Bioorganic & Medicinal Chemistry 17 (2009) 3394–3398

Contents lists available at ScienceDirect

Bioorganic & Medicinal Chemistry

journal homepage: www.elsevier.com/locate/bmc

Polystyrene-bound Mn(T4PyP): A highly efficient and reusable catalyst for biomimetic oxidative decarboxylation of carboxylic acids with sodium periodate

Majid Moghadam *, Shahram Tangestaninejad, Valiollah Mirkhani, Iraj Mohammadpoor-baltork, Narges Sirjanian, Somayeh Parand

Department of Chemistry, Catalysis Division, University of Isfahan, Isfahan 81746-73441, Iran

ARTICLE INFO

Article history:
Received 8 November 2008
Revised 16 March 2009
Accepted 20 March 2009
Available online 26 March 2009

Keywords:
Oxidative decarboxylation
Periodate
Metalloporphyrin
Polystyrene

ABSTRACT

In this report, highly efficient oxidative decarboxylation of carboxylic acids with sodium periodate catalyzed by a supported manganese(III) porphyrin is described. In the presence of manganese(III) tetra(4-pyridyl)porphyrin supported on cross-linked chloromethylated polystyrene, [Mn(T4PyP)-CMP], as catalyst, carboxylic acids were converted to their corresponding carbonyl compounds via oxidative decarboxylation with sodium periodate using imidazole as axial ligand. The oxidation of anti-inflammatory drugs such Indomethacin and Ibuprofen was carried out successfully and the decarboxylated products were obtained. This catalyst can be reused several times without loss of its catalytic activity in the oxidation reactions.

1. Introduction

Synthetic metalloporphyrin complexes have been used for mimicking the function of cytochrome P-450 dependent monooxygenation enzyme.[1–3] The main approach in this area is designing selective, stable, and high turnover catalytic systems.[4] Several simple oxidants such as iodosylbenzene, hypochlorite, *m*-chloroperbenzoic acid, hydrogen peroxide and periodates have been extensively used in the oxidation of organic compounds catalyzed by these metal complexes.[5–10] Unfortunately, these expensive catalysts are instable toward oxidative degradation and it is difficult to recover them, which limit the practical applications of metalloporphyrin catalysts in both synthetic chemistry and industrial processes. One way to overcome these limitations is to immobilize the metalloporphyrins on solid supports. Such immobilization can provide catalysts, which are easier to handle, and may exhibit improved selectivities and activities because of the support environment. Among the models of metalloporphyrin microenvironment, the polystyrene derivatives are often utilized, because they can provide suitable microenvironment for the 'accommodation' of porphyrin catalytic center.

Many supported metalloporphyrin catalysts have been reported for oxidation of organic compounds.[11–33] Previously, we have reported the use of supported manganese(III) porphyrins in the oxidation of organic compounds with sodium periodate.[34–50]

Oxidative decarboxylation reactions are oxidation reactions in which a carboxylate group is removed, forming carbon dioxide. They often occur in biological systems.

Anti-inflammatory drugs such as Indomethacin and Ibuprofen are decarboxylated during drug metabolism in vivo by cytochrome P-450. The released CO_2 reduces the pain effects.[51,52]

The high catalytic activity of Mn(T4PyP) supported on cross-linked chloromethylated polystyrene, [Mn(T4PyP)-CMP], in the alkene epoxidation and alkane hydroxylation,[38,39] oxidation of alcohols,[40] oxidation of 1,4-dihydropyridines[41] and oxidation of sulfides,[42] prompted us to investigate the catalytic activity of this catalyst in the oxidative decarboxylation of diphenylacetic acid with sodium periodate at room temperature in aqueous acetonitrile (Scheme 1).

