8b. After a 24-h reaction time, the reaction mixture was concentrated to half volume, poured onto water (20 mL), extracted with ether (3 × 10 mL), dried ($MgSO_4$), and concentrated in vacuo to give **12a** as a yellow oil (87%): ^1H NMR (MeOH-d_4) δ 3.30 (s, 3 H), 3.97 (s, 3 H), 4.35 (s, 2 H), 4.39 (s, 2 H), 4.43 (s, 2 H), 4.50 (s, 2 H), 7.27 (s, 10 H); IR (neat) 3029, 2940, 2857, 1553, 1507, 1064, 1027 cm^{-1}. Anal. Calcd for $C_{21}H_{24}N_2O_3$: C, 71.57; H, 6.86; N, 7.95. Found: C, 71.84; H, 6.76; N, 7.89.

4,5-Bis[(benzyloxy)methyl]-1-methyl-2-(phenylthio)imidazole (12d). The procedure used to make **10** was used with sulfone **8b** (except that the reaction mixture was not acidified before workup) to give **12a** as a clear yellow oil (3.72 g, 69%): ^1H NMR (acetone-d_6) δ 3.64 (s, 3 H), 4.48 (s, 2 H), 4.53 (s, 2 H), 4.58 (s, 2 H), 4.65 (s, 2 H), 7.28 (m, 15 H); IR (neat) 3077, 3028, 1441, 1358, 1067 s, 1028 s cm^{-1}. Anal. Calcd for $C_{26}H_{26}N_2O_2S{\cdot}0.25H_2O$: C, 71.78; H, 6.14; N, 6.44; S, 7.37. Found: C, 71.78; H, 6.14; N, 6.43; S, 7.27.

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Ab Initio Calculations on the Diazirinyl Anion. A Nonaromatic Species

Roseann L. Kroeker,[†,‡] Steven M. Bachrach,[*,§] and Steven R. Kass[*,†]

Department of Chemistry, University of Minnesota, Minneapolis, Minnesota 55455, and Department of Chemistry, Northern Illinois University, DeKalb, Illinois 60115

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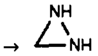
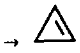
In 1965 Breslow proposed the term antiaromatic to describe compounds which are destabilized by cyclic conjugation.[1] This idea was extremely appealing because many 4π-electron systems were known to be difficult to prepare and quite reactive. Subsequent work on cyclopropenyl anion, cyclobutadiene, and cyclopentadienyl cation has led to a general consensus that these small antiaromatic systems are indeed destabilized by conjugation.[2] This point of view, however, has been questioned,[3] and given the continuing interest in this area, along with the recent gas-phase formation of the diazirinyl anion (**1a**),[4] we decided to investigate this novel species via molecular orbital calculations.

Ab initio calculations using the Gaussian series of programs[5] have been carried out on diazirine (**1**), four of its isomers, the corresponding conjugate bases, and several related compounds. Full geometry optimizations at the Hartree-Fock level were carried out with the 6-31+G* basis set.[6] All of the structures were characterized by their vibrational frequencies to insure that they correspond to local minima (no imaginary frequencies) or transition states (one imaginary frequency) on the potential energy surface. Polarization functions and diffuse orbitals, which are required to adequately describe molecules with heteroatoms, stained rings, and a negative charge, are included in this basis set.[7] Electron correlation was accounted for in the energy calculations with second-order Møller–Plesset theory (MP2),[8,9] and the resulting deprotonation energies (DPEs) were corrected for zero-point vibrational energies (calculated at HF/6-31+G*). The results are summarized in Table I and are in reasonable accord with experiment. It is interesting to note that the errors for the hydrocarbons are on the order of 1–2 kcal mol^{-1}, in agreement with previous results,[10] whereas they are somewhat larger for

