Volume 25
Number 8
April 9, 1986

Inorganic Chemistry

Communications

Synthesis, Characterization, and Structure of a Novel Hexanuclear Iron–Sulfur–Carbonyl Cluster, the $[Fe_6S_6(CO)_{12}]^{2-}$ Ion

Sir:

Clusters containing iron and sulfide[2] are of substantial interest, both as models for the iron–sulfur centers found in many proteins[3] and as examples of novel structural units in inorganic chemistry. Structurally characterized systems with thiolate, halide, or phenoxide terminal ligands include binuclear ($[Fe_2S_2L_4]^{2-}$[4]), trinuclear ($[Fe_3S(S_2\text{-}o\text{-xyl})_3]^{2-}$[5] and $[Fe_3S_4L_4]^{3-}$[6]), tetranuclear ($[Fe_4S_4L_4]^{1-,2-,3-}$[2,7]), and hexanuclear ($[Fe_6S_6L_6]^{2-,3-}$[8] and $[Fe_6S_9L_2]^{4-}$[9]) clusters. Related systems with carbonyl or phosphine ligation include binuclear ($Fe_2S_2(CO)_6$[10]), trinuclear ($Fe_3S_2(CO)_9$[11]), tetranuclear ($Fe_4S_4(CO)_{12}$[12] and $[Fe_4S_4(CO)_{12}]^{2-}$[13]), and hexanuclear ($[Fe_6S_8(PEt_3)_6]^{2+}$[14]) examples. The hexanuclear clusters are of particular interest as possible examples of novel structures that may be present in proteins and as starting materials for the synthesis of new structural models for the iron–molybdenum cofactor of nitrogenase.[15] We report herein the synthesis, structure, and some properties of a novel hexanuclear iron–sulfur–carbonyl cluster, the $[Fe_6S_6(CO)_{12}]^{2-}$ dianion (I).

Addition of a solution of $Fe_2S_2(CO)_6$[16] (857 mg, 2.95 mmol) in 10 mL of THF to a solution of "$[o\text{-xyl-}S_2]_2^{2-}$" (prepared from 424 mg (2.42 mmol) of $o\text{-xyl(SH)}_2$[17]) in 25 mL of THF produces a green solution that gradually becomes purple upon stirring at 22 °C for 4 days. Filtration of the purple solution into a solution of $BzEt_3N^+Cl^-$ (1.13 g, 4.95 mmol) in 10 mL of *i*-PrOH results in precipitation of a purple microcrystalline solid, which is collected, washed with Et_2O, and recrystallized from a minimum volume of MeCN. Cooling to −20 °C gives $[BzEt_3N]^+{}_2[I]$ as analytically pure[18] purple crystals (29%). The $[BzEt_2MeN]^+$ and $[PPN]^+$ salts are obtained in similar fashion. Complex I can also be prepared by reaction of a solution of $Fe_2(SH)_2(CO)_6$[19] (1.20 mmol) in THF (63 mL) with a solution of $[Et_4N]_2[Fe_2S_2Cl_4]$[20] (3.48 g, 0.602 mmol) and Et_3N (0.33 mL, 2.4 mmol) in 20 mL of DMF at 0 °C. Optical spectra of the reaction mixture show that I is produced in ~70% yield.[21]

Crystals of $[BzEt_2MeN]_2[I]$ suitable for X-ray diffraction studies[22] were obtained from MeCN/*i*-PrOH at −20 °C. The

---

(1) Alfred P. Sloan Foundation Fellow, 1981–1985.

(2) Berg, J. M.; Holm, R. H. In *Iron-Sulfur Proteins*; Spiro, T. G., Ed.; Wiley: New York, 1982; p 1.

(3) Orme-Johnson, W. H.; Orme-Johnson, N. R. In *Iron-Sulfur Proteins*; Spiro, T. G., Ed.; Wiley: New York, 1982; p 67.

