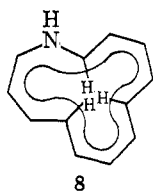


While the data relating to **3** and **6** serve to unequivocally establish the presence of monocyclic frames, they lack the type of information needed for structural detail; it is not clear, for instance, whether the molecule incorporates any trans double bonds and if so how many. On the other hand, brief examination of the nmr spectrum of the parent, **5**, reveals that the molecule (and likewise **3** and **6** which have been directly correlated to **5**) does indeed possess trans double bonds. Specifically it is noted that, unlike **3** and **6**, **5** displays three high field 1H signals ( $\tau$  5.99–7.22) whose major splitting (14.5–16 Hz) is clearly indicative of trans ethylenic H–H coupling. Furthermore, the significant upfield displacement of these resonances relative to the major absorption manifold ( $\tau$  2.8–4.88) serves to clearly trace their origin to a set of strongly shielded "inner" protons and hence to establish the presence of *significant ring diamagnetism* in **5**.<sup>7</sup> Conversely, the absence of such high field resonances in the nmr spectra of derivatives **3** and **6** established that these molecules are devoid of ring diamagnetism. In other words, the obvious conclusion to be drawn from the nmr information is that 1*H*-aza[13]annulene (**5**) is endowed with aromatic character while its *N*-substituted derivatives **3** and **6** are not. This interpretation draws added support from a comparison of thermal stabilities. In brief, we find that while **5** remains essentially unchanged on heating in deaerated (Ar) benzene-*d*<sub>6</sub> at 56° for 4.5 hr, the acetamide (**3**) cleanly and rapidly ( $t_{1/2}$  < 1 hr) rearranges to a tricyclic isomer<sup>5</sup> under analogous conditions.

No doubt the effect of the substituent is primarily electronic restricting the availability of the nitrogen lone pair for delocalization into the ring. In other words, the present situation strictly parallels that described earlier for the heteronins.<sup>3</sup>

The exact location of the trans bonds in **5** was established by successive double irradiation of the entire low-field nmr region ( $\tau$  0.6–4.88) which revealed an arrangement of alternating cis and trans bonds (no vicinal coupling between protons bound to different trans functions) and one in which the trans bond directly linked to nitrogen consists of an "inner"  $\alpha$ -proton (highest field dd signal ( $J$  = 14.5, 11.5 Hz) reducing to a clean doublet ( $J$  = 14.5 Hz) upon decoupling from the N–H proton) and an "outer"  $\beta$ -hydrogen. It follows that the 1*H*-aza[13]annulene described here is structured as shown in **8**.



Finally, we note that while potentially capable of assuming planarity, without developing prohibitive  $\sigma$ -strain or excessive "inner" proton crowding (Dreiding molecular model), **8** is not believed to be entirely flat insofar as the protons associated with the trans bonds show temperature-dependent nmr chemical shifts in-

(7) Upon contacting Professor Schröder on the matter (April 17, 1974), we learned that he made similar observation with a geometrical isomer of **5**, namely a 1*H*-aza[13]annulene incorporating only two trans bonds. See G. Schröder, G. Frank, H. Röttele, and J. F. M. Oth, *Angew. Chem.*, **86**, 237 (1974).

dicative of enhanced ring diamagnetism at the lower temperatures.<sup>8</sup>

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(8) In brief, we note that the "inner" protons bound to the trans function directly linked to nitrogen as well as those associated with a remote trans group undergo significant upfield shift on lowering the temperature, while the "outer" hydrogens of these two functions are shifted to lower field. The effect on the protons bound to the third trans group is precisely the reverse, i.e., here the "inner" hydrogen resonance shifts to lower field while the "outer" proton signal moves to higher field, indicating possibly that this trans function has rotational mobility. Interestingly, there is an alternate interpretation of the unusual temperature-dependent behavior of this trans bond to which Professor Schröder indicated preference in private discussion we had on the matter. In brief, the suggestion here is that the "inner"-"outer" proton assignment in the ambient temperature nmr spectrum must be reversed thus leading to normal temperature-induced shifts. It is not clear, of course, within the frame of this interpretation as to why the "inner" proton of this bond should, under normal conditions, resonate at substantially lower field than its "outer" counterpart. In contrast with **5**, all nmr resonances of **3** retain essentially the same chemical shifts on cooling from ca. +40 to –60°. A complete analysis of the variable-temperature nmr spectra of **5** and **3** will be given in the full report.

(9) NDEA Graduate Fellow, 1971–1974.

