ions is based on the resonance principle that an ion orbiting in a magnetic field at a frequency characteristic of its mass:charge ratio can absorb energy from an alternating electric field $E_1(t)$ if the frequency of $E_1(t)$ equals the cyclotron frequency of the ion. By operating at a fixed observing frequency for $E_1(t)$, a mass spectrum is obtained by sweeping the magnetic field. A highly specific double-resonance technique provides a means of determining whether two ions of different mass, even in a complex mixture of ions and neutrals, are coupled chemically. Experimentally this is achieved by observing changes in the signal intensity of a product ion upon irradiation of a reactant ion with a second radiofrequency electric field, $E_2(t)$, applied at the cyclotron frequency of the reactant ion. The resulting increase in kinetic energy of the reactant ion, in turn, changes the rate constants for reactions which it is undergoing, thus accounting for changes in product ion intensity.

The single-resonance negative ion spectrum[4a] of acetyl cyanide obtained with an ionizing electron energy of 2.2 eV (uncor) and at a low pressure ($<10^{-6}$ torr), where essentially no ion–neutral collisions occur, contains only one peak at m/e 26 (CN^-). For this low electron energy, the production of CN^- is probably the dissociative resonance capture process,[5] eq 1. As the pressure is increased, an $M - 1$ peak appears at m/e 68

$$CH_3\overset{O}{\overset{\|}{C}}CN + e^- \longrightarrow CH_3\overset{O}{\overset{\|}{C}}\cdot + CN^- \qquad (1)$$
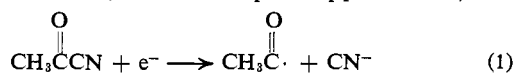
($^-CH_2COCN$) and increases relative to the m/e 26 peak until its intensity is greater than that of the m/e 26 peak. When a pulsed double-resonance[6] experiment is carried out at a pressure where the signal intensities of the m/e 26 and 68 peaks are comparable, irradiation of the m/e 26 peak (radiofrequency amplitude 0.044 V)[4b] results in a decrease in the m/e 68 ion intensity. This decrease is consistent with an exothermic ion–molecule reaction whose specific rate constant decreases with increasing reactant kinetic energy, typical of exothermic ion–molecule reactions observed thus far.[7] The relative intensity behavior of the m/e 26 and 68 peaks with changes in pressure and the double-resonance result give direct evidence for the proton-transfer reaction, eq 2.

$$CH_3\overset{O}{\overset{\|}{C}}CN + CN^- \longrightarrow {}^-CH_2\overset{O}{\overset{\|}{C}}CN + HCN \qquad (2)$$

A 1:1 mixture of acetyl cyanide and hydrogen cyanide under similar conditions gives identical results. In addition, no proton transfer can be observed from HCN to $^-CH_2COCN$, which suggests that this reverse reaction is endothermic.[8] Thus, CN^- has a greater proton affinity than $^-CH_2COCN$; $i.e.$, acetyl cyanide is a stronger acid than HCN in the gas phase.

The single-resonance spectrum of a 1:1 mixture of acetyl cyanide and acetylacetone (2.2 eV, uncor) contains only the peak for CN^- at low pressure. At higher pressures, an $M - 1$ peak for acetylacetone (Ac_2CH^-) at m/e 99 appears, as well as $^-CH_2COCN$ at m/e 68. Irradiation of ^-CN and $^-CH_2COCN$ results in a decrease in the intensity of Ac_2CH^-, but irradiation of Ac_2CH^- produces no change in the intensity of $^-CH_2COCN$. From these results the order of gas-phase acidity, $Ac_2CH_2 > AcCN > HCN$, is obtained.

The proton transfer observed from acetylacetone probably involves the enol, since in the gas phase $>90\%$ acetylacetone exists in this form.[9] Since the enol is thermodynamically more stable, it must be less acidic than the ketone; thus the order of the carbon acidities is maintained irrespective of whether the enol or keto tautomer of acetylacetone is transferring a proton.

The pK_a of acetylacetone[10] is 9.0 and that of hydrogen cyanide[11] is 9.2 in aqueous medium. Thus, the gas-phase and solution acidities of Ac_2CH_2 and HCN fall in the same order, although $a\ priori$ one could not have predicted this result.

Similar experiments show that toluene is a stronger acid than water and that both of these are weaker than HCN. Thus, we should eventually be able to generate a scale of relative gas-phase acidities. These studies are now in progress.

(8) See ref 7b,c,e,g.

