Tetrahedron. Vol. 26, pp.4269 to 4276 Pergamon Press 1970. Printed in Great Britain

GROUND STATES OF CONJUGATED MOLECULES—XVIII*

AZEPINES AND OXEPINES

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(*Received in the USA* 27 *January* 1970; *received in the UK for publication* 20 *April* 1970)

Abstract—Calculations have been carried out by a semiempirical SCF MO method for azepine, oxepine and their benzo derivatives. The results imply that these 7-membered ring systems are not aromatic, as would be expected since they are isoconjugate with the tropylium anion.

INTRODUCTION

IN CONTRAST to the vast and growing literature on heteroconjugated molecules containing 5- and 6-membered rings, comparatively little has been published on the chemistry of analogous compounds containing 7-membered rings. Compounds of this type, e.g. azepine (I) and oxepine (II), should admittedly be less stable than azoles, furans, etc, since they are isoconjugate with the tropylium anion (III) and should therefore be antiaromatic. Recent studies[1,2] have indeed shown I and II to be unstable.

Theoretical studies of these compounds have so far been limited to calculations by the Hückel method[3-5] which is known[6] to be unreliable for heteroatomic systems; here we report calculations for I, II, and their benzo derivatives using a recently developed semiempirical SCF MO treatment[6-10] which has proved very successful for conjugated molecules of all kinds containing carbon, hydrogen, nitrogen, and oxygen.

THEORETICAL APPROACH

The treatment used here[6-10] is based on the Hückel σ,π approximation, the heat of atomization of a molecule being expressed as a sum of independent contributions by σ and π bonds. The contribution of σ bonds is written as a sum of bond energies and compression energies, the latter being evaluated from suitable Morse potential functions. The π bond energy is calculated by a semiempirical SCF MO procedure based on the Pople method.[11] The parameters are chosen to fit heats of formation rather than light absorption; in particular the one-electron resonance integral (β^c_{ij}) is calculated by the thermocycle method of Dewar and Schmeising.[12]

Bond lengths are recalculated at each iteration using an assumed linear relation between bond order and bond length. The various 2-center integrals are then in turn recalculated; the final result is therefore self-consistent for variations in the 2-center integrals with bond length and estimates of bond lengths are automatically obtained. The parameters used here are taken from the final version of the treatment;[9,10] in

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* Part XVII: M. J. S. Dewar and A. J. Harget, *Proc. Roy. Soc.* **A315**, 457 (1970). This work was supported by the Air Force Office of Scientific Research through Grant No. AF-AFOSR-1050-67.