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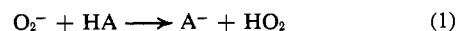
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Received April 26, 1974

## Gas Phase Reactions. Ionization by Proton Transfer to Superoxide Anions

Sir:

Gas phase proton transfer reactions leading to negative ions have been studied by high pressure (10 Torr) mass spectrometry,<sup>1</sup> ion cyclotron resonance,<sup>2</sup> and flowing afterglow<sup>3</sup> techniques. The recent development of an atmospheric pressure ionization (API) mass spectrometer<sup>4</sup> has made it possible to study negative ion formation at atmospheric pressure. We have found<sup>4</sup> that certain drugs, including the commonly used barbiturates and 5,5-diphenylhydantoin, are ionized in the API source by proton transfer to Cl<sup>–</sup>. Ordinary carboxylic acids (acetic, benzoic) are not ionized under these conditions. In the API source these acids can be ionized, however, by proton transfer to superoxide anion (eq 1). Superoxide anions can be generated



easily by employing oxygen or air as the carrier gas. A study of the properties of O<sub>2</sub><sup>–</sup> indicated that this ion is strongly basic in the gas phase. Reaction 1 occurs for many acidic organic compounds.

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(2) J. I. Brauman and L. K. Blair, *J. Amer. Chem. Soc.*, **92**, 5986 (1970); (b) J. I. Brauman and L. K. Blair, *ibid.*, **93**, 4315 (1971); (c) M. T. Bowers, D. H. Aue, H. M. Webb, and R. T. McIver, Jr., *ibid.*, **93**, 4314 (1971); (d) R. T. McIver, Jr., and J. R. Eyler, *ibid.*, **93**, 6334 (1971); (e) R. F. McIver, Jr., J. A. Scott, and J. M. Riveros, *ibid.*, **95**, 2706 (1973); (f) R. T. McIver, Jr., and J. H. Silvers, *ibid.*, **95**, 8462 (1973).

(3) (a) D. K. Bohme, E. Lee-Ruff, and L. B. Young, *J. Amer. Chem. Soc.*, **94**, 5153 (1972); (b) D. K. Bohme, E. Lee-Ruff, and L. B. Young, *ibid.*, **92**, 330 (1970).

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**Table I.** Comparative Gas Phase Acidities and Estimates (kcal/mol) of Bond Dissociation Energies and Electron Affinities

	Bond energies	Electron affinities <sup>a</sup>
Phenol	Lower Acidity than HO <sub>2</sub> [C <sub>6</sub> H <sub>5</sub> O-H] = 88.3 <sup>b</sup>	[C <sub>6</sub> H <sub>5</sub> O] 55 <sup>c</sup>
Benzoic acid	Higher Acidity than HO <sub>2</sub> but Lower than HCl [C <sub>6</sub> H <sub>5</sub> COO-H] = 110 <sup>d</sup>	75 < [C <sub>6</sub> H <sub>5</sub> COO] < 90
Acetic acid	[CH <sub>3</sub> COO-H] = 110 <sup>d</sup>	75 < [CH <sub>3</sub> COO] < 90 <sup>e</sup>
Malononitrile	Higher Acidity than HO <sub>2</sub> and HCl but Lower than HBr [(CH <sub>2</sub> ) <sub>2</sub> CH-H] = 80 <sup>f</sup>	60 < [(CN) <sub>2</sub> CH] < 70
<i>p</i> -Nitrophenol	[NO <sub>2</sub> C <sub>6</sub> H <sub>4</sub> O-H] = 88.3 <sup>b</sup>	68 < [NO <sub>2</sub> C <sub>6</sub> H <sub>4</sub> O] < 78
2,4,6-Trinitrotoluene	[(NO <sub>2</sub> ) <sub>3</sub> C <sub>6</sub> H <sub>2</sub> CH <sub>3</sub> -H] = 85 <sup>g</sup>	65 < [(NO <sub>2</sub> ) <sub>3</sub> C <sub>6</sub> H <sub>2</sub> CH <sub>2</sub> ] < 75
Picric acid	Higher Acidity than HO <sub>2</sub> , HCl, HBr, and HI [(NO <sub>2</sub> ) <sub>3</sub> C <sub>6</sub> H <sub>2</sub> O-H] = 88.3 <sup>b</sup>	88.3 < [(NO <sub>2</sub> ) <sub>3</sub> C <sub>6</sub> H <sub>2</sub> O]

<sup>a</sup> The limits of the electron affinities were estimated using  $D(H-X)$  and  $EA(X)$  for  $X = Cl, Br,$  and  $I$  from R. S. Berry and C. W. Riemann, *J. Chem. Phys.*, **38**, 1540 (1963). <sup>b</sup> Accurate values for phenol and several substituted phenols were recently determined (Lee R. Mahoney, private communication) to be 84–90 kcal/mol. These results indicate that the bond energies of phenol, *p*-nitrophenol, and picric acid will not be identical. However, the same value (88.3 kcal/mol) is used here in order to define the order of electron affinities. <sup>c</sup> Determined to be 55.0 kcal/mol, from recent studies of  $D(H-A) - EA(A)$ <sup>8</sup> and bond energy (L. R. Mahoney, private communication). <sup>d</sup> Accurate values for aromatic and aliphatic carboxylic acids are not available. The same value of 110 kcal/mol was used for both types of acids, from ref 5a. <sup>e</sup> Now known to be 79 kcal/mol.<sup>1</sup> <sup>f</sup> Estimated on basis of  $D(Cl_2CH-H) = 80$  kcal/mol from ref 5a. <sup>g</sup> Estimated on the basis of  $D(C_6H_5CH_2-H) = 85$  kcal/mol, from R. Walsh, D. Golden, and S. Benson, *J. Amer. Chem. Soc.*, **88**, 650 (1966).

