
**Comments on Inorganic Chemistry**
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455155

# An Explanation of the Relative Oxygen and Carbon Monoxide Affinities of Some Iron(II) Porphyrin Complexes

Toshiaki Hashimoto[a]; Fred Basolo[a]
[a] Department of Chemistry, Northwestern University, Evanston, Illinois

**To cite this Article** Hashimoto, Toshiaki and Basolo, Fred(1981) 'An Explanation of the Relative Oxygen and Carbon Monoxide Affinities of Some Iron(II) Porphyrin Complexes', Comments on Inorganic Chemistry, 1: 4, 199 — 205
**To link to this Article: DOI:** 10.1080/02603598108078092
**URL:** http://dx.doi.org/10.1080/02603598108078092

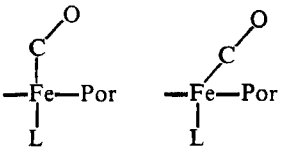
# An Explanation of the Relative Oxygen and Carbon Monoxide Affinities of Some Iron(II) Porphyrin Complexes

The selectivity of $O_2$ and CO binding of model iron(II) porphyrins is explained on the basis of the number of atoms which connect the porphyrin plane to the top of a cap or a strap. Examples are discussed which discriminate against CO, against both CO and $O_2$, and the unique example which discriminates against $O_2$.



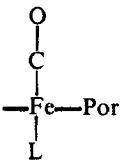
## INTRODUCTION

The role played by the heme cavity in causing some hemoproteins to discriminate against the binding of CO relative to $O_2$ is a subject of current active investigation by the use of model compounds.[1-4] A decade ago, Caughey[5] suggested that the lower CO relative to $O_2$ affinity of myoglobins, compared with hemoglobin A, results from the fact that "$O_2$ may be expected to assume a bent sterochemistry with greater ease than can CO." He had collected some IR spectra on MbCO and HbCO which allowed him to suggest that the Fe–C–O in MbCO is bent. Later x-ray studies[6] showed that the CO moiety is bent (I) and/or tilted (II)




(I) (II)

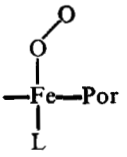
from the perpendicular to the porphyrin (Por) plane due to interactions with distal residues. This contrasts with the well-known normal linear metal carbonyl structure (III)[7]:




(III)

*Comments Inorg. Chem.*
1981, Vol. 1, No. 4, pp. 199–205
0260-3594/81/0104–0199/$06.50/0

It is also known from x-ray studies[8] on a model heme system that Fe–O–O is bent (IV):




(IV)

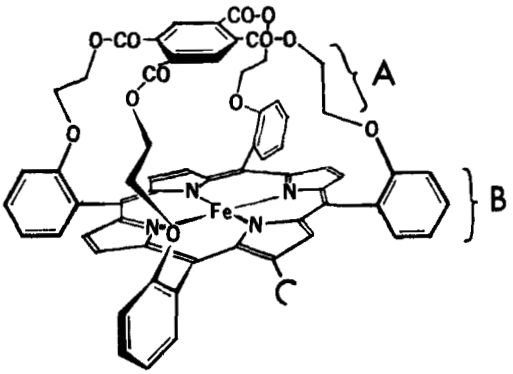
This is the structure which had been suggested by Pauling[9] and by Weiss[9] for the dioxygen adducts of hemoproteins.

On the basis of the preferred stable structure being linear for Fe–C–O and bent for Fe–O–O, it should be possible to prepare model complexes which mimic the hemoproteins in that they discriminate against CO, but not $O_2$, binding. Similarly, it should be possible to make iron(II) complexes which discriminate against both CO and $O_2$ binding, and complexes which discriminate only against $O_2$ binding. Examples of all three types of iron(II) complexes are now known.



