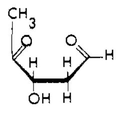

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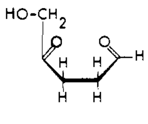

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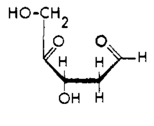

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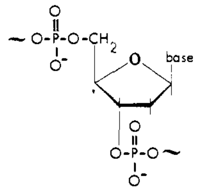

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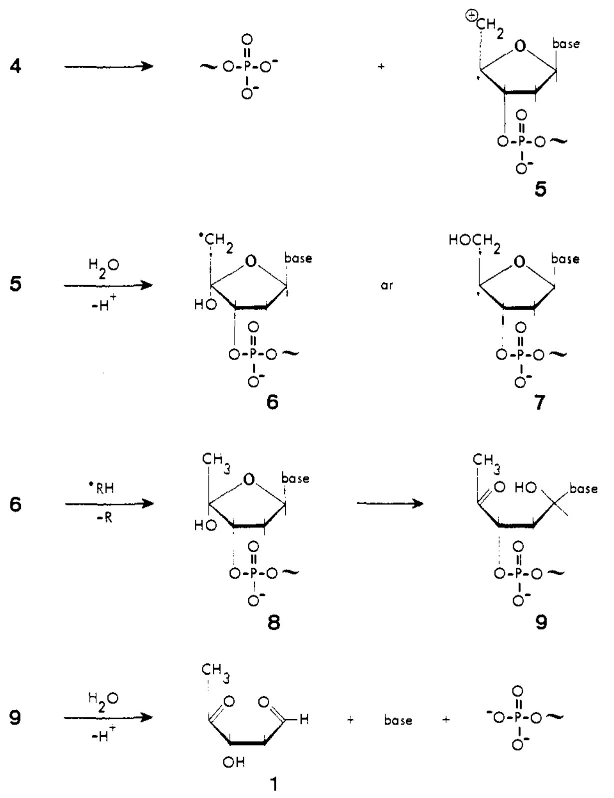
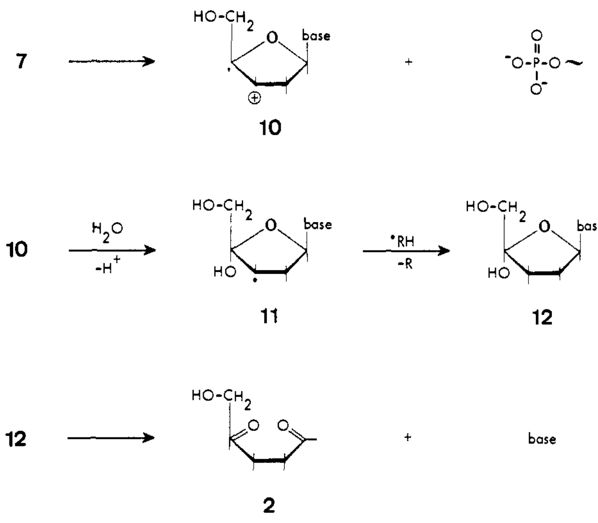


of compounds.[2] Retention indices substantiated the assignments.[3] Further details will be given elsewhere.[3]

When DNA is γ-irradiated in deoxygenated N_2O saturated aqueous solution, the OH radicals and H atoms produced in the system will attack the DNA. Nearly all H atoms and the major part of the OH radicals add to the double bonds of the bases but 10–20% of the OH radicals react with the sugar moiety by abstracting hydrogen.[4] About one-fifth[5,6] of these are expected to abstract the hydrogen atom bound to C-4 of the deoxyribose moiety to form radical **4**.

For the cleavage of the phosphate ester bond two possible routes have been postulated on the basis of studies on model compounds, e.g., glycerophosphates[7,8] and ribose 5-phosphate.[9,10] **4** may eliminate a phosphate ester anion involving a carbocation **5** as an intermediate which adds water with the loss of a proton to give **6** or **7**. Alternatively[9,10] radical **4** ring-opens by adding water and undergoes β-elimination.

In a disproportionation reaction with other radicals (·RH) present, **6** forms compound **8**. **8** is unstable and via **9** gives **1** together with free base and the other part of the DNA strand with a 5′-phosphate end group. The release of free base is observed in the radiation chemistry of DNA.[11,12]



Radical **7** in the same way as **5** will lose a phosphate ester anion giving carbocation **10**. Thus the second phosphate ester bond is cleaved without the labile phosphate ester **9** being an intermediate.