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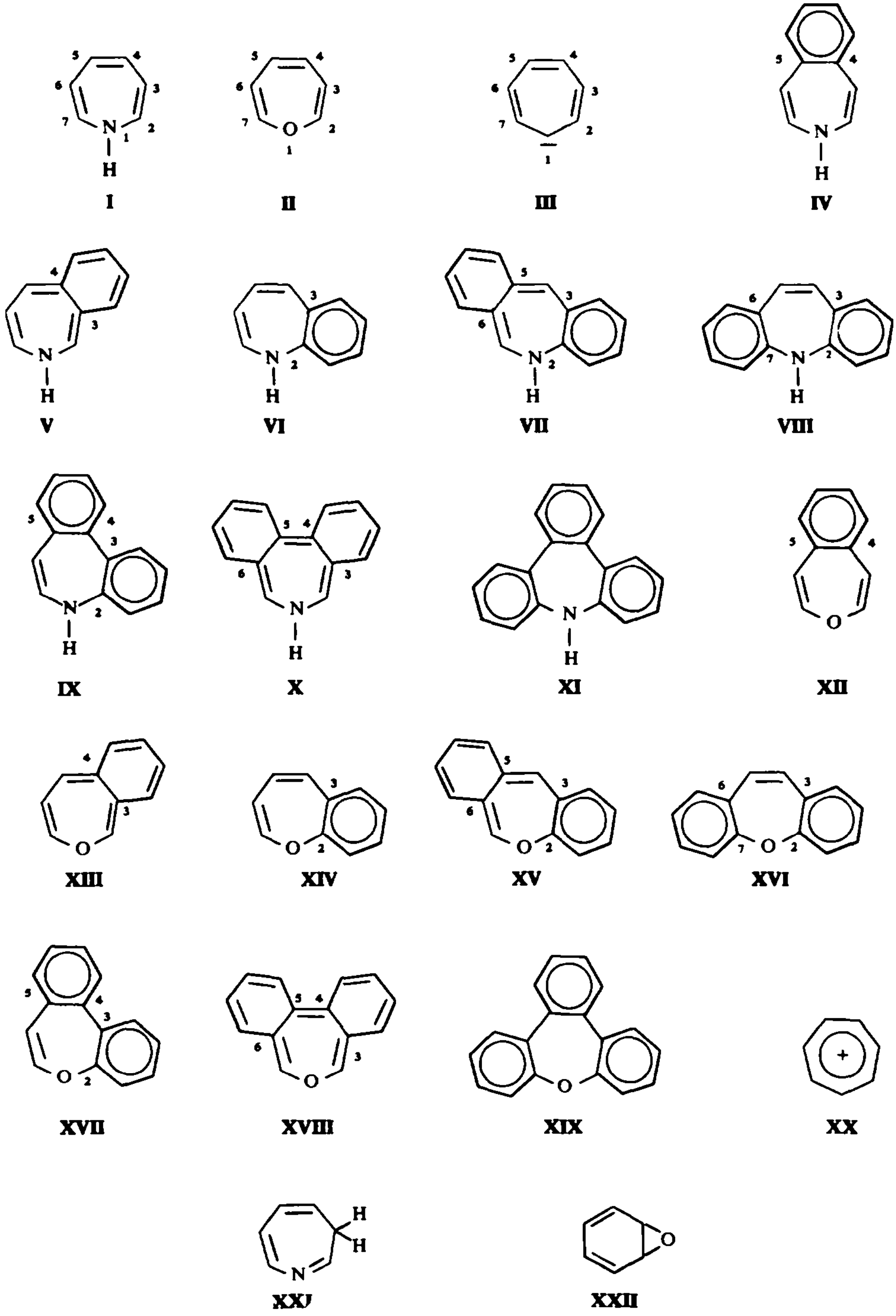


I II III IV

V VI VII VIII

IX X XI XII

XIII XIV XV XVI

XVII XVIII XIX XX

XXI XXII

FIG 1. List of formulae.

particular, allowance was made for σ polarization by the procedure of Dewar and Morita.[10]

Previous work[9] has indicated that the heats of atomization of classical polyenes can be written as sums of "polyene" C—H, C—C, and C=C bond energies, implying that the bonds in classical polyenes are localized.[13] This leads[9,13] to a simple definition of resonance energy as the difference between the heat of formation of a given conjugated hydrocarbon and that calculated for a corresponding classical polyene by summing the appropriate bond energies. This type of addivity has recently[14,15] been shown to extend to classical compounds containing nitrogen or oxygen and the definition of resonance energy can be accordingly extended to corresponding heteroconjugated molecules.

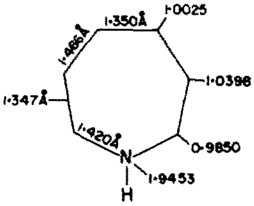
RESULTS

Table 1 shows calculated heats of atomization, resonance energies, and ionization potentials for I, II, and their benzo derivatives (see list of formulae on Fig 1). Calculations are also included for comparison for the tropylium anion (III) and cation (XX). The ionization potentials were calculated by using Koopmans' theorem with an appropriate value (9·84 eV[18]) for the ionization potential of methyl radical. The estimated bond lengths and corresponding π-electron densities are presented in diagrammatic form in Fig 2.

