

[CONTRIBUTION FROM THE CHEMISTRY DIVISION OF OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TENNESSEE]

Molecular Rearrangements. XXI. The Pinacol Rearrangement of 2-Phenylnorbornane-2,3-*cis-exo*-diol^{1a}

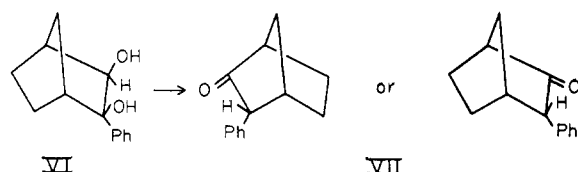
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RECEIVED JUNE 8, 1964

The rearrangement of 2-phenylnorbornane-2,3-*cis-exo*-diol (VI) in concentrated sulfuric acid at 0° takes place with intramolecular migration of hydrogen from C-3 to C-2. Rearrangement of the norbornane carbon skeleton also occurs, with an accompanying 6,1-shift of hydrogen. The configuration of the product, 3-*endo*-phenyl-2-norbornanone (VII), is inverted with respect to the configuration of reactant (VI). The results, attained with tritium, carbon-14, and stereochemical studies, can best be accommodated by assuming non-classical carbonium ion intermediates.

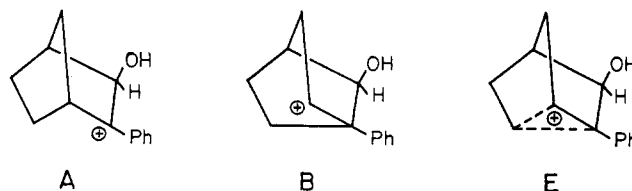
Introduction

In connection with their work on the performate oxidation of 2-phenylnorbornene (IV), Kleinfelter and Schleyer² noted that one of the compounds available through their route—namely, 2-phenylnorbornane-2,3-*cis-exo*-diol (VI)—upon being heated with a dilute aqueous dioxane-sulfuric acid mixture yielded 3-*endo*-phenyl-2-norbornanone (VII). The stereochemical relationship of reactant VI and product VII was



not specified. The fact that phenyl is *endo* in both VI and VII precludes a simple loss of tertiary hydroxyl followed by a 1,2-shift of hydrogen during the rearrangement. Three conceivable, but unattractive, mechanisms remain as possibilities. The first, secondary hydroxyl loss followed by migration of the phenyl, seems unlikely, since tertiary hydroxyl removal should be preferred, and, further, there is apparently no documented case^{2,3} of migration of an *endo* substituent in the rearrangement of a norbornyl compound. The second mechanism is formation of the tertiary carbonium ion A, followed by loss of the proton at C-3 and preferential reprotonation from the *exo*-direction.² This mechanism is identical with the theory of "vinyl dehydration" proposed many years ago by Tiffeneau⁴ and effectively negated, whenever tested, by the demonstration that deuterium undergoes intramolecular 1,2-shift during pinacol rearrangement.^{5,6} The third mechanism, rearrangement of the norbornyl carbon skeleton either through classical or nonclassical ions with an accompanying hydride shift,⁷ also presents an

a priori appearance of unlikelihood. Unlikely because: (a) we would expect the tertiary, benzyl-type carbonium ion A to be much more stable^{8,9} than the bridged ion E, and (b) we would not expect A, once formed, to



rearrange to the secondary carbonium ion B (see the discussion later in this paper).

Kleinfelter and Schleyer² clearly state the foregoing three mechanistic possibilities without choosing between "vinyl dehydration" and skeletal rearrangement. The prejudice of one of us¹⁰ against "vinyl dehydration" as a serious contender, and the knowledge that in spite of their apparent unlikelihood, one of the remaining mechanisms must operate, caused us to investigate the pinacol rearrangement of VI. Our approach to the problem was to combine studies of the consequences of tritium and carbon-14 labeling during the transformation VI → VII with an examination of its stereochemistry. We used concentrated sulfuric acid at 0° to bring about the rearrangements, rather than the conditions employed by Kleinfelter and Schleyer, because of the known⁵ tendency of warm, dilute acids to favor exchange of hydrogen α to carbonyl groups.

