

in the presence of benzoyl peroxide, methyl *exo,cis*-2-bicyclo[3.3.0]octyl ketone (II) which, after purification through its semicarbazone, m.p. 180.8–181.8° dec. (lit.⁹ m.p. 181.0–182.4° dec.), and recovery by the action of sodium nitrite in acetic acid,¹⁰ had the following properties: b.p. 93° (5 mm.), n_D^{25} 1.4732, λ_{\max} 5.87 μ , homogeneous in gas chromatography (lit.⁹ b.p. 94–95° (10 mm.), n_D^{25} 1.4655). Its infrared spectrum was indistinguishable from that of the authentic ketone II (prepared by the published⁹ procedure), and the infrared spectra of the semicarbazones as well as their melting points were the same, with no depression in the mixture melting point.

The reaction of *cis,cis*-1,5-cyclooctadiene and chloroform in the presence of benzoyl peroxide resulted in a 37% yield of 2-(trichloromethyl)bicyclo[3.3.0]octane (III), b.p. 110–111° (9 mm.), n_D^{25} 1.5110, no absorption in the infrared at wave length lower than 3.4 μ attributable¹¹ to =CH stretching vibrations, and no signals due to olefinic protons in its n.m.r. spectrum.¹² Compound III was inert to aqueous potassium permanganate and did not absorb hydrogen over a palladium-on-charcoal catalyst. Hydrogenation of III in methanol and triethylamine in the presence of Raney nickel gave *exo,cis*-2-methylbicyclo[3.3.0]octane, b.p. 143–144°, n_D^{25} 1.4538, transparent in the region of 3.6 to 6.8 μ ; and *exo,cis*-2-(dichloromethyl)bicyclo[3.3.0]octane, b.p. 108–112° (15 mm.), further purified by g.l.c., n_D^{25} 1.5005.

Hydrolysis of III by hot phosphoric acid gave 2-(dichloromethylene)bicyclo[3.3.0]octane, b.p. 68° (0.2 mm.), n_D^{25} 1.5191, λ_{\max} 6.13 μ (also prepared by dehydrochlorination of III with potassium hydroxide in ethanol); and *exo,cis*-bicyclo[3.3.0]octane-2-carboxylic acid,⁷ b.p. 93° (0.1 mm.), n_D^{25} 1.4847, λ_{\max} 5.9 μ , which gave an amide, m.p. 178–179° (lit.⁷ m.p. 179°). The infrared spectrum of this amide was indistinguishable from that of the authentic *exo,cis*-bicyclo[3.3.0]octane-2-carboxamide¹³ and the mixture melting point of two compounds was undepressed. This establishes the structure of III.¹⁴

The generality of these 1,5-cycloadditions in *cis,cis*-1,5-cyclooctadiene was established with further addends. Thus, carbon tetrachloride, dimethylformamide, γ -butyrolactone, ethyl chloroacetate, and ethyl trichloroacetate gave derivatives of bicyclo[3.3.0]octane, thus furnishing an easy and convenient entry into the bicyclo[3.3.0]octane system. The reaction mixtures were not examined for the presence of small amounts of *endo* derivatives of bicyclo[3.3.0]octane or of derivatives of bicyclo[4.2.0]octane. The details of this work as well as elaboration of the mechanism will be published at a later date.

(8) For free-radical initiated additions of aldehydes to olefins, see M. S. Kharasch, W. H. Urry, and B. M. Kuderna [*J. Org. Chem.*, **14**, 248 (1949)], and T. M. Patrick, Jr. [*ibid.*, **17**, 1009 (1952)].

(9) A. C. Cope, M. Brown, and H. E. Petree, *J. Am. Chem. Soc.*, **80**, 2853 (1958).

(10) S. Goldschmidt and W. L. C. Veer, *Rec. trav. chim.*, **65**, 796 (1946).

(11) L. J. Bellamy, "The Infrared Spectra of Complex Molecules," Methuen Co., Ltd., London, 1954, p. 38.

(12) Obtained by Mr. F. E. Dickson of the Mellon Institute, Pittsburgh, Pa., on a Varian A-60 NMR Spectrometer.

(13) The author is grateful to Professor A. C. Cope for his kindness in furnishing a sample of this amide.

