Oxidation of Malonic Acid Derivatives by Manganese(III) Acetate. Aromatic Malonylation Reaction. Scope and Limitations

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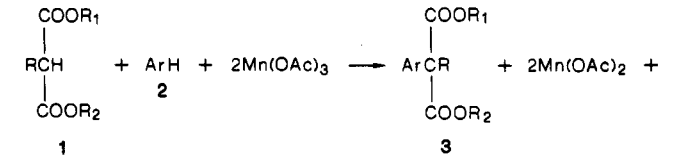
The oxidation of malonic acid derivatives $RCH(COOR_1)COOR_2$ (R_1 = or ≠ R_2 = H, Me, Et; R = H, Me, Et, *n*-Bu, *i*-Pr, C_6H_5, 4-$OMeC_6H_4$) by anhydrous or dihydrated manganese(III) acetate was studied in acetic acid in the presence of aromatic substrates at 20–80 °C, generally with stoichiometric amounts of reagents. Electron-rich aromatics (IP < 7.5 eV) underwent nuclear acetoxylation or quinone formation, the process being exclusive with anthracene and competitive with nuclear malonylation for 1- and 2-methoxynaphthalene. With other less electron-rich substrates (IP < 8.5 eV) only the products coming from the oxidation of the malonic acid derivatives (aryl malonates, tartronates, etc., or dimerization and disproportionation products) were observed. The selectivity and the yield of aromatic substitution by the malonyl group was found to be affected by the electron density of the aromatic ring, the steric inhibition of substituents in the Mn(III) oxidation of the malonic acid derivative, the oxidizability of malonyl radical by Mn(III), the base (acetate ions or water) eventually present in the medium, and the further easy oxidation of the primary aryl malonate product, when unsubstituted dialkylmalonates or malonic acid were used. A mechanism is suggested in which inner-sphere electron transfer from Mn(III)–malonate complex affords Mn(II) malonyl radicals that are partitioned between oxidation, dimerization (or disproportionation), and reversible addition to the aromatics.

Introduction

Extensive literature exists on manganese(III) acetate as source of electrophylic α-keto, α-carboxy, and α-nitro alkyl radicals, which can be trapped by olefins or aromatics, to give interesting functionalized products.[1] The details of the mechanism are however not fully defined. In particular, the exact role of acetic acid, generally used as solvent, the nature of the step of the carbon radical formation (if concurrent proton and electron transfer from a Mn(III)-coordinated ligand[2] or a similar process from an oxo-centered Mn(III) triangle[3] or hydrogen transfer from Mn(II)-complexed acetoxy radicals[4]), the involvement of free or Mn(II)-complexed carbon radicals, and the influence of the coordination on their electrophylic properties are unknown. It is well documented, however, that higher valence Mn complexes and free acetoxy radicals are not involved and that rate-determining hydrogen loss is operative in the product formation as deduced by the primary isotope effect (3.2–5.5).[2,3,5] In order to obtain further mechanistic evidence on these important radical sources and also to extend the synthetic scope of these oxidations, we studied the manganese(III) acetate oxidation of 1,1-disubstituted methanes or ethanes carrying electron-withdrawing groups in the presence of aromatics. These compounds are known to give thermally unstable Mn(III) complexes that generate carbon radicals efficiently.[6] Manganese(III) acetylacetonate in particular is a well-known polymerization initiator,[6] and several examples of manganese(III) acetate promoted intra- and intermolecular additions of β-diketones, β-keto esters, and dialkylmalonic acid derivatives to alkyl- or aryl-substituted olefins[7] or oxy-substituted[8] olefins have been reported. Examples of homolytic substitution of alkoxynaphthalenes by these radical sources in the aromatic series were earlier reported by us.[9] Later, a communication on Ce(IV)-promoted malonylation of aromatics was published.[10] Now, we present a more detailed study on the oxidation by manganese(III) acetate of malonic acid derivatives **1a–k** in the presence of aromatics **2a–i**, analyzing the selectivity and the factors affecting the aromatic substitution by the malonyl groups (compounds **3**, eq 1).



(1)

1a, R = Me; $R_1 = R_2$ = Et
1b, R = Et; $R_1 = R_2$ = Et
1c, R = *n*-Bu; $R_1 = R_2$ = Et
1d, R = *i*-Pr; $R_1 = R_2$ = Et
1e, R = phenyl; $R_1 = R_2$ = Et
1f, R = 4-MeO-phenyl; $R_1 = R_2$ = Et
1g, R = H; R_1 = Et; R_2 = H
1h, R = H; $R_1 = R_2$ = Et
1i, R = H; $R_1 = R_2$ = Me
1j, R = Me; R_1 = Et; R_2 = H
1k, R = H; $R_1 = R_2$ = H

2a = 2-MeO-naphthalene
2b = 1-MeO-naphthalene
2c = naphthalene
2d = phenanthrene
2e = anthracene
2f = anisole
2g = 1,2-dimethoxybenzene
2h = 1,4-dimethoxybenzene
2i = benzene

Results

Reactions of 1a and 1- or 2-Methoxynaphthalenes. The reaction between 2-methoxynaphthalene and dihydrated manganese(III) acetate has been previously re-

(1) De Klein, W. J. In *Organic Syntheses by Oxidation with Metal Compounds*; Mijs, W. J., De Jonge, C. R. H. I., Eds.; Plenum Press: New York, 1986; pp 261–314.
(2) Vinogradov, M. G.; Verenchikov, S. P.; Fedora, T. M.; Nikishin, G. I. *J. Org. Chem. (USSR)* **1975**, *11*, 937.
(3) Fristad, W. E.; Peterson, J. R.; Ernst, A. B.; Urbi, G. B. *Tetrahedron* **1987**, *42*, 3429.
(4) Okano, M. *Bull. Chem. Soc. Jpn.* **1976**, *49*, 1041.
(5) (a) Vinogradov, M. G.; Verenchikov, S. P.; Nikishin, G. I. *J. Org. Chem. (USSR)* **1975**, *12*, 2245. (b) Kurz, M. E.; Ngoviwatchai, P. *J. Org. Chem.* **1981**, *46*, 4672. (c) Kurz, M. E.; Baru, V.; Nguyen, P. N. *J. Org. Chem.* **1984**, *49*, 1603. (d) Dessau, R. M.; Kohel, W. J., Jr. *J. Am. Chem. Soc.* **1969**, *91*, 138.
(6) *Gmelin Handbuch der Anorganischen Chemie*; Springer-Verlag: Berlin, Heidelberg, 1979; System No. 56, Part D, Section 1, pp 85–105 and references therein.
(7) (a) Nishino, H. *Bull. Chem. Soc. Jpn.* **1985**, *58*, 217. (b) Mohan, R.; Kates, S. A.; Dobroski, M. A.; Snider, B. B. *Tetrahedron Lett.* **1987**, 845. (c) Fristad, W. E.; Hershberger, S. S. *J. Org. Chem.* **1985**, *50*, 1026. (d) Yang, F. Z.; Trost, H. K.; Fristad, W. E. *Tetrahedron Lett.* **1987**, 1493.
(8) Corey, E. J.; Ghosh, A. K. *Tetrahedron Lett.* **1987**, 175.
(9) Citterio, A.; Santi, R.; et al. *Gazz. Chim. Ital.* **1988**, *118*, 405.
(10) Baciocchi, E.; Dell'Aria, D.; Ruzziconi, R. *Tetrahedron Lett.* **1986**, 2763.