In similar steps as above, **10** via **11** and **12** eventually leads to product **2**. In the mechanism laid out above, radical **4** eliminates the 5′-phosphate ester. The 3′-phosphate ester bond is cleaved in a subsequent step. However, it is also possible that **4** eliminates the 3′-phosphate ester and the other phosphate ester bond is broken in the later step. This change in the mechanism also leads to the products **1** and **2**.

Product **3** will be formed if radical **4** or one of its successors is oxidized. This mechanism is presently under investigation.

Acknowledgment. We thank Miss Angelika Schmidt and Mr. Klaus Neuwald for their technical assistance.

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MINDO/3 Study of Some Simple Carbocations[1,2]

Sir:

It has been frequently stated that semiempirical MO methods cannot be used for ions with parameters appropriate to neutral molecules and in particular that they inevita-

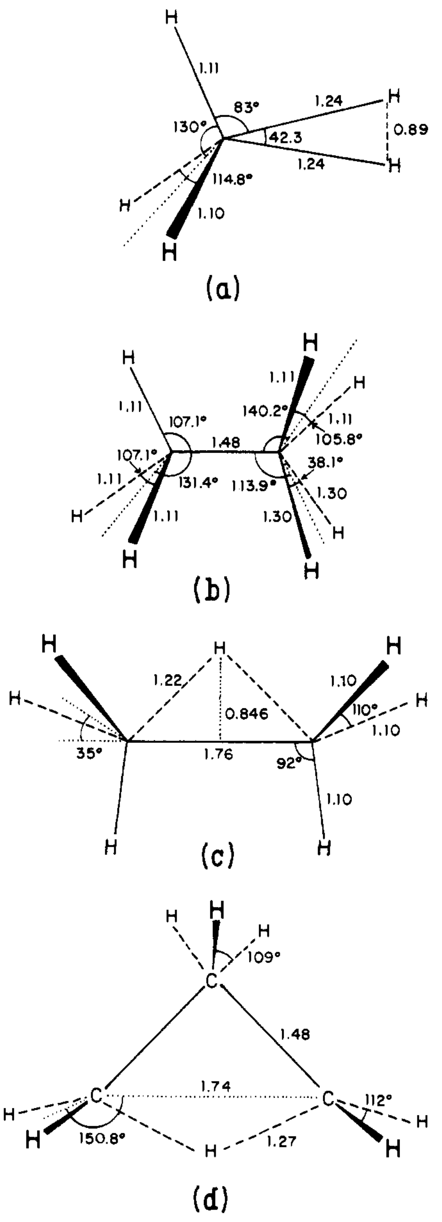


Figure 1. MINDO/3 geometries for (a) CH_5^+, (b) stable isomer of $C_2H_7^+$ (**1**), (c) unstable isomer of $C_2H_7^+$ (**2**), and (d) edge-protonated cyclopropane (**6**). Internuclear distances in Å (0.1 nm).

bly overestimate the stabilities of nonclassical ions relative to those of classical isomers. The first objection was refuted some time ago by the development of MINDO/2[3] and MINDO/2′[4] which gave good estimates of the heats of formation of classical ions. There were, however, indications that these procedures still overestimated the stabilities of nonclassical isomers to some extent. Here we present results for some simple classical and nonclassical ions which suggest that this difficulty has been overcome in the latest version of MINDO (MINDO/3[5]).

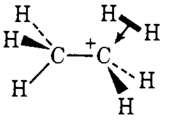
Figure 1a shows the MINDO/3 equilibrium geometry[6] for protonated methane (CH_5^+). This agrees very closely with those given by recent ab initio SCF MO studies,[7] corresponding to a σ complex[8] formed by H_2 as donor and CH_3^+ as acceptor; $H_2 \rightarrow CH_3^+$. The calculated heat of formation (219.3 kcal/mol) agrees well with experiment (222.1 kcal/mol[9]). We also studied the equilibration of the hydrogen atoms in CH_5^+ by pseudorotation, finding a barrier of 4.2 kcal/mol. We found no other minimum in the CH_5^+ potential surface.

