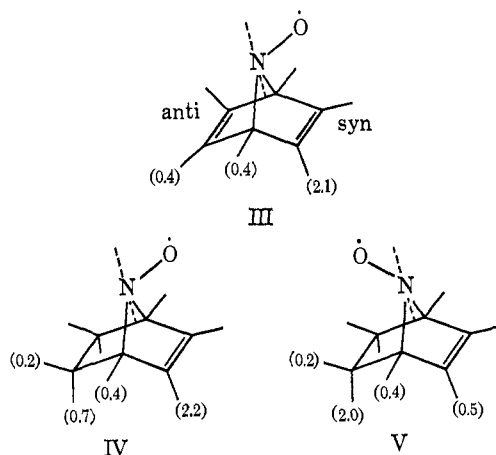


and Dr. T. Kawamura for helpful comments, and to Dr. T. Yonezawa for support and encouragement.

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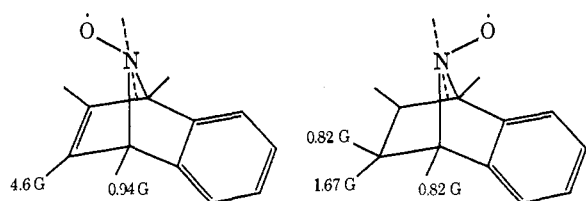
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sity induced on the syn proton (with respect to the bent N-O bond) is much larger than that on the anti proton.¹² The observed large hfsc (4.6 G) in I could be attributed to the syn β proton, and it could be, therefore, concluded that in I the N-O bond tilts in the opposite side of the benzene ring (toward the double bond).

By comparison with radical I and with the predicted splitting constants obtained for models IV and V, 0.82 G splitting in radical II is attributable to the bridgehead (1 and 4) and β -exo protons and 1.67 G splitting to the β -endo protons. The predicted splitting constants for III are a factor of 2 smaller than the experimental values of I. Arguing by analogy, one might expect that the conformation of IV is responsible for the esr splitting of II. On the basis of above discussion, we propose that the N-O bond of II tilts toward the benzene ring, contrary to the case of I.



The different orientation of the N-O bond in I and II appears to be quite interesting in terms of the study of neighboring group participation in these radicals.¹⁴ Specific orientation of the nitroxide group in II, for example, may stimulate us to study preferential participation of the N-O group with ethylene or benzene π electrons (the bishomoallylic or bishomobenzylic participation). Further detailed investigations are now under progress.

Acknowledgment. We are grateful to Dr. S. Terabe of Shionogi Research Laboratory for valuable help and discussions in the esr measurement, to Dr. T. Fujito

(13) G. A. Russel, "Radical Ions," Interscience, New York, N. Y., 1968, Chapter 4.

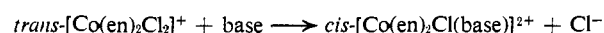
(14) NOTE ADDED IN PROOF. It is of interest to take a look at the preferential orientation of radical lobe on the nitrogen atom in I and II in relation to that in the corresponding hydrocarbon radicals. The bent structure of radical II is comparable to 7-norbornenyl radical in which the radical lobe occupies the anti position with respect to the double bond (J. K. Kochi, P. Bakuzis, and P. J. Krusic, *J. Amer. Chem. Soc.*, **95**, 1516 (1973)). In radicals I and II, the odd-electron orbital is also away from the ethylene double bond. Based on these discussions, stereoselectivity of reactions proceeding through the intermediacy of the 7-benzonorbornenyl radical could be expected.

Crystal and Molecular Structure of a Cobalt(III) Complex Containing Adenine as a Unidentate Ligand

Sir:

Recent advances in electron microscopy offer hope that the direct visualization of single heavy atoms will become a useful, rapid means of sequential analysis of nucleic acid biopolymers.¹ The small number of purine and pyrimidine bases (four) which constitute the nucleic acids make these biopolymers, in theory, most amenable to sequencing studies. However, the sequencing method requires that the heavy-metal-containing moiety exhibit some selectivity toward a particular base.¹ One way of solving this latter problem is to utilize the different interactions between the purine and pyrimidine bases and other ligands attached to the metal. This type of approach has received little attention and it is our purpose here to determine whether specific interligand interactions are of possible importance.

