derivatives of polycyclic aromatic hydrocarbons as compared to other typical epoxides.

Unlike the BcPh diol epoxides, the DBA diol epoxides exhibit low efficiency of covalent binding to DNA,[9,10] relative to hydrolysis. In general the DBA diol epoxides show some preference (cf. Table I) for dG adduct formation (60–80% of total adducts), whereas this preference is reversed in the case of the BcPh diol epoxides, such that 50–90% of the adducts formed from the BcPh diol epoxides involve dA residues. Despite these differences, some notable similarities do emerge in the patterns of adduct formation from the individual optically active isomers in the BcPh and the DBA series.

(i) For dA adduct formation, the ratio of cis to trans addition to diol epoxide-1 is highly dependent on the absolute configuration of the diol epoxide. For example, the ratio of cis to trans dA adducts from both DBA and BcPh (4*S*,3*R*)-diol (2*S*,1*R*)-epoxides-1 is ca. 1:3, whereas the ratio of cis to trans dA adducts from the enantiomeric (4*R*,3*S*)-diol (2*R*,1*S*)-epoxides-1 from both hydrocarbons is ca. 7:1. In the case of diol epoxide-2, trans dA adduct formation is preferred by a factor of 3:1 for the (4*S*,3*R*)-diol (2*R*,1*S*)-epoxide-2 from DBA and by a factor of 2:1 for this diol epoxide isomer from BcPh. A much greater preference for trans dA adduct formation is exhibited by the (4*R*,3*S*)-diol (2*S*,1*R*)-epoxide-2 enantiomers: >20:1 for DBA and >40:1 for BcPh.

(ii) Trans-adduct formation from dG and the (4*S*,3*R*)-diol (2*R*,1*S*)-epoxide-2 isomers is substantially favored over cis-adduct formation, by >10:1 for DBA and >20:1 for BcPh. With the (4*R*,3*S*)-diol (2*S*,1*R*)-epoxide-2 enantiomers, trans dG adduct formation is also preferred, by a factor of ca. 3 for DBA and of ca. 10 for BcPh.

(iii) Only the (4*S*,3*R*)-diol (2*R*,1*S*)-epoxide-2 isomer gives appreciable quantities of a dC adduct, in the case of both DBA and BcPh. Deoxycytidine adducts have also been reported from BaP diol epoxide-2 enantiomers,[3a,b] but they have not been well characterized, and it is not clear whether only one or both enantiomers of the diol epoxide give rise to these adducts.

From these results it is apparent that chiral interactions between the diol epoxides and the DNA molecule are highly important in determining the preferred sites and orientations of adduct formation. Further investigations using oligonucleotides of defined structure and sequence will be required to determine the nature of these interactions, as well as their possible implications for the differential mutagenicities and tumorigenicities of the optically active isomeric diol epoxides.

Supplementary Material Available: Listing of ^{1}H NMR chemical shifts for the base and sugar hydrogens of the acetylated deoxyribonucleoside adducts, as well as selected hydrogens of the hydrocarbon moieties in these adducts, and CD spectral traces of the adducts derived from (−)-dibenz[*a*,*j*]anthracene (4*R*,3*S*)-diol (2*R*,1*S*)-epoxide-1 and (−)-(4*S*,3*R*)-diol (2*R*,1*S*)-epoxide-2 (4 pages). Ordering information is given on any current masthead page.

Communications to the Editor

The Absolute Configuration and Synthesis of Natural (−)-Dolastatin 10[1]

George R. Pettit,* Sheo Bux Singh, Fiona Hogan, Paul Lloyd-Williams, Delbert L. Herald, Douglas D. Burkett, and Paul J. Clewlow

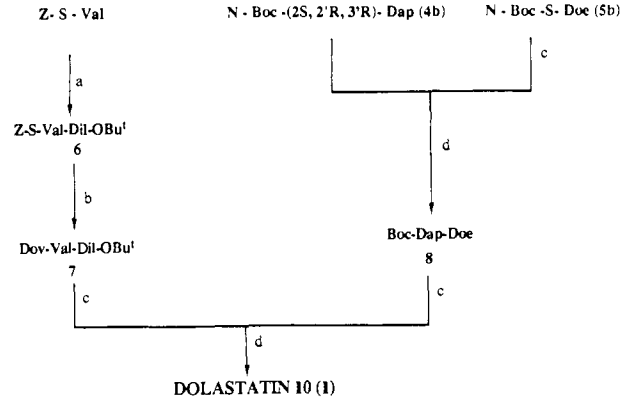
Cancer Research Institute and Department of Chemistry, Arizona State University Tempe, Arizona 85287-1604