The first series of experiments was concerned with the synthesis and rearrangement of 2-phenylnorbornane-2,3-*cis-exo*-diol-3-³H₁ (VIa). The reaction sequence is shown in Chart I and was carried out twice. In the first experiments the molar radioactivities, in millicuries, for selected compounds in the series were: IIIa, 1.177; IVa, 0.6192; Va, 0.6266; VIa, 0.6263; and VIIa, 0.3058. Thus approximately half of the tritium was retained during the rearrangement of VIa → VIIa and subsequent work-up, signifying that at least half of the reaction proceeded with intramolecular migration of tritium. In order to determine whether the partial loss of radioactivity was a con-

(1) (a) This paper is based upon work performed at Oak Ridge National Laboratory, which is operated by Union Carbide Corp. for the Atomic Energy Commission. Previous paper: C. J. Collins, M. M. Staum, and B. M. Benjamin, *J. Org. Chem.*, **27**, 3525 (1962). (b) Research Participant of the Oak Ridge Institute of Nuclear Studies.

(2) D. C. Kleinfelter and P. von R. Schleyer, *J. Am. Chem. Soc.*, **83**, 2329 (1961).

(3) J. Berson in "Molecular Rearrangements," P. de Mayo, Ed., Interscience Publishers, Inc., New York, N. Y., 1963, Chapter 3, p. 159.

(4) M. Tiffeneau, *Bull. soc. chim.*, **33**, 759 (1923).

(5) C. J. Collins and co-workers, *J. Am. Chem. Soc.*, **81**, 460 (1959).

(6) W. B. Smith and co-workers, *ibid.*, **81**, 997 (1959).

(7) J. D. Roberts, C. C. Lee, and W. H. Saunders, Jr., *ibid.*, **76**, 4501 (1954).

(8) C. J. Collins and B. M. Benjamin, *ibid.*, **85**, 2519 (1963), and previous papers.

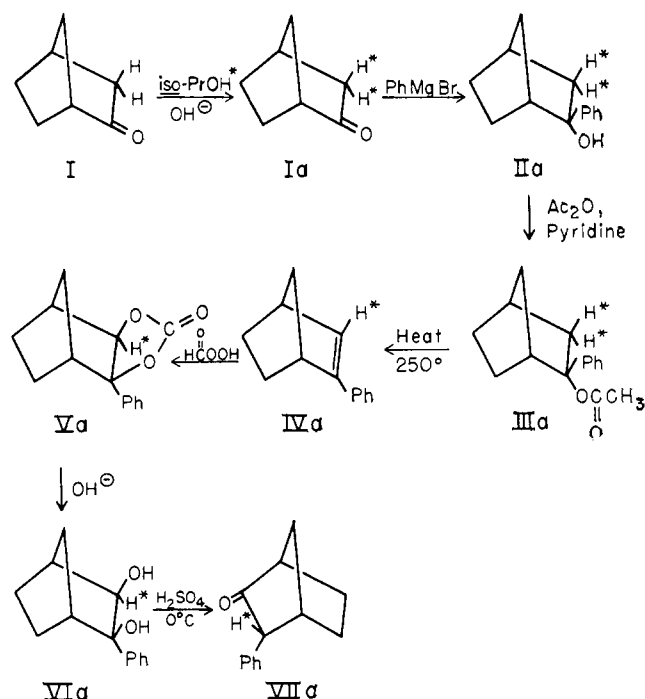
(9) P. von R. Schleyer, D. C. Kleinfelter, and H. G. Richey, Jr., *ibid.*, **85**, 479 (1963).

(10) C. J. Collins, *Quart. Rev. (London)*, **14**, 363 (1960).

sequence of duality of mechanism or of exchange of hydrogen for the tritium in VIIa during work-up, we

It remained only to establish the stereochemistry of the transformation VI \rightarrow VII. The stereochemical