(14) Although it is conceivable that *exo,cis*-bicyclo[3.3.0]octane-2-carboxylic acid could result from rearrangement of III, and not from the simple hydrolysis of the trichloromethyl group, the analogous transannular cycloadditions described here as well as other evidence seem to establish clearly the structure of the chloroform adduct as III.

PITTSBURGH PLATE GLASS COMPANY ROSTYSLAW DOWBENKO
RESEARCH LABORATORIES
COATINGS AND RESINS DIVISION
SPRINGDALE, PENNSYLVANIA

RECEIVED DECEMBER 20, 1963

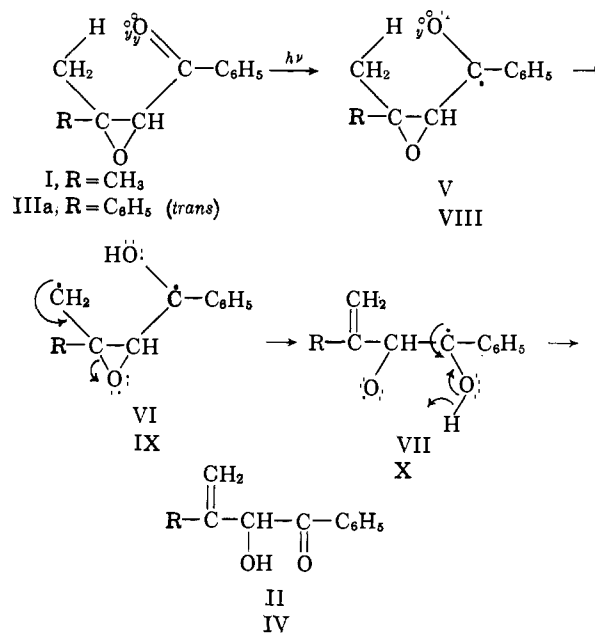
A General Theory of Photochemical Reactions. VII. Mechanisms of Epoxy Ketone Reactions

Sir:

In our previous publications on organic photochemistry,^{1,2} we presented a mechanistic treatment which allows discussion of the electronic details of photochemical transformations. As noted therein, our goals are exploration of the extent to which our hypothesis is correct, modification where necessary, and delineation of mechanistic subtleties. Presently we report two examples of a new photochemical rearrangement and an unusual case of a known photochemical rearrangement. We note (a) a unique difference in photochemical behavior of phenyl *vs.* alkyl ketones, (b) unusual migratory aptitude behavior, and (c) evidence in favor of our excited state description.^{1,2} In the first photochemical reaction, dimethylacrylophenone oxide (I) was observed to afford 1-phenyl-3-methyl-3-buten-2-ol-1-one (II) in 64% yield. Similarly *trans*-dypnone oxide (IIIa) afforded 1,3-diphenyl-3-buten-2-ol-1-one (IV) in 25% yield as the major product. In contrast the structurally related 3,4-epoxy-4-phenyl-2-pentanone (XV) led to 1-phenyl-2-methyl-1,3-butanedione (XVI) as the major product (25%).³

Aside from the synthetic utility of the new reaction described in Chart I, this transformation is of mechanis-

CHART I



tic interest, providing support for our concept of the excited state.^{1,2} Thus we have noted^{1,2,4} that because the single p_y (*i.e.*, n) electron not promoted in the $n-\pi^*$ excitation is localized in this oxygen orbital, the orbital will exhibit chemical behavior characteristic of reactive alkoxy radicals, one example being hydrogen abstraction.^{5,6} In the present instance reactants I and IIIa

(1) This approach was presented by H. E. Zimmerman at the 17th National Organic Symposium of the American Chemical Society, 1961, *cf.* Abstracts, p. 31.

(2) (a) For extended discussions, *cf.* paper IV: H. E. Zimmerman and D. I. Schuster, *J. Am. Chem. Soc.*, **84**, 4527 (1962); (b) H. E. Zimmerman, *Tetrahedron, Suppl. 2*, **19**, 393 (1963).

(3) Reactant syntheses and stereochemistry, photolysis details, degradative and other evidence for product structures, and nature of by-products—all will be detailed in our full paper where space permits.