(4) (a) Mayerle, J. J.; Denmark, S. E.; DePamphilis, B. V.; Ibers, J. A.; Holm, R. H. *J. Am. Chem. Soc.* **1975**, *97*, 1032. (b) Coucouvanis, D.; Swenson, D.; Stremple, P.; Baenziger, N. C. *J. Am. Chem. Soc.* **1979**, *101*, 3392. (c) Bobrik, M. A.; Hodgson, K. O.; Holm, R. H. *Inorg. Chem.* **1977**, *16*, 1851. (d) Coucouvanis, D.; Salifoglou, A.; Kanatzidis, M. G.; Simopoulos, A.; Papaefthymiou, V. *J. Am. Chem. Soc.* **1984**, *106*, 6081.

(5) (a) Henkel, G.; Tremel, W.; Krebs, B. *Angew. Chem., Int. Ed. Engl.* **1981**, *20*, 1033. (b) Hagen, K. S.; Christou, G.; Holm, R. H. *Inorg. Chem.* **1983**, *22*, 309.

(6) (a) Hagen, K. S.; Holm, R. H. *J. Am. Chem. Soc.* **1982**, *104*, 5496. (b) Hagen, K. S.; Watson, A. D.; Holm, R. H. *J. Am. Chem. Soc.* **1983**, *105*, 3905.

(7) (a) Mascharak, P. K.; Hagen, K. S.; Spence, J. T.; Holm, R. H. *Inorg. Chim. Acta* **1983**, *80*, 157. (b) Cleland, W. E.; Holtman, D. A.; Sabat, M.; Ibers, J. A.; DeFotis, G. C.; Averill, B. A. *J. Am. Chem. Soc.* **1983**, *105*, 6021. (c) O'Sullivan, T.; Millar, M. M. *J. Am. Chem. Soc.* **1985**, *107*, 4096.

(8) (a) Coucouvanis, D.; Kanatzidis, M. G.; Dunham, W. R.; Hagen, W. R. *J. Am. Chem. Soc.* **1984**, *106*, 7998. (b) Saak, W.; Henkel, G.; Pohl, S. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 150. (c) Kanatzidis, M. G.; Hagen, W. R.; Dunham, W. R.; Lester, R. K.; Coucouvanis, D. *J. Am. Chem. Soc.* **1985**, *107*, 953. (d) Kanatzidis, M. G.; Salifoglou, A.; Coucouvanis, D. *J. Am. Chem. Soc.* **1985**, *107*, 3358.

(9) (a) Christou, G.; Sabat, M.; Ibers, J. A.; Holm, R. H. *Inorg. Chem.* **1982**, *21*, 3518. (b) Strasdeit, H.; Krebs, B.; Henkel, G. *Inorg. Chem.* **1984**, *23*, 1816.

(10) Wei, C. H.; Dahl, L. F. *Inorg. Chem.* **1965**, *4*, 1.

(11) Wei, C. H.; Dahl, L. F. *Inorg. Chem.* **1965**, *4*, 493.

(12) Nelson, L. L.; Lo, F. Y.-K.; Rae, A. D.; Dahl, L. F. *J. Organomet. Chem.* **1982**, *225*, 309.

(13) Bose, K. S.; Sinn, E.; Averill, B. A. *Organometallics* **1984**, *3*, 1126.

(14) Cecconi, F.; Ghilardi, C. A.; Midollini, S. *J. Chem. Soc., Chem. Commun.* **1981**, 640.

(15) (a) Shah, V. K.; Brill, W. *Proc. Natl. Acad. Sci. U.S.A.* **1977**, *74*, 3249. (b) Burgess, B. K.; Newton, W. E. In *Nitrogen Fixation, The Chemical-Biochemical-Genetics Interface*; Müller, A., Newton, W. E., Eds.; Plenum: New York, 1981; p 83. (c) Averill, B. A. *Struct. Bonding (Berlin)* **1983**, *53*, 59. (d) Holm, R. H. *Chem. Soc. Rev.* **1981**, *10*, 455.

(16) (a) Hieber, W.; Gruber, J. *Z. Anorg. Allg. Chem.* **1958**, *296*, 91. (b) Seyferth, D.; Henderson, R. S.; Song, L.-C. *Organometallics* **1982**, *1*, 125.

(17) The term "$[o\text{-xyl-}S_2]_2^{2-}$" is used to designate the thiolate–disulfide mixture arising from reaction of $o\text{-xyl(SH)}_2$ (424 mg) in THF with 2 equiv of *n*-BuLi followed by oxidation of half the thiolates with 0.5 equiv of I_2 (316 mg) in THF. This undoubtedly produces a complex and dynamic mixture of polymeric disulfides and thiolates rather than the single species $[o\text{-xyl-}S_2]_2^{2-}$.