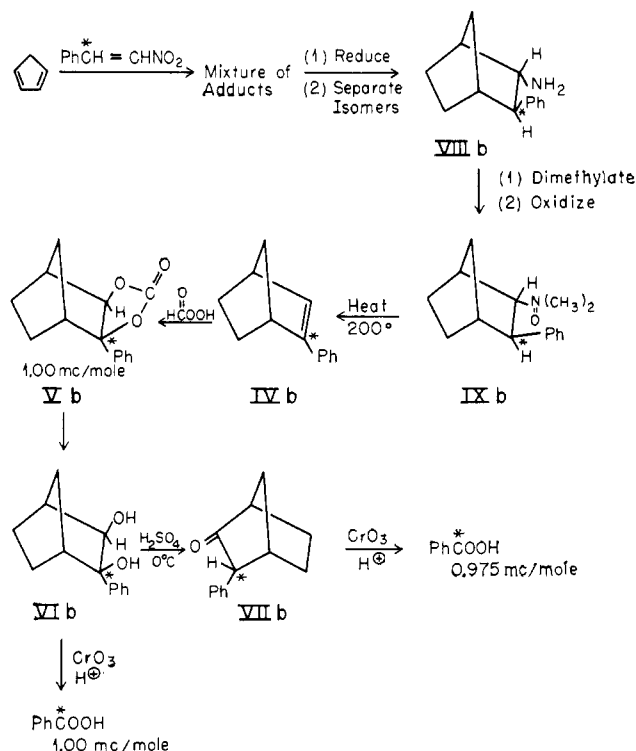
CHART I



repeated the experiment, but isolated the product quickly and, in addition, kept wash solutions as nearly neutral as possible. Tritium determinations, in millicuries per mole, for key compounds in the second experiments were: Va, 0.4901; VIa, 0.4869; and VIIa, 0.4148; corresponding to 15% loss of the tritium during rearrangement of VIa. Finally, a crude kinetic experiment was performed which indicated that in very weakly basic solution exchange of tritium for the hydrogen of VII is complete within a few hours. It has been established, therefore, that the hydrogen at position 3 of the glycol VI migrates intramolecularly to the extent of more than 85%, and it is possible that the intramolecularity is complete. From these results we can see that "vinyl dehydration" is not an important mechanism in the rearrangement of VI. Since the two remaining mechanisms require inversion of configuration during rearrangement, VIIa is drawn to show that the inversion has taken place.

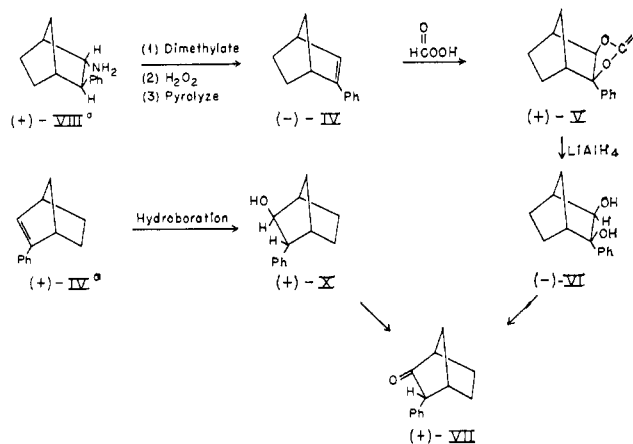
Our next series of experiments was constructed to differentiate rearrangement of the norbornyl carbon skeleton from secondary hydroxyl removal followed by a C-2 \rightarrow C-3 migration of the *endo*-phenyl. The sequence is shown in Chart II, in which the asterisk now refers to the carbon-14 label. The results are unequivocal, demonstrate that the labeled carbon remains attached to phenyl during rearrangement, and show conclusively that secondary hydroxyl removal followed by a Nametkin-type phenyl migration to the secondary (C-3) position cannot have occurred to any significant extent.

CHART II



study is outlined in Chart III. Optically pure ketone (+)-VII was formed upon rearrangement of the optically pure glycol (-)-VI. Since the enantiomers (+)-IV and (-)-IV in the sequence shown in Chart III both yield the same (+)-ketone (VII), it is clear that (-)-VI afforded (+)-VII whose configuration had been inverted during the rearrangement.

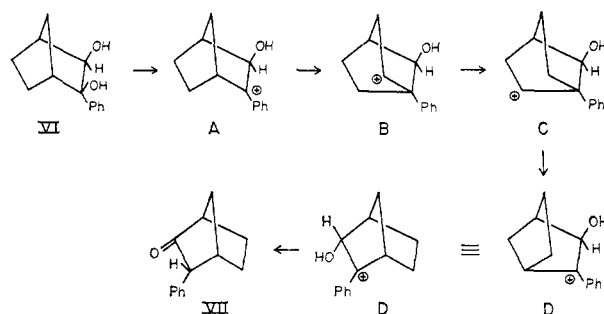
CHART III



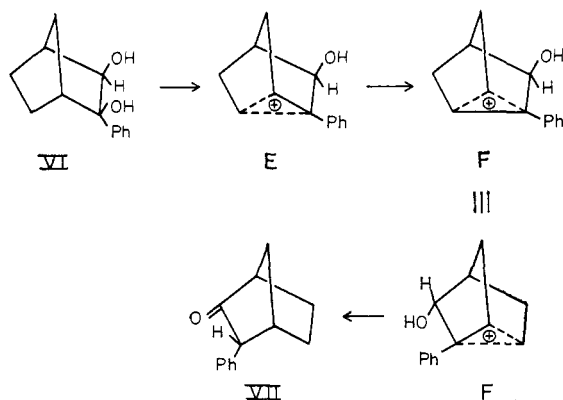
(a) Absolute configurations not intended.

