the ester solution was cooled with ice during addition of the Grignard solution. During the early stages of the reaction, addition of the Grignard proceeded smoothly with formation of a yellow suspension. Toward the end of the addition the suspended solid coagulated to form a tough, sticky lump which stopped the stirrer. The reaction mixture was hydrolyzed immediately with saturated aqueous ammonium chloride. The ammonium chloride solution was added slowly until the inorganic salts settled out to leave a clear brown ether solution. The sticky lump had dissolved during the hydrolysis. The clear ether solution was decanted through a filter and stored over anhydrous calcium sulfate. The precipitated salts were placed in a Soxhlet thimble and extracted with fresh ether. The combined ether solution and extract was filtered and the ether was displaced by simultaneous distillation of ether and addition of *n*-heptane. Cooling of the heptane solution afforded a white, crystalline precipitate accompanied by a red tar which solidified to a gum. The white solid was separated from the gum by decantation as a slurry. The heptane slurry was chilled overnight and filtered to give 6.9 g of crude product. Recrystallization from ethanol gave 4.7 g (11%) of diol **7**, mp 156–159°. A second recrystallization from *n*-heptane gave 3.9 g of white solid, mp 158–160°.[16]

The nmr spectrum of the diol has a multiplet centered at *ca.* τ 2.8 (aromatic), a triplet at 4.46 ($J = 2.2$ cps, exomethylene), a triplet at 7.51 ($J = 2.2$ cps, cyclopropyl), and a singlet at 8.12 (hydroxyl) in the correct ratio of integrated peak areas. The hydroxyl proton assignment was confirmed by deuterium exchange. In addition to the expected aromatic bands the infrared spectrum is characterized by absorptions at 3560 (hydroxyl and 890 cm^{-1} (*exo*-methylene).

Anal. Calcd for $C_{30}H_{26}O_2$: C, 86.09; H, 6.26. Found: C, 86.30; H, 6.30.

Reaction of Diol 7 with Glacial Acetic Acid.—In a preliminary test, 201 mg (0.480 mmole) of diol **7** was stirred for 50 min with 10 ml of glacial acetic acid at room temperature under a nitrogen atmosphere. The diol dissolved completely in the acetic acid. Quenching the reaction mixture with 30 ml of water caused a white solid to separate. The aqueous mixture was extracted with ether, and the ether extracts were washed with 10% sodium bicarbonate, dried, and evaporated to give a white solid. The infrared spectrum of the white solid is identical with that of the starting diol which indicates that the alcohol is stable under these conditions.

In another experiment, 200 mg (0.478 mmole) of diol **7** was dissolved in 10 ml of glacial acetic acid under a nitrogen atmosphere. The solution was brought rapidly to a boil, using a flame, and refluxed for 2 min. The reaction mixture was cooled and then quenched with 30 ml of water which caused a white, sticky precipitate to settle out. The reaction mixture was neutralized with sodium bicarbonate solution and extracted with ether containing a pinch of phenothiazine as a polymerization inhibitor. The ether extracts were washed with water, dried over sodium sulfate–magnesium sulfate, and evaporated under reduced pressure to give a pale yellow oil. The oil was dissolved in hot heptane and chilled to give white crystals, mp 109–111°. Recrystallization from heptane gave white crystals, mp 115–118°. The infrared spectrum (Nujol) of the product, in addition to the expected aromatic bands, is characterized by peaks at 1685 (PhCO), 1635 (conjugated C=C), and 910 cm^{-1} (CH_2=). The ultraviolet and nmr ($CDCl_3$) spectra are described in the discussion section.

In a larger scale reaction, 4.0 g (9.6 mmoles) of diol **7** was treated as above in 100 ml of acetic acid to give 2.8 g (73%) of the dehydration product, mp 115–117.5°. The structure of the dehydration product was shown, as described in the discussion section, to be 1,1,4,5-tetraphenyl-3-methylene-5-ketopentene-1 (**9**).

Anal. Calcd for $C_{30}H_{24}O$: C, 89.96; H, 6.04. Found: C, 89.99; H, 6.30.