(9) (a) J. Powling and H. J. Bernstein, *J. Am. Chem. Soc.*, 73, 4353 (1951); (b) E. Funck and R. Mecke in "Hydrogen Bonding," D. HadžI, Ed., Pergamon Press, Inc., New York, N. Y., 1959, p 433; (c) J. B. Conant and A. F. Thompson, Jr., *J. Am. Chem. Soc.*, 54, 4039 (1932).

(10) (a) R. G. Pearson and R. L. Dillon, *ibid.*, 75, 2439 (1953); (b) F. Hashimoto, J. Tanaka, and S. Nagakura, *J. Mol. Spectry.*, 10, 401 (1963).

(11) (a) R. M. Izatt, J. J. Christensen, R. T. Pack, and R. Bench, *Inorg. Chem.*, 1, 828 (1962); (b) K. P. Ang, *J. Chem. Soc.*, 3822 (1959).

(12) National Science Foundation Predoctoral Fellow, 1966–present.

John I. Brauman, Larry K. Blair[12]
Department of Chemistry, Stanford University
Stanford, California 94305

(4) (a) Spectra were obtained using a Varian V-5900 ICR spectrometer which has been described along with modifications for double resonance. See ref 3b–d. (b) Peak-to-peak voltage was measured externally at the input to the reaction cell.

(5) C. E. Melton in "Mass Spectrometry of Organic Ions," F. W. McLafferty, Ed., Academic Press, New York, N. Y., 1963, p 163.

(6) See ref 3b–d.

(7) For general information on ion–molecule reaction rate energy dependence see: (a) "Ion-Molecule Reactions in the Gas Phase," Advances in Chemistry Series, No. 58, American Chemical Society, Washington, D. C., 1966; (b) V. L. Tal'rose and G. V. Karachevtsev, *Advan. Mass Spectry.*, 3, 211 (1966); (c) D. P. Stevenson in "Mass Spectrometry," C. A. McDowell, Ed., McGraw-Hill Book Co., Inc., New York, N. Y., 1963, p 589; (d) C. E. Melton in "Mass Spectrometry of Organic Ions," F. W. McLafferty, Ed., Academic Press, New York, N. Y., 1963, p 65; (e) F. W. Lampe, J. L. Franklin, and F. H. Field, *Progr. Reaction Kinetics*, 1, 69 (1961); (f) K. R. Ryan and J. H. Futrell, *J. Chem. Phys.*, 43, 3009 (1965); (g) J. L. Beauchamp, Ph.D. Thesis, Harvard University, Cambridge, Mass., 1967.

Backside Attack on "Bent" σ Bonds

Sir:

Recently, we conclusively demonstrated that the addition of electron-deficient olefins and acetylenes to bicyclo[2.1.0]pentane occurred via the formation of a diradical intermediate.[1] It was suggested that this

(1) P. G. Gassman, K. T. Mansfield, and T. J. Murphy, *J. Am. Chem. Soc.*, 90, 4746 (1968); see also W. R. Roth and M. Martin, *Tetrahedron Letters*, 4695 (1967).
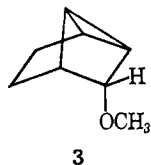
diradical intermediate was formed through formal attack of the olefin or acetylene on the inside of the "flap" formed by the fused rings of bicyclo[2.1.0]pentane. We now wish to present evidence which indicates that addition from the inside of the "flap" is a general phenomenon in that the same mode of attack occurs with derivatives of bicyclo[1.1.0]butane. Furthermore we wish to report that additions of acetylene-type reagents to strained cyclopropanes is relatively insensitive to steric hindrance on the inside of the "flap."

Several groups have shown that acetylenes and olefins react with derivatives of bicyclo[1.1.0]butane[2] in a manner similar to that initially reported[3] for additions to bicyclo[2.1.0]pentane. Unfortunately these reports provided no definitive evidence for the stereochemistry of these additions. In order to elucidate these stereochemical factors we investigated the reaction of tricyclo[4.1.0.0^{2,7}]heptane[4] (1) with benzyne. We specifically chose to study additions to 1 because the three-carbon bridge (C_3–C_4–C_5) of 1 provides considerable steric hindrance to the "backside" of the flap of the bicyclo[1.1.0]butane portion of the molecule.