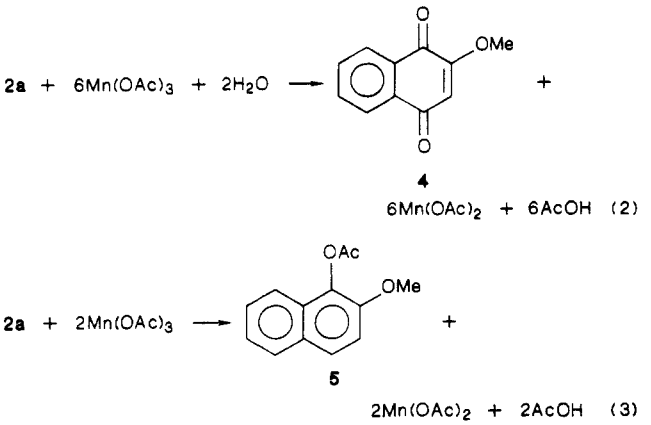
0022-3263/89/1954-2703$01.50/0

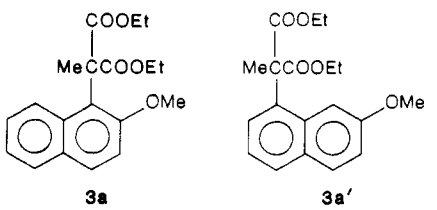
Table I. Manganese(III) Acetate Oxidation of 1a in the Presence of Aromatics (AcOH, 80 °C, [AcONa] = 2.5 M)

entry	ArH	time, h	aromatic convn, %	yield, % 3[a]	4, 5	6, 7, 9	3 isomer (distrib, %)
1	**2a**	4	61	52 (85)	10	11, 23, 3	1 (83), 8 (13), others (4)
2	**2b**	4	51	43 (84)	5	2, 0, 1	4 (>98), others (<2)
3	**2c**	4	20	19.2 (95)		17, 16, 22	1 (91), 2 (9)
4	**2d**	8	15	10 (88)		30, 12, 15	five isomers (42:7.7:10:33:6.7)
5	**2e**	1	88		72[b]		
6	**2f** (10)[c]	4	1.9	15 (80)		19, 12, 14	2 (60), 4 (40), 3 (<1)
7	**2g** (5)[c]	4	4.5	20 (89)		21, 16, 10	4 (96), 3 (4)
8	**2h** (5)[c]	4	2.6	12 (92)		15, 8, 4	2 (100)
9	**2i** (10)[c]	8	nd[d]			8, 11, 3	

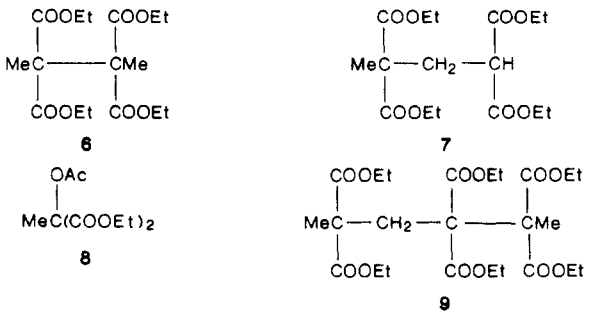
[a] Yield based on Mn(III) (based on converted aromatic). [b] 10-Acetoxyanthracene, anthraquinone (8%), and 1,10-diacetoxyanthracene (4%) were also detected. [c] Ratio of arromatic to **1a**. [d] nd = not detected.

ported[11] to afford 2-methoxy-1,4-naphthoquinone (**4**) (eq 2). Moreover, in our hands, the reaction with both anhydrous or dihydrated manganese(III) acetate afforded a mixture of 1-acetoxy-2-methoxynaphthalene (**5**) (eq 3) and **4** with the latter prevailing in a ratio ranging from 1:2 to 1:5 in inverse dependence of the amount of acetate ions eventually presents in the medium. When this reaction was carried out in the presence of a stoichiometric amount of diethyl methylmalonate (**1a**), compounds **4** and **5** were formed in low yield (5–9%), the main product being **3** (30–55%), the substitution product as a mixture of isomers, with **3a** and **3a′** prevailing (>95%) (entry 1, Table I).





Minor amounts of symmetric and unsymmetric dimers of the malonate (**6** and **7**, respectively) were formed along with diethyl α-acetoxy-α-methylmalonate (**8**) and the trimer (**9**).



(11) Andrulis, P. J., Jr.; Dewar, M. J. S. *J. Am. Chem. Soc.* **1966**, *88*, 5483.

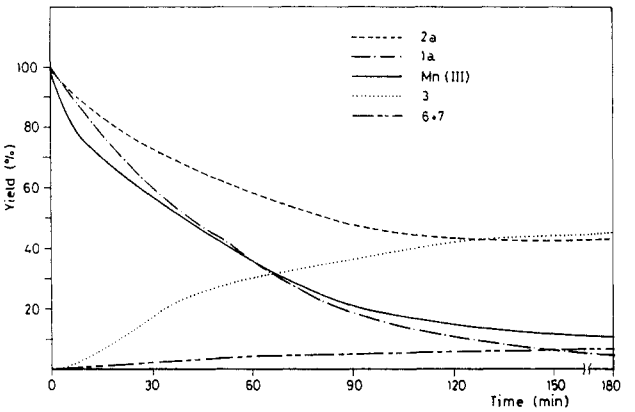
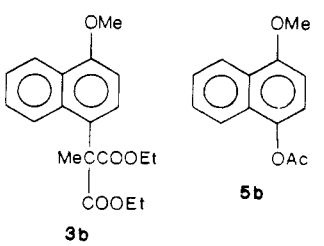


Figure 1. Product formation and reagents consumption vs time in the Mn(III) acetate oxidation of **1a** in the presence of **2a**.

In order to determine if all products were formed competitively, time-dependent studies were performed by following the consumption of Mn(III) and other reagents and the products formation (see Experimental Section). The results of these determination are plotted in Figure 1.

A sharp decrease of Mn(III) and malonate concentration was observed at the beginning, followed by an increase of substitution and oxidation products of **2a** and of dimers (**6** and **7**). The isomeric distribution of the substitution products on the aromatic nucleus did not change with time, with the isomer of addition in position 1 (**3a**) prevailing over the 8 isomer (**3a′**) and over all the others (relative ratio 75:21:4, respectively). The relative amounts of **6**, **7**, and **9** change during the reaction. Compound **8** was mainly formed at the beginning of the reaction. The reaction was found to be complete in acetic acid in 3 h at 80 °C; 88% of manganese(II) acetate was isolated by filtration of the cooled reaction mixture. Hydrolysis of the substitution products was not observed after 24 h at 80 °C. It was also verified that compound **8** cannot be the precursor of **3** under the reaction conditions. Similar reactions carried out in the presence of 1-methoxynaphthalene (**2b**) afforded mainly **3b**, the substitution product on position 4 with remarkable selectivity (>98%), along with the direct oxidation product **5b** (entry 2, Table I).

The dimers **6** and **7** and the trimer **9** were obtained in



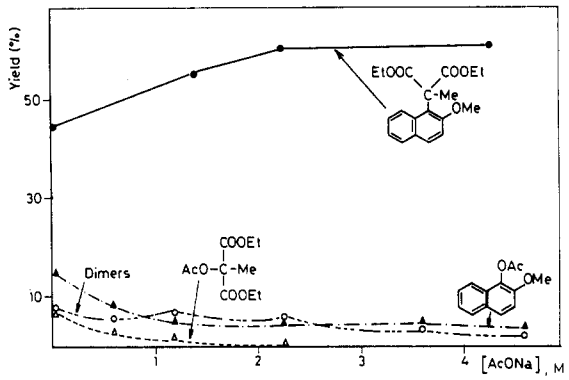


Figure 2. Product distribution vs sodium acetate concentration in Mn(III) acetate oxidation of diethyl methylmalonate (**1a**) in the presence of 2-methoxynaphthalene (**2a**). [**1a**] = [**2a**] = 0.21 M, [Mn(III)] = 0.42 M.