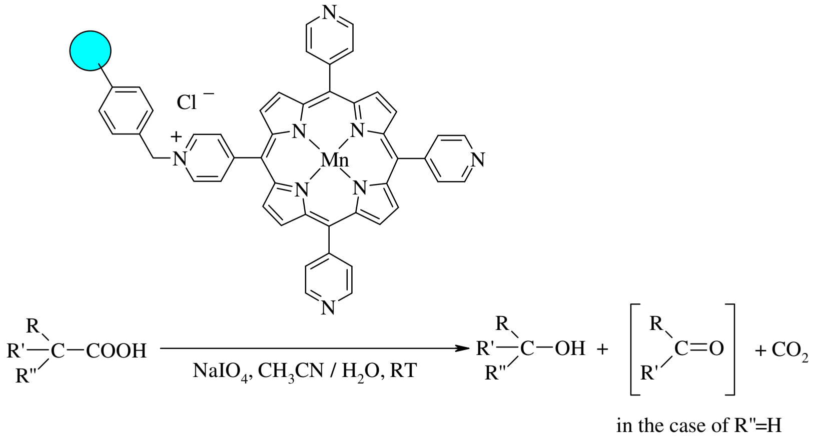
2. Experimental

All materials were commercial reagent grade. The tetrapyridylporphyrin ligand (T4PyP) was purchased from the Fluka Chemical Company, and metalated and supported according to literature procedures.[38,53] IR spectra were run on a Philips PU9716 spectrophotometer. ^1H NMR spectra were obtained with a Brucker 90 or 400 spectrometers in $CDCl_3$ as solvent and TMS as internal standard.

---

* Corresponding author. Tel.: +98 913 3108960; fax: +98 311 6689732.
E-mail addresses: moghadamm@sci.ui.ac.ir, majidmoghadamz@yahoo.com (M. Moghadam).

0968-0896/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.bmc.2009.03.038



Scheme 1.

2.1. General procedure for oxidative decarboxylation of carboxylic acid with $NaIO_4$ catalyzed by [Mn(T4PyP)-CMP]

In a 25 mL flask equipped with a magnetic stirring bar, a solution of $NaIO_4$ (2 mmol in 5 mL H_2O) was added to a mixture of α-aryl carboxylic acid (1 mmol), [Mn(T4PyP)-CMP] (700 mg, 0.021 mmol) and imidazole (0.2 mmol) in CH_3CN (5 mL). The progress of the reaction was monitored by GC or TLC. After the reaction was completed, the polystyrene beads were filtered and washed with EtOH. After then, water (20 mL) was added and the reaction products were extracted with Et_2O (2 × 10 mL) and were purified on a silica-gel plate or a silica-gel column (eluent: CCl_4–Et_2O). The identities of products were confirmed by IR and ^1H NMR spectral data.[54,55]

3. Results and discussion

3.1. Optimization of conditions

The catalytic activity of [Mn(T4PyP)-CMP] was investigated in the oxidative decarboxylation of diphenylacetic acid with sodium periodate. First, we optimized the catalyst amount in the oxidation of diphenylacetic acid with 2 mmol of $NaIO_4$. The results showed that the highest yield was obtained in the presence of 0.021 mmol (700 mg) of [Mn(T4PyP)-CMP]. Whereas, trace amounts of products (12%) was detected when the same reaction was carried out in the absence of catalyst at room temperature (Table 1).

Different solvents were checked for choosing the reaction media. In this manner, the mixture of methanol, ethanol, acetone, acetonitrile (single phase systems) and dichloromethane (two phase system with Bu_4NBr as phase transfer catalyst) with water were tested, and the 1:1 mixture of acetonitrile/water mixture was chosen as the reaction medium, in which the higher carbonyl compound was obtained (Table 2).

In biomimetic systems using manganese porphyrins as catalyst, addition of an axial base is necessary to obtain high catalytic activity. In this case, it is possible to obtain a pentacoordinate Mn(III) complex which leaves a vacant position on the manganese for catalysis. In this manner, the effect of different axial ligands such as imidazole, 1-methylimidazle, pyridine, and 4-*tert*-butylpyridine was investigated on the catalytic activity of [Mn(T4PyP)-CMP]. When imidazole or 1-methyl imidazole was added as axial ligand to this catalytic system, the higher yield was obtained in the oxidation of diphenylacetic acid (Table 3). Control experiments showed that in the absence of imidazole, this catalytic system is less efficient in the oxidative decarboxylation of carboxylic acids.

Table 1
Effect of catalyst amount on the oxidative decarboxylation of diphenylacetic acid with $NaIO_4$[a]

Row	Catalyst amount (mmol)	Time (min)	Conversion[b] (%)
1	0.021 (700 mg)	45	100
2	0.018 (600 mg)	45	90
3	0.015 (500 mg)	45	82
4	0.012 (400 mg)	45	61
5	0.009 (300 mg)	45	52
6	0.006 (200 mg)	45	39
7	0.003 (100 mg)	45	27
8	No catalyst	45	12

[a] Reaction conditions: diphenylacetic acid (1 mmol), $NaIO_4$ (2 mmol), imidazole (0.2 mmol), H_2O/CH_3CN (5 mL/5 mL).
[b] GC yields.

