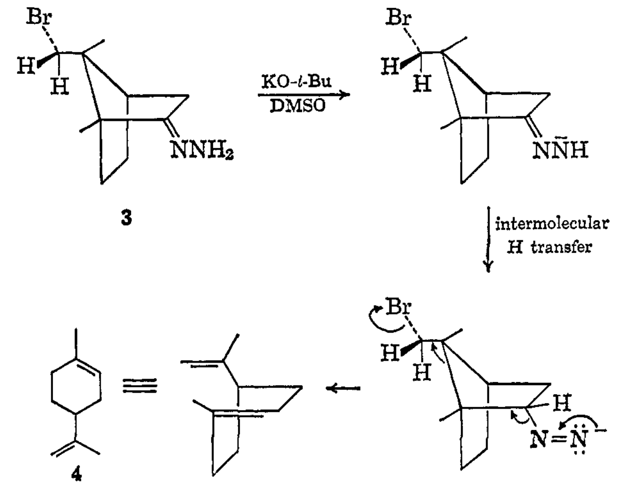
SCHEME I

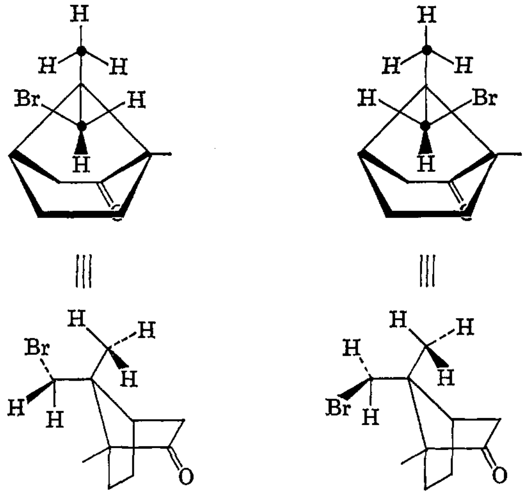


such a manner as to allow "zigzag" type coupling of only one of the hydrogens α to the bromo group with the bridge methyl group.[11–14] There are two conformations of **2** which would be capable of the specific long-range coupling described above, *i.e.*, **2a** and **2b**. Conformation **2b** would not be so favorable as **2a** owing to the additional interaction of the bromine atom with the bridgehead methyl group. Fragmentation would also be more favored from conformation **2a** than from **2b**.[1,5] Formation of the hydrazone **3** would not affect the conformation of the π-bromomethylene group, so that in the reaction of **3** with potassium *t*-butoxide the stereochemistry is the same as in the starting ketone.

Experimental[15]

***trans*-π-Bromocamphor** (2).—This compound was prepared as described by Corey[16] from α-bromocamphor in 50% over-all yield, m.p. 94–95° (lit.[16] m.p. 93–95°). The n.m.r. spectrum has an AB quartet with one doublet centered at τ 6.40 and the second doublet centered at 6.80 (J_{AB} = 10 c.p.s., area 2 protons). The doublet at lower field has additional splitting equal to 1 c.p.s. The methyl groups appear at τ 9.06 (bridgehead methyl, singlet, area 3 protons) and 8.99 (bridge methyl, doublet, J = 1.0 c.p.s.).

Wolff–Kishner Reduction of *trans*-π-Bromocamphor (2).[7,16]—To 46 g. (0.2 mole) of *trans*-π-bromocamphor in 150 ml. of absolute ethanol were added 27 g. (0.8 mole) of anhydrous hydrazine and 12 g. (0.2 mole) of glacial acetic acid. The mixture was heated under reflux for 3 hr., the ethanol was removed under reduced pressure, and the mixture was brought to its original volume with ether. The lower hydrazine layer was removed and the reaction mixture was washed once with 10% sodium hydroxide saturated with sodium chloride solution and three times with saturated sodium chloride solution and dried over sodium sulfate. The solvent was removed under reduced pressure and the crude hydrazone was reduced without further purification.



2a 2b

Figure 1.

To 10 g. of potassium *t*-butoxide (MSA Research Corp.) in 25 ml. of dimethyl sulfoxide, which had been dried over molecular sieves, was added a solution of 12.5 g. of *trans*-π-bromocamphor hydrazone in 25 ml. of dimethyl sulfoxide over a 20-min. period. Nitrogen was evolved and the reaction mixture turned a deep wine red during this addition. The mixture was stirred at room temperature for 16 hr. The mixture was heated to 35–45° at which temperature the reaction became exothermic and warmed to a maximum temperature of 80° where it was maintained for an additional 3 hr. The mixture was cooled, poured into 500 ml. of ice water, acidified with dilute hydrochloric acid, and extracted with ether. The combined ether extracts were washed with 3% hydrochloric acid solution, water, and saturated sodium chloride solution and dried over sodium sulfate. The ether was removed at reduced pressure, and the residue (5.7 g.) was distilled through a 10-cm. Vigreux column. The only fraction (1.97 g., 30% yield) obtained boiled at 58–59° (12 mm.): n^{23}_{D} 1.4747, single peak on gas chromatography [reported for limonene, b.p. 60.5–61° (13 mm.),[17] n^{20}_{D} 1.4722[18]]. The n.m.r. and infrared spectra and the gas chromatography retention time of our isolated product were identical with an authentic sample of limonene, b.p. 59° (12 mm.), n^{27}_{D} 1.4695, obtained from Eastman Organic Chemicals.

