Fragmentation of a Pyrazolenine Epoxide to an Unstable Oxabicyclobutane

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4,5-Epoxy-3,5-diphenyl-3-methyl-1-pyrazolenine (**1b**) pyrolyzes to a 2.8:1 mixture of (*E*)-dypnone **6a** and (*Z*)-2,3-diphenyl-2-butenal (**7a**). The latter product is most likely formed from an oxabicyclobutane intermediate. Photolysis of the epoxypyrazolenine (**1b**) does not extrude N_2, but rearranges to a mixture of two azine aldehydes **10a,b.**

The 2-oxabicyclobutane molecule is a close relative of several well-known isomeric systems which include cyclopropanones, epoxyallenes, and oxetenes. No one has yet prepared any member of the oxabicyclobutane family. The best evidence for oxabicyclobutanes as an intermediate is from kinetic studies of the peracid oxidation of cyclopropenes.[3,4] These studies were primarily aimed, however, at mechanistic questions. In this paper, we present our attempts to prepare oxabicyclobutanes by extrusion of nitrogen from bicyclic azo epoxides. This route is successful for the preparation of certain substituted bicyclobutanes, for example,[5]

Results

In an earlier report,[6] we studied the reactions of pyrazolenine epoxide **1a.** Although thermal extrusion of nitrogen gave mesityl oxide, sensitized and direct irradiation gave only

1a, $R_1 = R_2 = R_3 = Me$

azine aldehydes. Instead of C–N bond cleavage, irradiation initiated a vinylagous epoxide–carbonyl rearrangement that did not lead to loss of nitrogen.

In an attempt to eliminate the photolytic rearrangement, we have studied the chemistry of epoxide **1b.** The phenyl substituents in **1b** might stabilize the transition state for C–N bond cleavage and successfully lead to an oxabicyclobutane.

The synthesis of **1b** is shown below. Treatment of known[7] pyrazolenine **2** with acetyl hypobromite gave a 5:1 mixture of two bromo acetates, **3a** and **3b.** On treatment with methoxide, the mixture gave a small yield of the desired epoxide **1b** (from **3b**).

The major product from the methoxide treatment of **3a,b** was bromo alcohol **4a.** Acetylation of the alcohol **4a** regenerated acetate **3a.** The stereochemistry of the **3a–4a** pair is unknown, although the *lack* of epoxide formation from **3a** suggests that **3a** is a *cis*-bromoacetate.[8]

The stereochemistry of epoxide **1b** at position C-3 can be tentatively assigned from the ^{13}C NMR spectrum. The methyl carbon on C-3 resonates at δ 17.73 and is a *clean* quartet (J = 130 Hz). The quartet is due to geminal coupling with the methyl hydrogens. The absence of further splitting (≤1 Hz)

5

suggests that the dihedral angle between the C-3 methyl and C-4 hydrogen is near 90°. Vicinal coupling constants between ^{13}C and H follow the familiar Karplus relationship where small dihedral angles produce larger coupling constants than angles near 90°.[9]

In order to show that a stereochemical dependence of vicinal coupling constants exists, we have obtained the complete ^{13}C NMR spectrum of epoxide **1a.** This epoxide has methyl C's

1a

at position 3 that are cis and trans to the epoxide H. Dreiding models show an 85° dihedral angle between the *trans*-methyl C and the epoxide H. The angle between the *cis*-methyl C and the epoxide H is only ~25°. If the sterochemical assignment of structure **5** is correct, one of the methyl carbon nuclei on C_3 in compound **1a** will show no coupling to the epoxide H, while

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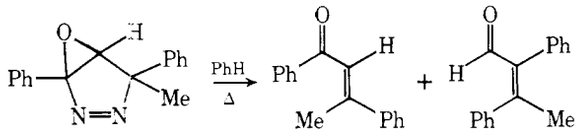
the other methyl carbon will show a finite coupling to the epoxide H.

The ^{13}C NMR of epoxide **1a** shows a remarkable set of coupling relationships. One methyl C at δ 13.4 is a clean quartet (J = 129 Hz) due to geminal ^{13}C–H coupling. Another methyl C at δ 19.1 is a quartet of quartets (J = 4, 129 Hz). The third methyl C at δ 22.1 is a doublet of quartets of quartets (J = 2, 5, 129 Hz). The latter two C's are the geminal methyl C's. Both show large geminal coupling with their respective H's (q, J = 129 Hz). Both also show mutual coupling with each other's three protons (q, J = 4–5 Hz), but, significantly, only the C at δ 22.1 also shows a finite coupling to the epoxide H (d, J = 2 Hz). This shows that the two geminal methyl C's do couple differently to the epoxide hydrogen. We don't have experimental proof which ^{13}C-methyl has no observable coupling with the epoxide hydrogen. Theoretically, however, it is the *trans*-methyl carbon in both structures **5** and **1a** which fails to show an observable coupling to the epoxide hydrogen.

The epoxide methyl ^{13}C at δ 13.4 also doesn't couple with the epoxide H. This result is not surprising, since vicinal coupling constants between two epoxide hydrogen nuclei are smaller (~2–4 Hz)[10] than might be anticipated.