Table I. Calculated and Experimental Acidities

	acidity[b]			
compound[a]	6-31+G*[c]	MP2[d]	AM1	expt
$CH_2{=}N{=}N$	392.6 (384.7)	375.0 (367.1)	384.9	373 ± 3[e]
NH_2CN	360.2 (351.8)	351.9 (343.5)	361.6	350 ± 3[f]
NH_2NC	372.7 (363.9)	357.8 (349.0)	361.7	–
 **1**	414.2 (404.9)	405.2 (395.9)	389.9	401 ± 3[f]
 **2**	364.8 (356.6)	362.3 (354.1)	362.4	–
 **3**	cis[g] 415.5 (406.5)	406.4 (397.4)	391.4	–
	trans 421.2 (411.8)	412.2 (402.8)	395.3	–
→ $CH_3CH{=}CH_2$	408.0 (398.1)	398.6 (388.7)	386.7	390.8 ± 2[e]
 **4**	438.5 (428.7)	428.4 (418.6)	423.2	–
 **5**	431.8 (422.2)	422.5 (412.8)	415.5	412 ± 3[h]

[a] When more than one acidic site is present the arrow indicates the position for which the acidity has been calculated. [b] All values in kcal mol^{-1}. [c] Geometries, energies, and frequencies were calculated at the 6-31+G*//6-31+G* level of theory. The numbers in parentheses have been corrected for zero point energy (zpe) differences using scaled frequencies (0.90). [d] MP2/6-31+G*//6-31+G* energies. The numbers in parentheses are acidities corrected for the z.p.e as explained in note c. [e] Reference 20. [f] Reference 4. [g] The two methylene hydrogens are distinct in the cis compound. The acidity reported here corresponds to the removal of the proton which is cis to the hydrogens on nitrogen. [h] The uncertainty is estimated.

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(4) Kroeker, R. L.; Kass, S. R. *J. Am. Chem. Soc.* **1990**, *112*, 9024.

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[†] University of Minnesota.

[‡] Departmental Fellow supported by the Amoco Foundation.

[§] Northern Illinois University.

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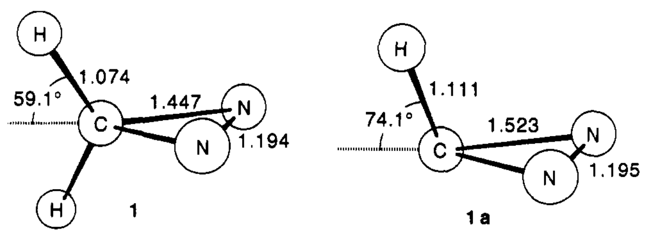
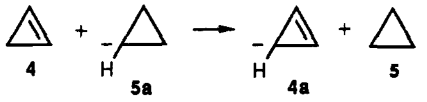


Figure 1. Optimized geometries of **1** and **1a** at 6-31+G*. All distances are in angstroms and all angles are in degrees.

the nitrogen containing compounds. These acidities are ~5 kcal mol^{-1} too low, which suggests that even larger basis sets and/or more complete accounting of electron correlation are needed to obtain the same precision for these heteroatom systems.[11] Relative DPEs, particularly when used in homodesmic reactions, should be significantly more accurate.[12]

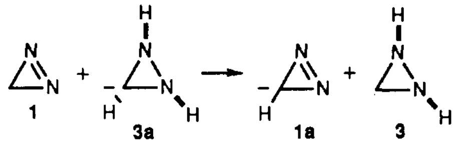
The structure of the diazirinyl anion (Figure 1) is quite interesting. Upon deprotonation of **1**, the remaining hydrogen bends further away from the plane of the ring by 15°, and the carbon-nitrogen and nitrogen-nitrogen bond lengths increase by 0.076 and 0.001 Å, respectively.[13] This change in geometry tends to localize the negative charge on carbon and minimizes the cyclic 4π-electron interaction. Cyclopropene (**4**) and cyclopropenyl anion (**4a**) behave similarly.[14,15] In addition, Schleyer et al. have pointed out that the destabilization energy can be modeled by the isodesmic reaction shown in eq 1.[15c] The calculated endothermicity indicates that **4a** is antiaromatic. In contrast, **1a** is actually found to be slightly more stable than its saturated counterpart (eq 2). This difference undoubtedly reflects changes in hybridization, polarization, and inductive effects, but is free of anion–lone pair interactions because *cis*-diaziridine (**3**) was chosen as the reference compound.[16] It is tempting to attribute the difference in energy between these two homodesmic reactions, 7.1 kcal mol^{-1}, to a more favorable resonance interaction in **1a**. However, other factors such as small variations in the degree of pyramidalization in **1a** and **4a** may be responsible.