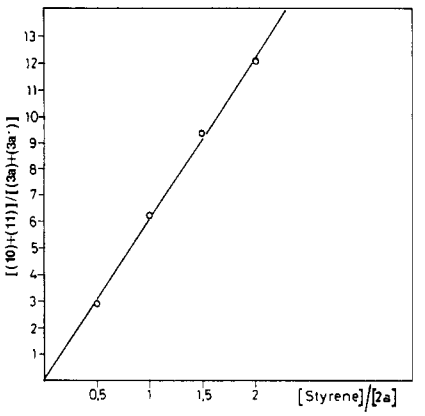
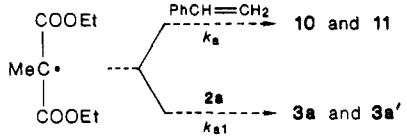


Figure 3. Methyldiethylmalonyl radicals competitive reaction with styrene and **2a**.

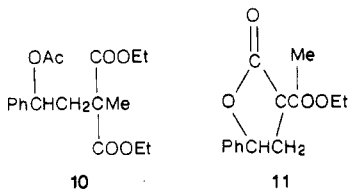
very low yields, conversely tartronate 8 was obtained in similar yield as for the case reported in eq 3. The presence of sodium acetate in the medium was found particularly useful with both **2a** and **2b**, resulting in higher yields and selectivities. Figure 2 shows the dependence of the yield of the product on the concentration of added acetate, when **2a** was used.

The direct oxidation products of **1a** (compound 8) and those of **2a** and **2b** (**4**, **5a**, and **5b**, respectively) show a linear decrease with increased acetate ion concentration whereas the malonylation products increase linearly. The distribution of malonylation isomers of **2a** shift in favor of **3a** and no more than trace amount (<1%) of other isomers are observed. The conversion of **1a** to byproducts (**6**, **7**, **8**, and **9**) decreases too, affording a yield on converted **1a** and **2a** of 73% and 95%, respectively, in the presence of 2.6 M sodium acetate. Under these conditions, manganese(II) acetate does not precipitate and the solution remains dark brown even after 6 h. The optimized oxidation conditions for **1a** and **2a** were used for a series of aromtic substrates (Table I).

In order to obtain some information about the involvement of radical intermediates, the generation of substituted malonyl radicals, by H-abstraction, was attempted through thermal decomposition of percarbonates, diacyl peroxides, and azo compounds, in the absence of any metal salt, and in the presence of **1a** and **2a**. Aromatic substitution, by malonyl group, was never observed. However, with peroxides, some nuclear acyloxylation was obtained. Thermal decomposition of percarbonates in the presence of anhydrous manganese(II) acetate affords the malonylation product in 7% yield. Aromatic substitution by the malonyl group appears to be a fast process as deduced from competitive experiments between styrene and **2a**.



$$R = ([10] + [11])/([3a] + [3a']) = k_a/k_{a1} \times [C_6H_5CH{=}CH_2]/[2a] \quad (4)$$



The addition products of the malonyl group to styrene (compounds **10** and **11**) and to **2a** (**3a** and **3a'**) were formed competitively and were found to be independent of the concentration of **1a**. Equation 4 was followed at low conversion (<15%), which allowed us to deduce the relative rate of addition (k_a/k_{a1}) from the dependence of the ratio of concentration of addition products vs the initial concentration of starting styrene and **2a**. The linear plot of Figure 3 gives a relative ratio $k_a/k_{a1} = 6.3 \pm 0.2$.

Reaction of 1a and Aromatics. Two limited cases were observed: Anthracene (entry 5, Table I) was directly oxidized to 9-acetoxyanthracene (**12**), 9,10-diacetoxyanthracene (**13**), and anthraquinone (**14**) in 72, 4, and 8% yield, respectively, with a 88% conversion. These results are in accord with those obtained in the absence of **1a**.[12] On the other hand, with benzene present in excess (entry 9, Table I), only oxidation and dimerization products of **1a** were obtained. In both cases the absence of sodium acetate or the presence of water or malonate in excess affords similar results.

Aromatics less electron rich than **2a** and **2b** (i.e., naphthalene (**2e**), anisole (**2d**), phenanthrene (**2f**), 1,2- and 1,4-dimethoxybenzene (**2h** and **2i**, respectively) afforded malonylation products in relative low yields; dimers and oxidation products of **1a** prevail, whereas no oxidation product of the aromatics was detected. An excess of the aromatic substrate (5–10 mol per mol of **1a**) was used with less reactive substrates. Generally, the yields of aryl malonates did not exceed 20%, based on Mn(III); however the yield on converted aromatics were high (85–95%).

The distribution of malonylation isomers of naphthalene was 91:9 for α and β positions, respectively, whereas with phenanthrene all five possible isomers were formed as deduced by GC-MS spectra. Their structures were, however, not assigned.

With anisole the substitution occurs at position 2 (60%), 4 (40%), and an indication of a trace of isomer 3. The isomer ratio was found to change slightly upon added sodium acetate, with the isomer of substitution in position 2 decreasing by adding sodium acetate (see Experimental Section). Similar high selectivity for the position of higher electron density was observed with 1,2-dimethoxybenzene (**2h**) with a 96:4 ratio for position 4 and 3, respectively. With 1,4-dimethoxybenzene only one product was obviously formed.

Reaction with 1b–g and 2b. The effect of substituents in the α position of diethyl malonates **1** ($R_1 = R_2 = Et$)

(12) Van Helden, R.; Bickel Kooijman, A. F. *Recl. Trav. Chim.* **1961**, *57*, 80.

Table II. Product Distribution in the Manganese(III) Acetate Oxidation of α-Substituted Diethyl Malonates in the Presence of 1-Methoxynaphthalene (2b) (AcOH, 80 °C, [AcONa] = 2.5 M)

		convn, %		products (yield, %)			
entry	R	2b	1	3	5b	dimer[a]	$RC(COOEt)_2(OAc)$
1	H	53.5	65	88 (1, 81, 6)[b]	1		10
2	Me	51	84	43	5	2	5
3	Et	48	75	30	13	11	4.2
4	n-Bu	35	80	23	15	16	23
5	i-Pr	40	60	3	32	6	24
6	C_6H_5	5	88		3	8[c]	10
7	p-$MeOC_6H_4$	2	94		2		91

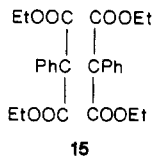
[a] Symmetric dimer. [b] Diethyl α-[1-(4-methoxynaphthyl)]-, α-acetoxy-α-[1-(4-methoxynaphthyl)]-, and α,α-[1-(4-methoxynaphthyl)]-malonate, respectively. [c] Several compounds with molecular weight higher than those of dimers were formed (60% of weight of the reaction residue) along with compound 18 (5% yield).