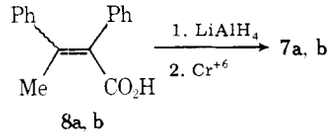
The pyrolysis of epoxide **1b** gave a 90% conversion to two major products, **6a** and **7a,** in a ratio of ~2.8:1. Both products



1b **6a** **7a**

were identified by comparison with authentic samples. Furthermore, a control experiment showed that (*Z*)-dypnone **6b** and (*E*)-2,3-diphenyl-2-butenal **7b** were not formed but were stable to the reaction conditions.

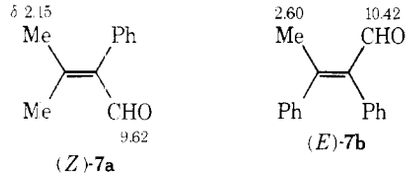
The two geometric isomers **7a,b** have not been previously distinguished. One of the two isomers had been prepared before by both Breslow[11] and Padwa.[12] We have prepared both aldehyde isomers **7a,b** from acids **8a,b.**[13] There is a large



8a, b

amount of indirect NMR chemical-shift data which might be used to distinguish isomers **7a,b.** We feel, however, that the best evidence for distinguishing **7a** from **7b** is the fact that **7b** isomerizes to **7a** in acidic methanol. Aldehyde **7a** is therefore probably the *Z* isomer in accord with the well-known thermodynamic stabilities of the two isomers of stilbene[14a] and α,α'-dimethylstilbene.[14b]

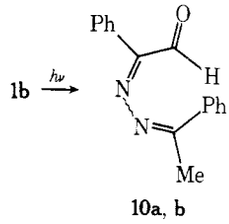
Additional evidence for assigning stereochemistry to **7a,b** is that the chemical shifts for the aldehyde and methyl protons



(*Z*)-**7a** (*E*)-**7b**

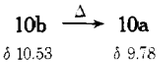
are higher field in **7a.** Such shifts are found in stilbene derivatives when the phenyl groups are cis to vicinal substituents.[15a] Furthermore, the methyl signal of (*Z*)-2-butenal is further downfield than in (*E*)-2-butenal.[15b]

Epoxide **1b** was irradiated through Pyrex in both PhH and CH_3CN solvents. Two products, **10a,b,** were formed at both short and long conversions. The yield of the two products was ~90%. The two aldehydes show ^1H NMR singlets at δ 9.78 and



10a, b

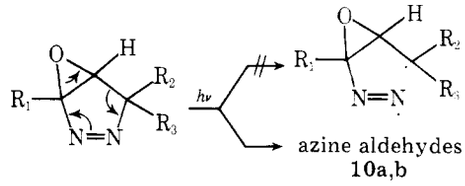
10.53. Heating of the product mixture at 85 °C caused conversion of **10b** into **10a.** This evidence, plus other spectral evidence (see Experimental Section), and a $C_{16}H_{14}ON_2$ empirical formula show that the irradiation caused a vinylogous epoxide–carbonyl rearrangement to produce two isomeric



azine aldehydes **10a,b.** Further work to characterize these photoproducts was not done, since the result completely parallels the result found for the irradiation of epoxide **1a.**[6]

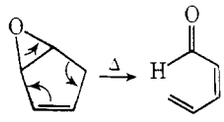
Discussion

Our hope was that the phenyl substituents of epoxide **1b** might stabilize the transition state for C–N bond cleavage and thereby reduce the photochemical epoxide rearrangement. The long-wavelength UV (λ_{max} 365), however, suggests that the π^* system of the azo group overlaps substantially with the strained epoxide σ bond. The pyrazolenine **2,** where such π-type conjugation is maximum, has λ_{max} 366 nm. As a result of the extensive conjugation of the epoxide group with the azo π^* system, the n,π^* excitation energy initiates a vinylogous epoxide–carbonyl rearrangement instead of C–N bond cleavage.



azine aldehydes **10a,b**

This rearrangement reaction has been observed previously with epoxide **1a.**[6] Another precedent is the known conversion of cyclopentadiene monoepoxide to pentadienal.[16] This re-

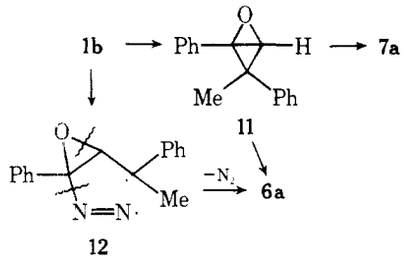


action, however, occurs in the ground-state manifold. In the ground state, epoxides **1a,b** do not undergo the vinylogous epoxide–carbonyl rearrangement. Rather, the weak C–N bonds fragment with the extrusion of N_2.

These results fit into a coherent scheme. The kinetically weakest bonds (most reactive) in the excited states of epoxides **1a,b** are not the C–N bonds, but rather the strained, π^*-conjugated σ bonds of the epoxide moiety. In the ground electronic state, the C–N bonds are the weakest bonds which do fragment with the extrusion of N_2. When the C–N bonds are replaced with the stronger C–C bonds in cyclopentadiene monoepoxide, then the weakest, most reactive bonds are once again the strained epoxide σ bonds.