Received November 7, 1988

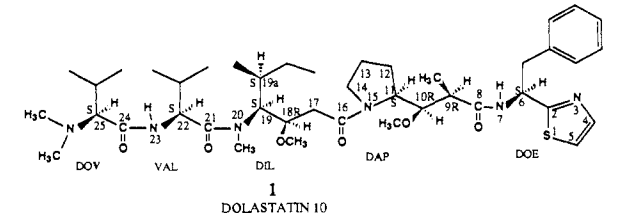
The fascinating sea hare *Dolabella auricularia* was known to certain ancient Greeks and Romans for various medical or nefarious[2,3] purposes. As early as 200 BC the Greek Nicandros recommended extracts of this opisthobranch (Subclass, Mollusca phylum) for treatment of certain diseases.[3] Over the past 16 years we have vigorously pursued the powerful cytostatic and antineoplastic constituents of *D. auricularia* collected in the Western Indian Ocean. In 1987 we reported the isolation and structure of dolastatin 10 (**1**), the most potent (i.e., lowest in vivo dose) antineoplastic substance known to date.[4] Due to the few milligrams of amorphous dolastatin 10 available for structure determination combined with the chiral complexity (9 asymmetric centers), the absolute configuration was not ascertained.

The most attractive solution to both the dolastatin 10 stereochemical and preclinical supply problems resided in an effective synthesis of the natural isomer from among 512 possible corresponding to the one-dimensional structure. We herein report that the absolute configuration of natural (−)-dolastatin 10 corresponds to structure **1** and we give its total synthesis. The genesis of a practical solution to these challenging problems arose from our

Scheme I[a]



[a] a. $(CH_3)_3COCl$, NMM, (3*R*,4*S*,5*S*)-Dil-OBu^t·HCl, $CHCl_3$. b. Dov-OPfp, 10% Pd/C, H_2, dioxane. c. CF_3CO_2H, CH_2Cl_2. d. Diethyl phosphorocyanidate (DEPC), TEA, DME, 1 h at 0 °C, 2 h at room temperature.



1
DOLASTATIN 10

(1) Dedicated to Professor Carl Djerassi's 65th birthday. Contribution 189 in the series Antineoplastic Agents. For Part 188 see: Singh, S. B.; Pettit, G. R.; Herald, D. L. *J. Am. Chem. Soc.*, in preparation.

(2) Pettit, G. R.; Ode, R. H.; Herald, C. L.; Von Dreele, R. B.; Michel, C. *J. Am. Chem. Soc.* **1976**, *98*, 4677–4678.

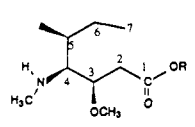
(3) Donati, G. *La Conchiglia* **1984**, May issue.

(4) Pettit, G. R.; Kamano, Y.; Herald, C. L.; Tuinman, A. A.; Boettner, F. E.; Kizu, H.; Schmidt, J. M.; Baczynskyj, L.; Tomer, K. B.; Bontems, R. J. *J. Am. Chem. Soc.* **1987**, *109*, 6883–6885.

0002-7863/89/1511-5463$01.50/0

earlier[5] and on-going dolastatin structural studies. These suggested the amino acid biosynthetic precursors of dolastatin 10 would likely carry the L- (*S* notation hereupon) and Ile the (*S,S*)-configuration. Furthermore, a synthetic[4] specimen of S-Dov-S-Val [DCCI-HBT coupling, mp 96–7 °C from acetone–hexane $[\alpha]^{30}_D$ −17° (*c* = 3.6, $CHCl_3$)][6] corresponded exactly to a dolastatin 10 acid hydrolysis product when derivatives of both were co-injected and chromatographed on a Chirasil Val column. With these clues in mind synthesis of dolastatin 10 was initiated.