Thus pinacol rearrangement of 2-phenylnorbornane-2,3-*cis-exo*-diol (VI) proceeds with intramolecular migration of hydrogen from C-3 to C-2, the configuration

of the ketone VII produced is inverted with respect to the configuration of VI, and the phenyl remains attached to the same carbon atom throughout the rearrangement. One mechanism which can be written for these results includes the formation of the classical carbonium ion A, followed by rearrangement through ions B and C (with accompanying 6,1-shift of hydrogen) to the classical ion D, which then yields the ketone VII. This mechanism, however, does not tell us why the *exo*-hydrogen of ion D undergoes such easy migration to the 2-position, whereas the *endo*-hydrogen in ion A does not. Further, rearrangement of the stable tertiary benzyl-type ion A to the secondary ion B seems unlikely. A much more satisfactory interpreta-



tion (despite our earlier reluctance to consider them) employs the nonclassical, bridged intermediates E and F, in which E rearranges to F accompanied by a hydride shift, possibly through an ion similar to the tricyclonium ion postulated by Roberts.⁷ Migration of the 3-*endo*-hydrogen in E is not possible because of bridging from the 6-position to the *same* side of C-2

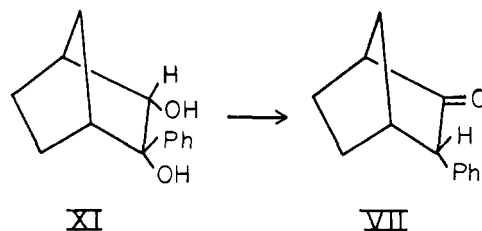


to which the hydrogen, if it migrated, would shift. In ion F, however, bridging is on the opposite side from the *exo*-hydrogen at C-3, which can now migrate without difficulty.

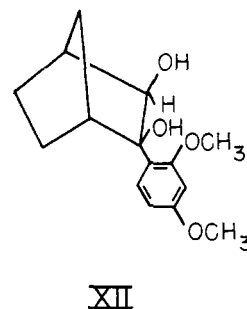
It seems to us remarkable that the tertiary, benzyl-type carbonium ion E, generated in cold, concentrated sulfuric acid should prefer the nonclassical structure. Perhaps the favorable geometry of the 1-, 2-, and 6-carbons and the added driving force attributed to the incipient formation of ketone VII are enough to overcome the usual^{8,9} tendency of such carbonium ions to remain open and unbridged. Professor H. C. Brown

suggests that the open ion A could lose a proton from C-6 with concurrent bonding at C₆-C₂ to produce a tricyclane which, upon reprotonation, would produce the open ion D. Professor Brown's suggestion has the twofold advantage that it not only removes the necessity for the unlikely rearrangement A → B, but it can be tested by carrying out the pinacol rearrangement of VI in deuterium- or tritium-containing sulfuric acid. The ketone VII so produced should then contain deuterium or tritium in the 6-*exo*-position. The intermediacy of a tricyclane, however, must still involve carbonium ion intermediates and thus leaves unexplained the very important reason for the disinclination for migration of the *endo*-hydrogen of VI, a phenomenon which has already been noticed for *endo*-alkyl groups.^{2,3} The steric interpretation¹¹ for the low *endo:exo* ratio of solvolysis rates for norbornyl derivatives is of no help here, nor were we able to conceive any other steric reason for our results.^{11a}

Following the experiment suggested by Prof. Brown, our next effort will be the synthesis and rearrangement, in cold, concentrated sulfuric acid, of 2-phenylnorbornane-2,3-*cis-endo*-diol (XI). We would like to know whether ketone VII can be produced during the reaction and, if so, whether the *exo*-hydrogen at C-3



migrates intramolecularly and unaccompanied by rearrangement of the norbornane skeleton. Prof. J. D. Roberts has recently suggested (in a letter) the possibility for *endo* migration of the no. 3 hydrogen during rearrangement of the glycol XII, for it is con-



ceivable that the two methoxyl groups at positions 2

(11) H. C. Brown, F. J. Chloupek, and M.-H. Rei, *J. Am. Chem. Soc.*, **86**, 1246, 1247, 1248 (1964).

(11a) NOTE ADDED IN PROOF.—We have now carried out the rearrangement VI → VII in tritiated sulfuric acid. The uptake of tritium per mole of VII was only 0.067% of the molar radioactivity of the sulfuric acid. Oxidation of ketone VII so obtained afforded benzoic acid whose molar radioactivity was 0.033% that of the original sulfuric acid. This evidence, we believe, rules out the intervention of a tricyclane intermediate in the rearrangement VI → VII.

and 4 (in the phenyl) could stabilize the tertiary, classical, open carbonium ion at the expense of the bridged ion similar to E. When time permits, we hope to study the rearrangement of XII.