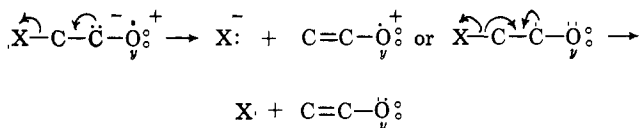
(4) Note H. E. Zimmerman, H. G. Dürr, R. G. Lewis, and S. Bram, *J. Am. Chem. Soc.*, **84**, 4149 (1962), for an example of p_y orbital reactivity toward a π -system.

(5) We have suggested (ref. 1, 2) that examples of p_y orbital hydrogen abstraction include the Norrish type II cleavage (R. G. W. Norrish, *Trans.*

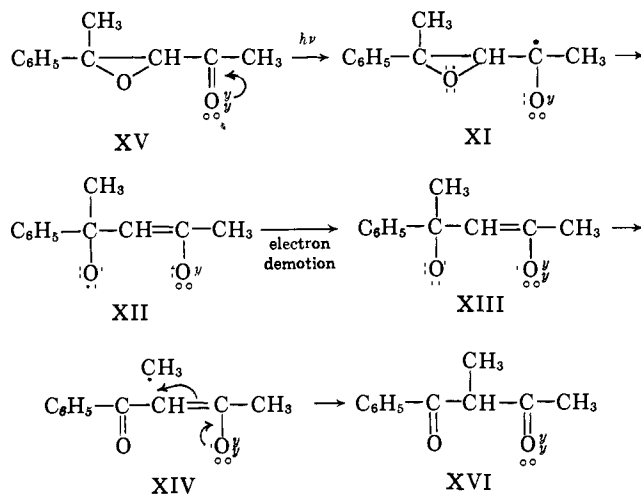
have $n-\pi^*$ excited states V and VIII, respectively (note ref. 2 for "circle, dot, y" notation). V and VIII have a γ -hydrogen which may be abstracted to give species VI (or IX) in which the methylenic odd electron is conjugated with a strained, epoxide ring which should open as indicated by homolytic β -elimination, thus affording diradical VII (or X). Intramolecular disproportionation leads to the observed products II and IV, respectively. This mechanism requires proximity of benzoyl and methyl groups; and in agreement with this, *cis*-dypnone oxide (IIIb) (CH_3 and benzoyl groups *trans*) was found to be largely unreacted under the usual conditions. Finally, we emphasize that hydrogen abstraction from a saturated carbon atom is generally strongly suggestive of radical and electron-deficient oxygen rather than electron-rich oxygen.

The second reaction described⁷ involves the formal migration of a methyl group to give β -diketonic product. This reaction is remarkable because the reactant (XV) differs only subtly from the cases of dimethylacrylophenone oxide (I) and dypnone oxide (IIIa) where the β -dicarbonyl product was a very minor product if formed at all. Secondly, the preferential migration of a methyl group rather than phenyl is uncommon and serves to cast mechanistic light on the reaction.

In our discussions of $n-\pi^*$ excited state reactivity,^{1,2} we noted that groups attached to the carbon adjacent to an excited carbonyl group might be expelled heterolytically or homolytically, *i.e.*



Clearly the reaction of XV begins with such a C-O fission, and the homolytic version nicely rationalizes the preferential methyl migration.⁸ Whether the methyl



Faraday Soc., **33**, 1521 (1937) and the Yang reaction (N. C. Yang and D. C. Yang, *J. Am. Chem. Soc.*, **80**, 2913 (1958)).

(6) An independent conclusion regarding hydrogen abstraction by the n orbital has been noted by M. Kaska, "Comparative Effects of Radiation," M. Burton, J. Kirby-Smith, and J. Magee, Eds., John Wiley and Sons, Inc., New York, N. Y., 1960, p. 72.

(7) After our discussion of this type photochemical reaction and presentation of an example (ref. 1), W. Reusch and C. K. Johnson (Abstracts of the 142nd National Meeting of the American Chemical Society, Sept., 1962, p. 89Q) described two further cases. Some further examples have also been described by C. Lehmann, K. Schaffner, and O. Jeger, *Helv. Chim. Acta*, **45**, 1031 (1962). Early examples of hydrogen migration have been described by S. Bodfors, *Chem. Ber.*, **51**, 214 (1918).