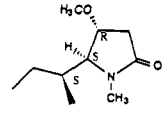
Careful 2D NMR (400 MHz) comparative interpretations of the natural product with the diastereoisomeric Dil (**2a**) and Dap (**4a**) synthetic intermediates were employed to select the most probable chiral isomers. Synthesis of the necessary Dil component



2

a. R = H, DOLAISOLEUINE (Dil)

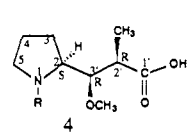
b. R = Bu^t



3

(3*R*,4*S*,5*S*)-Dil-OBu^t·HCl [**2b**, mp 145–7 °C from ether, $[\alpha]^{30}_D$ 7.3° (*c* = 4.5, $CHCl_3$)] was realized by methylating (NaH, CH_3I)[7] *Z*-(*S,S*)-isoleucine, followed by reduction (diborane–THF) to *N*-Z-*N*-Me-(*S,S*)-isoleucinol [95% overall, oil, $[\alpha]^{30}_D$ −11.3° (*c* = 5.6, $CHCl_3$)], oxidation (DMSO–SO_3–Py) to the aldehyde [78%, $[\alpha]^{30}_D$ −66° (*c* = 4.36, $CHCl_3$)], aldol condensation (at −78 °C, 45 min, in THF) with the lithium enolate (lithium diisopropylamide) from *tert*-butyl acetate to yield (87% total, following silica gel column chromatography, hexane–acetone) the (3*S*,4*S*,5*S*)- [23% yield, viscous oil, $[\alpha]^{35}_D$ −37.8° (*c* = 5.0 $CHCl_3$)] and (3*R*,4*S*,5*S*)- [(33% yield, viscous oil, $[\alpha]^{35}_D$ −3.10° (*c* = 4.25, $CHCl_3$)] β-alcohols where the 3*R*-isomer was methylated (diazomethane–boron trifluoride etherate, see below) and the product [67% yield, oil, $[\alpha]^{35}_D$ −15.5° (*c* = 4.9, $CHCl_3$)] subjected to hydrogenolysis (63% yield of **2b** with 3:1 ethyl acetate–methanol, 1 day, 5% Pd/C, H_2, then HCl at −60 °C in ether). The latter reaction also afforded pyrrolidinone **3** [29% viscous oil, $[\alpha]^{30}_D$ −6° (*c* = 0.9, $CHCl_3$)] required for ^1H NMR analysis[8] and in turn confirms stereochemical assignments for the Dil series. Lactam formation was almost completely eliminated by a short (2 h) hydrogenolysis period.

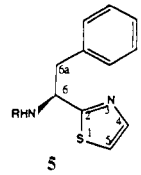
Synthesis of the more complex (3 chiral centers) *N*-Boc-DAP (**4b**) and stereochemical assignments proceeded as follows. Of the synthetic routes explored, an aldol condensation approach[9] was most successful. Reduction of Boc-*S*-Pro with diborane



4

a. R = H, DOLAPROINE (Dap)

b. R = Boc



5

a. R = H, DOLAPHENINE (Doe)

b. R = Boc

followed by modified (DMSO-trifluoroacetic anhydride) Swern[10] or Parikh-Doering (DMSO–SO_3–Py)[11] oxidation to Boc-*S*-prolinal [oil, $[\alpha]^{30}_D$ −96° (*c* = 1.19, $CHCl_3$)][12] proceeded well (~75% overall). Aldol condensation (at −95 °C for 2 h) of this aldehyde with the chiral enolate derived (lithium diisopropylamide) from (2*S*)-propionyloxy-1,1,2-triphenylethanol [mp 215–16 °C from acetone–hexane, $[\alpha]^{30}_D$ −203.5° (*c* = 1.44, $CHCl_3$)] in tetrahydrofuran containing freshly prepared magnesium bromide (to enhance stereoselectivity)[9] afforded the nearly correct (2*S*,2′*S*,3′*R*)-isomer [glistening crystals from acetone–hexane, mp 128–30 °C, $[\alpha]^{30}_D$ −146.9° (*c* = 2.45, $CHCl_3$)] as the major product (47% yield by silica gel column chromatographic separation). By HPLC analysis (RP-8 with acetonitrile–water, 50–100%) the four possible diastereoisomers were present in the ratio 64:6:15:15. When the aldol reaction was conducted at the warmer −78 °C, stereoselectivity was reduced leading to a 45:15:20:20 ratio of isomers. The diastereoisomer corresponding to dolaproine was not easily separated from the others. So as described below, simple 2′-position epimerization of the major isomer proved convenient and overcame this hurdle.[13]