Oxidative Degradation of Dehydration Product 9.—Using the procedure of Bass,[17] 0.5 g of dehydration product **9** was dissolved in 10 ml of pyridine, diluted with 3 ml of water, and heated to reflux. Solid potassium permanganate was added slowly in weighed, 0.2-g portions until the violet color of permanganate persisted. It was necessary to add 1.6 g of permanganate (theoretical, 1.45 g). The condenser sides were washed down periodically with a 10:3 pyridine–water mixture. The reaction mixture was refluxed for 1 hr after addition of permanganate was complete. The reaction mixture was then steam distilled until the distillate came over clear and gave a neutral reaction to litmus. The distillate was acidified with concentrated HCl and steam distilled again until the distillate came over clear. The second distillate was extracted with ether and the ether extracts were dried and evaporated to give 171 mg (75.0%) of impure benzophenone. Treatment with 2,4-dinitrophenylhydrazine reagent in ethanol afforded orange crystals which, after three recrystallizations from ethanol–ethyl acetate, had mp 246.5–249.0° (microhot stage). The melting point was not depressed on admixture with authentic benzophenone-2,4-dinitrophenylhydrazone.

The original reaction mixture, after the first steam distillation, was filtered from MnO_2 and the hot, yellow filtrate was acidified with concentrated HCl. After treatment with Norit, the acidified filtrate was extracted with ether. The ether extract was dried and evaporated to give 9.7 mg (3.2%) of impure benzoic acid. Vacuum sublimation afforded a white solid, mp 117.5–122.0°. The infrared spectrum of the white solid is superimposable upon that of authentic benzoic acid.

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[16] The synthesis of this compound, mp 157–157.5°, was reported during the course of this work: D. J. Connolly, Ph.D. Thesis, Cornell University, 1962. Connolly attempted the dehydration of the diol under a variety of conditions but was unable to characterize products.

[17] R. G. Bass, Ph.D. Thesis, University of Virginia, 1961.

Thermal Rearrangement of 1,1-Dibromo-*cis*-2,3-dimethylcyclopropane

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Numerous studies on the gas phase rearrangement of cyclopropane to propylene, for which a diradical forming process seems currently favored, show the reaction requires an Arrhenius activation energy of about 65 kcal/mole with an unsurprisingly large frequency factor of 10^{15}.[1] Saturated alkyl groups on the cyclopropane ring appear to have little effect on the activation parameters; *e.g.*, four methyl substituents lower the activation energy by less than 5 kcal/mole and affect the frequency factor negligibly.[2]

That the cyclopropane system is not generally indifferent to substituent effects, however, is apparent from the work of Ellis and Frey[3] on the rearrangement of *cis*-1-methyl-2-vinylcyclopropane to *cis*-1,4-hexadiene. From the product geometry, low activation energy (31.2 kcal/mole) and negative activation entropy (−11.8 eu/mole), these workers suggested a cyclic transition state for this reaction. In addition, DeSelms and Combs,[4] who have shown a large but seemingly erratic solvent dependence of the rate for the kinetically first-order rearrangement of 3,3-dichloro-*exo*-tricyclo[3.2.1.0^{2,4}]octane to 3,4-dichlorobicyclo[3.2.1]oct-2-ene, present data for this reaction in carbon tetrachloride from which we were able to calculate E_a and ΔS^* values of 22 kcal/mole and −7.4 eu/mole.

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[1] D. W. Setser and B. S. Rabinovitch, *J. Am. Chem. Soc.*, **86**, 569 (1964), and references cited therein.

[2] M. C. Flowers and H. M. Frey, *Proc. Roy. Soc.* (London), **A260**, 424 (1961); M. C. Flowers and H. M. Frey, *J. Chem. Soc.*, 1157 (1962); H. M. Frey and D. C. Marshall, *ibid.*, 3052 (1962).

[3] R. J. Ellis and H. M. Frey, *Proc. Chem. Soc.*, 221 (1964).

[4] R. C. DeSelms and C. M. Combs, *J. Org. Chem.*, **28**, 2206 (1963).