## DIOXYGEN AND CARBON MONOXIDE AFFINITIES OF SOME IRON(II) COMPLEXES

Some of the data we[10] collected using Baldwin's[11] iron(II) "capped" porphyrins (V) for equilibria (1) and (2)




(V)

A(-$(CH_2)_n$-) $n = 2$ $C_2$-Cap (7)
$n = 3$ $C_3$-Cap (8)

$$Fe(Cap)(L) + O_2 \rightleftharpoons Fe(Cap)(L)(O_2), \quad (1)$$

$$Fe(Cap)(L) + CO \rightleftharpoons Fe(Cap)(L)(CO), \quad (2)$$

are compared in Table I with similar data on other five-coordinate iron(II) complexes. The results show iron(II) capped-porphyrin complexes to be the first systems (model or natural) observed to discriminate against $O_2$ relative to CO binding. A direct comparison of all the data in Table I is not possible because of the different experimental conditions employed. Yet by selective cross comparisons, it is possible to assess the relative $O_2$ and CO binding in these systems.

A convenient place to start is with the $O_2$ affinity of the "flat-open" complex Fe(T*p*-OMePP) versus the iron(II) capped-porphyrins. The values of $P_{1/2}^{O_2}$ show that the $O_2$ affinities decrease in the order

Fe(T*p*-OMePP)(1,2-MeIm) > Fe($C_2$-Cap)(1,2-$Me_2$Im)

> Fe($C_3$-Cap)(1,2-MeIm).



TABLE I

Equilibrium data for $O_2$ and CO affinities of iron(II) porphyrins and hemoproteins

| System[a] | $P_{1/2}^{O_2}$, Torr[b] | $P_{1/2}^{CO}$, Torr[b] | Ref. |
|---|---|---|---|
| Fe($C_2$-Cap)(1-MeIm) | 23 | $5.4 \times 10^{-3}$ | 10 |
| Fe($C_3$-Cap)(1,5-DCIm) | 54 (0°C) | $4.1 \times 10^{-3}$ | 10 |
| Fe$Piv_3$(5ClmP)Por | 0.58 | $2.2 \times 10^{-5}$ | 13 |
| FePocPivP(1-MeIm) | 0.36 | $1.5 \times 10^{-3}$ | 3 |
| Chelated protoheme | 1.4 | $1 \times 10^{-3}$ | 15 |
| 7,7-Cyclophane(1,5-DCIm) | 1.4 | $9.1 \times 10^{-4}$ | 1 |
| 6,6-Cyclophane(1,5-DCIm) | 694 | $8.4 \times 10^{-2}$ | 1 |
| Mb (sperm whale) | 0.29 | $(1.2 \sim 2.8) \times 10^{-2}$ | 16 |
| Hb (human "R") | 0.17 | $(1 \sim 4) \times 10^{-3}$ | 17, 18 |
| Fe($C_2$Cap)(1,2-$Me_2$Im) | 4000 (27-45°C)[d] | $2.0 \times 10^{-1}$ | 10 |
| Fe($C_3$-Cap)(1,2-$Me_2$Im) | 880 (−63°C)[c] | $1.4 \times 10^{-1}$ | 10 |
| Fe(TPP)(1,2-$Me_2$Im) | | $1.4 \times 10^{-1}$ | 10 |
| Fe(T(*p*-OMe)PP)(1,2-MeIm) | 5.3 (−45°C)[c] | $8.0 \times 10^{-2}$ | 10 |
| Fe(TpivPP)($Me_2$Im) | 38 | $8.9 \times 10^{-3}$ | 13 |
| Fe(PocPivP)($Me_2$Im) | 12.6 | $6.7 \times 10^{-2}$ | 3 |
| Hb (human "T") | 26 | $(1 \sim 2.8) \times 10^{-1}$ | 17, 18 |

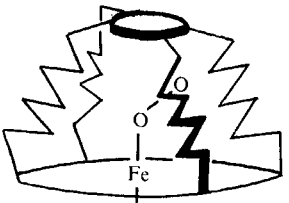
[a] Abbreviations: $C_2$-Cap and $C_3$-Cap, see (V); 1-MeIm, 1-methylimidazole; 1,5-DCIm, 1,5-dicyclohexylimidazole; $Piv_3$(5-ClmPor, dianion of "tailed picket-fence" porphyrin; chelated protoheme, see Ref. 15; 7,7-cyclophane and 6,6-cyclophane, see (X); Mb, myoglobin; Hb, hemoglobin; TPP, dianion of *meso*-tetraphenylporphyrin; T(*p*-OMe)PP, dianion of tetra-*p*-methoxy-*meso*-tetraphenylporphyrin; TpivPP, dianion of "picket-fence" porphyrin; 1,2-$Me_2$Im, 1,2-dimethylimidazole; PocPivP, dianion of "picket pocket" porphyrin, see (XI).