(18) Anal. Calcd for $C_{38}H_{44}Fe_6N_2O_{12}S_6$: C, 36.57; H, 3.55; Fe, 26.85; N, 2.24; S, 15.41. Found: C, 37.01; H, 3.44; Fe, 26.44; N, 2.37; S, 16.03.

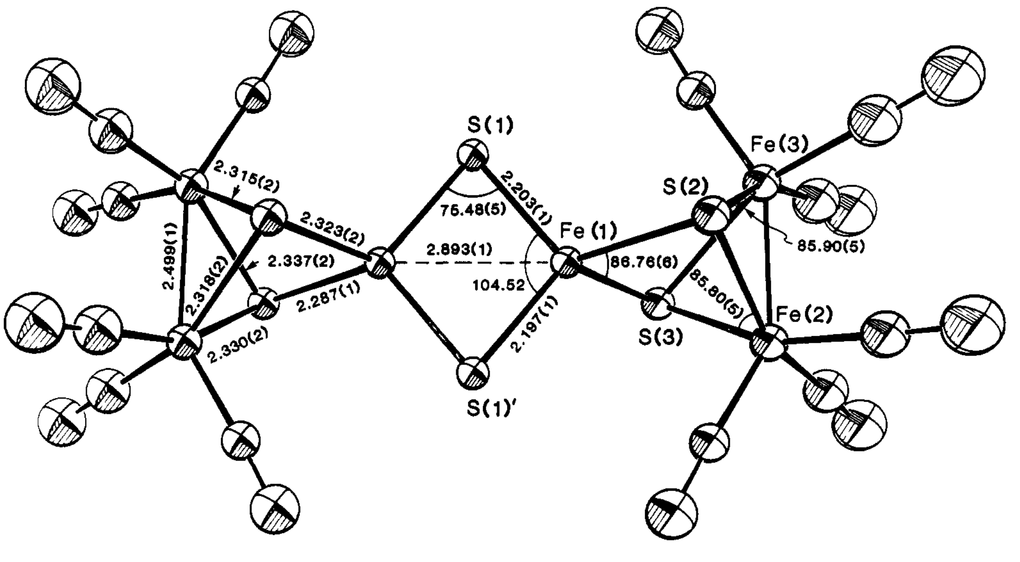
(19) Seyferth, D.; Henderson, R. S. *J. Organomet. Chem.* **1981**, *218*, C34.

(20) Cleland, W. E.; Averill, B. A. *Inorg. Chem.* **1984**, *23*, 4192.

(21) $[Et_4N]_2[I]$ could not be obtained from this solution in analytically pure form due to difficulty in separating it from $Et_3NH^+Cl^-$, which has similar solubility characteristics.

(22) (a) Measurements were performed on an Enraf-Nonius CAD-4 diffractometer using graphite-filtered Mo Kα radiation. The θ–2θ technique was used as previously described[22b] to record intensities for all nonequivalent reflections with $1.4° < 2\theta < 52°$. Intensities were corrected for Lorentz and polarization effects and for absorption. A total of 3690 independent data with $F^2 > 3\sigma(F^2)$ were used in the refinement. $[BzEt_2MeN]_2[I]$ crystallizes in space group $P\bar{1}$ with $a = 8.025$ (7) Å, $b = 12.956$ (8) Å, $c = 13.676$ (7) Å, $\alpha = 68.43$ (4)°, $\beta = 72.15$ (5)°, $\gamma = 89.44$ (4)°, $V = 1250$ Å^3, $Z = 1$, and $d_{calcd} = 1.62$. Heavy atoms were located from a three-dimensional Patterson synthesis; other nonhydrogen atoms were located from successive Fourier syntheses. The $[BzEt_2MeN]^+$ cation is partially disordered over two sites, assigned occupancies of 0.55 and 0.45. Full-matrix least-squares refinement[22b] with anisotropic temperature factors for the anion and isotropic temperature factors for the cation converged with $R = 9.9\%$ and $R_w = 10.8\%$. The computing programs used are described in ref 22b. (b) Freyberg, D. P.; Mockler, G. M.; Sinn, E. *J. Chem. Soc., Dalton Trans.* **1976**, 447.