Table 2
Effect of different solvents on the oxidative decarboxylation of diphenylacetic acid with $NaIO_4$ catalyzed by Mn(T4PyP)-CMP[a]

Solvent	Time (min)	Conversion[b] (%)
CH_3CN–H_2O	45	100
CH_3COCH_3–H_2O	45	79
CH_3OH–H_2O	45	42
CH_3CH_2OH–H_2O	45	25
CH_2Cl_2–H_2O	45	15

[a] Reaction conditions: diphenylacetic acid (1 mmol), $NaIO_4$ (2 mmol), imidazole (0.2 mmol), catalyst (0.021 mmol).
[b] GC yields.

Table 3
Effect of different axial ligands on the oxidative decarboxylation of diphenylacetic acid with $NaIO_4$ catalyzed by Mn(T4PyP)-CMP[a]

Axial base	Time (min)	Conversion[b] (%)
Imidazole	45	100
1-Methylimidazole	45	97
Pyridine	45	15
4-*tert*-Butylpyridine	45	34
No axial base	45	8

[a] Reaction conditions: diphenylacetic acid (1 mmol), $NaIO_4$ (2 mmol), axial base (0.2 mmol), H_2O/CH_3CN (5 mL/5 mL), catalyst (0.021 mmol).
[b] GC yields.

Table 4
Oxidative decarboxylation of α-aryl carboxylic acids with $NaIO_4$ catalyzed by [Mn(T4PyP)-CMP]

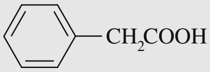
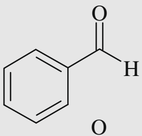
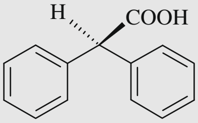
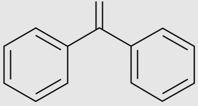
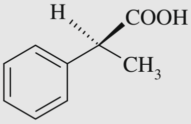
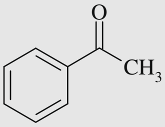
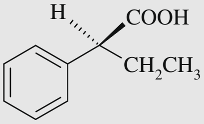
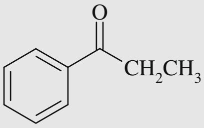
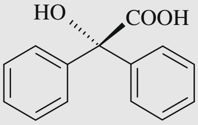
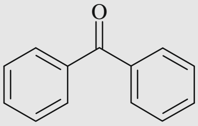
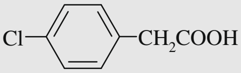
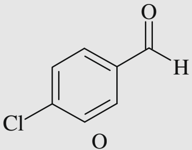
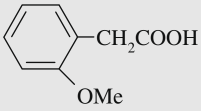
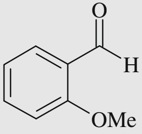
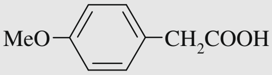
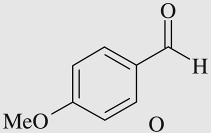
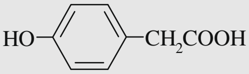
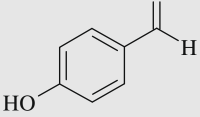
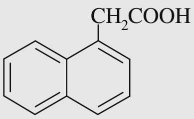
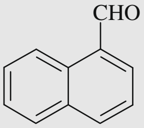
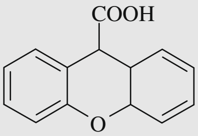
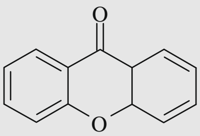
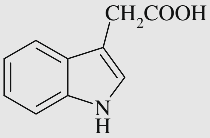
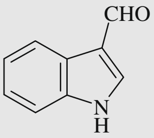
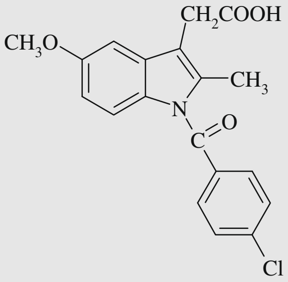
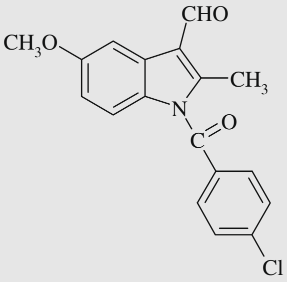
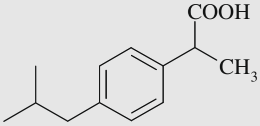
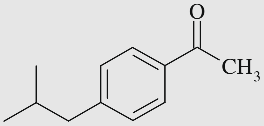
Entry	Acid		Product	Time (h)	Yield[a] (%)
1a		**1b**		30	96
2a		**2b**		45	95
3a		**3b**		45	93
4a		**4b**		75	92
5a		**5b**		30	95
6a		**6b**		30	94
7a		**7b**		30	94
8a		**8b**		15	92
9a		**9b**		30	92
10a		**10b**		30	93
11a		**11b**		60	92
12a		**12b**		105	94