Table III. Manganese(III) Acetate Oxidation of Dialkyl Malonates (1h–i) in the Presence of Aromatics

					products (yield, %)			
entry	ArH	1	R[a]	2 (convn, %)	3	17	others	17 isomers (distrn, %)
1	**2a**	**1h**	1	40	5 (11)	70 (78)	**4**, **5** (4)	1 (>95)
2	**2a**	**1i**	1	38	1	45	**18** (23), **19** (8)	1 (>95)
3	**2a**	**1i**	3	45	2	58	**18** (19), **19** (2)	1 (>95)
4	**2a**	**1i**	6	50	5	54	**18** (26), **19** (10)	1 (>95)
5	**2b**	**1h**	1	46	1	81		4 (>95)
6	**2b**	**1h**	6	48	6	74		4 (>95)
7	**2f**	**1h**	1	15	2	32	**20** (35)	o (47), p (53)
8	**2i**	**1h**	1	nd			*b*	

[a] 1:2 molar ratio. [b] Phenylacetic acid, benzyl acetate, and benzal diacetate were detected. [c] nd = not determined.

was also examined, as a function of the yield of the malonylation products arising from **2b**, in the presence of sodium acetate, 2.4 M (Table II). Compounds **3** were formed progressively in lower yields along the series **1a** > **1b** > **1c** > **1d** > **1h** and become practically undetectable for **1e** and **1f**. The direct oxidation of the aromatic substrate **2b** presents the inverse trend, increasing when more sterically crouded malonates are employed, except for malonates **1e** and **1f**, where only minor amounts of 1-acetoxy-4-methoxynaphthalene (**4b**) were formed. With these last substrates the oxidation involves essentially the malonate affording α-acetoxylation in the case of **1f** and a complex mixture of products when **1e** is used. Among the products arising from **1e**, the symmetric dimer **15** was isolated in 8% yield, along with several products that appear to be telomers of the starting malonate, corresponding to the general formula **16**.[13] The analysis of the



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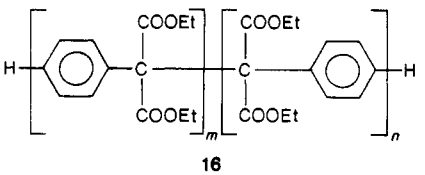

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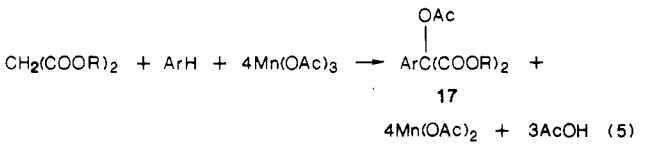
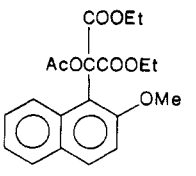
products, with more sterically crowded **1** (R = H, Me, Et, n-Bu, i-Pr) reveals a monotonic increase of dimers of malonates with respect to compounds of aromatic malonylation **3**. α-Acetoxylation (or hydroxylation) of the starting malonates was observed to be significant with n-butyl and isopropyl derivatives.

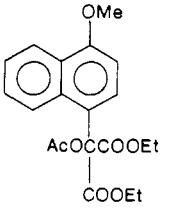
Reaction with 1h and 1i. The reaction between dialkyl malonates **1h–i** and aromatics affords mainly the product of further side-chain functionalization of the primary malonylation product **3** (Table III). The prevalent product was the α-acetoxymalonyl derivative **17** (eq 5). Compound **3** was formed, albeit in very low yield, when an excess (5–10 mol) of **1b** per mol of **2b** was used.



With diethyl malonate (**1h**) and 1-methoxy- and 2-methoxynaphthalene (**2b** and **2a**, respectively) the α-acetoxymalonylation products **17hb** and **17ha** prevailed with moderate conversion of the aromatic substrate.



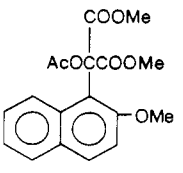
17ha



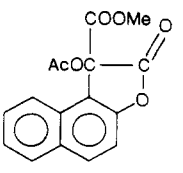
17hb

With dimethyl malonate (**1i**) and **2a** a more complex distribution of products was observed, which essentially appears to be related to the higher solvolytic rate of the methyl ester group. Along with minor amounts of the malonylation product **3c**, the compounds **17ia**, **18**, and **19** were formed, that is, products of further oxidation of **3c** that are again formed also in a 6-fold excess of **1i**.

With anisole the acetoxymalonylation products in pos-



17ia



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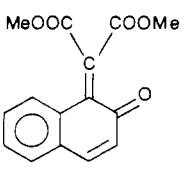

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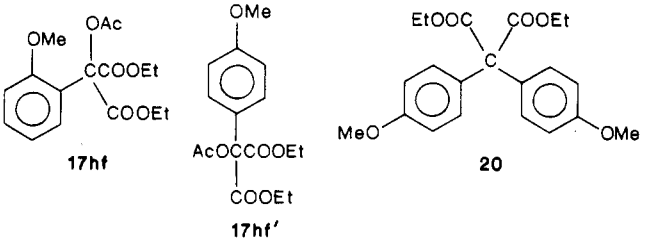
(13) (a) Citterio, A.; Finzi, C.; Santi, R.; Strologo, S. *J. Chem. Res.* **1988**, (S) 156, (M) 1301. (b) De Jongh, H. A. P.; De Jonge, C. R. H. I.; Simige, H. J. M.; De Klein, W. J.; Huysman, W. G. B.; Mijs, W. J. *J. Org. Chem.* **1972**, *37*, 1960.

Table IV. Manganese(III) Acetate Oxidation of α-Methylmalonate Monoethyl Ester (1j) and Malonic Acid (1k) in the Presence of Aromatics in AcOH

						products (yield, %)				
entry[a]	1	ArH	T, °C	time, h	ArH (convn, %)	21	22	23	24	isomers (distrn, %)
1	1j	2a	30	9	42	35	7			1 (>95)
2	1j	2a	73	0.5	30	21	<2			1 (>95)
3	1j	2b	80	0.5	32	1	1	24		4 (>95)
4[b]	1j	2b	73	0.5	31			13		4 (>95)
5[c]	1k	2a	80	3	69				53	1 (>90)

[a] [ArH] = 0.2 M, [AcONa] = 1 M, [Mn(III)] = 0.4 M. [b] [ArH] = 2.0 M, [AcONa] = 1 M, [Mn(III)] = 0.4 M. [c] [ArH] = 0.1 M, [AcONa] = 0.5 M, [Mn(III)] = 0.6 M.

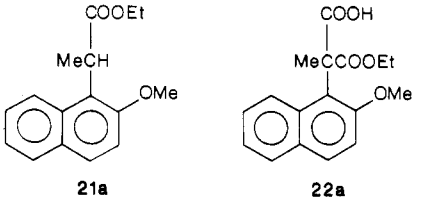
itions 2 (**17hf**) and 4 (**17hf'**) were formed along with the disubstituted derivative **20**.



The analogous ortho-disubstituted isomer was not formed. These data are quite different from those recently reported for the aromatic malonylation of anisole by Ce(IV)[10] where the reaction stops at the early malonylation stage. In our case the primarily formed malonylation product is further rapidly oxidized to give the α-acetoxy derivatives with electron-rich aromtics or to give dimers or telomers with less reactive substrates. Manganese(III) acetate oxidation of diethyl malonate in the presence of benzene (also in large excess) afforded diethyl ketomalonate as the main product, a small amount of phenylacetic acid was also isolated, but no diethyl α-phenylmalonate was detected.

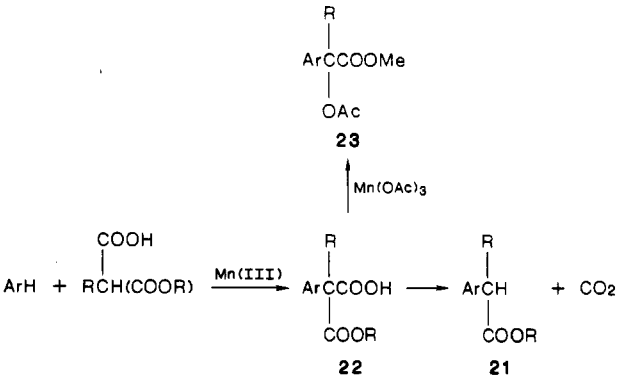
Reaction with 1j and 1k. Some reactions with methylmalonic acid monoethyl ester (**1k**) were also examined to verify further the potentiality of the aromatic functionalization with more reactive aromatics. These results are reported in Table IV.