0020-1669/86/1325-1073$01.50/0



$[Fe_6S_6(CO)_{12}]^{2-}$

Figure 1. Structure of the $[Fe_6S_6(CO)_{12}]^{2-}$ ion, showing the atomic labeling scheme and selected distances and angles.

structure of I (Figure 1) consists of a central $[Fe_2S_2]^{2+}$ core ligated by a $[Fe_2S_2(CO)_6]^{2-}$ unit on each Fe. Noteworthy features of the structure include (i) the acute S(2)–Fe(1)–S(3) angle (86.76 (6)°), (ii) the relatively large S(2)–Fe(2,3)–S(3) angle (average 85.95°), and (iii) the short Fe(2)–Fe(3) distance (2.499 (1) Å), consistent with an Fe–Fe bonding interaction. Structural feature i constitutes by far the smallest angle between terminal ligands to an $[Fe_2S_2]^{2+}$ core;[4] the smallest such angle previously reported is the O–Fe–O angle of 96.1° in $[Fe_2S_2(o,o'\text{-}C_{12}H_8O_2)_2]^{2-}$ [4d]. This result suggests that the rigid $[Fe_2S_2(CO)_6]^{2-}$ unit can accommodate only a small bite angle at a coordinated metal ion. This is consistent with feature ii, where coordination of the bridging sulfides of $[Fe_2S_2(CO)_6]^{2-}$ increases the S–Fe–S angle only slightly beyond that in $Fe_2(SEt)_2(CO)_6$ (81.0°[23]), where there is no S- -S bonding interaction. Dimensions within the central, planar $[Fe_2S_2]^{2+}$ core are virtually identical with those in other $[Fe_2S_2L_4]^{2-}$ systems.[4] Similarly, dimensions within the coordinated $[Fe_2S_2(CO)_6]^{2-}$ groups are very similar to those in $Ge(S_2Fe_2(CO)_6)_2$,[24] $[MoFe_3S_6(CO)_6]^{2-}$,[25a] and $[MoOFe_5S_6(CO)_{12}]^{2-}$.[25b]

Physical and spectroscopic properties of I are consistent with its formulation as a mixed-valence cluster containing localized Fe(I) and Fe(III) sites. The IR spectrum (ν_{CO}: 2032, 2004, 1943 cm^{-1} (MeCN)) is similar to those reported for other complexes containing the $[Fe_2S_2(CO)_6]^{2-}$ unit.[24-26] Electronic spectra show two principal bands (λ_{max}, nm (ϵ, mM^{-1} cm^{-1}): 335 (42.7), 508 (14.4), 655 (sh) (MeCN)). The 508-nm band is reasonably assigned to a μ_3-S $\rightarrow$ Fe(III) charge-transfer transition,[4a,20] while the highest energy feature is probably a composite of μ_2-S $\rightarrow$ Fe(III) charge transfer[4a,20] and transitions within the $Fe_2S_2(CO)_6$ unit.[27] Variable-temperature magnetic susceptibility studies show that χ_m increases with increasing temperature, with μ_{eff} = 1.96 μ_B/formula unit at 25 °C and $-J = 156 \pm 6$ cm^{-1}.[28] These results are very similar to those observed for $[Fe_2S_2L_4]^{2-}$ complexes[23,30,31] and indicate that I behaves magnetically as an $[Fe_2S_2]^{2+}$ core with diamagnetic $[Fe_2S_2(CO)_6]^{2-}$ ligands. The ^{57}Fe Mössbauer spectrum of $[BzEt_3N]_2[I]$ at 4.2 K shows two overlapping quadrupole doublets with relative intensities 1:2 (δ_1 = 0.30, ΔE_{Q1} = 0.91 mm/s; δ_2 = 0.07, ΔE_{Q2} = 0.80 mm/s; vs. metallic Fe at 298 K). Doublet 2 has parameters similar to those of $Fe_2S_2(CO)_6$ (δ = 0.08, ΔE_Q = 1.11 mm/s) and clearly arises from the four Fe atoms of the $Fe_2S_2(CO)_6$ units. Doublet 1 exhibits an isomer shift in the range reported for $[Fe_2S_2L_4]^{2-}$ complexes,[2,30,31] but the quadrupole splitting is significantly larger than those observed for such complexes, due to the significant distortion of the central Fe sites in I from tetrahedral symmetry (structural feature i above). Electrochemical measurements[32] show that I exhibits two quasi-reversible one-electron reductions at −1.13 and −1.73 V vs. SCE and an irreversible multielectron oxidation and reduction at −0.08 and −2.02 V, respectively. The first reduction process approximates electrochemical reversibility (CV: $E_{p_c} - E_{p_a}$, 70 mV; i_{p_a}/i_{p_c}, 1.13). The pattern of two reductions in these potential ranges is typical of $[Fe_2S_2(SR)_4]^{2-}$ salts.[2,4a,31]