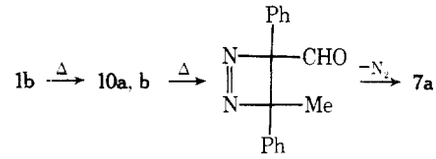
The most significant result of this work was the finding that aldehyde **7a** was a product in the pyrolysis of epoxide **1b.** No aldehydes were found in the previous study with epoxide **1a.**[6]

There are several possible routes for the formation of aldehyde **7a.** The only likely one is via oxabicyclobutane **11.** Such a mandatory intervention of an oxabicyclobutane is unprecedented.[3,4] Dypnone **6a** can also be formed from oxa-

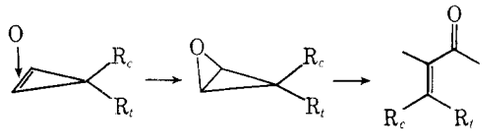


bicyclobutane **11**, although **6a** may be formed directly from diradical **12.**

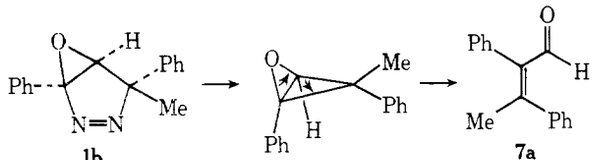
Another route to aldehyde **7a** might be the pyrolysis of azine aldehydes **10a,b.** We have observed no aldehydes, however, when an equilibrating mixture of azines **10a,b** was heated at 85 °C for 1 h.



A final question is whether the formation of the particular geometric isomer **7a** is *consistent* with an oxabicyclobutane intermediate. In part, the answer to this question is obscured by not having absolute proof for the stereochemistry of epoxide **1b,** but if one assumes that the stereochemistry of structure **5** (epoxide **1b**) is correct then a decision can be made. Our other studies on cyclopropane epoxidations show that the substituent trans to the entering oxygen is found predominantly cis to the carbonyl in the unsaturated enone product.[17]



The reaction shows an orbital symmetry control that is similar to the cycloreversion of bicyclobutanes. If epoxide **1b** (structure **5**) generates oxabicyclobutane **13** with retention of stereochemistry, then enal **7a** should be the major geometric isomer. This was observed.



Conclusion

Irradiation of epoxypyrazoline **1b** did not lead to loss of N_2. Rather, a rearrangement occurred to an azine aldehyde. Thermolysis of the epoxypyrazoline produces a reactive oxabicyclobutane which fragments to unsaturated carbonyl products. This is the first time this route to oxabicyclobutanes has been successful.

Experimental Section

Melting points were taken on a Fisher-Johns melting point apparatus and are uncorrected. UV spectra were obtained on a Cary 118 spectrophotometer. Infrared spectra were obtained on Perkin-Elmer 137 or 467 spectrometers. NMR spectra were obtained on a JEOLCO C-60 HL, MH-100, or PFT-100 spectrometer. Mass spectra were obtained on a Hitachi RMU-6E or DuPont 21-490B spectrometer. All solvent evaporations were done on a rotary evaporator. Elemental analyses were done by Chemalytics, Inc., Tempe, Arizona.

(*E*)- and (*Z*)-1,3-Diphenyl-2-buten-1-one [Dypnone (6a,b)]. The $AlCl_3$-catalyzed condensation of acetophenone was performed following the procedure of Calloway.[18] Distillation gave a 60% yield of (*E*)-dypnone **6a:** bp 150 °C (0.7 mm) [lit.[18] 160–165 (1 mm)]; IR (neat) 1660 cm^{-1}; ^1H NMR (CCl_4) δ 2.65 (d, J = 2 Hz, 3), 7.27 (br s, 1), 7.5–7.8 (m, 10), 8.1–8.2 (m, 2).

Irradiation of (*E*)-dypnone in ethanol by a sunlamp following the procedure of Lutz and Slade[19] gave a 1:2 mixture of (*E*)- and (*Z*)-dypnone. The ^1H NMR (CCl_4) absorptions of (*Z*)-dypnone **6b** were δ 2.25 (d, J = 2 Hz, 3), 6.41 (narrow triplet, 1), 6.9–7.9 (m, 10).

***syn*- and *anti*-(*E*)-1,3-Diphenyl-2-buten-1-one Tosylhydrazone.** The condensation of dypnone **6a** and tosylhydrazide was carried out by the procedure of Sato.[7] The product precipitated in 67% yield as a mixture of syn and anti isomers (stereochemistry unknown): mp 146–148 °C [lit.[7] 149–150 °C]; IR ($CHCl_3$) 3260, 1625, 1175 cm^{-1}; ^1H NMR ($CDCl_3$) (I) δ 1.83 (s, 3), 2.38 (s, 3), 6.18 (s, 1), 6.9–8.0 (m, 15); (II) 2.32 (s, 3), 2.38 (s, 3), 5.88 (s, 1), 6.9–8.0 (m, 15).