Acknowledgment.—The authors wish to acknowledge many helpful discussions with Dr. T. J. Flautt of these laboratories concerning the n.m.r. spectra. They are also grateful for helpful comments on the manuscript by Dr. P. J. Kropp.

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[12] C. W. Jefford, W. von Philipsborn, C. Viel, B. Waegell, and A. Melera, Abstracts, 148th National Meeting of the American Chemical Society, Chicago, Ill., Sept. 1964, p. 82S.

[13] C. N. Banwell and M. Sheppard, *Discussions Faraday Soc.*, **No. 34**, 115 (1962).

[14] (a) Professor Walter Meyer has also observed long-range spin–spin coupling in π-substituted camphor derivatives. Deuterium-labeling experiments, now in progress in his laboratories, should establish definitively the exact mode of coupling. We thank Professor Meyer for communicating this information to us prior to publication. (b) Tori similarly has observed long-range coupling in π-bromocamphor but has not discussed the coupling in terms of conformation. K. Tori, Y. Hamashima, and A. Takamizawa, *Chem. Pharm. Bull.* (Tokyo), in press.

[15] Melting points were determined on a micro hot-stage apparatus and are corrected. Boiling points are uncorrected. N.m.r. spectra were determined on a Varian A-60 spectrometer in deuteriochloroform or carbon tetrachloride solution using tetramethylsilane as an internal standard. Infrared spectra were determined on a Perkin-Elmer Model 137 infrared spectrometer in CH_2Cl_2 solution.

[16] E. J. Corey, S. W. Chow, and R. A. Scherer, *J. Am. Chem. Soc.*, **79**, 5773 (1957).

[17] H. G. Rule and A. R. Chambers, *J. Chem. Soc.*, 145 (1937).

[18] V. N. Ipatieff, H. Pines, V. Dvorkovitz, R. C. Olberg, and M. Savoy, *J. Org. Chem.*, **12**, 34 (1947).

Molecular Orbital Calculations of the Norbornyl Cation Using an Extended Hückel Theory

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Received November 17, 1964

Recently, Hoffmann has presented an extended Hückel theory (E.H.T.) suitable for calculations of

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molecular orbitals of relatively complex organic molecules.[2] These molecular orbitals are linear combinations of all the atomic orbitals (Slater orbitals) of the outer valence shells of the atoms of the molecule. Thus, this E.H.T. handles saturated and unsaturated molecules or ions equally well.

These calculations are carried out on an IBM 7094 computer. Input of the program consists of precise atomic coordinates of the various atoms; important output consists of a set of molecular orbitals and the energies associated with them, the total potential energy of the species, and electron densities or charge distributions. In order to calculate the preferred geometry of a molecule (or ion), one computes a set of molecular orbitals and consequently the total energy for a particular geometry of a species. The geometry is then varied in some systematic manner and a new set of molecular orbitals and a total energy is calculated. The procedure is repeated until a minimum energy and thus the preferred geometry is obtained. These calculations are for the gas phase and, of course, neglect solvation effects.

Although the treatment overemphasizes steric repulsions and the energies for ionic species are questionable, it appears to lead to correct molecular geometries and charge distributions.[2] It seemed desirable to use this method to calculate the preferred geometry of the norbornyl cation. These calculations would possibly shed some light on the nonclassical carbonium ion controversy as well as help determine the validity of this E.H.T. if the existence of nonclassical carbonium ions is ever proved or disproved experimentally.[3] Hoffmann has calculated the energies of the norbornyl cation which possesses the undistorted norbornane geometry, but he has not tried to minimize the energy by varying the structure. We have determined the most stable geometry of the norbornyl cation according to this E.H.T. by approaching the geometry of the ion from the π-route.[4] This geometry was then varied systematically and it was shown that any small variation of its geometry decreased the stability of the ion.

The geometry of the most stable form of the norbornyl cation, form S, is given in Figure 1. It should be noted that the ion is symmetrical and carbon atoms 1, 2, and 6 are trigonal. This geometry was constructed from the π-route[4] by taking the Δ^3-cyclopentenylethyl carbonium ion **1**,[5] rotating the ethyl chain back toward the ring to give conformation **2**, and then bending the cyclopentene ring along a line from C-3 to C-7 so that the carbonium ion is brought closer to the double bond. The most stable geometry of **3** is obtained when α equals 40°; this is form S which is 13.6 kcal. more stable than **2**.