[b] $P_{1/2}^{O_2(CO)}$ is the pressure of $O_2$(CO) necessary to occupy 1/2 of the iron sites; temp. 25°C, except where noted; solvent of toluene or benzene, except for aqueous solutions of chelated protoheme and hemoproteins.

[c] Temperature of measurement in parentheses.

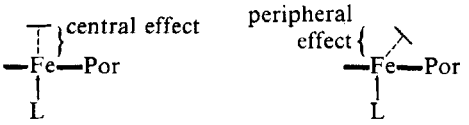
[d] Value of $P_{1/2}^{O_2}$ at −45°C in parentheses.

We[10b] now attribute this order to peripheral steric effects on the bent Fe–O–O structure (VI):




(VI)

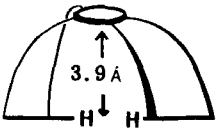
Note that distal steric effects on small molecules coordinated to iron(II) porphyrins have been discussed[1] in terms of *central steric effect* (VII) and of *peripheral steric effect* (VIII):




(VII) (VIII)

The central effect occurs primarily along the axial position, whereas the peripheral effect is more at an angle of about 45° with the plane of the porphyrin. Because of the bent Fe–O–O structure, the coordinated $O_2$ suffers peripheral steric strain due to the atoms which attach the aromatic group at the top of the cap to the porphyrin. This destabilizing strain is larger for $C_3$-Cap than for $C_2$-Cap, due to the additional methylene groups in $C_3$-Cap.

In contrast to the decrease in $O_2$ affinities of the capped relative to the flat–open systems, their CO affinities are all about the same ($P_{1/2}^{CO}$ values of $8.0 \times 10^{-2}$ to $1.4 \times 10^{-1}$ Torr). This suggests that the linear Fe–C–O structure experiences no distal steric effects in the capped systems. Such a result is in accord with the recent x-ray study of Jameson and Ibers[12] on $H_2$Cap which shows that the distance between the porphyrin plane and its aromatic top of the cap is 3.86–3.96 Å (IX):

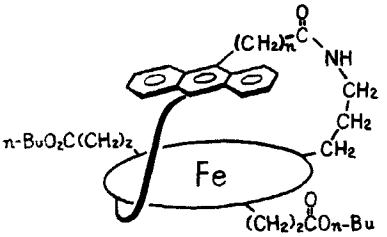



(IX)

Other studies[7] show a linear Fe–C–O distance of about 2.9 Å in these systems. This suggests that CO can bind with the iron(II) capped-porphyrins

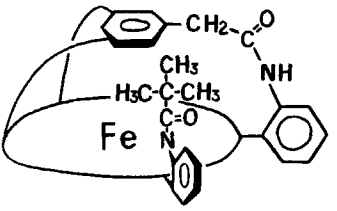
in the stable normal linear structure without any marked central steric hindrance. The net result then is that the capped systems discriminate against $O_2$ but not CO binding.