With **2a** the main reaction product was the ethyl 2-arylpropionate **21a** in low yield based on Mn(III) but high on the aromatics. This compound was accompanied by the corresponding arylmalonic acid monoethyl ester **22a** (Scheme I), identified after methylation with diazomethane. The yield increases as the reaction is carried out at lower temperatures.

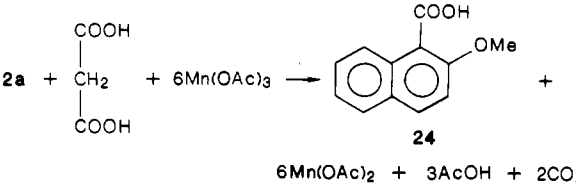


The substitution occurs selectively at the 1 position with **2a**, at the 4 position with **2b**, and with anisole at the ortho and para positions with a isomer distribution of 58 and 42%, respectively. α-Acetoxy-α-arylpropionic acid derivative compounds **23** were also identified in this reaction and in the case of 1-methoxynaphthalene it became the prevailing product. The oxidation of malonic acid **1k** in the presence of **2a** involves the α position of **1k** and the 1 position of the aromatic. The high reactivity of the primarily formed arylmalonic acid toward Mn(III) prevents, however, the possibility of isolating this compound and the reaction affords essentially the corresponding

Scheme I



naphthoic acid **24** (57% yield), according to the stoichiometry of eq 6.



$$6Mn(OAc)_2 + 3AcOH + 2CO_2 \quad (6)$$

Carboxylation of aromatics using manganese(III) acetate has been previously reported in low yields on the xanthenone series[14] by Mn(III) carboxymethylation and further oxidation.

Discussion

The results obtained in this study indicate that the oxidation of malonic acid derivatives by manganese(III) acetate, in acetic acid, is a fast process in the presence of aromatics. Mn(III) was in fact consumed in 2–10 h at 70 °C and aromatic substitutions by acetoxy or malonyl groups were competitively or exclusively observed only with electron-rich aromatics (i.e., 2- and 1-methoxynaphthalene or anthracene). On the basis of the reported ionization potentials[15] of these substrates (7.82, 7.70, and 7.4 eV, respectively), we are confident that the oxidation of the malonic acid derivative by Mn(III) to yield aromatic malonylation can occur only in the presence of aromatics whose IP is higher than 7.5–7.6 eV. On the other hand, the range of IP for which competition between the two processes can be observed is very limited, if we consider that no aromatic acetoxylation products can be found in reaction with naphthalene, anisole, and benzene (IP 8.09, 8.39, and 9.25 eV, respectively[15]).

The aromatic acetoxylation process is generally interpreted[16] to occur through an electron-transfer oxidation step (eq 7), which appears to be reversible at least in the

(14) Nishino, H.; Kurosawa, K. *Bull. Chem. Soc. Jpn.* **1983**, *56*, 474.
(15) Klasinc, L.; Kovac, B.; Güsten, H. *Pure Appl. Chem.* **1983**, *55*, 289.
(16) Eberson, L. In *Electron Transfer Reactions in Organic Chemistry*; Springer Verlag: 1987; Chapters VI and VII.

case of 1-methoxy- and 2-methoxynaphthalene and 4-methoxytoluene on the basis of the retarding effect of Mn(II) on the reaction rate.[11]

$$Mn(OAc)_3 + ArH \longrightarrow Mn(OAc)_2 + AcO^- + ArH^{\bullet+} \quad (7)$$

$$ArH^{\bullet+} + AcO^- \longrightarrow \left[\begin{array}{c} H \\ | \\ Ar \\ | \\ OAc \end{array}\right]^{\bullet} \xrightarrow[-Mn(II)]{Mn(III)} ArOAc + H^+ \quad (8)$$

For all substrates tested, reaction 7 is endothermic by at least 13 kcal/mol as deduced from the reported redox potentials of anthracene (1.61 V vs normal hydrogen electrode (NHE)[17]) and the couple Mn(III)/Mn(II) (1.04 V vs NHE[18]). However, it has been reported[19] that electron-transfer oxidation of olefins by manganese(III) acetate in acetic acid is possible for substrates having IP less than ca. 8.5 e.V. The absence of nuclear acetoxylation, in our conditions, for naphthalene and anisole indicates that either the oxidation of the malonic acid derivatives is less reversible than aromatic oxidation or intermediate species are involved with an IP of ca. 7.7–7.8 eV. In the second hypothesis, dialkyl malonate itself or the corresponding enolic form must be excluded because they must have an IP higher than that of enol ethers for which an IP of 8.1–8.5 eV have been reported.[20] However, we found that manganese(III) acetate oxidizes selectively 1- and 2-alkoxynaphthalenes also in the presence of ethyl enol ether or enol acetate of 2,4-pentanedione.[21] Therefore, we suppose that the possible intermediate in these oxidations could be the anion of the malonic derivative free or as ligand of Mn(III). The presence of an anion of dialkyl malonate in acetic acid is improbable, owing to the low acidity of C–H bond in these substance (i.e., the pK_a of dimethyl malonate is 15.9[22]) and the low dissociation of manganese(III) acetate in acetic acid.[23] The most plausible candidate appears, therefore, to be a malonate anion complexed to Mn(III) (i.e., **26**), whose formation can occur by base-catalyzed proton loss from complexed malonate ligand (**25**) (eq 9). Enhanced acidity of C–H bond α to

$$Mn(III)L_n \xrightarrow[-2L]{RCH_2(COOR)_2} L_{n-2}Mn(\text{OEt})(O{=}C)(CHR)(O{=}C)(\text{OEt}) \xrightarrow[-BH^+]{B} \quad (9)$$

25

26

carbonyl group by complexation with metal species has been reported,[24] as for malonic esters in the anti conformation or in cyclic arrangement, i.e., Meldrum's acid.[22,25]

We reported previously[9] that preformed Mn(III) complexes of β-diketones and β-keto esters alkylate efficiently methoxynaphthalenes without oxidation of the aromatic, indicating that the presence of these ligands decreases the oxidation ability of Mn(III) toward electron transfer from the aromatic. Several examples of radical reaction induced by thermal decomposition of manganese(III) acetylacetonate are known,[26] and although no isolated Mn(III) dialkyl malonate complexes have been reported, the corresponding Mn(II) complexes[6] are known. However, the results of Figure 2 indicate that the presence of sodium acetate favors the oxidation of diethyl methylmalonate over the oxidation of **2a**. If we extrapolate the results of Andrulis[11] (insensitivity, to acetate ions, of the initial rate of oxidation of 4-methoxytoluene by manganese(III) acetate) to methoxynaphthalenes, we can conclude that base-catalyzed deprotonation is involved in the oxidation of malonic acid derivative in every case. This is in accord with the linear relationship[27] between oxidation rate and pK_a of carbonyl derivatives and with the high H/D isotope effect reported[5] in the products of oxidation of carbonyl and nitro compounds by Mn(III). However, at least in the case of β-dicarbonyl compounds the fast H/D exchange rate and the sensitivity of the oxidation rate to the olefin[28] or to the aromatic substrate seem to exclude that proton loss is rate determining even if involved in the oxidation. We suggest that electron transfer from complexes **26** (eq 10) is probably a slow and reversible process and the effect of the base is to increase stationary concentration of reactive complexes **26**. The Mn(II)-complexed malonyl radical **27** could eventually dissociate to free malonyl radicals **28** (eq 11). The overall back process (eq 11 and

$$L_{n-2}Mn(\text{OEt})(O{=}C)(CR)(O{=}C)(\text{OEt}) \longleftrightarrow L_{n-2}Mn(\text{OEt})(O{=}C)(\bullet CR)(O{=}C)(\text{OEt}) \quad (10)$$