The synthesis of I from $Fe_2S_2(CO)_6$ and the o-xylylene-α,α'-dithiolate–disulfide mixture is an example of partial oxidative decarbonylation of $Fe_2S_2(CO)_6$. Previous work[4a] has shown that treatment of $Fe_2S_2(CO)_6$ with benzenethiolate–diphenyl disulfide mixtures results in complete decarbonylation with quantitative formation of $[Fe_4S_4(SPh)_4]^{2-}$. We find that formation of I is highly dependent on the nature of the thiol and on both the RS^-/RSSR and (RS^- + RSSR)/$Fe_2S_2(CO)_6$ ratios. Our results indicate that the precise product obtained in such systems depends strongly on the effective potential of the "redox buffer" used. Work in progress in our laboratory has shown that other new iron–sulfur–carbonyl clusters are formed when conditions are varied.

Acknowledgment. We thank T. A. Kent and E. Münck of the Grey Freshwater Biological Institute for measuring the Mössbauer spectra. This research was supported by the U.S. Department of Agriculture SEA/CRGO (Grant No. 82-CRCR-1-1123).

---

(23) Dahl, L. F.; Wei, C. H. *Inorg. Chem.* **1963**, *2*, 328.

(24) Nametkin, N. S.; Tyurin, V. D.; Aleksandrov, G. G.; Kuz'min, O. V.; Nekhaev, A. I.; Andrianov, V. G.; Mavlonov, M.; Struchkov, Yu. T. *Izv. Akad. Nauk SSSR, Ser. Khim.* **1979**, 1353.

(25) (a) Kovacs, J. A.; Bashkin, J. K.; Holm, R. H. *J. Am. Chem. Soc.* **1985**, *107*, 1784. (b) Bose, K. S.; Lamberty, P. E.; Kovacs, J. A.; Sinn, E.; Averill, B. A. *Polyhedron*, in press.

(26) Day, V. W.; Lesch, D. A.; Rauchfuss, T. B. *J. Am. Chem. Soc.* **1982**, *104*, 1290.

(27) Scovell, W. M.; Spiro, T. G. *Inorg. Chem.* **1974**, *13*, 304.

(28) Data were measured over the temperature range 4.2–300 K on an SHE SQUID magnetometer; the χ_m values were fit to an antiferromagnetically coupled $S_1 = S_2 = {}^5/_2$ exchange model[29] after correction for paramagnetic impurities.[30]

(29) O'Connor, C. J. *Prog. Inorg. Chem.* **1982**, *29*, 203.

(30) Gillum, W. O.; Frankel, R. B.; Foner, S.; Holm, R. H. *Inorg. Chem.* **1976**, *15*, 1095.

(31) Wong, G. B.; Bobrik, M. A.; Holm, R. H. *Inorg. Chem.* **1978**, *17*, 578.

(32) In MeCN solution with 100-mM $[Bu_4N][ClO_4]$ supporting electrolyte. Potentials measured vs. 0.1 M $AgNO_3$(MeCN)/Ag (+0.337 V vs. SCE). Techniques used: dc and differential pulse polarography at a dropping-Hg electrode; cyclic voltammetry (CV) at a glassy carbon electrode (100 mV/s).

Supplementary Material Available: Tables of atomic coordinates, interatomic distances and angles, and thermal parameters and a figure showing a cyclic voltammetry scan (5 pages). Ordering information is given on any current masthead page.