A reaction which exhibits interesting steric dependence is



where en is the bidentate ligand ethylenediamine. This reaction proceeds readily when base = glycine esters,² but does not proceed with alanine or other amino acid esters.³ Of the four nucleic acid bases tested, only adenine gives a reaction. Thus the above reaction of adenine with $\text{trans-}[\text{Co}(\text{en})_2\text{Cl}_2]^+$ exhibits base selectivity.

In order to understand what interactions, both bonding and nonbonding, may be present, we have determined the structure of the complex $\text{cis-}[\text{adeninatochlorobis}(\text{ethylenediamine})\text{cobalt(III)}]^+$, $[\text{Co}(\text{en})_2\text{Cl}(\text{C}_5\text{N}_5\text{H}_4)]^+$. The complex was prepared according to the above reaction scheme with adenine acting as the base. While Sletten⁴ has determined the structure of a dimeric copper(II) complex with deprotonated adenine as a bidentate ligand, this is to our knowledge the first report of a complex containing deprotonated adenine acting as a unidentate ligand. Although relatively few crystal structures of transition metal complexes con-

(1) D. W. Gibson, M. Beer, and R. J. Barrnett, *Biochemistry*, **10**, 3669 (1971); T. Koller, M. Beer, M. Muller, and K. Muhlethaler, *Cytobios*, **4**, 369 (1971); J. W. Wiggins and M. Beer, *Anal. Chem.*, **44**, 77A (1972).

(2) M. D. Alexander and D. H. Busch, *Inorg. Chem.*, **5**, 602 (1966).

(3) D. A. Buckingham, L. G. Marzilli, and A. M. Sargeson, unpublished results.

(4) E. Sletten, *Acta Crystallogr., Sect. B*, **25**, 1480 (1969).

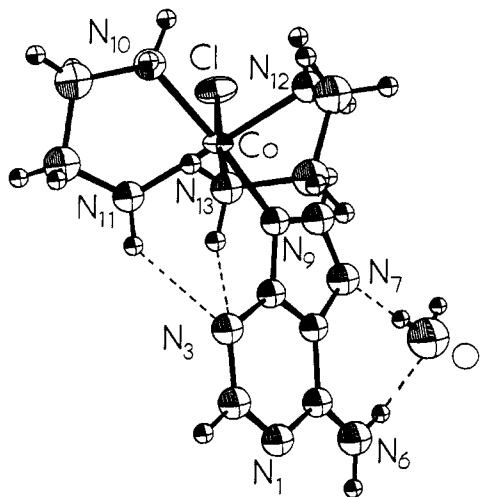


Figure 1. A perspective view of the complex [adeninatochlorobis(ethylenediamine)cobalt(III)]⁺. The water of crystallization and its hydrogen bonds to N(6) and N(7) are also shown.

taining nucleic acid bases have been reported, these have contributed greatly toward the understanding of the bonding in such systems, as evidenced particularly by the work of Sundaralingam.⁵