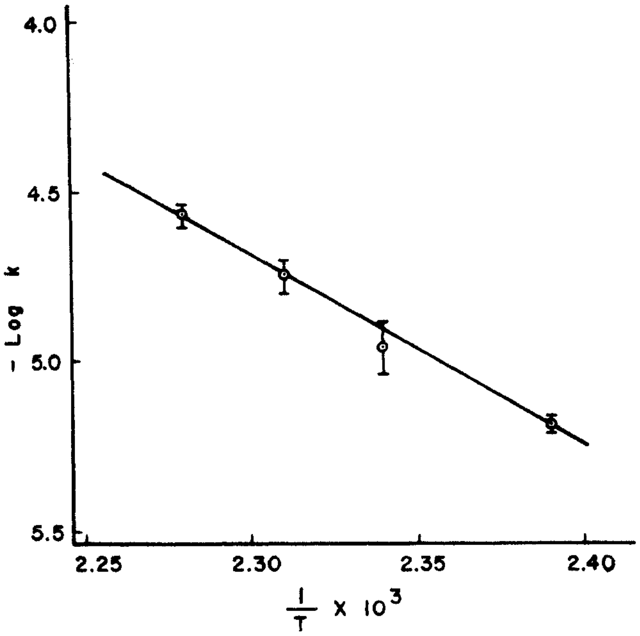
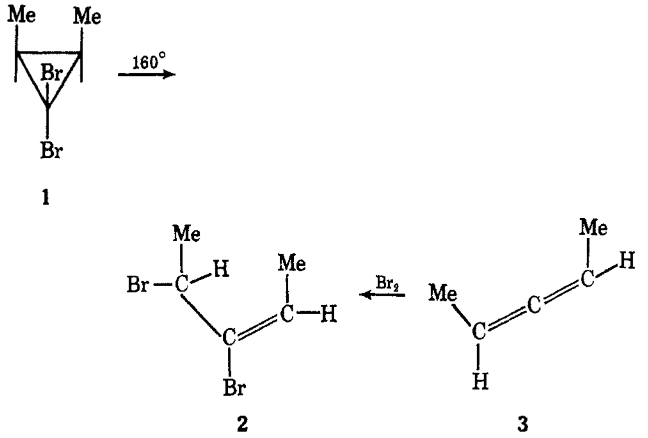


Figure 1.

The rearrangement of dibromomethylene adducts to unsaturated bicyclic hydrocarbons appears to be considerably more facile than for the corresponding dichloro compounds since in some cases only the rearrangement product could be isolated.[5] This factor and curiosity concerning possible differences stemming from ring opening as opposed to ring enlargement dictated our choice of 1,1-dibromo-*cis*-2,3-dimethylcyclopropane as a suitable structure for study of a cyclopropane ring opening reaction accompanied by bromine migration.

The rearrangement was found to proceed smoothly in the vicinity of 160° and resulted in the formation of the same product obtained by addition of bromine to 2,3-pentadiene as shown by the virtual identity of their boiling points and infrared and pmr spectra. The agreement between spectra of the products from the two reactions, the clearly defined, sharp pmr maxima, and the single symmetrical gas chromatogram product peak under conditions giving an 8-min retention time difference between reactant and product are evidences that both bromine addition to 2,3-pentadiene and rearrangement of 1,1-dibromo-*cis*-2,3-dimethylcyclopropane result in the formation of the same geometrical isomer of 3,4-dibromo-2-pentene or a mixture containing very little (<15%) of the other possible isomer. By analogy to the pmr spectrum of 2,3-dibromopropene[6] in which the vinyl proton *cis* to the bromine appears at τ 3.98, we suggest the quartet signal of 3,4-dibromo-2-pentene at τ 3.81 arises from a vinyl proton *cis* to the vinyl bromine. A vinyl proton *trans* to the bromine would be expected to appear nearer τ 4.38. The stereochemical courses of the two reactions are pictured in the conversions of **1** and **3** to **2**.