Other synthetic iron(II) porphyrin complexes examined for $O_2$ and CO binding are the "picket fence,"[13] the cyclophane[1] (X) and the "pocket"[3] (XI) systems:




(X)

$n = 1$ 6,6-cyclophane (6)
$n = 2$ 7,7-cyclophane (7)




(XI)

Pocket (5)

Discussing the cyclophane systems first, it is seen (Table I) that the 7,7-cyclophane iron(II) complex binds $O_2$ ($P_{1/2}^{O_2} = 1.4$ Torr) and CO ($P_{1/2}^{CO} = 9.1 \times 10^{-4}$ Torr) normally. Upon shortening the anthracene "strap," the 6,6-cyclophane iron(II) complex binds $O_2$ ($P_{1/2}^{O_2} = 694$ Torr) and CO ($P_{1/2}^{O_2} = 8.4 \times 10^{-2}$ Torr) weakly. Assuming the weaker binding of the 6,6-cyclophane system is due to distal steric effects, it appears that both central and peripheral effects are involved. It seems plausible to attribute the central steric effect to the distance between the porphyrin plane and the aromatic group at the top of the strap or the cap in these model compounds. One way to roughly assess this distance is on the number of atoms that attach the porphyrin plane to the central aromatic group. These numbers of atoms are given in parentheses with structures (V), (X) and (XI). From the data on the cyclophanes, it appears that if seven atoms are involved there is no central steric effect on the binding of CO, but if only six atoms are involved this effect becomes important. In accord with this is the observation that neither the $C_2$-Cap (seven atoms) nor the $C_3$-Cap (eight atoms) systems show discrimination against CO binding.

In keeping with this approach, it follows that the 6,6-cyclophane iron(II) complex binds $O_2$ weakly because of peripheral steric effects. This may be because the flexible strap flops back and forth, putting the large anthracene group in positions which create peripheral steric effects. The recently reported[3] equilibria data for the pocket porphyrin iron(II) complex also nicely lends itself to the above explanation. This system binds $O_2$ normally, but discriminates against CO. Since one side of the "cap" is open(XI), this

permits the unhindered binding of $O_2$ to give the stable bent Fe–O–O (IV). However, only five atoms hold the aromatic top to the porphyrin ring and this is expected to hinder binding of CO to give the stable linear Fe–C–O (III).

Although this assessment seems grossly successful in accounting for the $O_2$ and CO affinities of model iron(II) porphyrins, nothing is perfect. For example, the picket fence iron(II) complexes appear to bind CO too strongly (Table I). It is suggested[13] this may result from the lack of distal hindrance which allows the facile addition of CO. Such a reason is not in accord with the much larger CO affinity of FeTpivPP($Me_2$Im) compared with the flat-open porphyrin Fe(TPP)(1,2-$Me_2$Im). Another anomaly, on the basis of our interpretation, is the qualitative observation[2] that an anthracene strap system of type (X) involving nine atoms seems to discriminate against CO binding. If correct, this suggests that beyond a certain number of atoms there is enough flexibility in the strap to allow it to squash down towards the prophyrin plane and offer central steric resistance to CO binding. Finally, Busch[4] is investigating nonporphyrin iron(II) macrocyclics which somewhat resemble the cyclophane complexes. He, too, reports that the number of methylene groups in the strap plays an important role in the selective binding of $O_2$ and CO.



## CONCLUDING REMARKS

The anguish and frustration of coordination chemists for many years in being unable to prepare synthetic iron(II) complexes which behave as oxygen carriers similar to hemoproteins has finally come to pass. Now model iron(II) oxygen carriers are available,[14] and we understand what is required to prepare such systems. It is sometimes said that studies of model compounds are of little value, and that it is more important to study the natural systems. This cannot be valid, because there are many examples where studies of models have greatly assisted investigations of natural systems. Surely this is true with the iron(II) oxygen carriers where the structure of Fe–O–O was accurately determined in models, and where it is possible to assess factors which affect $O_2$ and CO binding. Our explanation of the selectivity of $O_2$ and CO affinities based on the number of atoms causing different distal effects may be an oversimplification and have to be abandoned. Surely more work is required and, for example, we plan to investigate the binding of NO, which, similar to $O_2$, forms a bent Fe–N–O structure.

**Acknowledgments**

Support of our research on synthetic oxygen carriers by the National Institutes of Health is gratefully acknowledged. We also thank Ube Industries Ltd. for the support of T. H., their employee. Busch and Traylor kindly sent us preprints of their papers, for which we are very thankful.