Table 4 (*continued*)

Entry	Acid		Product	Time (h)	Yield[a] (%)
13a		**13b**		170	85
14a		**14b**		160	88

[a] Isolated yields.

3.2. Oxidative decarboxylation of carboxylic acids with sodium periodate catalyzed by [Mn(T4PyP)-CMP]

The optimum condition used for the oxidation of diphenylacetic acid with this heterogenized system was catalyst, oxidant, imidazole and substrate in a molar ratio of 0.021:2:0.2:1 ratio, respectively.

Under the optimized reaction conditions, a wide range of aryl substituted carboxylic acids were subjected to oxidative decarboxylation at room temperature. The results are summarized in Table 4. It was found that the main product was carbonyl derivative and only small amount of the alcohol derivative was detected. This may due to the oxidation of alcohols to carbonyl compounds by this catalytic system.[38]

Anti-inflammatory drugs such as Indomethacin and Ibuprofen (entries 13 and 14) were decarboxylated by this catalytic system and afforded the corresponding carbonyl derivatives as the major products in 85% and 88% yields, respectively. These observations show that the metabolism of these drugs in vitro is as same as their in vivo metabolism by cytochrome P-450.

In comparison with our previously reported system for oxidative decarboxylation of carboxylic acid, this catalytic system showed higher catalytic activity.[50]

3.3. Catalyst reuse and stability

The stability of [Mn(T4PyP)-CMP] was studied in repeated oxidative decarboxylation reactions. The oxidation of diphenylacetic acid was chosen as a model substrate for studying of catalyst reuse and stability. The reaction was carried out as described above. At the end of the reaction, the catalyst was removed by filtration and washed with water, acetonitrile and diethyl ether, successively and reused. After the use of catalyst for four consecutive times, the carbonyl yield was 95%. The amount of leached Mn (1%) was determined by atomic absorption (Table 5). The nature of recovered catalyst was studied by diffuse reflectance UV–vis spectroscopy. The results showed that no changes were observed in the UV–vis spectra in comparison with fresh catalyst which confirmed the stability of the catalyst during the oxidation reaction.

Table 5
The results of [Mn(T4PyP)-CMP] catalyst recovery and the amounts of manganese leached in the decarboxylation of diphenylacetic acid with sodium periodate

Run	Conversion[a] (%)	Mn leached[b] (%)	Time (min)
1	100	1	45
2	96	0	45
3	94	0	45
4	94	0	45

[a] GLC yield based on starting diphenylacetic acid.

[b] Measured by atomic absorption spectrometry and based on the initial manganese concentration.

Acknowledgement

The partial support of this work by center of Excellence of Chemistry of University of Isfahan (CECUI) is acknowledged.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.bmc.2009.03.038.

