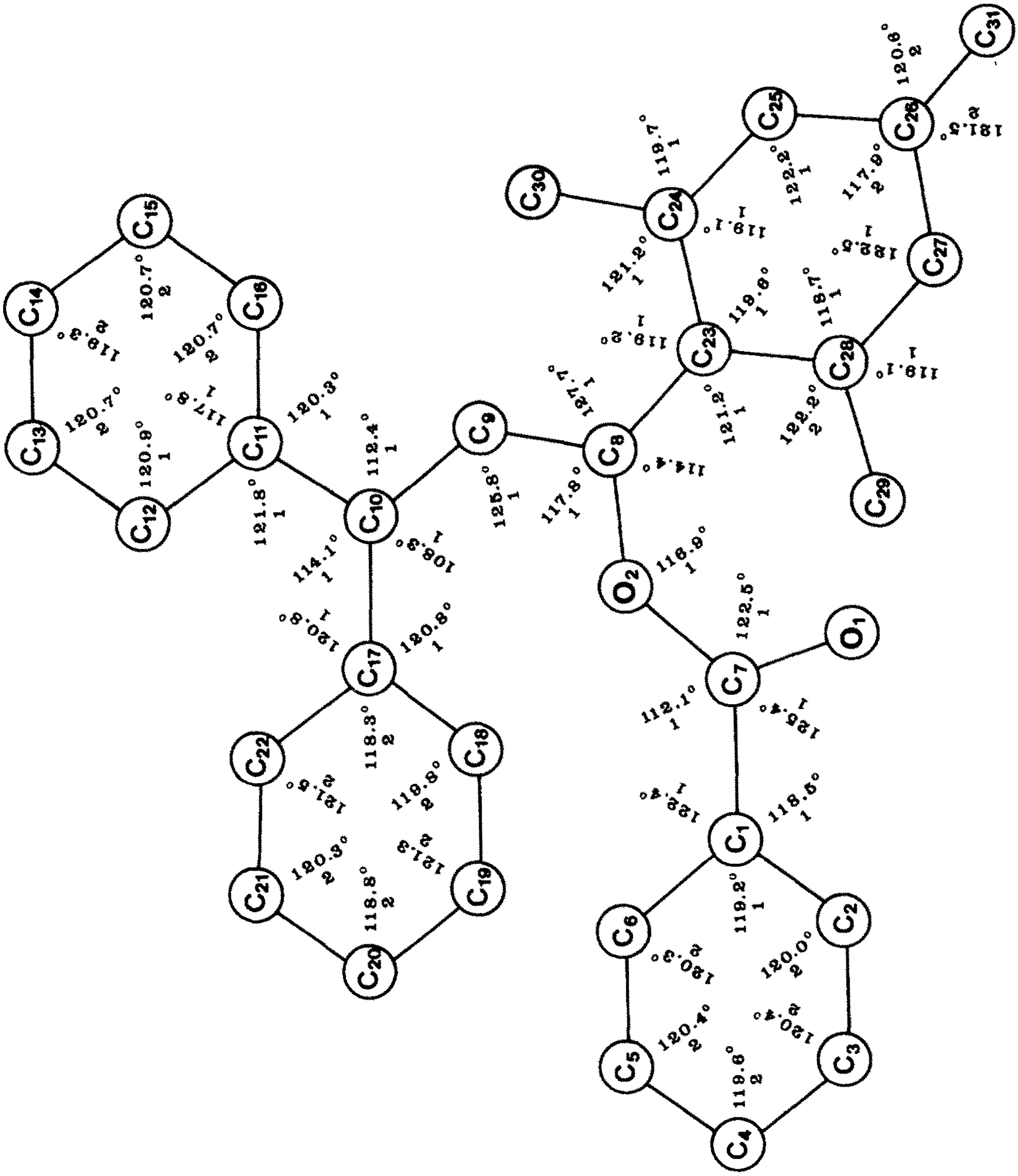


Figure 3. Bond angles (°) with the esd of the least significant digit given below each value.