The rearrangement of **1** to **2** in kerosene solution was found to give cleanly first-order kinetics over the range 10–80% reaction at temperatures from 145 to 165°. The initial rearrangement product **2** proved somewhat unstable at these temperatures, and at times corresponding to 40–60% reaction of **1** the product began decomposing faster than it was being generated from **1**. These subsequent reactions of **2** lead to charring to such an extent that centrifugation was necessary to clarify the solution before analysis in the late stages of the reaction, but the rate of disappearance of **1** seemed unaffected by these reactions.

The first-order rate constants with average deviations from the mean values are as follows (temperature accuracy and constancy were within $\pm 0.7°$): 145°, $0.64 \pm 0.03 \times 10^{-5}$; 155°, $1.1 \pm 0.2 \times 10^{-5}$; 160°, $1.8 \pm 0.2 \times 10^{-5}$; 165°, $2.7 \pm 0.2 \times 10^{-5}$ sec^{-1}.

From an Arrhenius plot of log k *vs.* $1/T$ we obtained activation parameters for the rearrangement reaction of 26 ± 3 kcal/mole and -22 ± 6 eu/mole for the activation energy (E_a) and entropy (ΔS^*). In this plot the straight line fell within the experimental range at each temperature (see Figure 1).

The low activation energy and especially the large, negative activation entropy and seemingly strong preference for a *cis* product configuration that does not appear likely to be favored thermodynamically lead us to suggest a largely concerted ring opening and bromine migration with a highly constrained transition state, a mechanism bearing greater similarity to the rearrangements of *cis*-1-methyl-2-vinylcyclopropane[3] and 3,3-dichloro-*exo*-tricyclo[3.2.1.0^{2,4}]octane[4] than to the ring openings of alkyl cyclopropanes.

Experimental Section[7]

1,1-Dibromo-*cis*-2,3-dimethylcyclopropane (**1**).—This compound [bp 40–41° (3 mm), n^{25}_{D} 1.5166, d^{25} 1.75] was prepared in 36% yield from 100 g of *cis*-2-butene and 174 g of bromoform by the method of Skell and Garner.[8] The infrared spectrum had maxima at 1460, 1400, 1245, 1155, 1130, 1082, 1050, 1000, 973, 933, 829, and 833 cm^{-1}. Pmr maxima occurred at τ 8.90 (unsymmetrical doublet, J = 5.5 cps, two methyls) and at 8.33 τ (complex multiplet, two ring protons) (TMS = τ 10.00).

3,4-Dibromo-2-pentene (**2**).—The addition of bromine to 2,3-pentadiene (0.75 g) in chloroform solution gave 2.7 g of the dibromo adduct [bp 87–90° (25 mm)].[9] The infrared spectrum had maxima at 1840, 1775, 1630, 1440, 1363, 1325, 1280, 1257, 1200, 1177, 1137, 1105, 1058, 1010, 990, 962, 905, and 812 cm^{-1}.

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[5] C. W. Jefford, *Proc. Chem. Soc.*, 64 (1963); W. R. Moore, W. R. Moser, and J. E. LaPrade, *J. Org. Chem.*, **28**, 2200 (1963); J. Sonnenberg and S. Winstein, *ibid.*, **27**, 748 (1962).

[6] "N.M.R. Spectra Catalog," Varian Associates, Palo Alto, Calif., 1962.

[7] Infrared spectra were determined neat or in solution in matched sodium chloride cells on a Perkin-Elmer Model 137B spectrophotometer; pmr spectra were determined as *ca.* 20% solution in carbon tetrachloride (tetramethylsilane standard) with a Varian Associates Model A-60 spectrometer; glpc purification was with an Aerograph Model A-700 gas chromatograph.

[8] P. S. Skell and A. Y. Garner, *J. Am. Chem. Soc.*, **78**, 3409 (1956).

[9] F. Acree and F. B. LaForge, *J. Org. Chem.*, **5**, 436 (1940).