Experimental

Procedures developed by Kleinfelter and Schleyer^{2,12} for the synthesis and rearrangement of 2-phenylnorbornanone-2,3-*exo-cis*-diol were used with the following exceptions: (a) 2-Phenylnorbornene was prepared by pyrolysis of 2-*exo*-phenyl-2-*endo*-norbornyl acetate which gave a product containing only 1-2% of phenylnortricyclene; (b) quantitative conversion of 2-*endo*-phenyl-2,3-*cis-exo*-norbornylene carbonate to the *cis-exo*-diol was accomplished by lithium aluminum hydride reduction of the carbonate; and (c) 3-*endo*-phenyl-2-norbornanone (VII) was obtained by the pinacol rearrangement of the diol VI at 0° in 96% sulfuric acid. Pertinent aspects of the reaction procedures in the tritium, carbon-14, and optically active series are described in detail.

2-Norbornanone-3-³H₁ (Ia).—To 20 ml. of tritiated isopropyl alcohol was added 0.25 g. of sodium, and when this had all dissolved, 15 g. of norcamphor was added. The mixture was heated for 1.5 hr. and then the isopropyl alcohol was evaporated under vacuum. The residue was taken up in ether and washed with water. The ether layer was dried with magnesium sulfate. After evaporation of the ether, there remained 15 g. of the tritiated ketone Ia.

2-*endo*-Phenyl-2,3-*cis-exo*-norbornylene-3-*endo*-³H₁ Carbonate (Va).—The product (Ia) from above was combined with an additional 7.8 g. of ketone and then converted to 2-*exo*-phenyl-2-*endo*-norbornanol-3-³H₁ (IIa).¹² The carbinol IIa was treated with acetic anhydride in pyridine to give the acetate (IIIa), 1.177 mc./mole, which was next heated under reflux in a metal bath at 270° for 5 min. The mixture was dissolved in ether and washed with sodium bicarbonate solution. After distillation, the product, 2-phenylnorbornene-3-³H₁ (IVa), 0.6192 mc./mole, was shown (g.p.c.) to contain only about 1% of phenylnortricyclene. The olefin, 5 g., was converted to 2.3 g. of tritiated carbonate (Va, 0.6266 mc./mole) by the method of Kleinfelter and Schleyer² and was then hydrolyzed³ to the glycol VIa, 2.1 g., 0.6263 mc./mole.

3-*endo*-Phenyl-2-norbornanone-3-³H₁ (VIIa).—The diol VIa, 2.0 g., was added to 100 ml. of 98% sulfuric acid at -8°. The mixture was stirred for 0.5 hr. and then poured onto ice. The ketone was recovered by ether extraction. The ether solution was washed thoroughly with 50 ml. of Na₂CO₃ solution which showed appreciable amount of tritium activity. The ketone was distilled; b.p. 108° at 0.5 mm.; radioactivity assay, 0.3058 mc./mole.

In a second experiment, the carbonate Va, 0.4901 mc./mole, was converted to glycol VIa, 0.4869 mc./mole, which was then subjected to the conditions of pinacol rearrangement. The ketonic product VIIa was washed quickly with sodium bicarbonate solution and distilled; the distillate contained 0.4148 mc./mole of tritium. A small amount of radioactivity appeared in the sodium bicarbonate washings. The ketone was shown by n.m.r. analysis to contain no detectable amount of 2-*exo*-phenylnorbornanone (no doublet at 2.94 p.p.m.). The products from both of the foregoing experiments were combined, and dissolved in ether; the ether solution was washed with two 100-ml. portions of 1 N sodium hydroxide. The recovered ketone was non-radioactive. Thus all the tritium was in the labile 3-*exo*-position. After the above treatment with basic solution, the material still contained no observable amount (n.m.r.) of the 3-*exo*-phenyl epimer. Hydrogen exchange is thus much more rapid than epimerization to the 3-*exo*-phenyl-2-norbornanone.

2-Phenylnorbornene-2-C¹⁴ (IVb).— β -Nitrostyrene- α -C¹⁴ was synthesized from benzaldehyde-*carbonyl*-C¹⁴ and nitromethane.¹³ Cyclopentadiene and the labeled β -nitrostyrene were converted through the Diels-Alder reaction, followed by reduction of the Diels-Alder product to 3-*exo*-phenyl-2-*endo*-norbornylamine-3-C¹⁴ (VIIIb) according to the method described in the literature for the nonradioactive compound.¹⁴⁻¹⁶

(12) D. C. Kleinfelter and P. von R. Schleyer, *J. Org. Chem.*, **26**, 3740 (1961).

