sulfurization of III (1.5 g.) proceeded at 100° in a refluxing ethanol–Methyl Cellosolve solution in the presence of a 15-fold weight of catalyst to give 0.8 g. (67%) of crude 2′,3′-dideoxyadenosine. After three recrystallizations from ethanol, colorless crystals of IV (0.25 g.) were obtained, chromatographically homogeneous. Pure 2′,3′-dideoxyadenosine (IV) melted at 184–186°, $[\alpha]^{25}D$ −25.2° (*c* 1.01, H_2O); λ_{max}^{MeOH} 259.5 mμ (ε 14,800). *Anal.* Calcd. for $C_{10}H_{13}N_5O_2$: C, 51.1; H, 5.54; N, 29.8. Found: C, 50.9; N, 5.32; N, 29.6; R_f 0.45, $R_{Adenine}$ 1.80 (NH_4OH:DMF:*i*-PrOH, 10:25:65); R_f 0.36, $R_{Adenine}$ 1.19 (*n*-BuOH saturated with H_2O). The proton magnetic resonance spectrum of IV in D_2O showed a complex multiplet corresponding to four protons at δ 2.0 to 2.8 (C-2′ and C-3′ protons) and no absorption at δ 4.63 in the region of the C-3′ proton in 2′-deoxyadenosine in the same solvent.

These procedures are presently being applied to the preparation of other novel purine deoxy- and polydeoxynucleosides utilizing the commercially available deoxynucleosides obtained from DNA.

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ARIZONA STATE UNIVERSITY
DEPARTMENT OF CHEMISTRY
TEMPE, ARIZONA
MORRIS J. ROBINS[21]
ROLAND K. ROBINS[22]

RECEIVED June 22, 1964

Synthesis of Deoxyribonucleoside-3′,5′ Cyclic Phosphates by Base-Catalysed Transesterification

Sir:

Hydrolysis of *p*-nitrophenyl thymidine-3′ phosphate in *aqueous* sodium hydroxide produces both thymidine-3′ and thymidine-5′ phosphates, thymidine-3′,5′ cyclic phosphate being an intermediate in the reaction.[1] This communication describes the reaction of *p*-nitrophenyl esters of deoxyribonucleotides with base in *anhydrous* solvents where deoxyribonucleoside-3′,5′ cyclic phosphates are produced in excellent yields.

5′-O-Di-*p*-methoxytritylthymidine[2,3] was reacted with *p*-nitrophenyl phosphate and dicyclohexylcarbodiimide in dimethylformamide–pyridine[4] to yield, after acetic acid treatment, *p*-nitrophenyl thymidine-3′ phosphate. The nucleotide (20 μmoles) as its ammonium salt in dimethyl sulfoxide (2.0 ml.)[5] was treated with molar potassium *t*-butoxide in *t*-butyl alcohol (1.0 ml.)[6] at 20°. Immediately an intense yellow color developed and chromatography in isopropyl alcohol–concentrated ammonia–water (7:1:2) indicated that formation of thymidine-3′,5′ cyclic phosphate was quantitative and complete in less than 5 min. The nucleotide was isolated by ion-exchange chromatography on diethylaminoethyl cellulose[7] and characterized by its spectral properties, paper chromatography in three systems, electrophoresis at pH 7.5, and hydrolysis to thymine in molar hydrochloric acid at 50°.[7-9]

Although *p*-nitrophenyl uridine-5′ phosphate is not hydrolysed by aqueous alkali *via* the nucleoside-3′,5′ cyclic phosphate,[1] the reaction of *p*-nitrophenyl thymidine-5′ phosphate (sodium salt) was next examined. Under the conditions described above, conversion to thymidine-3′,5′ cyclic phosphate was complete in 60 min.[10] Similarly, *p*-nitrophenyl deoxyadenosine-5′ phosphate[11] was completely converted to deoxyadenosine-3′,5′ cyclic phosphate, although the reaction proceeded at about 80% of the rate of the thymidine-5′ nucleotide. Deoxyadenosine-3′,5′ cyclic phosphate was characterized by its ion-exchange, spectral, chromatographic, and electrophoretic properties, by its resistance to molar hydrochloric acid at 50°, and by its hydrolysis by the adenosine-3′,5′ cyclic phosphate diesterase of brain.[7,12]

When formamide was substituted for dimethyl sulfoxide as solvent,[13] there was no detectable reaction of *p*-nitrophenyl thymidine-5′ phosphate after 60 min. In dimethylformamide, thymidine-3′,5′ cyclic phosphate was produced at about 75% of the rate in dimethyl sulfoxide.

