The Crystal Structures of Four New Cobalt Complexes of Glycylglycine

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Summary Crystal structures are reported for three anionic complexes and one cationic complex of Co^{III} and glycylglycine.

THREE crystalline compounds have been prepared by the oxygenation of 2:1 glycylglycine–cobalt(II) mixtures at pH 8—10, under conditions said to lead to the formation of brown 'reversible' and red 'irreversible' oxygen-carrying complexes.[1] The new complexes have formulae†

$[Co^{II}(H_2O)_6][D,L\text{-}Co^{III}(Gly\text{–}Gly)_2]_2,12H_2O$ (*A*),
$[Co^{II}(H_2O)_6][D,L\text{-}Co^{III}(Gly\text{–}Gly)_2]_2,6H_2O$ (*B*), and
$Ba[D,L\text{-}Co^{III}(Gly\text{–}Gly)_2]_2,nH_2O$ (*C*, n = 12—17).

None of them is identical with any of the thirteen anionic and six cationic complexes isolated under similar conditions and characterised by Gillard and his co-workers,[2,3] but *X*-ray crystal structure analyses show that *A*, *B*, *C*, and $NH_4[Co(Gly\text{-}Gly)_2],2H_2O$[4] all contain $Co(Gly\text{–}Gly)_2^-$ anions which are chemically identical (Figure, a). This fact clearly confirms chemical evidence that the end product of the oxygenation of glycylglycine–Co^{II} mixtures in alkaline solution is a Co^{III} complex and not an 'irreversible' oxygen adduct.[3,5]

The acidification of solutions containing $Co(Gly\text{–}Gly)_2^-$ ions leads to the rapid and reversible uptake of two protons per complex ion, yielding cations $Co(Gly\text{–}GlyH)_2^+$.[3,5–7] The rapidity of the protonation reaction and the lack of any major change in the circular dichroism spectrum indicate that no rearrangement occurs, and it has been inferred that protonation occurs at the N(peptide) atoms.[8] On the other hand, the co-ordinated N(peptide) atoms are less basic than the O(peptide) atoms[5] (since protonation at the former would cause the loss of the peptide group resonance energy). In the demonstrated absence of Co^{III}–N bond rupture, the O(peptide) atoms should be the most favourable proton acceptors, a possibility recognised also by McKenzie.[3]

We have therefore determined the crystal structure of a complex which is formed rapidly when perchloric acid is added to a solution of sodium bisglycylglycinatocobaltate(III). The complex, bisglycylglycinatocobalt(III) perchlorate (*D*), belongs to the cationic series reported by Beck and Gorog,[6] Caglioti,[7] McKenzie,[3] and Michailidis and Martin.[5] The complex cation has C_2 symmetry. The C–O(peptide) bond-lengths are 1·36 Å, compared with 1·23 Å in free peptides and 1·26 Å in anionic Co^{III} complexes. The C–N(peptide) bond-lengths are shortened from 1·31 Å to 1·25 Å. The bond-lengths for *D* have large e.s.d.'s (for technical reasons), but they show unequivocally that protonation increases the double-bond character of the C–N bond, and decreases that of the C–O bond. These changes are consistent only with protonation at the O(peptide) atom (Figure, b). In addition, the O(peptide) atom makes a very short contact (2·43 Å) with the O(carboxyl) atom of an adjacent complex. This short contact must be a hydrogen-bond, for whose formation the only available proton is that on the O(peptide) atom.

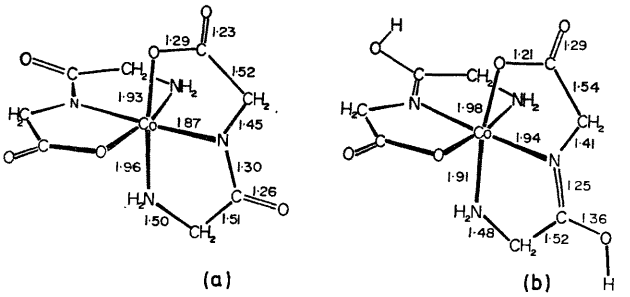

FIGURE. *Structural formulae and mean bond-lengths for* (a) *bis(glycylglycinato)cobaltate*(III) *ion in complexes* A, B, and C, *and* (b) *bis(glycylglycinato)cobalt*(III) *ion in complex* D. (*Estimated s.d.'s* = 0·007 Å *for metal–light-atom bond-lengths*, 0·01 Å *for light-atom–light-atom bond-lengths in* A, B, C; 0·01 Å *and* 0·015 Å, *respectively, in* D.)