TABLE 1. CALCULATED HEATS OF ATOMIZATION, RESONANCE ENERGIES, AND IONIZATION POTENTIALS

Compound	−(Heat of atomization) (eV)	Resonance energy (kcal/mole)	Ionization potential (eV)*
Azepine (I)	63·083	−1·80	8·21
Oxepine (II)	60·262	0·12	8·65
Tropylium anion (III)	67·103	—	—
4,5-Benzazepine (IV)	96·621	17·53	8·20
3,4-Benzazepine (V)	96·127	−0·78	7·61
2,3-Benzazepine (VI)	96·957	18·36	8·19
2,3,5,6-Dibenzazepine (VII)	130·006	19·49	7·62
2,3,6,7-Dibenzazepine (VIII)	130·826	38·40	8·19
2,3,4,5-Dibenzazepine (IX)	130·804	37·89	8·21
3,4,5,6-Dibenzazepine (X)	129·208	1·08	7·20
Tribenzazepine (XI)	164·683	58·14	8·21
4,5-Benzoxepine (XII)	94·071	18·77	8·57
3,4-Benzoxepine (XIII)	93·307	1·15	7·89
2,3-Benzoxepine (XIV)	94·122	19·95	8·51
2,3,5,6-Dibenzoxepine (XV)	127.166	20·94	7·86
2,3,6,7-Dibenzoxepine (XVI)	127·984	39·80	8·42
2,3,4,5-Dibenzoxepine (XVII)	127·950	39·03	8·51
3,4,5,6-Dibenzoxepine (XVIII)	126·394	3·14	7·44
Tribenzoxepine (XIX)	161·828	59·27	8·42
Tropylium cation (XX)	68·293	—	—

* From Koopmans' theorem.



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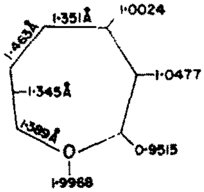

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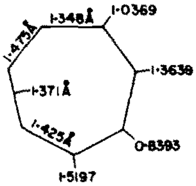

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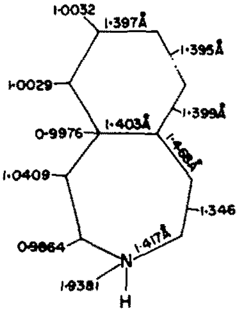

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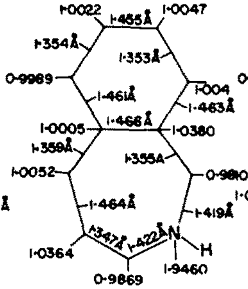

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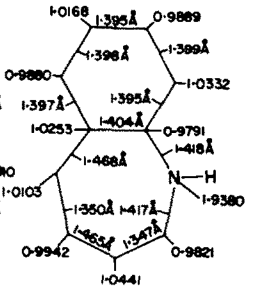

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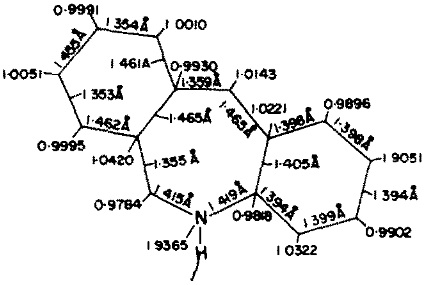

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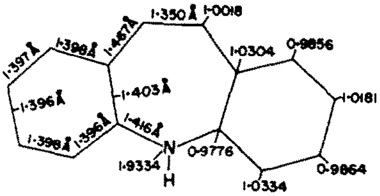

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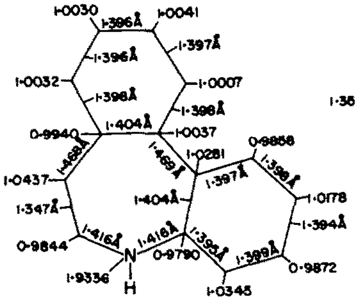