Experiments to determine the utility of this reaction in the synthesis of other deoxyribonucleoside-3′,5′ cyclic phosphates,[7] ribonucleoside-3′,5′ cyclic phosphates,[14] and internucleotide linkages are in progress.

(1) A. F. Turner and H. G. Khorana, *J. Am. Chem. Soc.*, **81**, 4651 (1959).

(2) H. Schaller, G. Wiemann, B. Lerch, and H. G. Khorana, *ibid.*, **85**, 3821 (1963).

(3) M. Smith, D. H. Rammler, I. H. Goldberg, and H. G. Khorana, *ibid.*, **84**, 430 (1962).

(4) This solvent system was first described by R. K. Ralph, W. J. Connors, H. Schaller, and H. G. Khorana, *ibid.*, **85**, 1983 (1963), and was used here because *p*-nitrophenyl phosphate is insoluble in anhydrous pyridine.

(5) Dimethyl sulfoxide is a useful solvent in nucleotide chemistry; see J. G. Moffatt, *Can. J. Chem.*, **42**, 599 (1964).

(6) R. B. Clayton, H. B. Henbest, and M. Smith, *J. Chem. Soc.*, 1982 (1957).

(7) G. I. Drummond, M. W. Gilgan, E. J. Reiner, and M. Smith, *J. Am. Chem. Soc.*, **86**, 1626 (1964).

(8) G. M. Tener, H. G. Khorana, R. Markham, and E. H. Pol, *ibid.*, **79**, 430 (1957).

(9) These criteria do not exclude the possibility of anomerization (at the glycosidic linkage). However, other experiments involving *t*-butoxide catalysis indicate that this is improbable. See R. Letters and A. M. Michelson, *J. Chem. Soc.*, 1410 (1961); A. M. Michelson and W. E. Cohn, *Biochemistry*, **1**, 490 (1962).

(10) Thymidylyl-(5′→3′)-thymidine is unaffected under the same conditions (unpublished results).

(11) Kindly donated by Dr. W. E. Razzell.

(12) G. I. Drummond and S. Perrot-Yee, *J. Biol. Chem.*, **236**, 1126 (1961).

(13) Formamide was used as solvent in the potassium *t*-butoxide catalysed transesterification of ribonucleic acid to ribonucleoside-2′,3′ cyclic phosphates; see D. Lipkin and P. T. Talbert, *Chem. Ind.* (London), 143 (1955).

(14) M. Smith, G. I. Drummond, and H. G. Khorana, *J. Am. Chem. Soc.*, **83**, 698 (1961).

FISHERIES RESEARCH BOARD OF CANADA
TECHNOLOGICAL RESEARCH LABORATORY
VANCOUVER 8, B. C., CANADA
MICHAEL SMITH

RECEIVED JUNE 24, 1964

Heat of Hydrogenation of Bicyclo[2.2.2]octa-2,5,7-triene

Sir:

In view of recent commentary on the question of delocalization energy in bicyclo[2.2.2]octa-2,5,7-triene ("barrelene"),[1] the author wishes to report the value obtained in this laboratory for the heat of hydrogenation of this substance. A purified sample, kindly provided by Dr. H. E. Zimmerman, was reduced in acetic acid solution at 25° with the uptake of 2.99 molar equivalents of hydrogen. The heat of hydrogenation was −93.78 ± 0.31 kcal./mole.

Since the heat of hydrogenation of bicyclo[2.2.2]-octa-2,5-diene is −56.21 ± 0.10 kcal./mole,[2] the heat evolved in reduction of the first double bond of barrelene

(1) H. E. Zimmerman and G. L. Grunewald, *J. Am. Chem. Soc.*, **86**, 1434 (1964), footnote 2.