Table I. Relative Heats of Formation of $C_3H_7^+$ Isomers

Compound		Heat of formation (kcal/mol) relative to that of *b*+					
		MINDO/3	Experiment	MINDO/2′[a]	STO-3G[b]	4-31G[b]	6-31G*[c]
n-Pr^+	(**3**)	18.6	16[d]	24.5	19.7	16.9	14.1
i-Pr^+	(**4**)	(0)	(0)	(0)	(0)	(0)	(0)
‖ → CH_3^+	(**5**)	12.3	7[e]	3.5	22.8	17.3	13.0
<:H^+	(6)	7.5		−3.9	27.1	27.1	19.1
◁--H^+	(7)	88.3		56.0	161.0	139.6	130.1

[a] Reference 16. [b] Reference 17. [c] Reference 18. [d] Reference 9. [e] Reference 9.

Protonated ethane ($C_2H_7^+$) would be expected to be derived from CH_5^+ through replacement by methyl of either a "CH_3" hydrogen (**1**) or a "H_2" hydrogen (**2**). MINDO/3 indeed predicts it to have a C_s structure **1** shown in detail in Figure 1b, i.e., $H_2 \rightarrow {}^+CH_2CH_3$. Note that the HH bond in the $H_2 \rightarrow C^+\equiv$ moiety is shorter, and the CH bonds longer, than in CH_5^+; this would be expected since $CH_3CH_2^+$ is inferior as an acceptor to CH_3^+ so the double bond to it from H_2 is correspondingly weaker. The calculated heat of formation (199.8 kcal/mol) is somewhat less than experiment (218.8 kcal/mol[9]).



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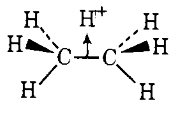


2

In this case the ab initio calculations of Pople et al.[7] led to a different result, predicting **1** to be less stable than the C_{2v} structure **2** by 14 kcal/mol. We found **2** to be unstable; in order to calculate its properties we had to enforce C_{2v} symmetry. The resulting structure (Figure 1c) agrees closely with that of Pople et al.[7] but the calculated heat of formation is greater than that of **1** by 15 kcal/mol.

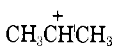
The experimental evidence, while not conclusive, certainly seems to suggest that **1** is more stable than **2**. It has been shown[10] that the reaction between CH_4 and CH_3^+ in crossed molecular beams leads to a $C_2H_7^+$ species which appears to be **1** rather than **2**. It is difficult to see how this could be the case if **2** were the lower in energy since it should be formed initially in the combination of CH_3^+ with CH_4. Moreover, Olah et al.[11] have found that ethane undergoes deuterium exchange in magic acid, implying that the protonation of ethane leads first to **1** rather than **2**. They suggested that the concomitant cleavage to (CH_4 + CH_3^+) might take place by a secondary isomerization of **1** to **2**; however, there is no need to postulate this since **1** could cleave directly to (CH_4 + CH_3^+).

The last series of ions comprise species formed by protonation of propene (**3**, **4**) or cyclopropane (**5**–**7**). MINDO/3 predicts only **4** and **6** to be stable, the other species being of higher energy than **6** and isomerizing to it without activation. Their properties were studied by imposing suitable geometrical constraints.[12] The structure of **6** is shown in Figure 1d. The calculated heat of formation of **4** (184.3 kcal/mol) agrees quite well with experiment (191.7 kcal/mol[9]). The heats of formation of **3**–**7**, relative to that of **4**, are listed in Table I.

The experimental evidence, from mass spectrometry[9,13] indicates that **3** is unstable, rearranging at once to **4**, and

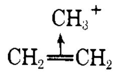
$CH_3CH_2CH_2^+$

3



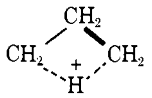
$CH_3\overset{+}{C}HCH_3$

4



$CH_2 \overset{CH_3^+}{\underset{}{\overset{\uparrow}{=}}} CH_2$

5



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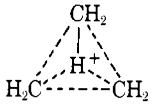

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that the only other stable $C_3H_7^+$ species is one of the protonated cyclopropanes (**5–7**). Moreover the relative energies of the three ions (Table I) are in essentially perfect agreement with our calculations, assuming that the stable form of protonated cyclopropane is **6**. All available calculations (Table I) agree with simple MO arguments in ruling out **7** as a candidate. The only other evidence comes from studies of the reactions of cyclopropanes with acid in solution.[14] These have been held to indicate that protonation of cyclopropane leads to **6** rather than **5**. However, the scrambling of hydrogen atoms under these conditions implies that **5** and **6** cannot differ much in energy; we predict the activation energy of the scrambling reaction to be ≤ 6 kcal/mol.[15]

MINDO/2′ calculations[16] (see Table I) had correctly predicted **4** and **6** to be the only stable $C_3H_7^+$ species; however, they incorrectly predicted **6** to lie below **4** instead of above. Apparently the small residual tendency of MINDO/2′ to overestimate the stabilities of nonclassical ions relative to classical ions has been overcome in MINDO/3.