Treatment of the major aldol product with boron trifluoride etherate–diazomethane,[14] or better by trimethyloxonium tetrafluoroborate[15] in methylene chloride, gave the (3′*R*)-methyl ether derivative [crystals from acetone–hexane, mp 130–2 °C, $[\alpha]^{30}_D$ −169.7° (*c* = 4.15, $CHCl_3$)]. Epimerization of the (2′*S*)-methyl group necessitated rather specific conditions, namely short contact (2–5 min and termination with saturated citric acid) with potassium *tert*-butoxide in THF at −20 °C to provide (57%) the (2′*R*)-methyl epimer [mp 130–2 °C from acetone–hexane, $[\alpha]^{30}_D$ −154.6° (*c* = 0.01, $CHCl_3$)]. Hydrogenolysis (Pd/C) of the benzyl ester led to *N*-Boc-(2*S*,2′*R*,3′*R*)-dolaproine [**4b**, mp 138–142 °C from acetone–hexane, $[\alpha]^{30}_D$ −40° (*c* = 3.0, CH_3OH)]. Mild treatment with trifluoroacetic acid led to natural (2*S*,2′*R*,3′*R*)-dolaproine as the *trifluoroacetate salt* [mp 215–220 °C from methanol–ether, $[\alpha]^{30}_D$ −10° (*c* = 0.5, CH_3OH)].

Preparation of dolaphenine (**5a**) followed the probable biosynthetic route we outlined in 1982 for thiazole amino acids.[16] Conversion of Boc-*S*-Phe to the corresponding *N*-Boc-*S*-phenylalaninal [powder, mp 67–69 °C, $[\alpha]^{30}_D$ −37.5° (*c* = 1.0, $CHCl_3$)] was performed as above (Dil sequence). Condensation with 2-aminoethanethiol and dehydrogenation (in dioxane, room temperature, through a column of battery grade manganese dioxide)[17,18] of the thiazolidines (98% yield) afforded (~77%) *N*-Boc-*S*-Doe [**5b**, crystals from acetone–hexane, mp 106–7 °C, $[\alpha]^{30}_D$ −23.2° (*c* = 0.6, $CHCl_3$)].

With some use of techniques from our recent synthesis of dolastatin 3,[5] pivaloyl anhydride coupling[19] for the *N*-methyl amino acid (Dil), and then proceeding (Scheme I) via peptides **6** [80%, oil, $[\alpha]^{30}_D$ −58° (*c* = 0.5, $CHCl_3$)], **7** [83%, crystals from acetone–hexane, mp 104–6°, $[\alpha]^{28}_D$ −50° (*c* = 1.06, CH_3OH)], and **8** (50%, viscous oil), natural (−)-dolastatin 10 (**1**) was obtained (74%, following purification on Sephadex LH-20, 2:7.5:2.5 hexane–dichloromethane–methanol, and silica gel, 1 → 5% gradient, dichloromethane → methanol) as an amorphous powder [mp 102–6 °C from acetone hexane, $[\alpha]^{27}_D$ −57° (*c* = 0.026, CH_3OH)]

(5) The Val-Pro-Leu-(gln)-Thz sequence of dolastatin 3 was found by total synthesis to be entirely in the L-amino acid configuration: Pettit, G. R.; Kamano, Y.; Holzapfel, C. W.; van Zyl, W. J.; Tuinman, A. A.; Herald, C. L.; Baczynskyj, L.; Schmidt, J. M. *J. Am. Chem. Soc.* **1987**, *109*, 7581–7582.

(6) Satisfactory elemental analytical and/or high resolution mass and NMR spectral data were obtained for each new substance reported herein.

(7) McDermott, J. R.; Benoiton, N. L. *Can. J. Chem.* **1973**, *51*, 1915.

(8) The pyrrolidinone prepared from the (3*S*,4*S*,5*S*)-isomer showed a convincing NOE between H-4 and H-5 (6 and 7%, respectively) and a larger coupling constant (H-5, dd, *J* = 7.0, 3.6 Hz, and H-4, q, *J* = 7.0 Hz) for those hydrogen atoms than that of their counterparts in pyrrolidinone 3.