(2) R. B. Turner, W. R. Meador, and R. E. Winkler, *ibid.*, **79**, 4116 (1957).

is 37.6 kcal./mole. This represents the highest value we have yet encountered for the heat of hydrogenation of an ethylenic linkage (cyclohexene, −27.1 kcal./mole[2]; *cis*-di-*t*-butylethylene, −36.2 kcal./mole[3]). The incorporation of a high degree of strain in the barrelene molecule is evident from examination of Dreiding models.

Although the present result does not rigorously exclude the possibility of ground-state delocalization in barrelene, it is clear that such stabilization, if present, is swamped by steric strain.

Acknowledgment.—The support of the National Science Foundation is gratefully acknowledged.

(3) R. B. Turner, D. E. Nettleton, and M. Perelman, *J. Am. Chem. Soc.*, **80**, 1430 (1958).

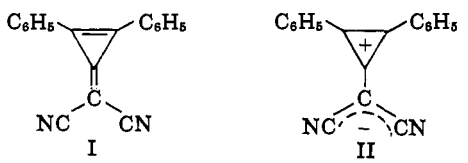
DEPARTMENT OF CHEMISTRY RICHARD B. TURNER
RICE UNIVERSITY
HOUSTON, TEXAS

RECEIVED July 9, 1964

1-Dicyanomethylene-2,3-diphenylcyclopropene ("1,1-Dicyano-3,4-diphenyltriafulvene")[1]

Sir:

Among the nonalternant pseudoaromatic systems that of methylenecyclopropene[2] ("triafulvene")[3] was unknown until recently, when three compounds of this type have been described.[4-6] We wish to report another representative of this group, 1-dicyanomethylene-2,3-diphenylcyclopropene, in which both the classical (I) and the dipolar (II) structure make a contribution to the ground state of the molecule. We expected the dipolar form of the triafulvene, in which the negative charge is localized mostly at the exocyclic carbon atom (C-1), to be enhanced by such electronegative substituents as the nitrile group.



Refluxing diphenylcyclopropenone[7] and malononitrile in freshly distilled acetic anhydride and recrystallization from benzene gave a 4.8% yield of yellowish crystals, m.p. 294° dec. *Anal.* Calcd. for $C_{18}H_{10}N_2$: C, 85.0; H, 4.0; N, 11.0; mol. wt., 254. Found: C, 85.2; H, 4.2; N, 10.8; mol. wt., 254 (by mass spectroscopy).[8,9] The infrared spectrum of the compound (in Nujol) showed strong peaks at 2227, 1890, 1618, 1522, 1488, 1466, 1397, 777, and 693 cm.$^{-1}$, the most interesting among them being the one at 1890 cm.$^{-1}$. It appears in the three other methylenecyclopropene derivatives known[4-6] at 1828, 1835, and 1852 cm.$^{-1}$, respectively, and represents, in our opinion, the shifted frequency (1818 cm.$^{-1}$) of the cyclic double bond observed in 1,2-diphenylcycloprop-1-ene derivatives.[10] This would tend to show that the classical form I makes a significant contribution to the ground state of the molecule.

The n.m.r. spectrum in anhydrous trifluoroacetic acid[11] showed two unresolved multiplets at τ 1.95 and 2.32 (tetramethylsilane as standard) with relative areas 2:3. As we found for diphenylcyclopropenone in trifluoroacetic acid (τ 2.05 and 2.37) and $CDCl_3$ (τ 2.20 and 2.55) the same ratio of areas (2:3), we assume that the two signals correspond to the *ortho*- and the *meta- plus para*-hydrogen atoms of the phenyl rings.[12]

It is noteworthy that C-1 of I is not protonated under these circumstances as only the above multiplets have been found.