TOSHIAKI HASHIMOTO and FRED BASOLO
*Department of Chemistry, Northwestern University, Evanston, Illinois 60201*

**References**

1. T. G. Traylor, D. Campbell, S. Tsuchiya, M. Mitchell and D. V. Stynes, J. Am. Chem. Soc. **102,** 5939 (1980); to be published in **103** (1981).
2. A. R. Battersby and A. D. Hamilton, J. Chem. Soc. Chem. Commun. **1980,** 117 (1980).
3. J. P. Collman, J. I. Brauman, T. J. Collins, B. Iverson and J. L. Sessler, J. Am. Chem. Soc. **103,** 2450 (1981).
4. D. H. Busch, L. L. Zimmer, J. J. Grybowski, D. J. Olszanski, S. C. Jackels, R. C. Callahan and G. G. Christoph, Proc. Natl. Acad. Sci. USA, in press.
5. W. S. Caughey, Ann. N. Y. Acad. Sci. **174,** 148 (1970) and references therein.
6. R. Huber, O. Epp, H. Formanek, J. Mol. Biol. **52,** 349 (1970); J. C. Norvell, A. C. Nunes and B. P. Schoenborn, Science **190,** 568 (1975); E. A. Padlan and W. E. Love, J. Biol. Chem. **249,** 4067 (1975); E. J. Heidner, R. C. Ladner and M. F. Perutz, J. Mol. Biol. **104,** 707 (1976).
7. J. L. Hoard, *Porphyrins and Metalloporphyrins,* edited by K. M. Smith (Elsevier, New York, 1975), pp. 356–358; S. Peng and J. A. Ibers, J. Am. Chem. Soc. **98,** 8032 (1976).
8. G. B. Jameson, G. A. Rodley, W. T. Robinson, R. R. Gagne, C. A. Reed and J. P. Collman Inorg. Chem. **17,** 850 (1978).
9. L. Pauling, Stanford Med. Bull. **6,** 215 (1948); Nature (London) **203,** 182 (1964); J. J. Weiss, *ibid.* **202,** 85 (1964).
10. (a) J. E. Linard, P. E. Ellis, Jr., J. Budge, R. D. Jones and F. Basolo, J. Am. Chem. Soc. **102,** 1896 (1980). (b) T. Hashimoto, J. E. Baldwin and F. Basolo, *ibid.,* in press.
11. J. Almog, J. E. Baldwin, R. L. Dyer and M. Peters, J. Am. Chem. Soc. **97,** 226 (1975).
12. G. B. Jameson and J. A. Ibers, J. Am. Chem. Soc. **102,** 2823 (1980).
13. J. P. Collman, J. I. Brauman, T. R. Halbert and K. S. Suslick, Proc. Natl. Acad. Sci. USA **75,** 564 (1978); J. P. Collman, J. I. Brauman and K. M. Doxsee, *ibid.* **76,** 6035 (1979).
14. J. P. Collman, Acc. Chem. Res. **10,** 265 (1977); R. D. Jones, D. A. Summerville and F. Basolo, Chem. Rev. **79,** 139 (1979).
15. T. G. Traylor and A. P. Berzinis, Proc. Natl. Acad. Sci. USA, **77,** 3171 (1980).
16. E. Antonini and M. Brunori, *Hemoglobin and Myoglobin in their Reactions with Ligands* (Elsevier, New York, 1971), pp. 221–225.
17. K. Imai, T. Yonetani and M. Ikeda-Saito, J. Mol. Biol. **109,** 83 (1977); J. Baldwin and C. Chothia, *ibid.* **129,** 175 (1979).
18. W. S. Caughey, Ann. N. Y. Acad. Sci. **174,** 148 (1970); R. MacQuarrie and J. H. Gibson, J. Biol. Chem. **246,** 5832 (1971); V. S. Sharma, M. R. Schmidt and H. M. Ranney, *ibid.* **251,** 4267 (1976); F. J. W. Roughton, J. Physiol. (London) **126,** 359 (1954); W. H. Huestis and H. M. Raftery, Biochemistry **14,** 1886 (1975).