The complex crystallizes in the monoclinic system, space group *I2/a* (equivalent to space group *C2/c-C_{2h}*⁶), with cell constants $a = 27.342(14)$, $b = 7.692(4)$, $c = 16.073(9)$ Å, and $\beta = 99.32(4)^\circ$. There is one independent cation, bromide anion, and water of crystallization per asymmetric unit. Intensity data were collected with molybdenum $K\alpha$ radiation on a Syntex PI computer-controlled diffractometer. A highly orientated graphite crystal monochromatized the incident beam of the spectrometer. A total of 3883 independent intensities (3545 intensities above zero) were collected by the θ - 2θ scan method to a maximum 2θ of 55° . The heavy-atom positions were determined by Patterson and Fourier techniques. The hydrogen atoms were located by difference Fourier methods. At the present stage of refinement, the Br, Co, and Cl atoms anisotropic and the rest of the nonhydrogen atoms isotropic, the R value, $\sum ||F_o| - |F_c|| / \sum |F_o|$, is 0.074 (3545 nonzero intensities) and the weighted R value, $(\sum \omega(F_o - F_c)^2 / \sum \omega F_o^2)^{1/2}$, = 0.062.

The coordination about the cobalt is approximately octahedral with the six coordination sites occupied by the four nitrogens of the two bidentate ethylenediamines, the chlorine, and N(9) of the adenine moiety. As was expected from the synthetic route to the complex, the chlorine and adenine ligands occupy cis positions of the octahedron about the metal center (Figure 1). The cobalt to ligated-atom distances (Å) are Co-N(9), 1.945 (5); Co-N(10), 1.973 (5); Co-N(11), 1.951 (5); Co-N(12), 1.955 (5); Co-N(13), 1.958 (5); and Co-Cl, 2.259 (2). The inner-sphere bond angles about the cobalt range from 85.4° for both of the ethylenediamine chelate angles to 93.1° for the angle N(11)-Co-N(13). The bond lengths and angles in the ethylenediamine ligands are normal. The dimensions of the adenine system are very similar to those in adeno-

(5) M. Sundaralingam and J. A. Carrabine, *J. Mol. Biol.*, **61**, 287 (1971).

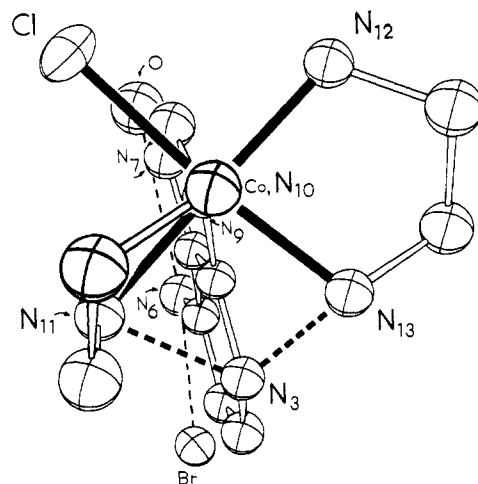


Figure 2. A view of the complex down the N(10)-Co bond. Note the disposition of the adenine ring system and in particular the intramolecular hydrogen bonds from N(11) and N(13) to N(3).

sine⁶ (maximum difference 0.03 Å). The crystal is a racemic mixture of $\Delta\lambda\lambda$ and $\Lambda\delta\delta$ complex cations.

As noted above, our principal interest in determining the structure of this complex is to elucidate the interactions which determine the molecular conformation. The orientation of the adenine ring system is the principal conformational parameter in the complex. Figure 2 is a view of the complex down the N(10)-Co bond. As can easily be seen, the adenine ring system has positioned itself nearly symmetrically between the bonds Co-N(11) and Co-N(13). In the assumed position, N(3) acts as a hydrogen bond acceptor from N(11) and N(13). The hydrogen bond parameters are given in Table I. The other three possible positions of

Table I. Intramolecular Hydrogen Bond Parameters

A	B	A-H	A...B	H...B	\angle A-H...B
N(11)	N(3)	0.95 Å	2.849 Å	2.034 Å	143°
N(13)	N(3)	0.95 Å	3.128 Å	2.344 Å	140°

the adenine ring are less favorable because of intramolecular repulsion, *i.e.*, with C(13) of the N(12), N(13) ethylenediamine chain, or the chlorine ligand. As seen in Figures 1 and 2, the adenine system also forms hydrogen bonds with the water of crystallization and the bromide ion. While these interactions may play a role in the unsymmetrical positioning of the ring between N(11) and N(13), it is surely the intramolecular hydrogen bonds that determine the molecular conformation of the complex. Interligand hydrogen bonding may play an important role in understanding metal-promoted recoiling of nucleic acids.^{5,7} The existence of interligand hydrogen bonding in the complex reported here lends support, albeit indirect, owing to the fact that N(9) is involved in the glycosidic bond to the sugar in the nucleoside. The specific interactions

(6) T. F. Lai and R. E. Marsh, *Acta Crystallogr., Sect. B*, **28**, 1982 (1972).