(13) "Organic Syntheses," Coll. Vol. I, John Wiley and Sons, Inc., New York, N. Y., 1932, p. 413.

(14) W. E. Parham, W. T. Hunter, and R. Hanson, *J. Am. Chem. Soc.*, **73**, 5068 (1951).

The primary amine was then treated with formic acid and formaldehyde to give N,N-dimethyl-3-*exo*-phenyl-2-*endo*-norbornylamine.¹⁶ About a 20% yield of a mixture of epimeric 3-phenylnorbornanones was isolated from the reaction mixture. The tertiary amine, 18.3 g., was mixed with 60 ml. of methanol and 32 g. of 30% hydrogen peroxide, and the mixture was stirred for 5 days. Excess hydrogen peroxide was destroyed by the addition of a few mg. of Adams catalyst. Solvents were evaporated under vacuum at 40-50° and the sirupy amine oxide was transferred to a distilling flask. It was heated slowly under vacuum (0.5 mm.) to 250° during which treatment a distillate appeared over a range of 70-130°; the liquid was dissolved in ether, then washed with dilute hydrochloric acid, and finally redistilled to yield 5.3 g. of product, b.p. 80-83° (0.5 mm.). It was shown to be pure 2-phenylnorbornene-2 by comparison of its n.m.r. spectrum with that of an authentic sample.

3-*endo*-Phenyl-2-norbornanone-3-C¹⁴ (VIIb).—The carbon-14-labeled olefin IVb was treated with performic acid. The carbonate Va obtained from this reaction was crystallized from ethanol to give 5.1 g. of crystals, m.p. 101°; radioactivity assay, 0.3955 mc./mole. It was reduced with lithium aluminum hydride to give 4.2 g. of oily diol VIb whose infrared spectrum was identical with that of the nonradioactive material. A 300-mg. portion of the diol VIb was oxidized with chromic acid in acetic acid to give 160 mg. of benzoic acid; radioactivity assay, 0.3967 mc./mole. The remainder of the diol was treated with sulfuric acid at 0° as described above to give ketone VIIb. A sample of ketone VIIb, 480 mg., was oxidized with chromic acid to give 193 mg. of benzoic acid, whose radioactivity assay was 0.3868 mc./mole.

(-)-2-Phenylnorbornene ((-)-IV).—3-*exo*-Phenyl-2-*endo*-norbornylamine (VIII) was mixed with an equimolar amount of tartaric acid and the resulting salt was fractionally crystallized from absolute ethanol. A fraction, $[\alpha]_D^{25}$ 42.5° (c 1, H₂O), m.p. 192-194°, was obtained whose specific rotation was unchanged after two further crystallizations.

Anal. Calcd. for C₁₇H₁₈NO₆: C, 60.52; H, 6.87. Found: C, 59.00; H, 7.20.

The free (+)-amine VIII was obtained by treating an aqueous solution of the tartaric acid salt with sodium hydroxide and extracting the solution with ether. The amine, $[\alpha]_D^{25}$ 32.6°, which remained after the ether was evaporated was not suited for analysis because it rapidly absorbed carbon dioxide. The hydrochloride was prepared and crystallized from alcohol, m.p. 235-236°, $[\alpha]_D^{25}$ 47.6° (c 1, ethanol).

Anal. Calcd. for C₁₃H₁₈NCl: C, 69.78; H, 8.11. Found: C, 70.06; H, 8.16.

The amine VIII was also resolved through fractional crystallization from acetone of its *d*-10-camphorsulfonic acid salt, m.p. 210-211°, $[\alpha]_D^{25}$ 46.2° (c 1, ethanol).

Anal. Calcd. for C₂₃H₃₃NO₄S: C, 65.84; H, 7.93. Found: C, 65.82; H, 7.78.

The resolved (+)-amine, 24.9 g., was treated for 4 hr. at reflux temperature with 34 g. of 90% formic acid and 27 g. of 37% formaldehyde. From the reaction mixture was isolated 10.8 g. of ketonic material and 16.9 g. of tertiary amine Im. Without further purification the optically active amine was oxidized over a period of 4 days (room temperature) with a solution of 25 ml. of 30% hydrogen peroxide in 30 ml. of methanol. After the excess peroxide had been destroyed, all solvent was evaporated and, without further purification, the amine oxide was pyrolyzed at 250° and 0.8 mm. The distilled material was washed with dilute hydrochloric acid and was then redistilled; yield 3 g., $[\alpha]_D^{25}$ -180.3° (c 1, ethanol). The n.m.r. spectrum was the same as that of the authentic material.