Two methyl doublets (J = 6.0 cps each) appeared in the pmr spectrum at τ 8.16 and 8.21 (vinyl and allylic methyls, respectively), while the vinyl and allylic protons each gave rise to a quartet (J = 6.0 cps) at 3.81 and 5.21, respectively. Compound **2** was also prepared by heating **1** at 160° for 1 hr. The material boiling at 87–90° (25 mm) was found to contain about 15% **1**. In this case **2** was purified by preparative glpc on a 20 ft × $^3/_8$ in. 20% DEGS column at 150°, helium flow of 200 ml/min, and trapped at liquid nitrogen temperatures. The retention time of **2** was 16 min.

Kinetic Study.—Kerosene solvent was purified by dilute acid wash, distillation, and drying over anhydrous sodium sulfate. A series of standards of **1** and **2** (glpc pure) in this solvent was prepared and the 1000–833-cm^{-1} region recorded four times for each concentration (constant base-line adjustment) in 0.46-mm matched cells, kerosene reference. The absorbance maxima at 933 and 905 cm^{-1} were employed for analysis with a base point at 870 cm^{-1}. Linear calibration curves (base-point method) for each component at each wavelength were obtained and converted to analytical expressions which reduced to

$$C_1 = 97A_{933} - 8A_{905}$$

where C_1 is the concentration (mg/ml) of **1** and A_{933} and A_{905} are net absorbance values at the respective wavelengths.

Kinetic runs at 145, 155, 160, and 165° were made in a constant-temperature oil bath. A 10% solution (w/v) of **1** in kerosene was introduced rapidly into a preheated reaction flask at desired temperature, the initial time was taken, and from eight to ten aliquots (1–2 ml) were withdrawn at irregular intervals until about 80–90% of **1** had rearranged. Aliquots were chilled and stored at 0° until the run was complete. Infrared analysis was done then after centrifugation and twofold dilution with solvent. The instrument was adjusted each time to a constant base-point absorbance equal to the initial sample value. All samples were included in computing the rate constants and mean deviations.

Selective Borane Reduction of a Trifluoroacetamide Substituent in the Presence of a Carbamate

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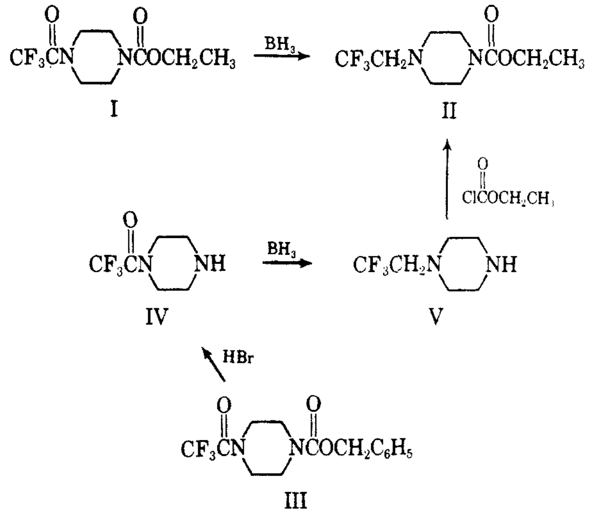
A number of selective reductions utilizing borane and metal borohydrides have been described recently.[1] In a similar manner we have found that borane will reduce the carbonyl of a trifluoroacetamido group[2] without affecting the carbonyl of a carbamate[3] moiety present in the same molecule.[4]

Ethyl 4-trifluoroacetylpiperazine-1-carboxylate (I) was prepared by the reaction between ethyl piperazine-1-carboxylate and ethyl trifluoroacetate. Compound I was treated with refluxing borane in tetrahydrofuran[5] to afford ethyl 4-trifluoroethylpiperazine-1-carboxylate[6] (II) in an 80% yield.



The structure of compound II was firmly established by a four-step synthetic sequence involving (1) trifluoroacetylation of benzyl piperazine-1-carboxylate to give III; (2) decarbobenzoxylation of III to 1-trifluoroacetylpiperazine (IV); (3) borane reduction to N-trifluoroethylpiperazine (V); followed by (4) reaction of V with ethyl chloroformate to afford II.