Table I also shows the results of ab initio SCF calculations by Pople et al. using STO-3G,[17] 4-31G,[17] and 6-31G*[18] basis sets. It will be seen these make a rather poor showing. The first two[17] incorrectly predict a distorted *n*-propyl cation (**3**) to be more stable than *any* of the protonated cyclopropanes, and, while the most recent calculations[18] make **5** and **6** marginally more stable than **3**, the difference is still less than that observed and this small improvement is achieved only at the expense of a worse estimate of the difference between **3** and **4**. Moreover none of these methods can give estimates of the heats of formation of the various species—only their relative energies.

The fact that so little improvement was achieved by passing from 4-31G to 6-31G* is particularly disturbing. It certainly seems to suggest that the ab initio SCF approach tends to *underestimate* the stabilities of nonclassical structures relative to those of classical isomers. As pointed out above, this seems also to have been the case for $C_2H_7^+$, and other examples could be cited.[19]

Part of the error here may have been due to the use of assumed (STO-3G) geometries in the 4-31G and 6-31G* calculations.[17,18] It is unfortunately expensive to calculate geometries using large basis sets. This difficulty does not arise in the case of MINDO/3 where calculations for much larger systems, with complete geometry optimization, are trivial. Since the results are apparently also more accurate than those given by the best available ab initio methods, this would seem to be the method of choice at present for the study of "nonclassical" carbonium ions.[23]

References and Notes

(1) This work was reported at the 23rd National Organic Symposium of the American Chemical Society, Tallahassee, Fla., June 1963, and at the South West Regional Meeting of the American Chemical Society, El Paso, Texas, Dec 1963.

(2) This work was supported by the Air Force Office of Scientific Research (Contract No. F44620-71-C-0119) and by the Robert A. Welch Foundation (Grant No. F-126). The calculations were carried out using the CDC 6400/6600 computer at the University of Texas Computation Center.

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(6) All the geometries reported here were found by minimizing the energy with respect to *all* geometrical variables, no assumptions of any kind being made—except in the case of unstable species (e.g., *n*-Pr$^+$; see below) where specific geometrical constraints had to be imposed to prevent rearrangement to more stable species.

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(15) Since the potential surface is rather complicated, we are not sure that there may not be a path of lower energy than the one we found, which corresponded to a barrier of 6.0 kcal/mol.

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(23) Since this manuscript was submitted, Dr. W. Thiel has found an additional minimum on the potential surface for $C_2H_7^+$, similar to **2** but with the methyl groups staggered instead of eclipsed. The calculated heat of formation (211.8 kcal/mol), while less than that for **2**, is still greater by 7 kcal/mol than that for **1**. The central CH and CC distances are 1.25 and 1.67 Å, respectively, compared with 1.22 and 1.76 Å for **2**.

(24) Robert A. Welch Postdoctoral Fellow.

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Evidence for Ion Pairing of Carbanions in Methanol

Sir:

A recent communication by Hogen-Esch,[1] described an elegant spectral investigation of the solution environment of fluoradenide salts. No evidence was found for ion pairing in methanol or ethanol. This observation seriously damages the only simple explanation of the mysterious cation dependent effects which have been observed when methoxide salts have been employed to measure the kinetic and equilibrium acidities of carbon acids in methanol.[2] As methoxide-methanol is one of the most common media for carbanion studies and is a prototype in its class of polar, protic solvents, a knowledge of its capacity to solvate and separate ions is of crucial importance. We have therefore extended the work of Hogen-Esch[1] and wish to report the first direct evidence for carbanion ion pairing in methanol.

Reaction between fluoradene and potassium methoxide or lithium methoxide in methanol gave solutions with spectral characteristics identical with those attributed by Hogen-Esch to hydrogen bonded, free fluoradenide ions. (See Figure 1.) To our surprise, however, the use of tetramethylammonium methoxide gave an altered spectrum in which the broad absorption at ca. 536 nm was replaced by two distinct maxima at 516 and 549 nm. (See Figure 1.)