(+)-3-*endo*-Phenyl-2-norbornanone ((+)-VII).—Optically active olefin (-)-IV, 2.6 g., was converted to the carbonate (+)-V which was crystallized from ethanol; m.p. 123°, $[\alpha]_D^{25}$ 63.2° (c 1, ethanol).

The carbonate (+)-V was reduced with lithium aluminum hydride to produce the solid diol (-)-VI, which was crystallized from hexane; m.p. 80°, $[\alpha]_D^{25}$ -24.7° (c 1, ethanol). The infrared spectrum was indistinguishable from that of racemic VI.

(-)-2-Phenylnorbornene-2,3-*cis-exo*-diol (-)-VI, 1.4 g., was treated with 25 ml. of sulfuric acid at 0° for 10 min. The product was isolated, after pouring the mixture onto ice, and

(15) G. I. Poos, S. Kleis, R. R. Wittekind, and J. D. Rosenau, *J. Org. Chem.*, **26**, 4898 (1961).

(16) T. Weinstock, N. Schwartz, and M. F. Kormendy, *ibid.*, **26**, 5247 (1961).

then distilled. A quantitative yield, 1.3 g., of solid ketone (+)-VII was obtained, m.p. 55–55.5°, $[\alpha]_D^{25}$ 141° (*c* 1, ethanol). The melting point and specific rotation were the same after two crystallizations from hexane. The n.m.r. spectrum was identical with that of the racemic sample.

Anal. Calcd. for $C_{13}H_{14}O$: C, 83.83; H, 7.58. Found: C, 82.7%; H, 7.41%.¹⁷

In one model experiment a batch of racemic ketone VII, prepared by our method, crystallized after being stored in the refrigerator. Subsequently all samples of the ketone crystallized if they did not contain detectable amounts of the *exo*-phenyl epimer. The ketone has previously been reported² as a liquid. It was crystallized from ice-cold hexane; m.p. 33–35°.

(+)-3-*endo*-Phenyl-2-*exo*-norbornanol ((+)-X).—Partially resolved (–)-3-*exo*-phenyl-2-*endo*-norbornylamine ((–)-VIII) was recovered from the mother liquors after resolution of (+)-VIII. It was converted to the (+)-2-phenylnorbornylene-2, $[\alpha]_D^{25}$ 103.7° (57.5% optically pure). This olefinic material, 5.9 g., was dissolved in 43 ml. of diglyme, and 1.1 g. of sodium borohydride was added. To the mixture was then slowly added 4.5 g. of boron trifluoride dietherate in 10 ml. of diglyme. The mixture was stirred for 3.5 hr. after which 7.5 ml. of 3 *N* sodium hydroxide was added, followed by 7.5 ml. of 30% hydrogen peroxide. Stirring was continued for 0.5 hr. and the contents of the flask were washed with ether and water into a separatory funnel. The water layer was removed and the ether layer was washed three times with water. The ether was evaporated and the residue was distilled. Most of the material, 4 g., was collected at 125–126° at 0.15 mm. It partially crystallized; $[\alpha]_D^{25}$ 52.8° (*c* 1, ethanol).

Anal. Calcd. for $C_{13}H_{16}O$: C, 82.93; H, 8.57. Found: C, 82.06; H, 8.37.

Oxidation of (+)-X to (+)-VII.—To 17 ml. of pyridine cooled in an ice bath was carefully added 2 g. of chromium trioxide. After the yellow complex had been formed, there was added 2 g. of carbinol (+)-X dissolved in 5 ml. of pyridine. The mixture

was stirred at room temperature for 2 hr., after which time it was mixed with 200 ml. of water. The aqueous solution was extracted with three portions of ether, and the ether extracts were washed with water and dilute hydrochloric acid. After evaporation of the ether, the product was distilled to give 1 g. of ketone (+)-VII; b.p. 103–106° at 0.1 mm., $[\alpha]_D^{25}$ 74.8° (*c* 1, ethanol, 53% optical purity). The infrared spectrum indicated the presence of a small amount of unreacted carbinol.

Summary of Evidence for Assignment of *endo*-Phenyl Configuration in Ketone VII.—At the suggestion of a referee we summarize our evidence which establishes the *endo* configuration of the phenyl group in ketone VII: (1) Borohydration of olefin IV gave 3-*endo*-phenyl-2-*exo*-norbornanol (X) whose configuration is assumed from the established¹⁸ stereochemical course for borohydration of norbornene, α -pinene, camphene, and other similar bicyclic olefins. Oxidation of X with chromium trioxide in pyridine afforded a ketone (VII) whose n.m.r. spectrum was identical with that of the ketone VII obtained upon rearrangement of VI in sulfuric acid.