3,5-Diphenyl-3-methylpyrazolenine (2). The NaH-induced decomposition of the tosylhydrazone was carried out by the procedure of Sato.[7] The collected crystalline precipitate was formed in 70% yield: mp 85–86 °C [lit.[7] 83–84 °C]; UV (hexane) 366 (ϵ 200), 283 (4000), 232 nm (18 800); IR ($CHCl_3$) 1650, 1600, 1495, 1450, 1030 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.76 (s, 3), 7.1–7.5 (m, 9, looks like the vinyl H may be a singlet at 7.17), 7.8–8.2 (m, 2).

5-Bromo-4-acetoxy-3,5-diphenyl-3-methyl-1-pyrazoline (3a,b). A solution of 1.0 mL (19 mmol) of bromine (Mallinkrodt) in 20 mL of CCl_4 was added dropwise to a solution of 4.0 g (24 mmol) of silver acetate (Baker analyzed reagent) in 160 mL of CCl_4 at 0 °C (30 min). The mixture was stirred at 0 °C until the orange color turned to yellow (~30 min). The mixture was filtered, and 3.00 g (12.5 mmol) of 3,5-diphenyl-3-methylpyrazolenine (**2**) was added to the filtrate. The mixture was kept in the refrigerator overnight. A 50-mL portion of 50% (w/v)Na_2SO_3 and 5% (w/v) $NaHCO_3$ solution was added to decompose any unreacted acetyl hypobromite. The CCl_4 solution was washed with 50 mL of water and dried over sodium sulfate. The solvent was removed and gave 4 g (100%) of residue. Silica gel chromatography (Baker analyzed reagent, 40–140 mesh) with 1:1 hexane–$CHCl_3$ solution as eluent gave a 2-g (50%) mixture of impure bromoacetates, **3a,b,** in an approximate 5:1 ratio: IR ($CHCl_3$) 1750 cm^{-1}; ^1H NMR (CCl_4) of the major isomer **3a** 1.76 (s, 3), 2.22 (s, 3), 5.67 (s, 1), 7.0–7.5 (m, 10). The minor isomer has a 6.03 singlet for 1 H. The two isomers have not been isolated in pure forms.

4,5-Epoxy-3,5-diphenyl-3-methyl-1-pyrazoline (1b). A modified procedure of Ellington, Hey, and Meakins[20] was used. A 15.1-g portion (28.5 mmol) of the two isomers of 5-bromo-4-acetoxy-3,5-diphenyl-3-methyl-1-pyrazoline (**3**) in a 5:1 ratio (~70% pure) was dissolved in 150 mL of methanol and chilled to 0 °C. A 2.5-g portion (46 mmol) of sodium methoxide was added. The mixture was kept in the refrigerator for 2 h. The mixture was added to 200 mL of 1:1 CCl_4–hexane solution and washed with 200 mL of water. The organic layer was dried over sodium sulfate and concentrated to one-third of its original volume. The solution was stored in the refrigerator overnight to give 2.05 g (30%) of impure 5-bromo-4-hydroxy-3,5-diphenyl-3-methyl-1-pyrazoline (**4a**): mp 118 °C (dec); UV (MeOH) 346 nm (ϵ 100); IR ($CHCl_3$) 3540 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.73 (s, 3), 2.65 (d, J = 10 Hz, 1), 4.21 (d, J = 10 Hz, 1), 7.2–7.6 (m, 8), 7.7–7.9 (m, 2). The two doublets were often singlets in other spectra, showing that the coupling involves a hydroxyl proton. Anal. Calcd for $C_{16}H_{15}N_2BrO$: C, 58.02; H, 4.57; N, 8.45; Br, 24.13. Found: C, 57.90; H, 4.42; N, 7.50, Br, 26.33.

The solvent was evaporated from the filtrate. The residue was dissolved in 30 mL of CCl_4 and 120 mL of hexane. The solution was kept in the freezer for 2 weeks which resulted in 0.7 g of crude crystalline 4,5-epoxy-3,5-diphenyl-3-methyl-1-pyrazoline (**1b**). The crude product was recrystallized from CCl_4–hexane solution and yielded 0.3 g of epoxide **1b:** mp 102–103 °C; UV (hexane) 365 nm (ϵ 240); IR (CCl_4) 3000, 1495, 1450, 1410, 1220, 970, 695 cm^{-1}; ^1H NMR (CCl_4) δ 1.83 (s, 3), 3.79 (s, 1), 7.1–7.8 (m, 10); ^{13}C NMR ($CDCl_3$) δ 17.73 (q, J = 130 Hz), 68.96 (d of closely spaced multiplets, J = 200 Hz), 91.23 (s) 93.72 (s), 122–137 (m, 7 peaks are visible in the H-decoupled spectrum); MS (20 eV) *m/e* 250 (p, 1), 223 (6), 222 (41), 221 (100), 207 (12), 145 (21), 131 (12), 119 (53), 105 (41), 104 (47), 77 (29). Anal. Calcd for $C_{16}H_{14}ON_2$: C, 76.80; H, 5.60; N, 11.20. Found: C, 76.74; H, 5.85; N, 11.79; and C, 75.77; H, 5.66; N, 10.80.