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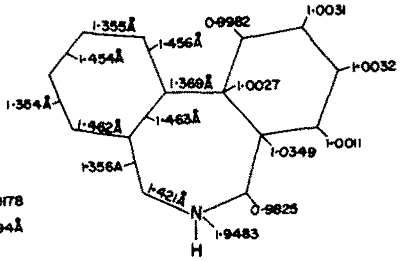
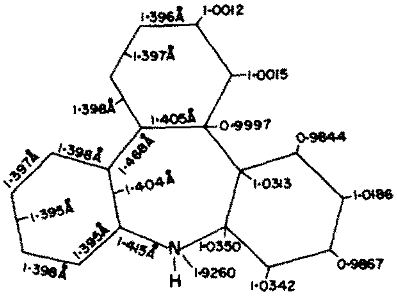


X

FIG 2. SCF molecular orbital diagrams for molecules I–XX.



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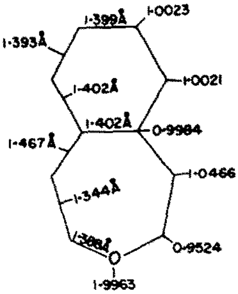

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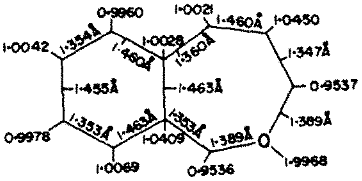

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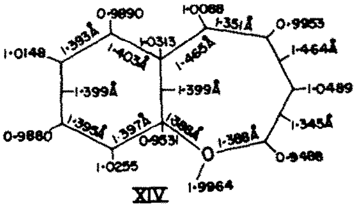

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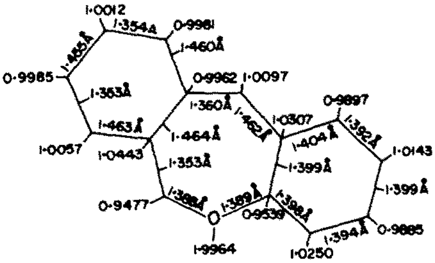

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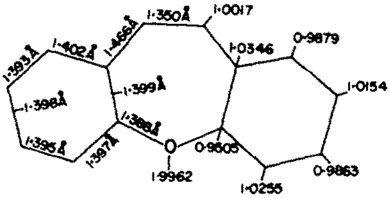

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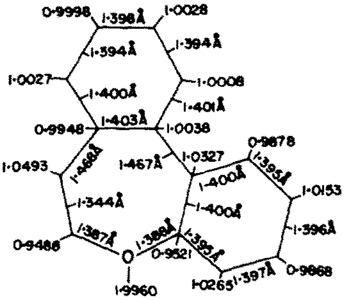

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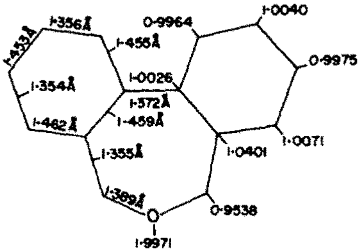

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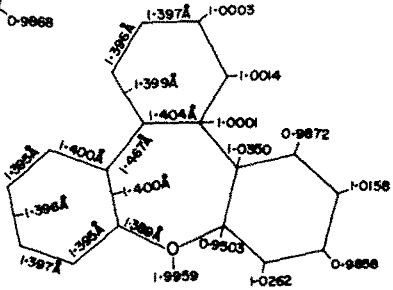

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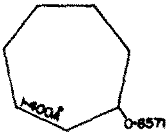

XX

DISCUSSION

According to simple MO theory,[19] tropylium anion should be antiaromatic. The results in Table 1 and Fig 2 support this conclusion. The heat of atomization calculated for tropyliun anion is less by about 25 kcal/mole than that for tropylium cation, and whereas the bond lengths in the cation are predicted to be equal, those in the anion are not. Indeed, the predicted structure for the anion corresponds to a pentadienate system joined across the ends by a localized double bond. The lengths of the 3–4 and 5–6 bonds are if anything somewhat greater than those predicted for essential single bonds in classical polyenes, while the length of the 4–5 bond is close to that of a double bond. The charges on the remaining atoms are also similar to those calculated for the *cis*-pentadienate anion.[18] The available evidence supports these predictions. Thus while tropylium cation has been known for some time[19-21] as an exceptionally stable species, the corresponding anion has only recently been prepared by Dauben[22] and is highly reactive.*