When a slurry of 3 equiv of benzenediazonium-2-carboxylate[5] and 1 equiv of 1 in methylene chloride was refluxed for 4 hr, a single adduct was isolated in 61% yield.[6] Both mass spectral measurements and chemical analysis (Anal. Calcd for $C_{13}H_{14}$: C, 91.71, H, 8.29. Found: C, 91.83; H, 8.27) confirmed that the product was formed from the addition of 1 equiv of benzyne to 1 equiv of 1. This adduct was assigned structure 2 on the basis of both spectroscopic and chemical evidence.

1   2
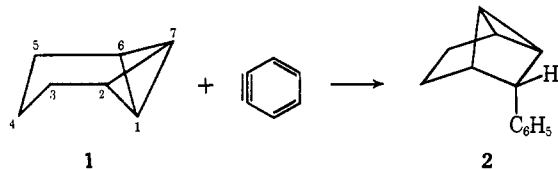
The nmr spectrum of 2 showed a five-proton singlet at τ 2.94, indicating that the product contained a monosubstituted benzene ring. The remainder of the nmr spectrum consisted of a quartet at τ 6.38 (1 H), a doublet with complex fine structure at τ 7.24 (1 H), a one-proton multiplet at τ 7.75, and a broad multiplet from τ 8.1 to 9.0 (6 H). The aliphatic hydrogen part of the spectrum closely resembled that described for 3 by Tanida and coworkers.[7] The near-infrared spectrum

3

of 2 showed maxima at 1.657 and 1.673 μ characteristic of a strained cyclopropane C–H stretching overtone

and aryl C–H stretching overtone, respectively.[8] In the mass spectrum, the base peak was the parent ion. The second most intense peak had m/e 91, corresponding to $C_7H_7^+$. The presence of the monosubstituted benzene ring (ir and nmr) and the large tropylium peak in the mass spectrum indicated that the benzyne had abstracted a hydrogen after its initial addition.

The chemical evidence for the presence of a highly strained cyclopropane was based on the failure of 2 to react with either ozone or osmium tetroxide, coupled with the rapid uptake of hydrogen over 5% Pd–C and the rapid reaction of 2 with elemental bromine. This type of chemical reactivity was typical of that expected for a derivative of tricyclo[4.1.0.0^{3,7}]heptane.[4,7] Mechanistically, derivatives of tricyclo[4.1.0.0^{3,7}]heptane have been derived via carbene insertion[4] and carbonium ion trapping experiments.[7,9] In our example the formation of a carbene would require the intramolecular transfer of the hydrogen initially on the bicyclo[1.1.0]-

4   5

6   7
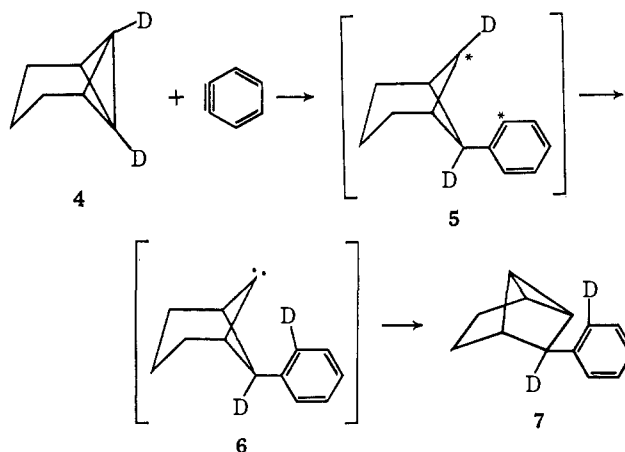
butane bridgehead to the aromatic nucleus. When the addition reaction was carried out with dideuteriotricyclo[4.1.0.0^{2,7}]heptane[10] (4), no such deuterium transfer occurred, as shown by nmr spectroscopy (five aromatic protons vs. seven aliphatic protons) and mass spectrometry (the presence of $C_7H_6D^+$ as the major fragmentation product). This type of mechanism was also eliminated by the stereochemistry of the phenyl group. The intermediacy of 5 and 6 would require that the phenyl group be exo, as shown in 7. However, catalytic hydrogenation of 2 over 5% Pd–C gave endo-2-phenylbicyclo[2.2.1]heptane (8), identical in all respects with an authentic sample.[11]

2   8

The stereochemistry of the phenyl group required that the benzene attack 1 from the same side as the trimethylene bridge. In view of the surmounting evidence for the formation of diradical intermediates in additions to bicyclo[2.1.0]pentanes,[1,3] we feel that the

(2) A. Cairncross and E. P. Blanchard, Jr., J. Am. Chem. Soc., 88, 496 (1966); M. Pomerantz, ibid., 88, 5349 (1966); M. R. Rifi, ibid., 89, 4442 (1967).