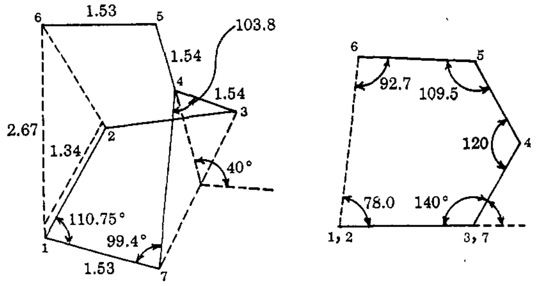
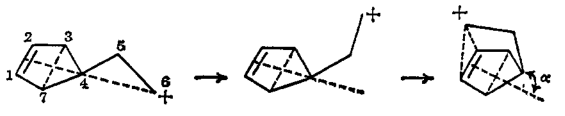
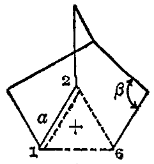


Figure 1.—The geometry of the most stable form (form S) of the norbornyl cation according to E.H.T. All C–H bonds = 1.1 Å.



1 **2** **3**

Small changes in form S were then systematically introduced. All of the modifications increased the energy of the ion arguing that according to this E.H.T., form S is the most stable form of the norbornyl cation. Form S was modified by (a) changing C-6 to an sp^3 carbonium ion with the hydrogens pointing away from the double bonds (19 kcal.)[6]; (b) rotating the C-6–C-5 bond so that the empty p orbital on C-6 was pointing toward C-1 (2 kcal.); (c) repeating b but making C-6 tetrahedral (20 kcal.); (d) rotating the C-4–C-5 bond so that the C-5–C-6 bond was pointing toward C-1 (4 kcal.); (e) lowering the H-1 and H-2 hydrogens (to tetrahedral positions) keeping C-6 trigonal (58 kcal.); (f) lowering the H-1 and H-2 hydrogens making C-6 tetrahedral with the hydrogens pointing away from the double bond (79 kcal.); (g) bending the C-4–C-5 bond (5°) toward the olefin (1.5 kcal.); and (h) bending the C-5–C-6 bond (5°) toward the olefin (1.5 kcal.). In addition to these slight modifications of form S, more drastic modifications were tried without finding any model more stable than form S. These forms were (i) the form with all the bonds and bond angles of the cyclopentene base equal, with the bonds being 1.54 Å. and the angles being 108° (1 kcal.); (j) the trisymmetric[7] form **4** with $a = 2.0$



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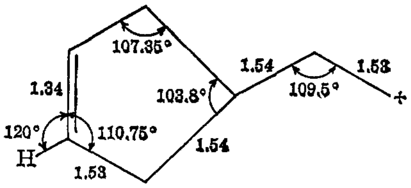
(2) (a) R. Hoffmann, *J. Chem. Phys.*, **39**, 1397 (1963); (b) *ibid.*, **40**, 2480 (1964).

(3) H. C. Brown and M.-H. Rei, *J. Am. Chem. Soc.*, **86**, 5008 (1964), and references cited therein.

(4) S. Winstein and P. Carter, *ibid.*, **83**, 4485 (1961).

(5) The geometry for this molecule is



where all C–H bonds are 1.1 Å. This geometry was obtained by using ordinary C–C bond distances, assuming the ring was flat, and calculating angles so that the angle strain was evenly distributed. The exact geometry is somewhat arbitrary but should not affect the relative calculations since it was kept constant in a series of calculations.

(6) The number in parentheses is the ΔE in going from form S to the modified form.

(7) The term trisymmetric refers to the carbon skeleton; the molecule is not trisymmetric because carbon-6 has two hydrogens and carbon-1 and -2 have only one hydrogen each.

Å. and $\beta = 109.5°$ and C-1, C-2, and C-6 being trigonal (77 kcal.); (k) the trisymmetric form **4** with a = 1.54 Å. and $\beta = 109.5°$ with C-1, C-2, and C-6 being trigonal (195 kcal.); and (l) the same form as k but with C-1, C-2, and C-6 being tetrahedral with the hydrogens pointing away from the threefold axis of symmetry of the carbon skeleton (132 kcal.). In addition to these forms, Hoffmann's calculations show that the simple undistorted norbornyl cation is less stable (51 kcal.) than form S.