References and notes

1. Meunier, B. *Chem. Rev.* **1992**, *92*, 1411.
2. *Metalloporphyrins in Catalytic Oxidations*; Sheldon, R. A., Ed.; Marcel Dekker: New York, 1994.
3. Meunier, B.; Robert, A.; Pratviel, G.; Bernadou, J.. In *The Porphyrins Handbook*; Kadish, K., Smith, K. M., Guilard, R., Eds.; Academic Press: New York, London, 2000; Vol. 4,.
4. Sheldon, R. A. In *Biomimetic Oxidations Catalyzed by Transition Metal Complexes*; Meunier, B., Ed.; Imperial College Press: London, 2000.
5. Coon, M. J.; White, R. E. In *Dioxygen Binding and Activation by Metal Centers*; Spiro, T. G., Ed.; Wiley: New York, 1980.
6. Groves, J. T.; Nemo, T. E. *J. Am. Chem. Soc.* **1983**, *105*, 5786.
7. Bartolini, O.; Meunier, B. *J. Chem. Soc., Perkin Trans. 2* **1984**, 1967.
8. Meunier, B.; Guilmet, E.; De Carvalho, M. E.; Poilblanc, R. *J. Am. Chem. Soc.* **1984**, *106*, 6668.
9. Mohajer, D.; Tangestaninejad, S. *J. Chem. Soc., Chem. Commun.* **1993**, 240.
10. Mohajer, D.; Tangestaninejad, S. *Tetrahedron Lett.* **1994**, *35*, 945.
11. Nakamura, M.; Tatsumi, T.; Tominaga, H. *Bull. Chem. Soc. Jpn.* **1990**, *63*, 3334.
12. Tatsumi, T.; Nakamura, M.; Tominaga, H. *Chem. Lett.* **1989**, 419.
13. Nam, W.; Han, H. J.; Oh, S. Y.; Lee, Y. J.; Choi, M. H.; Han, S. Y.; Kim, C.; Woo, S. K.; Shin, W. *J. Am. Chem. Soc.* **2000**, *122*, 8677.
14. Naik, R.; Joshi, P.; Umbarkar, S.; Deshpande, R. K. *Catal. Commun.* **2005**, *6*, 125.
15. Vinhado, F. S.; Martins, P. R.; Masson, A. P.; Abreu, D. G.; Vidoto, E. A.; Nascimento, O. R.; Iamamoto, Y. *J. Mol. Catal. A: Chem.* **2002**, *188*, 141.
16. Cooke, P. R.; Lindsay Smith, J. R. *Tetrahedron Lett.* **1992**, *33*, 2737.