The structural evidence is supported by both i.r. and ^1H n.m.r. spectroscopic data. The i.r. spectrum of complex *D* (Nujol mull) has a sharp amide carboxyl absorption at 1700 cm^{-1}, compared with the same absorption at 1605 cm^{-1} in $Na[Co(Gly\text{–}Gly)_2],3H_2O$ (both Nujol mull and D_2O solution, 0·05 mm path length). The large frequency increase is consistent with protonation on the amide oxygen atom to form the iminol tautomer of glycylglycine. From a consideration of the ^1H n.m.r. spectrum the same conclusion may be reached for the protonated complex in aqueous solution. The AB systems for the α- and β-CH_2 protons in $Na[Co(Gly\text{–}Gly)_2],3H_2O$ are the same in D_2O and 10^{-3}M-D_2SO_4 but on protonation (2M-D_2SO_4) the α-CH_2 shifts 47 Hz to lower field while the β-CH_2 is little affected ($\Delta\nu$ = 12 Hz). The proton assignments are based on ^1H n.m.r. results for the similar L-alanyl-glycine and glycyl-L-alanine complexes.[9] A recent ^1H n.m.r. study of the protonation of (glycinamidato)tetramminecobalt(III) likewise requires the added proton to be on the O(amide) and precludes it from being on the N(amide) atom.[10]

A differs from the other three complexes described here, by being the only one which does not have a layer structure. In *A*, each $Co(Gly\text{–}Gly)_2^-$ anion is completely surrounded by free and co-ordinated water molecules. In *B* and *C* there are well-defined and hydrogen-bonded layers of

† Abbreviations: $Co(Gly\text{–}Gly)_2^-$ = bis(glycylglycinato)cobaltate(III)anion, $Co(Gly\text{–}GlyH)_2^+$ = bis(glycylglycinato)cobalt(III) cation.

$Co(Gly–Gly)_2^-$ ions, separated by layers of $Co(H_2O)_6^{2+}$ cations in *B* and of $Ba(H_2O)_8^{2+}$ cations in *C*. In *D* there are layers in which each $Co(Gly–GlyH)_2^+$ cation is linked to four others by means of the short O(peptide) · · · O(carboxyl) hydrogen bonds mentioned earlier. Formal neutrality of the layers is preserved by the presence of the ClO_4^- ions which occupy holes between four linked metal–peptide cations. Compounds *B* and *C* both have interstitial sites for non-co-ordinated water molecules; the three such sites in *C*, and eight of the ten in *C*, are only fractionally occupied.

Complex *A* was prepared by bubbling oxygen slowly through a solution of glycylglycine (0·0077 mole) and cobalt(II) sulphate-7-water (0·013 mole) in water (15 ml,) the pH being kept at 10·0—10·5 by periodic additions of saturated $Ba(OH)_2$ solution (0·18 M). Purple crystals were obtained by slow evaporation. Complex *B* was prepared similarly. Reddish, thin square plates were grown by carefully adding ethanol so that it formed a strongly alcoholic layer on top of the aqueous solution. Complex *C* crystallised from the same solution as *A* in the form of red-purple tabular plates. Complex *D* was crystallised as purple plates by adding 70% perchloric acid to a concentrated solution of $Na[Co(Gly–Gly)_2],3H_2O$ which had been prepared by a method similar to that of Manyak, Murphy, and Martell.[11]

The data for *A*, *C*, and *D* were recorded on a manually operated Buerger–Supper equi-inclination diffractometer, using Ni-filtered Cu-K_α radiation. For *B*, the reflexion intensities were measured on a G.E. XRD-5 diffractometer using Zr-filtered Mo-K_α radiation. All data were corrected for absorption. The structures of *A*, *C*, and *D* were refined by full-matrix least-squares and that of *B* by block-diagonal least-squares. The residuals *R* are 0·083, 0·060, 0·087, and 0·123 for *A*, *B*, *C*, and D, respectively. Refinement of *D* was hampered by disorder or very large thermal motions of the perchlorate ions.

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[1] J. B. Gilbert, M. C. Otey, and V. E. Price, *J. Biol. Chem.*, 1951, **190**, 377; C. Tanford, D. C. Kirk, and M. K. Chantooni, *J. Amer. Chem. Soc.*, 1954, **76**, 5325.
[2] R. D. Gillard, E. D. McKenzie, R. Mason, and G. B. Robertson, *Co-ordination Chem. Rev.*, 1966, **1**, 263.
[3] E. D. McKenzie, *J. Chem. Soc.* (*A*), 1969, 1655.
[4] R. D. Gillard, E. D. McKenzie, R. Mason, and G. B. Robertson, *Nature*, 1966, **209**, 1347.
[5] M. S. Michailidis and R. B. Martin, *J. Amer. Chem. Soc.*, 1969, **91**, 4683.
[6] M. T. Beck and S. Gorog, *Acta Chim. Acad. Sci. Hung.*, 1961, **29**, 401.
[7] V. Caglioti, P. Silvestroni, and C. Furlani, *J. Inorg. Nuclear Chem.*, 1960, **13**, 95.
[8] R. D. Gillard, P. M. Harrison, and E. D. McKenzie, *J. Chem. Soc.* (*A*), 1967, 618.
[9] R. D. Gillard, P. R. Mitchell, and N. C. Payne, *Chem. Comm.*, 1968, 1151.
[10] D. A. Buckingham, D. M. Foster, and A. M. Sargeson, *J. Amer. Chem. Soc.*, 1969, **91**, 3451.
[11] A. R. Manyak, C. B. Murphy, and A. E. Martell, *Arch. Biochem. Biophys.*, 1955, **59**, 373.