The relative importance of conjugation in these systems can be probed, in principle, by comparing the inversion barriers of the diazirinyl and cyclopropenyl anions to their saturated analogs. In practice, the transition states for the saturated compounds are readily located (the barriers are 16.3, 42.2, and 37.9 kcal mol^{-1} for **5a**, **3a**, and the conjugate base of *trans*-diaziridine (**3b**) at the MP2 level),[8] but they are not for the unsaturated ions. The symmetric structures corresponding to inversion, C_{2v} for **1a** and C_s for **4a**, have two imaginary frequencies and are not transition states. The negative vibrational modes indicate that inversion is accompanied by a distortion of the ring system and a breaking of symmetry. In this way, both ions can minimize the unfavorable effects of conjugation. Nevertheless, if the MP2 energies[8] of the symmetric structures are used to calculate the barriers (51.6 and 37.1 kcal mol^{-1} for **1a** and **4a**, respectively) and the results are compared to **3b** and **5a** then the difference between the two (7.1 kcal mol^{-1}) is found to be identical to the energy obtained by comparing eqs 1 and 2.[17] It therefore appears that conjugation is more favorable in the diazirinyl anion and the ion is probably best described as nonaromatic.



(1)

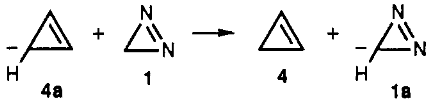
ΔH = +5.9 kcal mol^{-1} (MP2/6-31+G*//6-31+G*)



(2)

ΔH = −1.2 kcal mol^{-1} (MP2/6-31+G*//6-31+G*)

Diazirine is calculated to be 23.2 kcal mol^{-1} more acidic than cyclopropene (eq 3). Most of this energy is due to inductive stabilization as indicated by the greater acidity of **3** relative to **5** (16.1 kcal mol^{-1}). The remainder (eq 2 − eq 1, 7.1 kcal mol^{-1}) can be attributed to the effects of cyclic conjugation. The total enthalpy difference corresponds to an acidity differential of 17 pK_a units assuming that $\Delta S \approx 0$ for eq 3. Combining this ΔpK_a with the measured acidity of cyclopropene, pK_a = 51–56,[18] leads to a predicted pK_a (**1**) of 34–39 in dimethyl sulfoxide.[19] This suggests that the diazirinyl anion will be a reasonably stable species in solution, despite the fact that it has yet to be reported in the condensed phase. Efforts to verify these predictions are currently being carried out and will be reported in due course.



(3)

ΔH = −23.2 kcal mol^{-1} (MP2/6-31+G*//6-31+G*)

Calculations. The ab initio calculations were carried out using Gaussian-86[5a] on a DEC MicroVax II and Gaussian-88[5b] on a Cray-2 and Cray X-MP.

Acknowledgment. A generous allocation of computer resources from the Minnesota Supercomputer Center and financial support from the National Science Foundation (CHE-8907198), the donors of the Petroleum Research Fund, administered by the American Chemical Society,

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[11] The acidity of 1 has also been calculated at the MP4/6-31+G*//6-31+G* and MP2/6-31+G*//MP2/6-31+G* levels (6-31+G* z.p.e. corrections). The values are 396.3 and 396.5 kcal mol^{-1}, respectively.

[12] Hehre, W. J.; Radom, L.; Schleyer, P. v. R.; Pople, J. A. *Ab Initio Molecular Orbital Theory*; John Wiley and Sons: New York, 1986. (b) George, P.; Trachtman, M.; Bock, C. W.; Brett, A. M. *Theor. Chim. Acta* **1975**, *38*, 121. (c) George, P.; Trachtman, M.; Bock, C. W.; Brett, A. M. *J. Chem. Soc., Perkin Trans. 2* **1976**, 2, 1222. (d) George, P.; Trachtman, M.; Bock, C. W.; Brett, A. M. *Tetrahedron* **1976**, *32*, 317, 1357.

[13] A planar anion structure having short C–N bonds (1.273 Å) and a long N–N bond (1.819 Å) was also located. This structure has an orbital occupancy that differs from both 1 and 1a, it corresponds to a double electronic transition, and thus does not appear to be relevant to the present study.

[14] Upon deprotonation of cyclopropene the remaining hydrogen bends 13° further from the plane of the ring and the C–C bond lengths increase by 0.059 and 0.009 Å.