The results in Table 1 and Fig 2 predict azepine (I) and oxepine (II) to be likewise nonaromatic species, azepine being predicted to have a small negative resonance energy and oxepine a virtually zero one; the predicted bond lengths are also very close to those expected for a structure with localized bonds. Similar considerations apply to benzo derivatives of I and II in which the benzene rings are annelated with "double" bonds; the resonance energies of such compounds are predicted to be almost exactly the same as those of a corresponding number of molecules of benzene. On the other hand 3,4-benzazepine (V), 3,4-benzoxepine (XIII), 3,4,5,6-dibenzazepine (X), and 3,4,5,6-dibenzoxepine (XVIII), are predicted to have very small resonance energies and bond lengths which correspond closely to those predicted for the single uncharged classical resonance structures indicated in Fig 1. In these compounds the benzene rings could be aromatic only if there were extensive charge separation leading to unfavorable zwitterionic structures. Here again the admittedly scanty experimental evidence is consistent with our calculations. Thus some N-substituted derivatives of azepine are known,[23-26] but most of them are stable only in the absence of air, or at low temperatures, or in dilute solution. It has been reported[1] that azepine itself can be prepared by cautious alkaline hydrolysis of a solution of its N-ethoxycarbonyl derivative but that it is very unstable and rearranges rapidly to the tautomeric 3H-azepine (XXI). We have calculated the heat of atomization of XXI (64·200 eV) and its resonance energy (0·23 kcal/mole); these results correctly imply that XXI should be more stable than I.

Oxepine on the other hand appears to be more stable than azepine and was prepared some time ago by Vogel *et al.*[27] This is consistent with our calculations which indicate that oxepine should have a small positive resonance energy while azepine should have a small negative one. However oxepine is apparently in equilibrium with its bicyclic tautomer,[2,27,28] benzene oxide (XXII), so it is certainly not an aromatic molecule and indeed it appears to be very reactive.

The reactivity of oxepine and azepine is of course due to the presence in them of reactive localized double bonds and to the fact that they are not resonance stabilized. One would therefore expect their benzo derivatives to be more stable, provided that the

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* While reactivity is not of course a direct measure of stability, it seems in practice to provide a fairly reliable criterion between aromatic and nonaromatic compounds and may serve as such in cases where, as here, neither thermochemical nor structural data are available.

annelation takes place in such a way as not to destroy the aromaticity of the benzene rings. A number of such benzo derivatives of azepine and oxepine are known: 4,5-benzazepine (IV),[29] 4,5-benzoxepine (XIII),[30–32] 2,3-benzoxepine (XIV),[33,34] 2,3,6,7-dibenzazepine (VIII),[35,36] 2,3,6,7-dibenzoxepine (XVI),[37–39] tribenzoxepine (XIX).[40] On the other hand our calculations imply that annelation of benzene with the 3,4 bond of azepine or oxepine should be extremely unfavourable; no compounds of this type have as yet been prepared.

It is unfortunate that so few of the properties of these compounds have been reported; in particular there seem to be no measurements of their ionization potentials and few structural studies have as yet been described.[41] Very recently it was announced that an X-ray examination of the 3-acetyl derivative of the unsubstituted azepine is in progress.[42]

We hope that the calculations reported here may stimulate studies of this kind, and that they may also prove useful in connection with work directed to the synthesis of materials of biological interest. Thus certain N-substituted derivatives of dibenzazepine have proved useful as rapid acting antidepressants,[43] and certain natural products (pigments) appear to be oxepine derivatives.[44,45]

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