5-Bromo-4-acetoxy-3,5-diphenyl-3-methyl-1-pyrazoline (3a). A 1.50-g portion (19.2 mmol) of freshly distilled acetyl chloride (Eastman Chemicals) was added dropwise to a stirring solution of 3.3 g (10 mmol) of bromohydrin **4a** in 80 mL of 1:1 pyridine–ether solution. The mixture was kept at 40 °C for 3 h and stirred overnight. The solution was filtered, and a 100-mL portion of ether was added to the filtrate. The resulting solution was washed with 160-mL of 6 M HCl solution and 100 mL of 5% (w/v) $NaHCO_3$ solution. The ether extract was dried over Na_2SO_4 and the solvent was evaporated. ^1H NMR of the residue showed a 1 to 1 mixture of the bromohydrin **4a** and the

bromoacetate **3a**. The mixture was dissolved in 50 mL of 1:1 CCl_4–hexane solution and refrigerated overnight and filtered. The solvent was evaporated from the filtrate to give 1.3 g (70%) of 80% pure 5-bromo-4-acetoxy-3,5-diphenyl-3-methyl-1-pyrazoline (**3a**): IR (neat) 3450, 1750, 1450, 1375, 1225 cm^{-1}; ^1H NMR ($CDCl_3$) same as before; see above.

This material, when hydrolyzed as above with NaOMe in MeOH, gave a 70% yield of 5-bromo-4-hydroxy-3,5-diphenyl-3-methyl-1-pyrazoline (**4a**). This compound was identified by ^1H NMR and IR.

3,3,5-Trimethyl-4,5-epoxy-1-pyrazoline (1a). The material was prepared as described by Friedrich, de Vera, Hoss, and Warren:[6] ^{13}C NMR ($CDCl_3$) δ 13.35 (q, J = 129 Hz), 19.05 (q of q, J = 4, 129 Hz), 22.14 (d of q of q, J = 2, 5, 129 Hz), 65.28 (m of d, J = 191, each multiplet has ca. seven peaks spaced ~3 Hz apart), 85.36 (m, ca. seven peaks spaced ~4 Hz apart), 90.34 (m, ca. four peaks spaced ~5 Hz apart).

Pyrolysis of 4,5-Epoxy-3,5-diphenyl-3-methyl-1-pyrazoline (1b). A 40-mg portion (0.16 mmol) of epoxide **1b** was dissolved in 250 μL of benzene-d_6 and placed in an NMR tube. A 2-μL portion of cyclohexane was added as an internal standard. The NMR tube was sealed in vacuo and heated at 85 °C. The disappearance of epoxide **1b** was first order with a half-life of ~2 h. As epoxide gradually disappeared, two new CH_3 signals appeared at 0.44- and 1.13-ppm downfield from cyclohexane in a ratio 1:2.8 with >90% proton balance. Another signal that is one-third as intense as the upfield CH_3 signal appeared 8.40-ppm downfield from cyclohexane. Comparison with authentic spectra in PhH-d_6 solution showed the two products to be (**Z**)-2,3-diphenylbut-2-en-1-al (**7a**) and (*E*)-dypnone (**6a**), respectively. Samples of (*Z*)-dypnone **6b** and (*E*)-aldehyde **7b** which have CH_3 signals downfield from cyclohexane by 0.54 and 0.76 ppm, respectively, were stable to the reaction conditions (in the presence of decomposing epoxide) but were not found.

The reaction mixture was thick-layer chromatographed on silica gel. Elution with CCl_4 produced two bands which were identified by ^1H NMR and IR as (*Z*)-aldehyde **7a** and (*E*)-dypnone **6a**.

1,2-Diphenylpropan-2-ol. The procedure of Hell[21] was used which condenses benzylmagnesium chloride and acetophenone. A 95% yield of crude alcohol was obtained: ^1H NMR (CCl_4) δ 1.45 (s, 3), 1.78 (s, 1), 2.90 (d, J = 12 Hz, 1), 3.00 (d, J = 12, 1 Hz), 6.8–7.3 (m, 10).

(*E*)-1,2-Diphenylpropene. The procedure of Koelsch[13] was used to dehydrate 1,2-diphenylpropan-2-ol with HOAc–H_2SO_4: yield 67%; mp 81–82 °C [lit.[13] 79–82 °C]; ^1H NMR (CCl_4) δ 2.22 (d, J = 1.5 Hz, 3), 6.70 (br s, 1), 7.0–7.5 (m, 10). The ^1H NMR agrees with the literature.[22]

1,2-Diphenyl-1,2-dibromopropane. A 40-mL (0.75 mol) portion of bromine (Mallinckrodt) was added to 145 g (0.750 mol) of (*E*)-1,2-diphenyl-1-propene in 800 mL of CCl_4 over a period of 20 min. The mixture was stirred for another 5 min. The excess bromine was removed by adding 150 mL of a 10% (w/v) sodium sulfite solution and stirring until the orange color disappeared (10 min). The product was recrystallized from the CCl_4 solution: yield 185.5 g (70%) of a 3:5 mixture of relatively pure diasteriomeric 1,2-diphenyl-1,2-dibromopropanes; mp 122–129 °C (dec); IR (CCl_4) 1500, 1455, 1450, 1380, 1220, 1040 cm^{-1}; ^1H NMR (CCl_4) (I) δ 2.42 (s, 3), 5.50 (s, 1), 6.8–7.6 (m, 10); (II) δ 2.34 (s, 3), 5.53 (s, 1), 7.0–7.6 (m, 10); MS (70 eV) *m/e* 356 (p + 4, 3), 354 (p + 2,7), 352 (p, 3), 273 (66), 194 (100), 179 (47), 105 (43), 91 (18). Anal. Calcd for $C_{15}H_{14}Br_2$: C, 50.88; H, 3.99; Br, 45.13. Found: C, 50.32; H, 3.82; Br, 46.52.