(9) Ewing, W. R.; Harris, B. D.; Bhat, K. L.; Joullie, M. M. *Tetrahedron* **1986**, *42*, 2421–2428. Interestingly, in this helpful series of experiments directed at the synthesis of detoxinine, aldol condensation of a prolinal with an acetate enolate yielded the *S*-hydroxy isomer as the major product.

(10) Smith, A. B., III; Leenay, T. L.; Liu, H.-J.; Nelson, L. A. K.; Ball, R. G. *Tetrahedron Lett.* **1988**, *29*, 49–52.

(11) (a) Hamada, Y.; Shioiri, T. *Tetrahedron Lett.* **1982**, *23*, 1193–1196. (b) Hamada, Y.; Shioiri, T. *Chem. Pharm. Bull.* **1982**, *30*, 1921–1924. (c) Hamada, Y.; Kohda, K.; Shioiri, T. *Tetrahedron Lett.* **1984**, *25*, 5303–5306. (d) Parikh, J. R.; Doering, W. von E. *J. Am. Chem. Soc.* **1967**, *89*, 5505–5507.

(12) Hanson, G. J.; Baran, J. S.; Lindberg, T. *Tetrahedron Lett.* **1986**, *27*, 3577.

(13) Absolute configuration of the major (2*S*,2′*S*,3′*R*)-isomer was unequivocally established by X-ray crystal structure (refer to the Supplementary Material) determination of the easily formed (by hydrogenolysis, esterification, trifluoroacetic acid, and potassium carbonate) lactam derivative [mp 121–2 °C from acetone–cyclohexane, $[\alpha]^{30}_D$ −115° (*c* = 1.85, $CHCl_3$)].

(14) Deferrari, J. O.; Gros, E. G.; Mastronardi, I. O. *Carbohydrate Res.* **1967**, 432.

(15) Diem, M. J.; Burow, D. F.; Fry, J. L. *J. Org. Chem.* **1977**, *42*, 180.

(16) Pettit, G. R.; Kamano, Y.; Brown, P.; Gust, D.; Inoue, M.; Herald, C. L. *J. Am. Chem. Soc.* **1982**, *104*, 905. See footnote 18 of this report.

(17) Hamada, Y.; Shibata, M.; Sugiura, T.; Kato, S.; Shioiri, T. *J. Org. Chem.* **1987**, *52*, 1252.

(18) Barton, M. A.; Kenner, G. W.; Sheppard, R. C. *J. Chem. Soc.* **1966**, 1061.

(19) Wenger, R. M. *Helv. Chim. Acta* **1983**, *60*, 2672. Wenger, R. M. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 77.

identical by HPLC, TLC, ^{13}C NMR, and, most importantly, by 400-MHz ^1H NMR (in CH_2Cl_2 solution) with an authentic specimen. Synthetic dolastatin 10 also exhibited the same level (ED_{50} 10^{-4} μg/mL) of activity against the P388 lymphocytic leukemia as routinely obtained with the natural product.

The preceding total synthetic solutions to the dolastatin 10 stereochemical and availability problems will now greatly accelerate preclinical development, synthesis of potentially useful structural and chiral modifications, and a broad assessment of biological properties.

Acknowledgment. Very necessary financial support was provided by the Fannie E. Rippel Foundation, the Arizona Disease Control Research Commission, Herbert K. and Dianne Cummings (The Nathan Cummings Foundation, Inc.), Eleanor W. Libby, the Waddell Foundation (Donald Ware), Grant CA-16049-10-12 awarded by the National Cancer Institute, and DHHS and NSF equipment Grants CHE-8211164, CHE-8620177 (to the University of Nebraska, Midwest Center for Mass Spectrometry), and CHE-8409644. We also thank Drs. Y. Kamano, C. L. Herald, and C. Dufresne and Chemetals, Maryland, for their assistance.