26 **27**

$$27 \longleftrightarrow (EtOOC)_2C^{\bullet}R + L_{n-2}Mn(II) \quad (11)$$

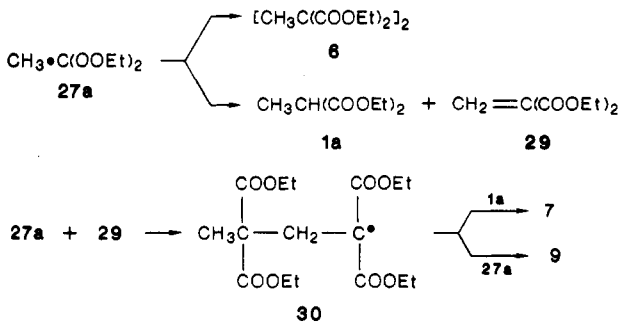
28

10) is probably important, taking into account the high redox potential of malonyl radicals (0.94 V and 1.1 V vs NHE have been reported[29,30] for $^{\bullet}CH(COOEt)_2$ and for $^{\bullet}CH(COOH)_2$, respectively). These values are similar to the redox potential of the couple Mn(III)/Mn(II) in acetic acid (1.01 V vs NHE[18]). The interpretation is certainly complicated by the observation that the last redox potential decreases with increasing sodium acetate concentration,[18] and this would also affect, in principle, the oxidation rate of aromatic substrate.

The involvement of malonyl radicals, complexed (**27**) or free (**28**), in the reaction analyzed can be inferred from products of dimerization, disproportionation, and oligomerization observed with α-alkyl and α-aryl derivatives **1**. With diethyl methylmalonate, for instance, along with symmetric dimer **6**, an unsymmetrical dimer (**7**) and a

(17) Parker, V. D. *J. Am. Chem. Soc.* **1976**, *98*, 98.
(18) Khrishnam, R. U. G.; Venkat, R. V.; Sethuram, B.; Naraneeth, R. T. *J. Electroanal. Chem.* **1982**, *133*, 317.
(19) Norman, J. A.; Thomas, C. B.; Burrow, M. J. *J. Chem. Soc., Perkin Trans. 1* **1985**, 1087; **1987**, 1103.
(20) Hyisgen, R.; Mayr, H. *Tetrahedron Lett.* **1975**, 2965.
(21) Citterio, A.; Santi, R. Unpublished results.
(22) Arnett, E. M.; Harrelson, J. A. *J. Am. Chem. Soc.* **1987**, *109*, 809. Arnett, E. M.; Harrelson, J. A. *Gazz. Chim. Ital.* **1987**, *117*, 237.
(23) Proll, P. J.; Sutcliffe, L. H. *Trans. Faraday Soc.* **1961**, *57*, 1078.
(24) Farago, M. E.; Smith, M. A. R. *J. Chem. Soc. D* **1972**, 2120.
(25) Wang, X.; Houk, K. N. *J. Am. Chem. Soc.* **1988**, *110*, 1870. Wiberg, K. B.; Laidig, K. E. *J. Am. Chem. Soc.* **1988**, *110*, 1872.
(26) *Gmelin Handbuch der Anorganischen Chemie*; Springer-Verlag: Berlin, Heidelberg, 1980; System No. 56, Part D, Section 2, pp 190–1.
(27) Fristad, W. E.; Peterson, J. R. *J. Org. Chem.* **1985**, *50*, 10.
(28) Corey, E. J.; Kang, M. *J. Am. Chem. Soc.* **1984**, *106*, 5384.
(29) Keru, J. M.; Federlin, P. *Tetrahedron Lett.* **1977**, 837.
(30) Drummond, A. Y.; Waters, W. A. *J. Chem. Soc.* **1954**, 2457.

Scheme II



trimer (**9**) were observed. These products can be interpreted as arising from a contemporary C–C dimerization of radical **27a** or **28a** (R = CH_3, R′ = R″ = Et) and disproportionation to methylenemalonate **29** and starting **1a**. Addition of **27** (or **28**) radicals to the last compound affords radical **30**, which reacts by hydrogen abstraction from **1a** to give compound **7** or by cross dimerization with radical **27** (or **28**) to afford the trimer **9** (Scheme II).

Tertiary alkyl radicals having hydrogen on the carbon β to the radical center are known to afford a relatively high disproportionation to dimerization ratio.[31] Blank experiments carried out in the presence of low concentration (10^{-3} M) of **29** support further the hypothesis of disproportionation as a source of **7** and **9** because these compounds were found to increase with the symmetric dimer **6**, other higher oligomers being also detected.

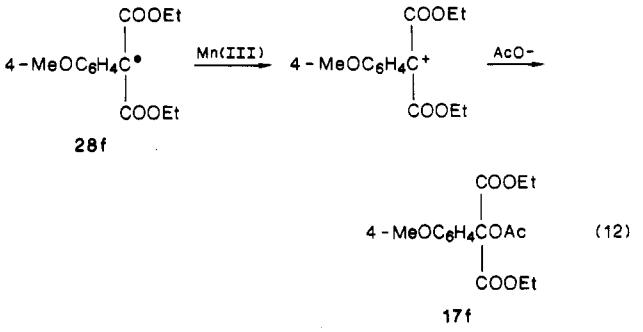
In the oxidation of diethyl α-phenylmalonate (**1e**) the oligomers **16** are formed by benzylic-C-para-C coupling of the corresponding α-phenylmalonyl radicals in analogy to other tertiary benzylic radicals having unsubstituted para positions.[13,32]

Products of two-electron oxidation of dialkyl malonates (α-acetoxy- or α-hydroxymalonates) were observed generally in the reaction under study, but their yield was quite dependent on the presence of oxygen, the substituent in the α-position of the malonate, and the reactivity of the aromatic substrate toward substitution.

α-Hydroxymalonates were found to be mainly formed in the presence of oxygen; this is a further indication of the involvement of malonyl radicals, which readily react with oxygen, preventing both the dimerization/disproportionation or substitution process. The α-acetoxymalonates were observed in progressively high yield when compounds **1** had electron-donating α-substituents (Table II), or in the presence of aromatics having high IP. These facts and the competition found between α-acetoxymalonates and dimerization or aromatic substitution products suggest that they arise from oxidation of radicals **27** (or **28**) by Mn(III) and not from a two-electron oxidation of a Mn(IV) specie eventually formed by disproportionation of Mn(III).[33] The process is probably a ligand transfer oxidation of malonyl radicals by mononuclear manganese(III) acetate or a trinuclear oxo complex.[34] However, the selectivity for this type of oxidation observed with diethyl (4-methoxyphenyl)malonate (**1f**), (Table II, entry 7) compared with the corresponding phenyl derivative **1e** (Table II, entry 6), indicates a significant contribution of benzylic cation stabilized by strongly electron releasing groups (i.e., methoxy).