17. Sacco, H. C.; Iamamoto, Y.; Lindsay Smith, J. R. *J. Chem. Soc., Perkin Trans. 2* **2001**, 181.
18. Vinhado, F. S.; Prado-Manso, C. M. C.; Sacco, H. C.; Iamamoto, Y. *J. Mol. Catal. A: Chem.* **2001**, *174*, 279.
19. Li, Z.; Xia, C.-G.; Zhang, X.-M. *J. Mol. Catal. A: Chem.* **2002**, *185*, 47.
20. Poltowicz, J.; Serwicka, E. M.; Bastardo-Gonzalez, E.; Jones, W.; Mokaya, R. *Appl. Catal. A: Gen.* **2001**, *218*, 211.
21. Schiavon, M. A.; Iamamoto, Y.; Nascimento, O. R.; Assis, M. D. *J. Mol. Catal. A: Chem.* **2001**, *174*, 213.
22. Assis, M. D.; Lindsay Smith, J. R. *J. Chem. Soc., Perkin Trans. 2* **1998**, 2221.
23. Doro, F. G.; Lindsay Smith, J. R.; Ferreira, A. G.; Assis, M. D. *J. Mol. Catal. A: Chem.* **2000**, *164*, 97.
24. Battioni, P.; Brigaud, O.; Desvaux, H.; Mansuy, D.; Traylor, T. G. *Tetrahedron Lett.* **1991**, *32*, 2893.
25. Traylor, T. G.; Byun, Y. S.; Traylor, P. S.; Battioni, P.; Mansuy, D. *J. Am. Chem. Soc.* **1991**, *113*, 7821.
26. Battioni, P.; Bartoli, J. F.; Mansuy, D.; Byun, Y. S.; Traylor, T. G. *J. Chem. Soc., Chem. Commun.* **1991**, 1051.
27. Benaglia, M.; Danelli, T.; Pozzi, G. *Org. Biomol. Chem.* **2003**, *1*, 454.
28. Brule, E.; Hii, K. K.; de Miguel, Y. R. *Org. Biomol. Chem.* **2005**, *3*, 1971.
29. Zhang, J.-L.; Liu, Y. L.; Che, C.-M. *Chem. Commun.* **2002**, 2906.
30. Zhang, R.; Yu, W.-Y.; Sun, H.-Z.; Liu, W.-S.; Che, C.-M. *Chem. Eur. J.* **2002**, *8*, 2495.
31. Yu, X.-Q.; Huang, J.-S.; Yu, W.-Y.; Che, C.-M. *J. Am. Chem. Soc.* **2000**, *122*, 5337.
32. Zhang, J.-L.; Che, C.-M. *Org. Lett.* **2002**, *4*, 1911.
33. Liu, C.-J.; Yu, W.-Y.; Li, S.-G.; Che, C.-M. *J. Org. Chem.* **1998**, *63*, 7364.
34. Tangestaninejad, S.; Mirkhani, V. *J. Chem. Res. (S)* **1998**, 788.
35. Tangestaninejad, S.; Moghadam, M. *J. Chem. Res. (S)* **1998**, 242.
36. Tangestaninejad, S.; Moghadam, M. *Synth. Commun.* **1998**, *28*, 427.
37. Tangestaninejad, S.; Habibi, M. H.; Mirkhani, V.; Moghadam, M. *J. Chem. Res. (S)* **2001**, 444.
38. Moghadam, M.; Tangestaninejad, S.; Habibi, M. H.; Mirkhani, V. *J. Mol. Catal. A: Chem.* **2004**, *217*, 9.
39. Tangestaninejad, S.; Moghadam, M.; Mirkhani, V.; Kargar, H. *Ultrason. Sonochem.* **2006**, *10*, 32.
40. Moghadam, M.; Tangestaninejad, S.; Mirkhani, V.; Mohammadpoor-Baltork, I.; Kragar, H. *Bioorg. Med. Chem.* **2005**, *13*, 2901.
41. Moghadam, M.; Nasr-Esfahani, M.; Tangestaninejad, S.; Mirkhani, V.; Zolfigol, M. A. *Can. J. Chem.* **2006**, *84*, 1.
42. Moghadam, M.; Mirkhani, V.; Tangestaninejad, S.; Mohammadpoor-Baltork, I.; Abbasi-Larki, A. A. *Appl. Catal. A: Gen.* **2008**, *349*, 177.
43. Moghadam, M.; Tangestaninejad, S.; Mirkhani, V.; Kargar, H.; Komeili-Isfahani, H. *Catal. Commun.* **2005**, *6*, 688.
44. Tangestaninejad, S.; Habibi, M. H.; Mirkhani, V.; Moghadam, M. *Molecules* **2002**, *7*, 264.
45. Tangestaninejad, S.; Mirkhani, V. *Chem. Lett.* **1998**, *12*, 1265.
46. Mirkhani, V.; Tangestaninejad, S.; Moghadam, M.; Yadollahi, B. *J. Chem. Res. (S)* **2000**, 515.
47. Nasr-Esfahani, M.; Moghadam, M.; Tangestaninejad, S.; Mirkhani, V. *Bioorg. Med. Chem. Lett.* **2005**, *15*, 3276.
48. Moghadam, M.; Tangestaninejad, S.; Mirkhani, V.; Karami, B.; Rashidi, N.; Ahmadi, H. *J. Iran Chem. Soc.* **2004**, *3*, 64.
49. Mirkhani, V.; Moghadam, M.; Tangestaninejad, S.; Mohammadpoor-Baltork, I.; Kargar, H.; Araghi, M. *Appl. Catal. A: Gen.* **2009**, *353*, 61.
50. Mirkhani, V.; Tangestaninejad, S.; Moghadam, M.; Karimian, Z. *Bioorg. Med. Chem. Lett.* **2003**, *13*, 3433.
51. Komuro, M.; Nagatsu, Y.; Higuchi, T.; Hirobe, M. *Tetrahedron Lett.* **1992**, *33*, 4949.
52. Komuro, M.; Higuchi, T.; Hirobe, M. *Bioorg. Med. Chem.* **1995**, *3*, 55.
53. Harriman, A.; Porter, G. *J. Chem. Soc., Faraday Trans. 2* **1979**, *75*, 1532.
54. The Aldrich Library of NMR Spectra, Edition II, 1981.
55. The Aldrich Library of IR Spectra, Edition III, 1983.