A strong qualitative theoretical argument for the existence of nonclassical ions in systems such as norbornane is that the ion assumes a new geometry in order to gain energy from charge delocalization and release of strain. Since the energy decrease calculated by this E.H.T. in going from the classical carbonium ion to form S is 51 kcal., one might say this idea is confirmed. However, the difference seems much too high since norbornane has only about 18 kcal. of strain energy[8] and it seems unlikely that the ion would lose so much energy by dispersing its charge. More likely, the larger difference is a confirmation that Hoffmann's E.H.T. overemphasizes steric interactions.[2] Thus, the calculations for these two forms only are weak arguments for a nonclassical carbonium ion. However, the calculations of the slightly modified forms of form S favor the nonclassical ion since all slight changes from the truly symmetrical, nonclassical ion toward the classical ion lead to less stable ions. Hoffmann contends that the stability changes for slight geometrical variations of ions give at least the correct qualitative conclusions.[2] Thus, according to this E.H.T. the nonclassical carbonium ion is an energy minimum in going from one form to the classical norbornyl cation to the other form. This is in opposition to Brown's arguments that the nonclassical ion is an energy maximum or transition between the two classical ions.[3] Although these calculations do not prove the existence of nonclassical carbonium ions since this E.H.T. is far from being established, they do represent an additional theoretical argument in favor of nonclassical cations. Moreover, these calculations offer a potential test of this E.H.T. since they indicate it favors nonclassical ions; it is a potential test since unequivocal experimental proof or disproof of the existence of nonclassical carbonium ions is still lacking. It is highly desirable to confirm this E.H.T. since it offers the organic chemist a simple way to calculate molecular orbitals and thus preferred geometries, energies, charge distributions, substituent effects, etc., for fairly complex molecules.

Acknowledgment.—The author is indebted to Dr. R. Hoffmann for initiating him to his extended Hückel theory, for many helpful discussions during the course of these calculations, and for use of his computer time. He also acknowledges the inspiration, encouragement, and advice of Professor P. D. Bartlett and a postdoctoral fellowship from the National Science Foundation.

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(8) The editor has noted that the strain energy of norbornane is calculated to be 18.5 kcal. from heats of combustion by A. F. Bedford, A. E. Beezer, C. T. Mortimer, and H. D. Springall [*J. Chem. Soc.*, 3823 (1963)].

Neighboring Hydroxyl Group Assistance.
VI. In Amide Hydrolysis

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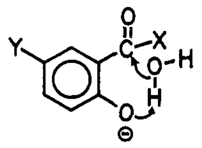
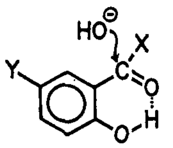
Received December 22, 1964

We wish to report the first instance of intramolecular general-base catalysis of the hydrolysis of an amide bond by a neighboring hydroxyl group. The model compounds employed were substituted *o*-hydroxybenzamides. It has been previously demonstrated that a hydroxyl group, suitably placed, as in γ-hydroxybutyramide, will facilitate the hydrolysis of an amide bond presumably *via* nucleophilic catalysis through intermediate lactone formation.[3,4] Suitably situated aliphatic hydroxyl groups have also been established in numerous cases to facilitate ester hydrolysis by intramolecular nucleophilic catalysis or, where direct attack of the hydroxyl group on the ester bond is sterically prevented, by specific-base, general-acid, or the kinetically equivalent general-base catalysis.[5]

Bender,[6] in an important investigation of the influence of neighboring phenolic hydroxyl groups on ester hydrolysis, found that the pH–rate profile for the hydrolysis of *p*-nitrophenyl 5-nitrosalicylate exhibits two plateaus: one in the acid and one in the alkaline region. Kinetically equivalent rate equations for intramolecular general-base (**1a**) and general-acid (**1b**) catalysis were found to fit the experimental data satisfactorily. Mechanism **1a** was favored by Bender on the basis that little or no facilitation was provided by the neighboring hydroxyl group for attack by nucleophiles not susceptible to general base assistance (*e.g.*, nucleophiles without acidic hydrogens as N_3^- and SO_3^{2-}).



1a



1b

X = NH_2, $C_6H_4NO_2$-*p*; Y = H, NO_2

In Figure 1 are presented pH–rate profiles for the hydrolysis of several substituted benzamides (salicylamide, I; 5-nitrosalicylamide, II; *o*-methoxybenzamide, III; and benzamide, IV). The points of Figure 1 are experimental and the curves are derived from theoretical rate equations, *viz.*

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[2] A portion of the material to be submitted by D. W. Tanner for the Ph.D. in Chemistry, Cornell University, Ithaca, N. Y.

(3) H. Zahn and L. Zürn, *Ann.*, **613**, 76 (1958).

(4) T. C. Bruice and F.-H. Marquardt, *J. Am. Chem. Soc.*, **84**, 365 (1962).

(5) For a review of work in this area, see T. C. Bruice and T. H. Fife, *ibid.*, **84**, 1973 (1962).

(6) M. L. Bender, F. J. Kèzdy, and B. Zerner, *ibid.*, **85**, 3017 (1963).