(31) Landolt-Börnstein. *Radical Reactions Rates in Liquids*; (Fisher, H., Ed; Springer-Verlag: Berlin, 1984; Vol. 13, Subvol. a, pp 21–41.
(32) Neuman, W. P.; Stapel, R. In *Substituent Effects in Radical Chemistry*; Viehe, H. G., Ed.; NATO ASI Series 189; Reidel: 1986; p 219.
(33) Anderson, J. M.; Kochi, J. K. *J. Am. Chem. Soc.* **1970**, *92*, 2450.
(34) Hessel, L. W.; Romers, C. *Recl. Trav. Chim.* **1969**, *88*, 545.

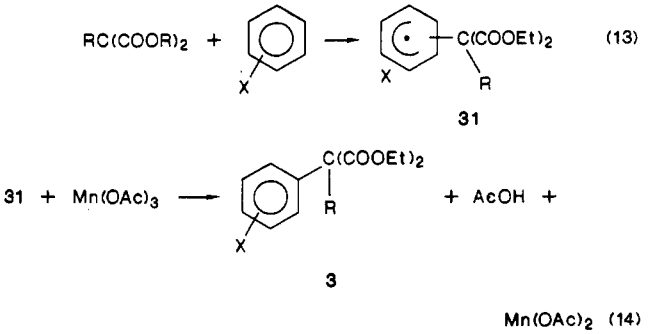
In spite of conjugation with alkoxycarbonyl substituents, carbenium ions substituted with π-electron-withdrawing groups are stable species[35] that can be isolated in low nucleophilic media. Therefore the electron-transfer oxidation of eq 12 cannot be fully excluded. This observation



is particulary important for understanding the high yield of products **17** observed in the reaction of dialkylmalonates in the presence of alkoxy-substituted aromatics. With this substrate, in fact, the preference in the aromatic malonylation reaction for ortho and para positions to methoxy group affords products that are structurally prone to further selective oxidation to **17**. On the other hand, the oxidation rates of α-arylmalonates were found to vary significantly for ortho- and para-substituted derivatives and in general to be higher (8–15 times faster) than that of the starting malonate. Therefore, great care must be taken to deduce selectivity of aromatic substitution from distribution of primary product, if further reactivity of these last is unknown.

The yields of substitution were moderate based on the Mn(III) and malonic derivatives but high on the converted aromatic when reactions are carried out in the presence of sodium acetate. The possibility, however, of using strictly stoichiometric amounts of reagents makes this process synthetically attractive.

For a specific aromatic substrate the yields of substitution were found to decrease with an increase in the bulkness and electron-releasing properties of substituent on the α-position of the malonate derivative (Table II). This result is attributed both to the increase of the oxidation rate of the malonyl radical intermediate and to the reversibility of the addition step to the aromatic (eq 13).



However, for a specific malonate derivative the yield of aromatic substitution decreases with increasing redox potential of the aromatic and becomes practically negligible with benzene.

A recent MO study[36] indicates that the carbon radical of malonic acid is more stable in the π than in the σ configuration and the SOMO coefficient is higher for the

(35) Gassman, P. G.; Tidwell *Acc. Chem. Res.* **1983**, *16*, 279. Creary, X. *Acc. Chem. Res.* **1985**, *18*, 3.
(36) Bernardi, F. Unpublished results.

central carbon atom, suggesting significant electrophilic behavior for this specie, and also for the corresponding diethyl ester.[29] The final product of substitution was dependent on the stability of the primary substitution products toward the oxidant; products[3] having hydrogens or carboxylic groups in the benzylic position were prone to further oxidation. The first ones afford compounds **17** when alkoxy substituents were present on aromatics, whereas dimers or a complex mixture of oligomers were observed with unsubstituted or halo-substituted aromatics.

Diethyl esters were generally preferred in this study because the methyl derivatives were found to give a more complicated reaction mixture. For instance, oxidation of dimethyl malonate in the presence of **2a** afforded besides compound **17** compounds **18** and **19**, formally the product of oxidative demethylation of the primary product **3**.

Malonic hemiesters and malonic acids were found to react mainly at the carbon atoms, in spite of tendency of carboxylic acid to suffer oxidative decarboxylation by manganese(III) acetate.[33] This conclusion is based on the observation that compound **22** (α-arylmalonic hemiester) were in fact isolated, although in low yield, in spite of their high reactivity toward thermal decarboxylation to α-arylacetic ester **23**. Moreover, the positional selectivity is high and very close to that observed with malonic esters, and a previous study of oxidation products of malonic acid by manganese(III) pyrophosphate in water support the involvement of oxidant carbon radicals.[30] Compounds **21** and/or **23** were the major products with malonic hemiesters (Table IV), the first prevailing in the reaction with 1-methoxynaphthalene and the latter in the reaction with 2-methoxynaphthalene. Probably a steric effect plays a role in favoring thermal over oxidative decarboxylation with the 2-methoxy derivative. Compound **21** was found to be stable to further oxidation by Mn(III) as were other arylacetic esters (i.e., ethyl 4-methoxyphenylacetate). Sequential oxidative decarboxilation could explain the presence of 2-methoxynaphthoic acid observed in the reaction between malonic acid and 2-methoxynaphthalene. Concerning the positional selectivity of the aromatic malonylation, it was, generally, high and close to electrophilic aromatic substitutions. The reactivity ratio for the α and β positions of naphthalene was 9 with diethyl methylmalonate, 1-methoxynaphthalene was found to react practically exclusively at position 4, and 2-methoxynaphthalene at position 1 with malonic acid and with its mono- or diethyl esters. The substition on anisole with **1a** or **1b** occurs at ortho and para positions, whereas with 1,2-dimethoxybenzene position 4 was preferentially involved.

Exceptions to this behavior are the results of diethyl methylmalonate reactivities with phenanthrene and 2-methoxynaphthalene, where all five possible isomers were detected with the former substrate and 1 and 8 isomers with the latter. In these cases, however, the products of addition at the position of highest electron density are particularly strained and the strength of the new C–C bond formed must therefore be low,[37] making possible reversibility phenomena and addition to a position with less steric demand.

The peculiarity of reactions with diethyl methylmalonate can also be seen in the increase of positional selectivity observed with 2-methoxynaphthalene (Figure 2) and anisole (Experimental Section) with increasing sodium acetate concentration. If we suppose that no different intermediates are involved in the substitution process, the only possible discriminating step must be the further oxidation of the radical adduct **31** by Mn(III) (eq 14). The decrease of the redox potential of Mn(III) in the presence of acetate ion can differentiate the radical adducts in favor of the more reducing ones (1 adduct with **1a** and para adduct with anisole). Similar modification of selectivity of homolytic aromatic substitution from the oxidant properties of the medium is known for other radicals[38] and similarly interpreted. However, this interpretation needs to take into account the reversibility of the addition step (eq 13), which is also supported by the coexistence of substitution and dimerization products and by the several evidences reported in the addition to olefins.[39]

The reversibility could also explain the impossibility of observing the aromatic malonylation with malonyl radicals, generated by thermal decomposition of peresters or diacyl peroxides, in the presence of malonic acid derivatives. These sources are in fact not efficient oxidants for cyclohexadienyl radicals and suffer also several problems in the selective generation of malonyl radicals in the presence of aromatics. In any case these results are surprising in view of the large use made by peroxides in addition processes of carbonyl compounds to olefins.[39] In these cases, however, radical chain processes and not stoichiometric redox processes were involved.

The importance of the presence of metals in high oxidation state for the aromatic substition is apparent from experiments of the thermal decomposition of bis(4-*tert*-butylcyclohexyl) percarbonate in the presence of manganese(II) acetate where the substitution of **2a** was observed albeit in low yield. Mn(III) could modify, by complexation, the electrophilic properties of malonyl radicals; however, the involvement of free or complexed radicals in these reaction is again not defined.