[15] (a) Li, W. *J. Chem. Res. Synop.* **1988**, *7*, 220. (b) Schleyer, P. v. R.; Kaufmann, E.; Spitznagel, G. W.; Janoschek, R.; Winkelhofer, G. *Organometallics* **1986**, *5*, 79. (c) Winkelhofer, G.; Janoschek, R.; Fratev, F.; Spitznagel, G. W.; Chandrasekhar, J.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1985**, *107*, 332.

[16] The trans isomer of 3 is more stable but its conjugate base (3b) suffers from an unavoidable lone-pair lone-pair interaction. As a result, the enthalpy for eq 1 is too negative (−7.0 kcal mol^{-1} at MP2).

[17] The *trans*-diaziridine ion (3b) is used in this case to minimize the effect of lone pair–lone pair interactions. The cis isomer leads to an unrealistically large difference of 11.5 kcal mol^{-1}.

[18] (a) Wasielewski, M. R.; Breslow, R. *J. Am. Chem. Soc.* **1976**, *98*, 4222. (b) Lowry, T. H.; Richardson, K. S. *Mechanism and Theory In Organic Chemistry*, 3rd ed.; Harper and Row: New York, 1987.

[19] This prediction is based on the assumption that the difference in gas phase acidities will be the same as in solution. See: (a) Bordwell, F. G. *Acc. Chem. Res.* **1988**, *21*, 456. (b) Taft, R. W.; Bordwell, F. G. *Acc. Chem. Res.* **1988**, *21*, 463 and references therein.

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American Society for Mass Spectrometry (research award), and University of Minnesota (McKnight Professorship) are gratefully acknowledged.

Supplementary Material Available: Full geometries and energies of all structures (19 pages). Ordering information is given on any current masthead.

Reaction of 3-Bromo-2,5-dimethylthiophene 1,1-Dioxide with Some Grignard Reagents. The Formation of a Heterotricycloheptane Derivative

Grigorios Nikitidis,[†] Salo Gronowitz,*[,†] Anders Hallberg,[†,‡]
and Claes Stålhandske[§]

Division of Organic Chemistry 1 and Division of Inorganic Chemistry 2, Chemical Center, University of Lund, P.O. Box 124, S-221 00 Lund, Sweden

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We have previously studied the reaction of 2,5-dialkyl-3-bromothiophene 1,1-dioxides with organolithium derivatives and found two competing reactions to occur with bromo derivatives. One reaction path, starting with halogen–metal exchange followed by ring opening, leads to lithium enyne sulfinates, which can be trapped with electrophiles such as benzyl bromide. The other path consists of a 1,6-Michael-type addition of the lithium reagent to the 5-carbon of the thiophene 1,1-dioxide, followed by ring opening and elimination of sulfur dioxide and lithium bromide to give enynes (Scheme I). When the same reaction conditions were applied to 3-chloro derivatives, the product was found to be a mixture of the enyne isomers, indicating that the latter reaction path was followed exclusively.[1-3]

We have now studied the reaction of 3-bromo-2,5-dimethylthiophene 1,1-dioxide with Grignard reagents.

The addition of ethylmagnesium bromide to an ethereal solution of 1 at −20 °C gave a compound in high yield with melting point 83–85 °C, which gave a correct analysis for $C_{14}H_{19}BrO_2S$. The number of carbon atoms indicated that it had been formed from 2 mol of the thiophene 1,1-dioxide and 1 mol of ethylmagnesium bromide. Its IR spectrum indicated the presence of a triple bond (2230 cm^{-1}). The presence of a methylacetylenic group was further confirmed by mercury(II) sulfate-catalyzed hydration[4] of the product to yield a carbonyl derivative with an acetonyl grouping.

A detailed NMR study was carried out on the product. DEPT (distortionless enhancement by polarization transfer) experiments showed the presence of five CH_3 groups with ^{13}C shifts at δ 3.75, 3.85, 6.34, 10.20, and 14.58. Two of the methyl groups (at δ 1.37 and 1.30) were singlets, and one (at 1.41) showed a very small coupling in the ^1H NMR spectrum, and therefore are most probably bound to quaternary carbons. In addition, the DEPT experiments showed one CH_2-carbon at δ 18.41, two CH-carbons at δ 44.66 and 52.65, and six carbons without hydrogens at δ 32.68, 40.52, 48.52, 64.16, 72.16, and 83.47.