The ultraviolet spectrum was measured in dioxane (longest band: 363 mμ (log ϵ 4.00)), acetonitrile (352 (4.07)), trifluoroacetic acid (335 (4.23)), and mesitylene (373 (3.91)). The dependence of the wave length on the solvent seems to indicate that in the excited state the "fulvenic" (dipolar) form of the molecule (II) makes a significant contribution; of interest is the considerable shift observed in concentrated sulfuric acid: 386 mμ (log ϵ 3.64). This may be due to a *chemical* reaction of the solvent with the solute. This hypothesis is supported by the observation that heating of I with 90% sulfuric acid at 100° (15 min.) gives a product (from acetic acid, m.p. 199–200° (dec.)) which, according to the analysis, is the corresponding diamide *plus* one molecule of H_2SO_4. *Anal.* Calcd. for $C_{18}H_{16}N_2O_6S$: C, 55.7; H, 4.2; N, 7.2; S, 8.2. Found: C, 55.9; H, 4.1; N, 7.0; S, 7.8.

Finally, we wish to report the dipole moment 7.9 ± 0.1 D. of I (in dioxane at 30°). This figure points to the contribution of the dipolar form (II) to the ground state of the molecule as shown by comparison with the moments of cyclohexylidenemalononitrile (5.45 ± 0.02 D. in benzene at 30°), diphenylmethylenemalononitrile (5.85 ± 0.05 D. in benzene at 30°), ω,ω-dicyanodibenzofulvene (5.53 ± 0.07 D. in benzene at 30°), and ω,ω-dicyanoheptafulvene (7.49 D. in dioxane at 25°).[13] Thus, 1,1-dicyano-3,4-diphenyltriafulvene in its ground state is a resonance hybrid of I and II.

(1) Fulvenes and Thermochromic Ethylenes, part 34. Part 33: E. D. Bergmann and R. Ikan, *J. Org. Chem.*, **28**, 3341 (1963).

(2) *Cf.* E. D. Bergmann, "The Fulvenes," in "Progress in Organic Chemistry," Vol. 3, 1955, p. 81.

(3) "Triangle" is the trivial name recently suggested by O. Chalvet, R. Daudel, and J. J. Kaufman, *J. Phys. Chem.*, **68**, 490 (1964).

(4) A. S. Kende, *J. Am. Chem. Soc.*, **85**, 1882 (1963).

(5) M. A. Battiste, *ibid.*, **86**, 942 (1964).

(6) W. M. Jones and J. M. Denham, *ibid.*, **86**, 944 (1964).

(7) R. Breslow, J. Posner, and A. Krebs, *ibid.*, **85**, 234 (1963). We are grateful to Professor R. Breslow for a detailed descripion of the preparation of this ketone.

(8) The analogous heptafulvene derivative has been prepared by the same method by Y. Kitabara and K. Doi [Japanese Patent 13071; *Chem. Abstr.*, **59**, 9914 (1963)].

(9) We are indebted for the mass-spectroscopic investigation of the compound to Dr. Z. Pelah at the Chemistry Department, Stanford University, Stanford, Calif.

(10) See, *e.g.*, R. Breslow, J. Lockhart, and H. W. Chang, *J. Am. Chem. Soc.*, **83**, 2375 (1961); R. Breslow and H. W. Chang, *ibid.*, **83**, 2367 (1961).

(11) The substance proved insoluble in deuteriochloroform.

(12) For this explanation, *cf.* R. Breslow, H. Höver, and H. W. Chang, *J. Am. Chem. Soc.*, **84**, 3168 (1962).

(13) This value was reported by M. Yamakawa, *et al.*, *ibid.*, **82**, 5665 (1960).

DEPARTMENT OF ORGANIC CHEMISTRY ERNST D. BERGMANN
HEBREW UNIVERSITY, JERUSALEM ISRAEL AGRANAT

RECEIVED JUNE 4, 1964

An Aliphatic Triafulvene[1]

Sir:

The synthesis of the crystalline quinocyclopropene I,[2] the first stable derivative of the triafulvene system,

(1) "Triafulvene" is the concise trivial name suggested by E. D. Bergmann and I. Agranat for the methylenecyclopropene system.

(2) A. S. Kende, *J. Am. Chem. Soc.*, **85**, 1882 (1963).