(*E*)- and (*Z*)-1-Bromo-1,2-diphenyl-1-propene. A modified procedure of Cram[23] was used. An alcoholic potash solution was prepared by adding 50 g (0.68 mol) of potassium hydroxide pellets (Fisher) to 720 mL of absolute ethanol. A 113-g (0.320 mol) portion of 1,2-diphenyl-1,2-dibromopropane was added. The resulting mixture was refluxed for 7 h and stirred overnight at room temperature. The mixture was filtered. The precipitate was washed with 600 mL of hexane. The alcoholic solution was concentrated and the hexane wash was added. The organic solution was washed with 2 × 400 mL of water and dried over sodium sulfate. Crystallization yielded 70 g (80%) of a 1:4 mixture of (*Z*)- and (*E*)-1-bromo-1,2-diphenyl-1-propene (stereochemistry unassigned). The crystals were dissolved in 200 mL of hexane and cooled. Crystals were formed: mp 155–159 °C; UV (hexane) 260 nm (ϵ 6450); IR (CCl_4) 1600, 1495, 1450, 880, 710 cm^{-1}; ^1H NMR (CCl_4) δ 1.98 (s, 3), 7.1–7.4 (m, 10). Anal. Calcd for $C_{15}H_{13}Br$: C, 65.95; H, 4.80; Br, 28.98. Found: C, 66.14; H, 5.02; Br, 28.92. The filtrate was chilled in an acetone–dry ice bath. Light-orange impure crystals were collected: mp 40–42 °C; UV (hexane) 274 (ϵ 7100), 224 nm (18 600); IR (CCl_4) 1600, 1495, 1450, 1380, 920, 885, 710 cm^{-1}; ^1H NMR (CCl_4) δ 2.35 (s, 3), 6.95 (m, 10). Anal. Calcd for $C_{15}H_{13}Br$: C, 65.95; H, 4.80; Br, 28.98. Found: C, 65.36, H, 4.65; Br, 29.02.

The literature sample may have been a low-melting mixture, bp 153–156 °C (0.001 mm).[13]

(*E*)- and (*Z*)-2,3-Diphenyl-2-butenoic Acids (8a,b). A solution of 70 g (0.26 mol) of (*E*)- and (*Z*)-1-bromo-1,2-diphenyl-1-propene (1:4) in 720 mL of ether cooled to 0 °C and 18.5 g (0.780 mol) of magnesium turnings (Mallinckrodt) was added. The mixture was stirred under a nitrogen atmosphere for 4 h. The yellowish suspension was poured over 4 lb of dry ice and allowed to stand overnight. The magnesium salt was hydrated by the addition of 250 g of ice into the reaction vessel. A 20% (v/v) acetic acid solution was added until the aqueous layer was acidic to litmus paper. The ether phase was separated, and the aqueous layer was extracted with 250 mL of ether. The combined ether solutions were concentrated and extracted several times with saturated sodium bicarbonate solution until the aqueous layer was basic. The combined aqueous extracts were acidified with glacial acetic acid. The white precipitate was collected and washed with 400 mL of water. The precipitate was air dried overnight and yielded 30 g (50%), mp 126–143 °C, of mixed acids in a 1 to 3 ratio (stereochemistry unassigned): ^1H NMR ($CDCl_3$) (I) δ 2.38 (s, 3), 6.7–7.3 (m, 10), 10.00 (br s 1); (II) δ 1.98 (s, 3), 7.1–7.5 (m, 10), 10.0 (br s, 1). The precipitate was recrystallized from a 1:3 $CHCl_3$–hexane solution. The filtrate was kept in the refrigerator overnight. The crystals that were formed were identified as isomer I: mp 162–164 °C; UV (MeOH) 256 nm (ϵ 12 300); IR ($CDCl_3$) 3000 (br), 1690, 1495, 1445 cm^{-1}; MS (70 eV) *m/e* 238 (p, 60), 220 (32), 166 (41), 118 (32), 96 (35), 91 (100), 82 (42). Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.65; H, 5.92. Found: C, 80.55; H, 5.77. Isomer II was always contaminated with isomer I. The literature sample melted at 124–126 °C.[13]