(3) P. G. Gassman and K. T. Mansfield, Chem. Commun., 391 (1965); see also P. G. Gassman and K. T. Mansfield, J. Am. Chem. Soc., 90, 1517, 1524 (1968).

(4) W. R. Moore, H. R. Ward, and R. F. Merritt, ibid., 83, 2019 (1961).

(5) L. Friedman and F. M. Logullo, ibid., 85, 1549 (1963); L. Friedman, ibid., 89, 3071 (1967).

(6) Vpc analysis of the crude reaction mixture showed less than 3% of material with retention time similar to 2 indicating that the reaction was particularly clean.
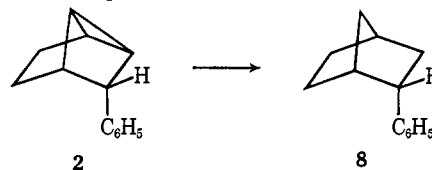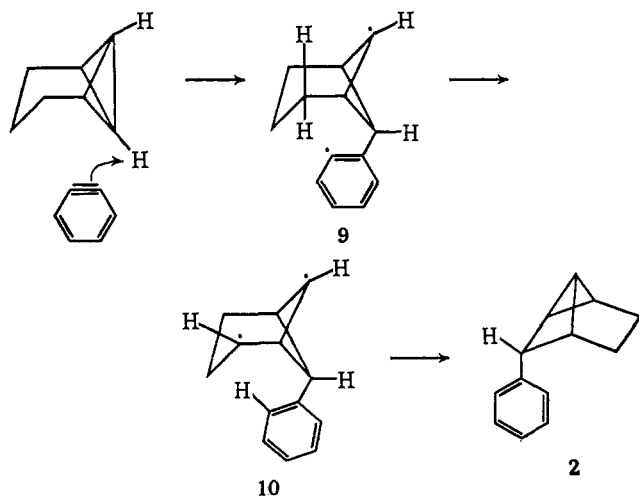
(7) H. Tanida, T. Tsuji, and T. Irie, J. Am. Chem. Soc., 88, 864 (1966).

(8) P. G. Gassman and W. M. Hooker, ibid., 87, 1079 (1965).

(9) H. C. Brown and H. M. Bell, ibid., 85, 2324 (1963); S. Winstein, A. H. Lewin, and K. C. Pande, ibid., 85, 2324 (1963).

(10) G. L. Closs and L. E. Closs, ibid., 85, 2022 (1963). Mass spectral analysis indicated that our sample of 4 was greater than 90% dideuterated.

(11) K. Takeuchi and H. C. Brown, ibid., 90, 2693 (1968). We wish to thank Professor Brown for providing an authentic sample of 8.

9

10   2

(IV), 1-methylcyclohexene (6–8%) (V),[3] and a tar material were isolated.

The presence of III among the reaction products is interpreted as evidence for the formation of carbene.[4] The mechanisms of the formation of IV and V need further study, although these products have a tendency to isomerize and polymerize under the present reported reaction condition.[5]

I did not react significantly with ethyl iodide by refluxing the mixture for a long period. However, I reacted with ethyl iodide (using five to six times excess) under 4000–5000 atm at 100–110° for 16–18 hr. The reaction gave ethylene and 2,6,N-trimethyl-N-ethyl-anilinium iodide (75–80%) yield) (VI).[6] The formation of VI may be due to an exchange reaction of the ethyl moiety of ethyl iodide with the N-methyl of II, which is the first product from I with ethyl iodide by the elimination reaction.[7] Under similar conditions, I also reacted with isopropyl iodide to yield II and propylene.

The reaction of simple alkyl halides with amines gave, in general, the substituted product and very little of the elimination product. However, one would expect the elimination reaction to proceed preferentially over the substitution on increasing the steric requirement of the amines. Thus, the above-reported reactions are *extreme examples* of those reactions which produce quantitatively elimination products and none of the substituted compounds.

most probably mechanistic path involves initial formation of 9 followed by hydrogen transfer to give 10 and subsequent closure of the diradical to yield 2.[12]

The addition of benzyne to 1 from inside the sterically hindered "flap" formed by the fused rings of the bicyclo[1.1.0]butane portion of 1 indicates the overwhelming preference for "backside" attack on the bent C_1–C_7 bond. Studies designed to further elucidate the steric and strain requirements of this reaction are in progress.