Carrying out the reaction with 3-bromo-4-deuterio-2,5-dimethylthiophene 1,1-dioxide (2) led to a product in which the ^1H resonances at δ 3.12 and 2.67 had disappeared. In the ^2H NMR spectrum, the deuterium resonances were observed at δ 3.07 and 2.63. The NMR spectral investigation thus indicated a cage structure.

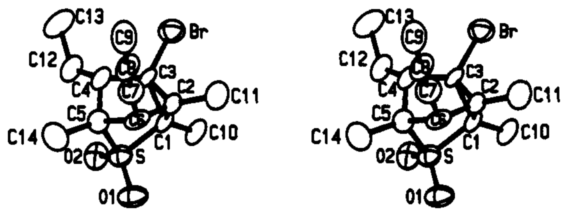

Figure 1. Stereoscopic view of one of the two independent molecules with atomic numbering.

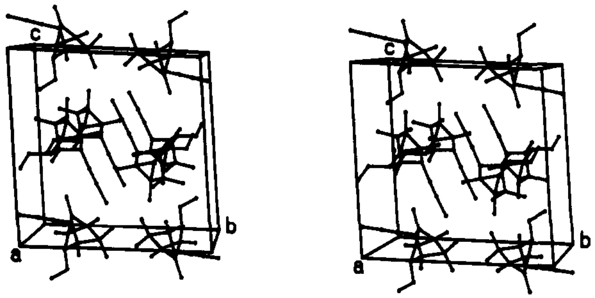

Figure 2. The packing of the molecules in the unit cell.

In order to prove the structure and to determine the stereochemistry of the compound, an X-ray crystallographic investigation was undertaken, the results of which clearly showed that the compound obtained from 1 was 2-bromo-*exo*-3-ethyl-1,4,6-trimethyl-*endo*-5-(1-propynyl)-7-thiatricyclo[2.2.1.$0^{2,6}$]heptane 7,7-dioxide (6). The NMR data are in complete accordance with this structure. The formation of 6 can probably be rationalized in the following way (Scheme II). 1,4-Michael addition of ethylmagnesium bromide to the 3-position of 1 gives the carbanion 3,[5] which in Michael fashion adds to another molecule of 1 in the 3-position, giving the carbanion 4. An intramolecular attack of this carbanion on the 4-position of the first sulfone molecule gives the carbanion 5, which in a nucleophilic substitution attacks the 5-position with sulfinate as leaving group. Elimination of sulfur dioxide and bromide ion then gives 6. This type of elimination leading to acetylenes has been observed by us in many reactions of thiophene 1,1-dioxides, for instance, the tandem cyclodimerization ring opening that leads to unsymmetrical highly substituted benzene derivatives.[6,7]

Reaction of the deuterated compound 2 provided compound 7. *n*-Propylmagnesium chloride reacted similarly

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[†] Division of Organic Chemistry 1.

[‡] Present address: Department of Organic Pharmaceutical Chemistry, Box 574, Uppsala Biomedical Center, S-751 23 Uppsala, Sweden.

[§] Division of Inorganic Chemistry 2.

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(3) Svensson, A.; Karlsson, J. O.; Hallberg, A. *J. Heterocycl. Chem.* **1983**, *20*, 729.

(4) According to the literature, the carbonyl group would be formed preferentially next to a secondary or tertiary carbon: March, J. *Advanced Organic Chemistry. Reactions, Mechanisms and Structure*; Wiley-Interscience: New York, 1985; p 683.

(5) Michael addition at the 3-position of thiophene 1,1-dioxides has been observed in the reaction with secondary amines in aqueous solution: (a) Wrobel, J. T.; Kabzinska, K. *Bull. Acad. Pol.* **1974**, *22*, 129. (b) Gronowitz, S.; Hallberg, A.; Nikitidis, G. *Tetrahedron* **1987**, *43*, 4793. In the reaction with thiolates and alkoxides: Gronowitz, S.; Nikitidis, G.; Hallberg, A. *Chem. Scr.* **1988**, *28*, 289. Organolithium derivatives prefer to attack the 5-position of the thiophene 1,1-dioxides in a 1,6-Michael-type addition reaction (see refs 1–3).

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