(8) (a) Preferred loss of methyl from XIII has analogy in the radical decomposition of cumene hydroperoxide (*cf.* M. S. Kharasch, A. Fono, and W. Nudenberg, *J. Org. Chem.*, **16**, 113 (1951)). (b) Fission of the α,β -carbon to carbon bond appears to be a reversible epoxy ketone reaction for which evidence will be discussed elsewhere.

migration is (1) by methyl radical expulsion with intermolecular recombination, (2) expulsion and recombination within a solvent cage, or (3) direct migration of diradicaloid species XII with concomitant electron demotion is presently under study. The occurrence of C-O fission in epoxy ketone XV *vs.* γ -hydrogen abstraction in I and IIIa is attributed to the greater excited (π^*) electron localization in the carbonyl group of XV and hence greater probability for β -elimination. In the excited benzoyl groups of I and IIIa the excited electron is distributed throughout the phenyl group as well as the carbonyl group and is less available.

From the occurrence of C-O fission we may conclude that the carbonyl carbon of the excited state has odd electron capabilities; indeed such a fission is strongly suggestive of an electron-rich carbon rather than the reverse.

Acknowledgment.—Support by Grant GM-07487 of the National Institutes of Health is gratefully acknowledged as are research assistantships supported by Grant DA-ORD-36 of the U. S. Army Research Office (Durham) and by the Research Committee of the Graduate School from Wisconsin Alumni Research Foundation funds.

DEPARTMENT OF CHEMISTRY
UNIVERSITY OF WISCONSIN
MADISON, WISCONSIN 53706

HOWARD E. ZIMMERMAN
BRIAN R. COWLEY
CHING-YUAN TSENG
JOSEPH W. WILSON

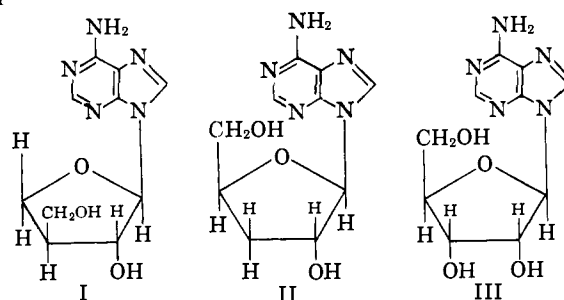
RECEIVED SEPTEMBER 30, 1963

The Biosynthesis of Cordycepin¹

Sir:

A number of nucleoside analogs have been found in nature.² One of these, cordycepin (I), was isolated from culture filtrates of *Cordyceps militaris* and the sugar moiety reported to be a branched chain pentose.³ More recently, Kaczka, *et al.*,⁴ have suggested that the sugar moiety of cordycepin is 3-deoxyribose (II). Kredich and Guarino,⁵ in their studies on the biosynthesis of cordycepin, reported that acetate and isovalerate were not precursors for cordycepose. Also, glucose-1-C¹⁴ and glucose-6-C¹⁴ were incorporated into cordycepose, whereas ribose-1-C¹⁴ was essentially not utilized. Adenine-8-C¹⁴ was incorporated into the purine moiety of cordycepin. Glucose was the sole carbon source.

This communication reports the results of studies on incorporation of formate-C¹⁴ and adenosine-U-C¹⁴ (III) into cordycepin and the distribution of C¹⁴ in the cordycepin.



The adenosine-U-C¹⁴ used was obtained by hydrolysis of adenosine 5'-phosphate-U-C¹⁴ with snake venom and

(1) This investigation was aided by Grant G8685-03 from the National Institutes of Health, United States Public Health Service.

(2) S. S. Cohen, *Science*, **139**, 1017 (1963).

(3) K. G. Cunningham, S. A. Hutchinson, W. Manson, and F. S. Spring, *J. Chem. Soc.*, 2299, 2301 (1951).

(4) F. A. Kaczka, N. R. Trenner, B. Arison, R. W. Walker, and K. Folkers, *Biochem. Biophys. Res. Commun.*, **14**, 456 (1964).

(5) N. M. Kredich and A. J. Guarino, *Biochim. Biophys. Acta*, **47**, 529 (1961).