It can be noted that an s-cis conformation of benzalacetomesitylene (3) is required for the 6-membered ring. However, Alexander and Coraor[11], reported that in reactions of Grignard reagents with 2-cyclohexen-1-one (4) the relative amounts of conjugate addition products were comparable to those with open chain analogs. They pointed out that a six-membered cyclic transition state is geometrically not possible with 2-cyclohexen-1-one (4) in which an s-trans arrangement is fixed by the ring and concluded that the cyclic mechanism was not applicable to all such conjugate addition reactions. House and Thompson[12] reported that $\Delta^{8,9}$-octal-1-one (5) which has a cisoid conjugate system (favorable for the cyclic mechanism) reacted with phenylmagnesium bromide to yield only 43% of the conjugate addition product whereas an acyclic analog, trans-3-penten-2-one (6) yielded 50% under

Table 2. Torsion Angles (°) for (Z)-α-(2,2,-Diphenylethylidene)-2,4,6-trimethylbenzenemethanol Benzoate (1)

C9	-	C8	-	C23	-	C24	-117.03	(14)
C24	-	C23	-	C8	-	O2	58.62	(14)
O2	-	C7	-	C1	-	C2	167.64	(11)
O1	-	C7	-	C1	-	C2	-11.64	(19)
C8	-	O2	-	C7	-	O1	6.31	(16)
C8	-	O2	-	C7	-	C1	-172.99	(09)
C7	-	O2	-	C8	-	C9	-110.00	(12)
C12	-	C11	-	C10	-	C9	-150.19	(12)
C18	-	C17	-	C10	-	C9	-111.85	(14)

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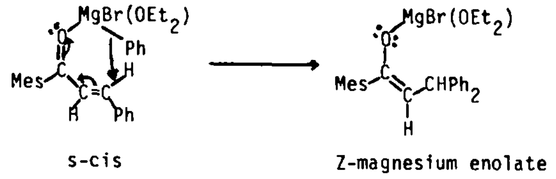
[a] ESD in parentheses refers to the least significant digit in the preceeding quantity. Looking from 2 to 3 the CW rotation of bond 34 with ref. to 21 is given.



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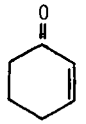

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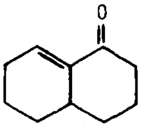

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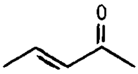
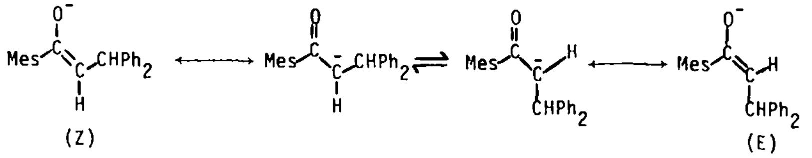


(6)

comparable conditions. They proposed a mechanism resembling that for the Michael addition with transfer of a phenyl group to the 4-position from the less hindered side of the double bond in order to explain the stereochemistry observed with their compound. The stereochemical aspect of the House-Thompson (H-T) mechanism does not apply to the present case with respect to the reaction from the least-hindered side of the C=C bond. Because of the symmetry of the molecule, both sides are stereochemically equivalent. Also the H-T mechanism does not explain the Z-configuration which is observed. In addition an anionic species proposed in the H-T scheme might equilibrate between E and Z enolates (eq. 4). Under certain



(4)

conditions, Nesmeyanov, et al.[2] showed that an equilibrium mixture of E- and Z-enolates was obtained. No E-enol benzoate was found in conjugate addition from the reaction in which the Z-enol benzoate was formed[1,2]. Although conjugated ketones have also been reported that react as expected[13] according to the House-Thompson mechanism, others have been reported that do not[14] or where the mechanism is not applicable.[15]

In summary, although the Lutz-Reveley mechanism predicts a Z configuration as observed in the present case for the reaction of Grignard reagents with α,β-unsaturated ketones, it is not a general mechanism for conjugate addition since it is not applicable to 2-cyclohexen-1-one and related "fixed s-trans" structures nor to "1,6-addition" and related reactions. Either a dual mechanism including the Lutz-Reveley cyclic mechanism or some other general mechanism not yet proposed may be applicable. Since neither the conjugate addition nor the enolization reactions of Grignard reactions have yet been experimentally tested for possible single electron transfer[16] involvement, it is recognized that the postulated mechanisms may have their SET counterparts.

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