(*E*)- and (*Z*)-2,3-Diphenyl-2-buten-1-ol. A 22-g portion (0.092 mol) of (*E*)- and (*Z*)-2,3-diphenyl-2-butenoic acids (1:3) was added over a period of 10 min to 7.0 g (0.18 mmol) of lithium aluminum hydride (Ventron) in 400 mL of anhydrous ether. The mixture was stirred for 1.5 h under a nitrogen atmosphere. The grayish slurry was cautiously and slowly added to 200 g of ice and stirred until the mixture turned white. The white suspension was acidified with concentrated HCl. The ether layer was separated, and the aqueous layer was extracted with 100 mL of ether. The combined ether solutions were evaporated to one-half of their original volume and washed with several portions of saturated sodium bicarbonate solution until the washing was basic. The ether solution was dried over sodium sulfate, and the solvent was evaporated. The residue yielded 18 g (87%) of a 2:1 ratio of (*Z*)- and (*E*)-2,3-diphenyl-2-buten-1-ol (stereochemistry undetermined): bp 123 °C (0.25 nm); ^1H NMR (CCl_4) (I) δ 1.72 (s, 1, OH), 2.08 (s, 3), 4.27 (s, 2), 7.10 (m, 10); (II) δ 1.72 (s, 1, OH), 1.75 (s, 3), 3.93 (s, 2), 6.82 (m, 10). Chromatography on silica gel with benzene as eluent yielded isomer I pure: mp 95–96 °C; UV (MeOH) 239 nm (ϵ 10 200); IR ($CHCl_3$) 3580, 1490, 1440, 1380, 990 cm^{-1}; MS (70 eV) *m/e* 224 (p, 72), 209 (30), 191 (23), 178 (20), 115 (32), 91 (67), 77 (30). Anal. Calcd for $C_{16}H_{16}O$: C, 85.68; H, 7.19. Found: C, 85.84; H, 7.27.

Preparation of (*Z*)- and (*E*)-2,3-Diphenyl-2-butenal (7a,b). A 13-g portion (58 mmol) of (*E*)- and (*Z*)-2,3-diphenyl-2-buten-1-ol was dissolved in 300 mL of dried acetone and 45 g (0.25 mol) of CrO_3–pyridine complex was added. The mixture was kept at room temperature for 58 h. A 600-mL portion of ether was added and filtered. The filtrate was washed with 2 × 200 mL of water, 100 mL of 15% aqueous HCl, and 200 mL of 5% (w/v) $NaHCO_3$ solution. The ether solution was dried over Na_2SO_4 and the solvent was evaporated to give 8.1 g (60%) of the mixed aldehydes in a ratio 2:1 (Z:E). The solid was recrystallized from a 1:1 $CHCl_3$–hexane solution to give the yellow (*Z*)-2,3-diphenyl-2-butenal (**7a**): mp 131–133 °C (lit. 128–129,[12] 127–128[11]); IR ($CHCl_3$) 2750 (weak), 1668, 1395, 1380 cm^{-1}; UV (MeOH) 275 nm (ϵ 9500); ^1H NMR ($CDCl_3$) δ 2.15 (s, 3), 6.9–7.5 (m, 10), 9.62 (s, 1); MS (70 eV) *m/e* 222 (p, 100), 207 (20), 193 (19), 179 (35), 178 (40), 115 (63), 91 (43). Anal. Calcd for $C_{16}H_{14}O$: C, 86.45; H, 6.35. Found: C, 86.30; H, 6.51.

Further evaporation of the solvent produced crystals which when recrystallized from 1:3 $CHCl_3$–hexane gave (*E*)-2,3-diphenyl-2-butenal (**7b**): mp 105–106 °C; UV (MeOH) 292 nm (ϵ 13 300); IR ($CDCl_3$) 2750 (weak), 1670, 1377, 1330 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.60 (s, 3), 6.7–7.4 (m, 10), 10.42 (s, 1); MS (70 eV) *m/e* 222 (p, 100), 207 (15), 193 (15), 179 (20), 178 (20), 115 (35), 91 (15). Anal. Calcd for $C_{16}H_{14}O$: C, 86.45, H, 6.35. Found: C, 87.08; H, 6.49 and C, 85.97; H, 6.46.

Isomerization of (*E*)-2,3-Diphenyl-2-butenal (7b). A 24.3-mg portion (0.11 mmol) of (*E*)-2,3-diphenyl-2-butenal (**7b**) was dissolved in 5 mL of methanol containing 120 μL of concentrated HCl. The mixture was stirred for 40 min at room temperature. A 40-mL portion of ether was added, and the mixture was washed with 20 mL of 5% (w/v) $NaHCO_3$ solution. The ether extract was dried over Na_2SO_4.

The solvent was evaporated to yield (*Z*)-2,3-diphenyl-1-butenal (**7a**) (^{1}H NMR). No *E* isomer **7b** was found. A quantitative experiment performed in CH_3OD in the ^{1}H NMR spectrometer showed an 80% conversion to the *Z* isomer.