(12) An alternate mechanism which cannot be ruled out on the basis of the evidence presently available would be a thermal 2 + 2 + 2 concerted reaction. For a discussion of symmetry considerations in relation to 2 + 2 + 2 reactions see R. Hoffmann and R. B. Woodward, *J. Am. Chem. Soc.*, 87, 2046 (1965).
(13) Alfred P. Sloan Research Fellow, 1967–1969.
(14) National Institutes of Health Predoctoral Fellow, 1965–1968.

Paul G. Gassman,[13] **Gary D. Richmond**[14]
Department of Chemistry, The Ohio State University
Columbus, Ohio 43210
Received July 1, 1968

Elimination Reactions under High Pressure. Reactions of Alkyl Iodides with 2,6,N,N-Tetramethylaniline

Sir:

It is well established that a highly sterically hindered amine, 2,6,N,N-tetramethylaniline (I), does not react with methyl iodide under conventional methods.[1]

We wish now to report that I reacted with methyl iodide under high pressure to yield 2,6,N,N-tetramethylanilinium iodide (II) instead of 2,6,N,N,N-pentamethylanilinium iodide. The reaction was carried out with an excess of methyl iodide (mole ratio 1:4) under 5000–5500 atm at 120–130° for 15 hr.[2] II could result from the α elimination of hydrogen iodide from methyl iodide with the base. Thus, the reaction was carried out in the presence of excess cyclohexene as a carbene acceptor. In the liquid products of the reaction, norcarane (3–5%) (III), 3-methylcyclohexene (15–20%)

(1) H. C. Brown and M. Grayson, *J. Am. Chem. Soc.*, 75, 20 (1953). The failure of the reaction was attributed to the large strain energy of the expected product, 2,6,N,N,N-pentamethylanilinium iodide (strain energy was estimated as 17 kcal).
(2) The detailed procedure of a high-pressure reaction was reported in a previous paper: Y. Okamoto and H. Shimizu, *J. Am. Chem. Soc.*, in press.

(3) Products were characterized and identified by gas chromatographic and infrared comparisons with authentic samples. The yields were calculated based on the amount of compound I added.
(4) W. Kirmse, "Carbene Chemistry," Academic Press, New York, N. Y., 1964, p 40.
(5) The reaction of benzyl chloride with *n*-butyllithium in the presence of cyclohexene also produced a considerable amount of 3-benzyl-cyclohexene: G. L. Closs and L. E. Closs, *Tetrahedron Letters*, No. 24, 26 (1960).
(6) II: yield 65–60%; mp 160° dec; nmr (D_2O, internal TMS), δ 2.58 (singlet, six *o,o'*-dimethyl protons), 3.42 (singlet, six N-dimethyl protons), 7.27 (three aromatic protons). VI: mp 133–135°; nmr (D_2O, internal TMS), δ 1.12 (triplets, three methyl protons, N–C_2H_5), 2.58 (singlet, six *o,o'*-dimethyl protons), 3.42 (singlet, three N-methyl protons), 3.85 (multiplets, two methylene protons, N–C_2H_5).
(7) A similar exchange reaction was reported in a previous paper.[2]

Yoshiyuki Okamoto
Department of Chemical Engineering
New York University, New York, New York 10453
Received July 19, 1968

Slaframine. Absolute Stereochemistry and a Revised Structure

Sir:

We recently assigned structure I to the parasympathomimetic fungal alkaloid slaframine;[1,2] we now revise this structure to II,[3] (1S,6S,8aS)-1-acetoxy-6-aminooctahydroindolizine.

Spin-decoupling experiments performed on N-acetyl-slaframine hydrochloride (100 MHz, D_2O solution) reveal that H-8a (3.41 ppm), coupled to H-1 (5.49 ppm,

(1) S. D. Aust, H. P. Broquist, and K. L. Rinehart, Jr., *J. Am. Chem. Soc.*, 88, 2879 (1966).
(2) After our earlier publication appeared, another group [B. J. Whitlock, D. P. Rainey, N. V. Riggs, and F. M. Strong, *Tetrahedron Letters*, 3819 (1966)] employed arguments much like ours to assign the same structure (I) to slaframine.
(3) The key mass spectral peak at M − 43 earlier attributed[1] to loss of C_3H_7 has been shown in a high-resolution mass spectrum (determined at the Purdue Mass Spectrometry Center) to be a doublet in the spectrum of slaframine, arising from loss of C_2H_5N (major ion) and C_2H_3O (minor ion); in deacetylslaframine the M − 43 peak is also due to loss of C_2H_5N (major) and C_2H_3O (minor).