(7) G. L. Eichhorn, N. A. Berger, J. J. Butzow, P. Clark, J. M. Rifkind, Y. A. Shin, and E. Tarien, *Advan. Chem. Ser.*, No. 100, 135 (1971).

evident in the complex suggest that chelate complexes of heavier metals may exhibit selectivity.

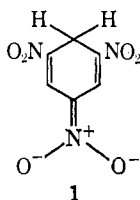
Acknowledgments. Support of this work through grants (to T. J. K. and L. G. M.) from the donors of the Petroleum Research Fund, administered by the American Chemical Society, and from the National Institutes of Health Biomedical Science Support Grant is gratefully acknowledged. The diffraction equipment was purchased through a grant from the National Science Foundation.

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Bovine Serum Albumin as a Catalyst. Accelerated Decomposition of a Meisenheimer Complex¹

Sir:

Recently we have begun investigating various Meisenheimer complexes (MC) as possible biophysical probes² for studying the physical chemistry of immunoglobulins specific for polynitrophenyl haptens.³ In the course of this work we have discovered that bovine serum albumin (BSA) significantly increases the rate of the base-catalyzed decomposition of MC **1** and we now report the results of our preliminary studies.



The tetramethylammonium salt of **1** was prepared by previously published methods.⁴ It is relatively stable in water, and its decomposition (observed by following the decrease in absorbance at 478 m μ of aqueous solutions of **1**) is base catalyzed (Table I). In the presence of BSA, this decomposition is accelerated by factors of *ca.* 10⁴, in the neutral to slightly basic region (Table I). At higher pH values (\sim 11–12) the base-catalyzed decomposition of **1** is rapid ($t_{1/2} \sim$ 105 sec at pH 11.5) and in this region, where BSA is known to undergo a conformational transition,⁵ rate accelerations due to this protein are eliminated.

Decomposition of **1** in the presence of BSA liberates 1 mol of hydroxide anion/mol of **1**. The final product isolated from this decomposition reaction was 3,5,3',5'-tetranitroazoxybenzene (**5**).⁶ This product was

(1) Publication no. 86 from the Laboratory for Biophysical Chemistry.

(2) R. P. Taylor and S. B. Farnham, *J. Chem. Phys.*, to be submitted for publication.

(3) J. R. Little and H. N. Eisen, *Biochemistry*, **5**, 3385 (1966).

(4) R. P. Taylor, *Chem. Commun.*, 1463 (1970).

(5) D. Wetlaufer and R. Lovrien, *J. Biol. Chem.*, **239**, 596 (1964).