Registry No. 1, 110417-88-4; **2b**, 120205-48-3; **2b** (*N*-Z derivative), 120205-58-5; **2b** (*N*-Z, 3-OH derivative), 120294-43-1; (3*S*,4*S*,5*S*)-**2b** (*N*-Z, 3-OH derivative), 120205-57-4; **3**, 120205-49-4; **4a**·TFA, 120205-63-2; **4b**, 120205-50-7; **4b** ((*S*)-CHPhCHPh$_2$ ester), 120294-47-5; **4b** (3′-OH, (*S*)-CHPhCHPh$_2$ ester), 120294-46-4; (2*S*,2′*S*,3′*R*)-**4b** (3′-OH, (*S*)-CHPhCHPh$_2$ ester), 120205-60-9; (2*S*,2′*S*,3′*S*)-**4b** (3′-OH, (*S*)-CHPhCHPh$_2$ ester), 120294-44-2; (2*S*,2′*R*,3′*S*)-**4b** (3′-OH, (*S*)-CHPhCHPh$_2$ ester), 120294-45-3; (2*S*,2′*S*,3′*R*)-**4b** ((*S*)-CHPhCHPh$_2$ ester), 120205-61-0; **5**, 120205-51-8; (2*S*,6*S*)-**5b** (2,3,4,5-tetrahydro derivative), 120205-64-3; (2*R*,6*S*)-**5b**, (2,3,4,5-tetrahydro derivative), 120205-65-4; **6**, 120205-52-9; **7**, 120205-53-0; **8**, 120205-54-1; Z-Ile-OH, 3160-59-6; (*S*,*S*)-ZNMeCH(CHMeEt)CH$_2$OH, 120205-55-2; (*S*,*S*)-ZNMeCH(CHMeEt)CHO, 120205-56-3; AcOBu-*t*, 540-88-5; BOC-Pro-OH, 15761-39-4; (*S*)-CH$_3$CH$_2$COOCHPhCHPh$_2$, 120205-59-6; BOC-Phe-OH, 13734-34-4; (*S*)-(BOC)NHCH(CH$_2$Ph)CHO, 72155-45-4; H$_2$NCH$_2$CH$_2$SH, 60-23-1; Z-Val-OH, 1149-26-4; Dov-OPfp, 97800-78-7; BOC-(*S*)-prolinal, 69610-41-9.

Supplementary Material Available: X-ray crystal structure determination summary (including tables of distances and angles and coordinates and an ORTEP drawing) for the lactam derived from (2*S*,2′*S*,3′*R*)-dolaproine (8 pages). Ordering information is given on any current masthead page.

The Electron Affinity of (η^4-1,3-Butadiene)iron Tricarbonyl, η^4-Bd·Fe(CO)$_3$

G. W. Dillow, G. Nicol, and P. Kebarle*

Department of Chemistry, University of Alberta Edmonton, Alberta, Canada T6G 2G2

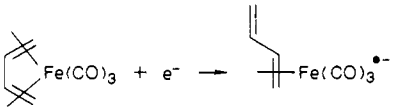
Received January 6, 1989

Although formation of negative ions in the gas phase from organometallic compounds has long been known,[1,2] only very limited information is currently available on the electron affinities of organometallic species. Electron affinities have been determined by laser photodetachment for simple metal carbonyls such as Fe(CO)$_{1-4}$[3] and Ni(CO)$_{1-3}$,[4] but very little is known about the electron affinities of more complex substituted metal carbonyls.

In this communication we report the first determination of the free energy of electron attachment, ($-\Delta G°_a \approx$ EA), for η^4-Bd·Fe(CO)$_3$ by pulsed high pressure mass spectrometry (PHPMS). PHPMS has been shown to be highly suitable for the determination of EAs of molecules which undergo resonance electron capture and has been used to determine the EAs of a wide variety of organic compounds.[5] While the majority of metal carbonyls undergo dissociative electron capture, reaction 1, rather than

$$\text{L·metal(CO)}_n + e^- \rightarrow \text{L·metal(CO)}_{n-1}^{\bullet -} + \text{CO} \qquad (1)$$

resonance electron capture in order to avoid violation of the 18-electron rule,[1,2] certain substituted metal carbonyls bearing tetra- and hexahaptate ligands may undergo resonance electron capture by reducing the hapticity of the ligand.[6-9] A well-known example is η^4-Bd·Fe(CO)$_3$ which forms the stable 17-electron anion, η^2-Bd·Fe(CO)$_3^{\bullet -}$, as shown in reaction 2.[6,8,9] Studies of the equivalent



(2)

reduction in solution, where the product ion may be fully characterized, have confirmed the dihapto coordination of the butadiene ligand and indicated that the negative charge is located largely on the metal.[10]

The PHPMS experiments with η^4-Bd·Fe(CO)$_3$ were performed with instrumentation that has been described in detail previously,[5] with standard experimental conditions. Chemical reactions were initiated by directing 10-100 μs pulses of energetic (2000 V) electrons into methane gas maintained at 6 Torr pressure and 150 °C and containing mTorr quantities of the reactants. Product ions which diffused from the ion source through a narrow orifice were accelerated, mass selected, and collected by a multichannel analyzer as a function of time after the initiating electron pulse.