Experimental Section

All distillations were carried out using a Nester–Faust spinning-band column.

1-Trifluoroacetylpiperazine Hydrobromide (IV).—Benzyl 4-trifluoroacetylpiperazine-1-carboxylate[7] (40.9 g, 0.13 mole) was dissolved in 160 ml of freshly prepared saturated hydrogen bromide in acetic acid and allowed to stand at room temperature for 1.0 hr. The reaction mixture was diluted with 800 ml of anhydrous ether and chilled to give a solid product, yield 23.9 g, (70%), mp 158–162°. For analyses a small portion of the compound was recrystallized from ethanol–ether, mp 160–165°.

Anal. Calcd for $C_6H_9F_3N_2O \cdot HBr$ (mol wt, 263): C, 27.4; H, 3.8; Br, 30.4; F, 21.7; N, 10.6. Found: C, 27.1; H, 4.3; Br, 30.5; F, 21.6; N, 10.4.

1-Trifluoroethylpiperazine (V).—1-Trifluoroacetylpiperazine hydrobromide (26.5 g, 0.10 mole) was dissolved in 25 ml of water, covered with 100 ml of ether, and cooled in an ice bath. The mixture was saturated with sodium bicarbonate and extracted with ten 100-ml portions of ether and four 100-ml aliquots of chloroform. The combined extracts were dried over $MgSO_4$ and evaporated to give 16.5 g of the free base. This product was dissolved in 100 ml of dry tetrahydrofuran and added dropwise to 150 ml of 1.0 M borane–tetrahydrofuran in an ice bath with good stirring in a nitrogen atmosphere. The mixture was refluxed for 1.0 hr, then cooled, and decomposed carefully with 25 ml of 6.0 N hyrochloric acid. The mixture was filtered and the filtrate was evaporated to dryness. The residue was diluted with 25 ml of water, made strongly basic by adding solid sodium hydroxide, and then extracted with four 40-ml portions of ether. The combined ether extracts were dried over magnesium sulfate and evaporated, and the residue was distilled, yield 4.3 g, bp 151–152°, $n^{24}\text{D}$ 1.4079.

One gram of this product was dissolved in 25 ml of anhydrous ether and saturated with anhydrous hydrogen chloride to give a white, crystalline dihydrochloride, yield 1.4 g. The compound

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[1] See (a) H. C. Brown, *J. Chem. Educ.*, **38**, 173 (1961); (b) H. C. Brown and P. M. Weissman, *J. Am. Chem. Soc.*, **87**, 5614 (1965), and previous articles in that series.

[2] (a) E. R. Bissell and M. Finger [*J. Org. Chem.*, **24**, 1256 (1959)] have prepared trifluoroethylamines by reduction of trifluoroacetamides using sodium borohydride–aluminum chloride, or sodium borohydride–boron trifluoride mixtures. Borane is known to be the active reducing agent in both cases. (b) Z. B. Papanastassiou and R. J. Bruni [*ibid.*, **29**, 2870 (1964)] have also reported the reduction of monofluoroacetamides using borane.

[3] N. G. Gaylord ["Reduction with Complex Metal Halides," Interscience Publishers, Inc., New York, N. Y., 1956, p 636] reports the reduction of carbamates to methylamines with $LiAlH_4$.

[4] Since H. C. Brown and P. Heim [*J. Am. Chem. Soc.*, **86**, 3566 (1964)] have described the borane reduction of a number of simple aliphatic and aromatic amides to amines under conditions similar to those used by us, it would seem likely that the selective reduction of amides in the presence of carbamates may be quite general.

[5] This solution is commercially available from Metal Hydrides Inc., Beverly, Mass. The preliminary data sheet on this product indicates that the borane forms a 1:1 molar complex with tetrahydrofuran.

[6] Attempts to prepare compound II by the direct alkylation of ethyl piperazine-1-carboxylate with trifluoroethyl iodide were not successful.

[7] H. P. Dalalian, L. N. Starker, and L. Goldman, U. S. Patent 2,909,524 (1959).