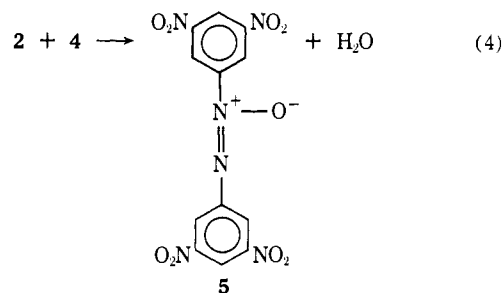
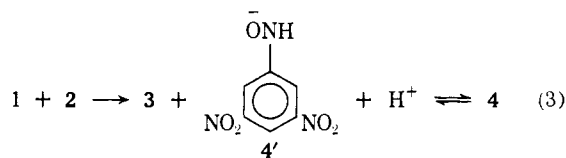
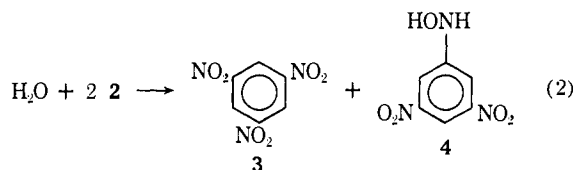
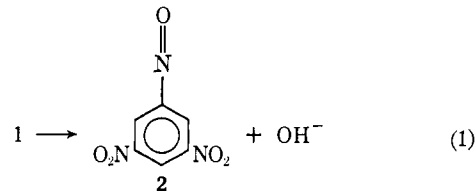
(6) BSA (526 mg) was used to decompose 781 mg of **1** (previously dissolved in \sim 50 ml of acetonitrile) in \sim 3 l. of water. The pH was maintained at \sim 7–9 by periodic addition of HCl. The decomposition (decolorization) was over in about 20 min. The cloudy yellow solution was stirred for 48 hr at room temperature and the precipitate was isolated through filtration on a fine sintered glass filter. No precipitate is obtained if filtration is attempted immediately after the decomposition. Precipitated product (272 mg) (containing about 10% water by weight after drying at room temperature for a few hours) was obtained. This represents (after subtracting out the water contribution) a yield of about 72%, based on eq 1–3.

Table I. Rates of Decomposition of **1**^{a,b}

pH	7.0	7.5	8.0	8.5
k_1 , sec ⁻¹ ^c	1.9×10^{-5}	3.7×10^{-5}	4.2×10^{-5}	7.2×10^{-5}
k_{BSA} , sec ⁻¹ ^d	0.11	0.26	0.46	0.52

^a 25°, 0.05 M phosphate, 1% or less acetonitrile. ^b The molar extinction coefficient of aqueous solution of **1** is 2.0×10^4 at 478 m μ . Under the conditions of the experiment (initial concentration of **1** was 8×10^{-5} M) the product had essentially no OD at 478 m μ after decomposition was complete. ^c First-order rate constants were determined based on the time needed for 50% decomposition. Kinetics were approximately first order over this time range; these results are to be taken as estimates to be compared to the BSA-catalyzed rates. ^d These are "turnover numbers" which were determined under conditions of saturation of "enzyme" (BSA) by "substrate" (**1**). A $\Delta\epsilon$ of 2.0×10^4 was used to calculate rate constants by standard "initial rate" methods (B. Zerner, R. P. M. Bond, and M. L. Bender, *J. Amer. Chem. Soc.*, **86**, 3674 (1964)). Conditions: [BSA] $\approx 10^{-6}$ M; [**1**] $\approx 8 \times 10^{-5}$ M. At lower substrate concentrations the rates decreased; the rate was reduced to 50% at a concentration of **1** of 17 μ M; the rate was 25% of maximum at substrate concentrations of 6 μ M. Uncertainties in rate constants are 10% or less.

identified by its nmr spectrum ((Me₂SO-*d*₆) τ 9.37 (d, rel intensity 2, $J = 2.1$ Hz), 9.25 (d, rel intensity 2, $J = 2.1$ Hz), 9.10 (t, rel intensity 1, $J = 2.1$ Hz), 8.87 ppm (t, rel intensity 1, $J = 2.1$ Hz)) and by high resolution mass spectroscopy (calcd mol wt, 378.0195; obsd mol wt, 378.0190).⁷ In addition, trinitrobenzene (**3**) was isolated from the reaction mixture by ether extraction. The precipitated product obtained from the high pH (\sim 11–12) base-catalyzed decomposition of **1** was also **5**. The results suggest the following possible scheme (eq 1–5) for the decomposition of **1**, in the



(7) Mass spectra were taken on an MS 30 double beam mass spectrometer at 10,000 resolution.