With η^4-Bd·Fe(CO)$_3$ present as the only reactant in the methane mixture, an abundant molecular ion, η^2-Bd·Fe(CO)$_3^{\bullet -}$, was observed along with a fragment ion identified as η^4-Bd·Fe(CO)$_2^{\bullet -}$. Figure 1 shows the time profiles of these ions for a period of 2 ms after the electron pulse. It is evident that under our experimental conditions, the η^2-Bd·Fe(CO)$_3^{\bullet -}$ molecular ion undergoes a slow unimolecular loss of CO (rate constant $\approx$ 600 s^{-1}) to

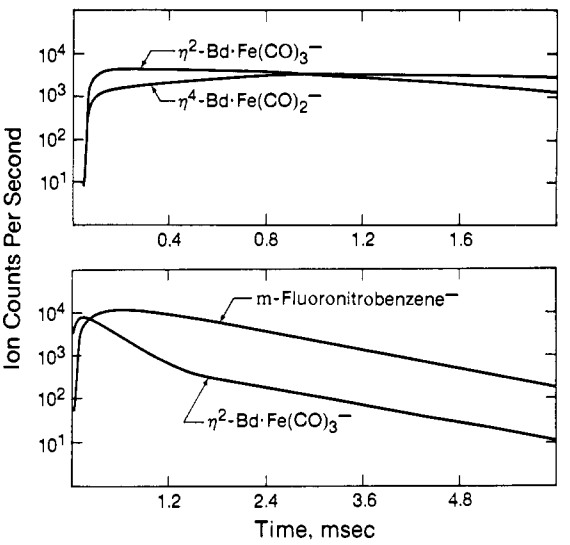


Figure 1. (top) Time profiles for the η^2-Bd·Fe(CO)$_3^{\bullet -}$ and η^4-Bd·Fe(CO)$_2^{\bullet -}$ produced in a mixture of 2.6 mTorr η^4-Bd·Fe(CO)$_3$ in 6 Torr methane; 10 μs electron pulse. (bottom) Time profile for the molecular ions produced in a mixture containing 12.9 mTorr η^4-Bd·Fe(CO)$_3$ and 17.1 mTorr *m*-fluoronitrobenzene in methane (6 Torr) following a 100-μs electron pulse. Both experiments at 150 °C temperature.

(1) Gregor, I. K.; Guilhaus, M. *Mass Spectrom. Rev.* **1984**, *3*, 32.
(2) Squires, R. R. *Chem. Rev.* **1987**, *87*, 623.
(3) Engelking, P. C.; Lineberger, W. C. *J. Am. Chem. Soc.* **1979**, *101*, 5569.
(4) Stevens, A. E.; Feigerle, C. S.; Lineberger, W. C. *J. Am. Chem. Soc.* **1982**, *104*, 5026.
(5) Kebarle, P.; Chowdhury, S. *Chem. Rev.* **1987**, *87*, 513.
(6) Blake, M. R.; Garnett, J. L.; Gregor, I. K.; Wild, S. B. *J. Chem. Soc., Chem. Commun.* **1979**, 496.
(7) Blake, M. R.; Garnett, J. L.; Gregor, I. K.; Wild, S. B. *J. Organomet. Chem.* **1979**, *178*, C37.
(8) McDonald, R. N.; Schell, P. L.; Chowdhury, A. K. *J. Am. Chem. Soc.* **1985**, *107*, 5578.
(9) Wang, D.; Squires, R. R. *Organometallics* **1987**, *6*, 905.
(10) Krusic, P. J.; San Filippo, J., Jr. *J. Am. Chem. Soc.* **1982**, *104*, 2645.

0002-7863/89/1511-5465$01.50/0