Department of Chemistry
University of Virginia
Charlottesville, Virginia 22901

G. L. Lilley
E. Sinn
B. A. Averill*[1]

Received November 18, 1985

High-Salt and Low-Salt Models for Kinked Adducts of *cis*-Diamminedichloroplatinum(II) with Oligonucleotide Duplexes

Sir:

DNA, the likely in vivo target of the anticancer drug *cis*-diamminedichloroplatinum(II) (*cis*-DDP), undergoes certain geometrical changes upon drug binding. There is general agreement that *cis*-DDP binds predominantly to d(GpG) units,[1] and following the recent crystal structure determination of the complex *cis*-$[Pt(NH_3)_2\{d(pGpG)\}]$,[2] metrical parameters for the platinum–d(GpG) chelate have been provided. Details about the structural changes caused by *cis*-DDP binding to oligonucleotide duplexes and to DNA itself, however, are not yet available and are currently the subject of several theoretical and experimental investigations.

By using molecular mechanics calculations, we recently derived a model[3] for the adduct of *cis*-$\{Pt(NH_3)_2\}^{2+}$ with oligonucleotides that revealed disruption of GC base-pairing at the 5′-end-coordinated guanine of the platinum-cross-linked d(GpG) site, a switching of sugar pucker to C(3′)-endo for the same 5′-guanosine, and a hydrogen bond between the coordinated ammine ligand and the 5′-phosphate group. The directionality of the helix axis, however, was largely unperturbed. In this study we have found two alternative models having comparable conformational energies where the helix axis is substantially kinked. These new results prove that kinking of DNA upon platination, as previously suggested,[4] is energetically feasible and provide atomic coordinates for refined model structures of kinked *cis*-$\{Pt(NH_3)_2\}^{2+}$–oligonucleotide adducts.

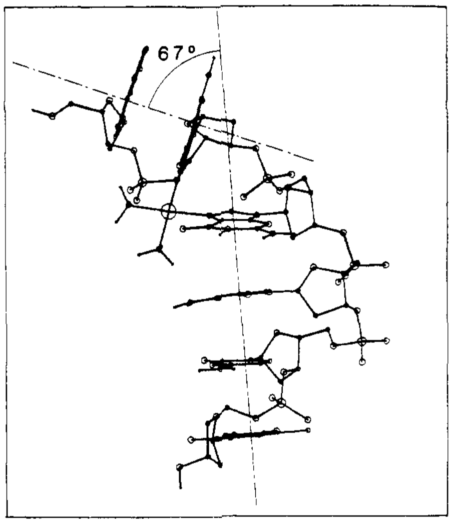


Figure 1. Side view of *cis*-$\{Pt(NH_3)_2\}$–[d(AGGCCT)-*N*7(2),*N*7(3)] (B-DNA model[5] after energy minimization).

The kinked models were constructed by using coordinates from the platinated adduct (**1**) of the single-stranded hexanucleotide, d(AGGCCT), which, after energy refinement, showed a kink of approximately 67° (Figure 1).[5] We started with the unplatinated, energy-refined B-DNA structure of the decanucleotide duplex investigated previously,[3] [d(TCTCG*G*TCTC)-d(GAGACCGAGA)] (**2**), where the asterisks designate the platinum binding sites, in which the sugar pucker of the 5′-G* guanosine was switched from C(2′)-endo to C(3′)-endo. The duplex was divided into two parts along the G*pG* site (dashed line in Chart I). Each of the G* designated guanine rings of **2** was then fit by a least-squares procedure into the appropriate guanine residue of the platinated hexanucleotide **1**, so that the resultant kinked duplex had the same G*pG* fragment geometry as the single-stranded adduct **1**. The *cis*-$\{Pt(NH_3)_2\}^{2+}$ unit with coordinates from **1** was then added to the new coordinate file, yielding a kinked platinated duplex. This duplex showed a gap at p16–C15 in the backbone of the unplatinated strand, with a P–O(3′) bonding distance of ~10 Å. In order to reduce this distance and enable the energy-minimizing program AMBER[7] to close the gap without destroying the kink, we subsequently rotated each duplex part about an axis passing through the coordinated N(7) atom and paralleling the helix axis of the rotated part, so that the P–O(3′) distance was diminished. The factors limiting the extent of the rotations were the two cytosines base-paired with the central G*pG* unit, the amino groups of which would have clashed if the rotation were carried too far. The final P–O(3′) distance at the site of the break was 4–5 Å. This distance could have been diminished even further by rotating the O(5′)–P group at the 5′-side of the gap about the C(4′)–C(5′) bond. This adjustment was also easily accomplished by AMBER, and the outcome of the refinement did not depend on whether or not we had performed the latter rotation. Manual rotations were accomplished by using the computer graphics system FRODO PS-300.[8] The resultant kinked structures were then refined with the program AMBER. In the first three cycles we constrained all base atoms to their positions with a penalty function $E = \sum k(\Delta r_i)^2$, where Δr_i are the shifts of the atoms from their initial sites, added to the total energy.[7] The constant k was reduced from 100 to 10 kcal/(mol Å^2) in the second step of refinement and finally to 1 kcal/(mol Å^2). Subsequently, the constraint was completely removed and the structure refined again. The purpose of the constraint was to allow the backbone to adjust while the kinked structure of the duplex remained unchanged. This procedure of rotating the least-squares-fitted structure followed by energy minimization yielded two distinct models, identified as B and C in the following text in order to distinguish them from the unkinked model A reported previously.[3]