The gas phase acidity of an acid, HA, will be higher the smaller the heterolytic dissociation energy,  $HA = H^+ + A^-$ . Therefore, acidity increases as the difference between the bond dissociation energies and electron affinities,  $D(H-A) - EA(A)$ , decreases. The  $D(H-A) - EA(A)$  for HO<sub>2</sub> is estimated on the basis of  $D(H-O_2) = 47$  kcal/mol<sup>5</sup> and  $EA(O_2) = 11.4$  kcal/mol<sup>6</sup> to be 35.6 kcal/mol. This can be compared with the corresponding value for CH<sub>3</sub>COOH which is 31.8 kcal/mol.<sup>1</sup> The fact that acetic acid is a stronger gas phase acid than HO<sub>2</sub> was verified experimentally by the formation of acetate ions in the API source through reaction with O<sub>2</sub><sup>-</sup>.

Compounds whose acidities were examined are listed in Table I. The acidities of these compounds, with the exception of acetic acid, have not been reported previously. The H-A bond energies, and the estimated limits which must hold for  $EA(A)$  values, are also in Table I. All experiments were carried out at atmospheric pressure with a source temperature of 200°, with air as the carrier gas, and with low concentrations (picogram samples) of acids to avoid cluster ion formation.

The strongest gas phase acid found in this study was picric acid (2,4,6-trinitrophenol). This was ionized by O<sub>2</sub><sup>-</sup>, Cl<sup>-</sup>, Br<sup>-</sup>, and I<sup>-</sup>. *p*-Nitrophenol also ionized readily; both O<sub>2</sub><sup>-</sup> and Cl<sup>-</sup> led to phenolate ion formation. The relatively high acidity of malononitrile (ionized by O<sub>2</sub><sup>-</sup> and Cl<sup>-</sup>) was not unexpected; carbanion formation through gas phase ionization was encountered earlier for *N,N'*-dimethylbarbituric acid.<sup>7</sup> 2,4,6-Trinitrotoluene was also found to be a strong gas phase acid (ionized by O<sub>2</sub><sup>-</sup> and Cl<sup>-</sup>). The acidity of hydrogen atoms attached to a benzylic carbon atom was noted by Brauman and Blair<sup>2a</sup> in work with toluene. The

acidity is greatly increased in this instance by nitro groups in the ortho and para positions.

Benzoic and acetic acids are stronger acids than HO<sub>2</sub> in the gas phase, so that the electron affinities of the corresponding radicals are above 75 kcal/mol (based on an estimate of 110 kcal/mol for the dissociation energy of the RCOO-H bond). The value found by Yamdagni and Kebarle<sup>1</sup> for the acetate radical was 79 kcal/mol.

Phenol was not ionized by O<sub>2</sub><sup>-</sup>. The recently measured value of  $D(H-A) - EA(A)$  for phenol is 33.3 kcal/mol.<sup>8</sup> Since the corresponding value for HO<sub>2</sub> is 35.6 kcal/mol, phenol was expected to be a stronger acid than HO<sub>2</sub>. This observation indicates that the actual value for  $D(H-O_2) - EA(O_2)$  is probably a few kcalories per mole lower than that estimated from available data.<sup>5,6</sup> In a previous study<sup>1</sup> ordinary aliphatic and aromatic carboxylic acids were ionized by F<sup>-</sup> ions. The use of O<sub>2</sub><sup>-</sup> instead of F<sup>-</sup> has the advantage that its production does not require the use of highly corrosive gases.

**Acknowledgment.** This work was aided by Grants 13901 and 16216 of the National Institute of General Medical Sciences, Grant 05435 of the National Heart and Lung Institute, and Grant Q-125 of the Robert A. Welch Foundation.

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### Crystallographic Studies on Manganese Hemoglobin

Sir:

The role of the heme iron in hemoglobin may be examined through the effects on structure and function of replacement of the iron by other metals. The functional properties of coboglobin (CoHb),<sup>1</sup> in which

(1) Abbreviations: CoHb, cobaltohemoglobin; MnHb, manganese hemoglobin; Mn<sup>III</sup>Hb, manganihemoglobin; Hb, ferrohemoglobin; Fe<sup>III</sup>Hb, ferrihemoglobin.

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