Photolysis of 4,5-Epoxy-3,5-diphenyl-3-methyl-1-pyrazoline (1b) in PhH. A 132.3-mg portion of (0.529 mmol) of epoxide **1b** was dissolved in 2 mL of benzene. Six 300-μL portions were placed in individual NMR tubes. One of the tubes was kept in the refrigerator while the other five tubes were photolyzed at 5 °C using a sunlamp. One tube was removed every hour and kept in the refrigerator. ^{1}H NMR analysis of each tube showed two products appearing in a 2:1 ratio. In ppm downfield from the epoxide CH_3 (which occurs 0.30-ppm downfield from cyclohexane), the two products appeared at 0.37 (3 H), 8.83 (1 H), and 0.20 (3 H), 8.23 (1 H), respectively. The contents of each tube were evaporated, dissolved in CCl_4, and analyzed by ^{1}H NMR. In ppm downfield from the epoxide CH_3 (δ 1.83 ppm), the two products appear at 0.60 (3 H), 8.70 (1 H), and 0.46 (3 H), 7.95 (1 H), respectively. The integrals showed a 90% conversion to these two products.

The tubes were combined and the solution was heated at 85 °C for 1 h. ^{1}H NMR showed a small amount of the thermolysis products (see above). In addition, about half of the major photolysis product had disappeared with a corresponding increase in the minor photoproduct.

The PhH was evaporated, the residue was dissolved in 5:1 hexane–CCl_4, and the solution was put in the freezer. A yellow impure precipitate was formed: mp 95–96 °C; UV (hexane) 268 nm (ϵ 16 600); IR (CCl_4) 2820, 1710, 1650, 1450, 1370, 1250, 870 cm^{-1}: ^{1}H NMR (CCl_4) δ 2.30 (s, 3), 7.2–7.5 (m, 9), 7.6–7.8 (m, 2), 9.80 (s, 1); MS (70 eV) *m/e* 250 (p, 2), 221 (4), 119 (100), 104 (100), 77 (100), 51 (47). Anal. Calcd for $C_{16}H_{14}N_2O$: C, 76.77; H, 5.63; N, 11.20. Found: C, 77.42; H, 5.85; N, 10.74.

Irradiations in CD_3CN showed similar results with formation of the same two photoproducts. In all cases, comparison of the ^{1}H NMR's of the irradiated solutions with ^{1}H NMR's of aldehydes **6a,b** and dypnones **7a,b** showed the latter four compounds were not present (<10%). Control experiments showed that both the aldehydes and dypnones were stable to the reaction conditions.

Registry No.—**1a**, 54541-36-5; **1b**, 63904-61-0; **2**, 22675-60-1; **3**, 63904-62-1; **4a**, 63904-63-2; **6a**, 22573-24-6; **6a** *anti*-hydrazine, 63904-64-3; **6a** *syn*-hydrazone, 63904-65-4; **6b**, 54435-79-9; **7a**, 63904-66-5; **7b**, 63904-67-6; **8a**, 60728-10-1; **8b**, 60728-09-8; **10a**, 63904-68-7; **10b**, 63904-69-8; acetophenone, 98-86-2; tosylhydrazide, 1576-35-8; 1,2-diphenylpropan-2-ol, 5342-87-0; (*E*)-1,2-diphenylpropene, 833-81-8; (*R,*R**)-1,2-diphenyl-1,2-dibromopropane, 63904-70-1; (*R*S*)-1,2-diphenyl-1,2-dibromopropane, 63904-71-2; bromine, 7726-95-6; (*E*)-1-bromo-1,2-diphenyl-1-propene, 63904-72-3; (*Z*)-1-bromo-1,2-diphenyl-1-propene, 63904-73-4; (*E*)-2,3-diphenyl-2-buten-1-ol, 63904-74-5; (*Z*)-2,3-diphenyl-2-buten-1-ol, 22641-64-1.

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Phenylacetone Dianion: Alkylation with Iodomethane[1]

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The alkylation products of the phenylacetone dianion have been examined. It has been shown that the alkylation is nonregioselective, carbon–carbon bond formation taking place at either the α or α′ position. Both the ease of formation of the dianion and the monoalkylation product ratio are affected by the metal ions present. Methylation at the terminal position does not predominate in any case examined.

In recent years carbon–carbon bond formation by means of dianion alkylation has become an increasingly important synthetic tool.[3] Although such reactions have most frequently involved β-dicarbonyl compounds,[3a] carboxylic acids,[3b] β-keto sulfones[3c] and imides[3d] have also proven useful. With each of these precursors the dianion alkylation is normally regioselective, carbon–carbon bond formation taking place at the position from which the second proton has been removed. This observation has been succinctly summarized in the generalization that "the more basic (and less stable) enolates usually react more readily with alkylating agents".[4] Versatility is thus available, since regioselective alkylation can be accomplished in a predictable fashion using either monoanion or dianion alkylation procedures; the position of alkylation is normally well defined and different with each method.

Of course it is well known that many factors contribute to the relative rates and regioselectivity of alkylation of enolate anions. Among these considerations are charge densities,[5] steric interactions in the transition state, solvent, metal ion effects,[6] and the principle of least motion.[7] All of these contribute to the relative nucleophilicity observed for separate enolate anions or for differing positions on the same dianion. Despite these other factors, however, dianion alkylation regioselectivity has generally been successfully predicted simply on the basis of relative pK_a values.

In 1967 Hauser reported[8] that the combination of a phenyl

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