The AMBER refinements were carried out by using standard parameters.[9] To examine the robustness of the solutions, several models for the environmental dielectric constant were used. While these models had a substantial effect on the magnitude of the energies, they had little effect on the relative energies or the resultant geometry. Here we report models and energies derived by using a dielectric constant of $4r$, where r is the internuclear separation, and with no additional shielding of 1-4 neighbors.

The refined structures showed a number of unusual backbone torsional angles at the site of kinking and an unexpected N-type

---

(1) Pinto, A. L.; Lippard, S. J. *Biochim. Biophys. Acta* **1985**, *780*, 167–180.

(2) Sherman, S. E.; Gibson, D.; Wang, A. H.-J.; Lippard, S. J. *Science* (*Washington, D.C.*) **1985**, *230*, 412–417.

(3) Kozelka, J.; Petsko, G. A.; Quigley, G. J.; Lippard, S. J. *J. Am. Chem. Soc.* **1985**, *107*, 4079–4081.

(4) (a) den Hartog, J. H. J.; Altona, C.; van Boom, J. H.; van der Marel, G. A.; Haasnoot, C. A. G.; Reedijk, J. *J. Biomol. Struct. Dyn.* **1985**, *2*, 1137–1155. (b) Miller, K. J.; Taylor, E. R.; Basch, H.; Krauss, M.; Stevens, W. J. *Ibid.* **1985**, *2*, 1157–1171. (c) Sundaralingam, M.; Rubin, J. R.; Rao, S. T. In "The Molecular Basis of Cancer, Part B: Macromolecular Recognition, Chemotherapy, and Immunology"; Rein, R., Ed.; A. R. Liss: New York, 1985; pp 175–184.

(5) Kozelka, J.; Petsko, G. A.; Quigley, G. J.; Lippard, S. J., manuscript in preparation.

(6) Arnott, S.; Campbell-Smith, P.; Chandresekharan, P. "Handbook of Biochemistry and Molecular Biology", 3rd ed.; Fasman, G. D., Eds.; Chemical Rubber Co.: Cleveland, OH, 1976; Vol. 2, pp 411–414.

(7) Weiner, P.; Kollman, P. *J. Comput. Chem.* **1981**, *2*, 287–303.

(8) (a) Jones, T. A. In "Computational Crystallography"; Sayre, D., Ed.; Clarendon Press: Oxford, 1982; pp 303–317. (b) Pflugrath, J. W.; Saper, M. A.; Quiocho, F. A. In "New Generation Graphics System for Molecular Mechanics", presented at the International Summer School on Crystallographic Computing, Kyoto, Japan, 1983.

(9) Weiner, S. J.; Kollman, P. A.; Case, D.; Singh, U. C.; Ghio, C.; Alagona, G.; Profeta, S., Jr.; Weiner, P. *J. Am. Chem. Soc.* **1984**, *106*, 765–784.

0020-1669/86/1325-1075$01.50/0