Further evidence for the correctness of the assigned *endo*-phenyl configuration of VII can be obtained by comparing its n.m.r. spectrum with that of 3-*exo*-phenylnorbornanone-2 obtained by the Nef reaction² or by isomerization of VII in alkaline solution. The signal for the tertiary proton at C-3 of ketone VII appears as a doublet, $J = 4.5$ c.p.s. at 3.27 p.p.m. downfield from the signal for tetramethylsilane. The signal for the same proton of the "Nef" ketone appears as a doublet, $J = 3.1$ c.p.s. at 2.93 p.p.m. It has been shown¹⁹ that the *exo* protons in bicycloheptyl compounds are less shielded than *endo* protons and appear at lower fields. This then establishes VII as having a 3-*exo* proton. The doublet separation of 3.1 c.p.s. for the "Nef" ketone probably arises from coupling of the 3-*endo* proton with the 7-*anti* proton²⁰ rather than with the 4-bridgehead proton (which should be nearly zero).²¹ Details of the n.m.r. spectra of several phenyl-substituted norbornane compounds will be the subject of a later paper.

(17) Carbon and hydrogen analyses were performed by Huffman Micro-analytical Laboratories, Wheatridge, Colo. The analysis of the ketone is somewhat low, about 1%, because this compound reacts with oxygen from the air and is converted to a mixture of *cis*-3-benzoylcyclopentanecarboxylic acid and other oxygen-containing compounds.

(18) H. C. Brown, "Hydroboration," W. A. Benjamin, Inc., New York, N. Y., 1962, pp. 126–131.

(19) J. I. Musher, *Mol. Phys.*, **6**, 93 (1963).

(20) J. Meinwald and Y. C. Meinwald, *J. Am. Chem. Soc.*, **85**, 2514 (1963).

(21) P. Laszlo and P. von R. Schleyer, *ibid.*, **86**, 1171 (1964).

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF NOTRE DAME, NOTRE DAME, INDIANA]

Aromatic N-Oxides. IV. The Mechanism of the Reaction of 2-Alkylpyridine N-Oxides with Acetic Anhydride^{1,2}

BY VINCENT J. TRAYNELIS AND PIER L. PACINI

RECEIVED JULY 23, 1964

The reaction of 1-acetoxy-2-methylpyridinium perchlorate and the corresponding 2-benzyl and 2-*p*-nitrobenzyl compounds with base to produce the corresponding 2-pyridylmethyl acetates is reported. Attempts to detect the intermediacy of the anhydro base IV in the above reactions spectrally were all negative. These results along with the absence of deuterium exchange are interpreted mechanistically.

Since the reaction of 2-alkylpyridine N-oxides with acid anhydrides to produce 2-(α -acetoxyalkyl)pyridines was reported about 10 years ago,^{3,4} considerable attention has been directed toward the mechanism of this reaction. In a recent report, Oae⁵ reviewed the contributions of various workers toward elucidating the mechanism of this reaction and provided important evidence about the nature of the bond-breaking process leading to the rearranged product. The pres-

ent paper offers a discussion about the anhydro base intermediate and the rate-controlling step of this reaction.

The generally accepted mechanism as diagrammed below requires a nucleophilic attack by the N-oxide (I) oxygen on acetic anhydride (II) with the generation of the 1-acetoxy-2-alkylpyridinium ion (III) and an acetate anion. Abstraction of a proton from III by the acetate anion produces acetic acid and the anhydro-base IV which undergoes an intramolecular rearrangement to V. Direct evidence for the nature of step 1 is not available; however, studies in the 2-methylquinoline N-oxide system^{6,7} provided spectral evidence that 2-methylquinoline N-oxide in acetic anhydride was

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(2) For paper III in this series see V. J. Traynelis, Sr., A. I. Gallagher, and R. F. Martello, *J. Org. Chem.*, **26**, 4365 (1961).

(3) V. Boekelheide and W. J. Linn, *J. Am. Chem. Soc.*, **76**, 1286 (1954); G. Kobayashi and S. Furukawa, *Pharm. Bull. Japan*, **1**, 347 (1953); *Chem. Abstr.*, **49**, 10948e (1955).

(4) For leading references see V. J. Traynelis and R. F. Martello, *J. Am. Chem. Soc.*, **80**, 6590 (1958).

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(7) C. W. Muth and R. S. Darlak, private communication.