On the basis of competitive experiments between **2a** and styrene (Figure 3), the aromatic substitution process by diethylmethylmalonyl radicals appears to be fast, but an absolute rate cannot be deduced owing to the lack of reference data for malonyl radical reactivity. In any case some aromatic substrates appear to be as reactive as olefin toward malonyl radical and this could be the starting point for an extension to the aromatic series of the wide synthetic examples described with olefin.[7]

Experimental Section

General Methods. Melting points were taken on a Hoover capillary melting point apparatus and are uncorrected. Boiling points refer to a short path distillation apparatus (Büchi). IR spectra were recorded on a Perkin-Elmer Model 140 spectrophotometer. ^{1}H NMR spectra were obtained in deuteriochloroform on either a Brücker WH 90 or a AM 300 spectrometer; all data are reported in ppm relative to TMS. Mass spectra were recorded on a Varian Mat 112F spectrometer. GC analyses were performed on Carlo Erba 4130 and Dani 6500 gas chromatographs using (1) a silica fused capillary column 25 m × 0.22 m id) coated with Carbowax 20 M (CB), film thickness 1 μm; (2) a glass column (10 m × 0.22 mm i.d.) coated with SP 2100 (CB), film tickness 0.5 μm; or (3) a silica fused capillary column (30 m × 0.22 mm i.d.) coated with SE-30 (CB), film thickness 1 μm. Peak areas were obtained by using a Spectra Physics SP 4200 computing integrator. Silica gel 60 (230–400 mesh) (Merck) was used for flash chromatography.[40] HPLC analyses were performed on a Brücker LC 21-51 instrument equipped with an autosample injection port under isocratic conditions (20 cm × 0.25 cm silica

(37) Birkhofer, H.; Beckaus, H. D.; Rüchardt, C. In *Substituent Effects in* Radical Chemistry; Viehe, H. G., Ed.; NATO ASI series 189; Reidel: 1986; p 189.

(38) (a) Steenken, S.; Raghavan, N. V. *J. Phys. Chem.* **1979**, *24*, 3101. (b) Citterio, A.; Minisci, F.; Franchi, V. *J. Org. Chem.* **1980**, *45*, 4752.

(39) Julia, M. *Pure Appl. Chem.* **1974**, *41*, 553. Julia, M.; Maumy, M. *Bull. Soc. Chim. Fr.* **1969**, 2415, 2427. Vogel, H. H. *Synthesis* **1970**, 99.

(40) Still, W. C.; Kahn, M.; Mitra, A. J. *J. Org. Chem.* **1978**, *43*, 2923.

60 column, 5 μm, Merck, flow rate 1 mL/min, UV detection at 254 and 290 nm).

All reactions were run under an argon atmosphere.

Materials. Manganese(III) acetate dihydrate was used after checking the purity by iodometric titration.[41] Anhydrous manganese(III) acetate was prepared from manganese(II) nitrate and acetic anhydride.[42] Acetic acid, anhydrous sodium acetate, malonic acid, diethyl and dimethyl malonate, diethyl methylmalonate, diethyl phenylmalonate, benzene, methoxybenzene, 1,2- and 1,4-dimethoxybenzene, 1- and 2-methoxynaphthalene, anthracene, and phenanthrene were reagent grade (Carlo Erba or Fluka) and were used as received.

Methylmalonic acid monoethyl ester and malonic acid monoethyl ester were obtained as described.[43]

The following diethyl arylmalonates were prepared from the corresponding arylacetic or propionic acids by known procedures:[43] methylphenyl (bp 165 °C/20 mmHg), 2-methoxyphenyl (bp 131–2 °C/0.2 mmHg), methyl-2-methoxyphenyl (bp 142–3 °C/1.5 mmHg), 3-methoxyphenyl (bp 138–40 °C/0.2 mmHg), methyl-3-methoxyphenyl (bp 145–7 °C/0.2 mmHg), 4-methoxyphenyl (bp 160–1 °C/2 mmHg), methyl-4-methoxyphenyl (bp 144–6 °C/0.2 mmHg), 1-naphthyl (mp 62 °C), 2-naphthyl (mp 100 °C), methyl-1-naphthyl (bp 159/60 °C/0.1 mmHg), methyl-2-naphthyl (165–6 °C/2 mmHg).

Some compounds were isolated from the reaction mixture and compared with authentic samples: 1-acetoxy-4-methoxynaphthalene (mp 50–1 °C), 1-acetoxy-4-methoxynaphthalene (mp 69–70 °C), 2-methoxy-1,4-naphthoquinone (mp 181–2 °C), 9-acetoxyanthracene (mp 129–30 °C), 9,10-anthraquinone (mp 284–5 °C), ethyl phenyl glyoxylate (bp 138–9 °C/18 mmHg), diethyl 2-oxomalonate (bp 208–10 °C), diethyl tartronate (bp 121 °C/15 mmHg), diethyl 1-acetoxy-1-methylmalonate (bp 102–4 °C/1 mmHg), 2-methoxy-1-naphthoic acid (mp 177–8 °C lit.[44] mp 178–9 °C).

General Procedure for Manganese(III) Acetate Reactions. A 50-mL round-bottom flask equipped with a reflux condenser, magnetic stirrer, and an argon inlet was charged with the aromatic hydrocarbon indicated (4.3 mmol), the manganese(III) acetate (8.6 mmol), sodium acetate (if specified), the malonic acid derivative (4.3 mmol), and acetic acid (20 mL). The mixture was heated to the desired temperature (20–80 °C) for the times reported in the tables. The reaction mixture was then cooled, diluted with water (60 mL), and extracted with ether (3 × 15 mL). The combined extracts were washed with water and saturated sodium bicarbonate, dried (MgSO4), and analyzed by gas chromatography. Decane or dodecane were used as internal standard.

Alternatively, the dried extracts were concentrated in vacuo. The crude product was purified by column chromatography over silica gel with mixtures of ethyl acetate and hexane as eluent. The pure fractions (by TLC) were dried to a constant weight and their NMR, IR, and MS spectra were recorded.

Manganese(III) Acetate Oxidation of 2-Methoxynaphthalene (2a). The reaction of manganese(III) acetate, following the general procedure, but in the absence of malonic esters and sodium acetate, at 80 °C for 6 h allowed the isolation by column chromatography of 1-acetoxy-2-methoxynaphthalene (**5**) (7.3% yield) and 2-methoxy-1,4-naphthoquinone (**4**) (24% yield, 73% based on Mn(III)). Carrying out the reaction in the presence of 2.5 M sodium acetate, the two products were isolated in a similar total yield, but in ratio [**5**]:[**4**] = 0.5.

Effect of Added Sodium Acetate. Standard solutions (0.25 M) of **2a** (or **2b** or **2d**) and **1a** were made under argon. Aliquots (6.7 mL) were poured into a stirred flask and immersed in a thermostatic bath at 75 ± 1 °C, containing variable amounts of sodium acetate. After 10 min, manganese(III) acetate (0.77 g, 3.32 mmol) was added to each reaction mixture. After 4 h, the reaction was cooled and a mixture of 15% $TiCl_3$ solution (5 mL) and diethyl ether (30 mL) was added. The organic phase was removed, the water layer was extracted with ether (2 × 5 mL), and the combined organic extracts were dried and directly analyzed by capillary GC (column 1) for conversion and yield determination (Figure 2). In the case of anisole the ortho/para ratio was found to range from 1.9 to 1.2, increasing the added sodium acetate concentration from 0 to 3.9 M.

Products vs Time Study. A solution of 2-methoxynaphthalene (**2a**) (1.58 g, 10 mmol), diethyl methylmalonate (**1a**) (1.74 g, 10 mmol), and *n*-dodecane (0.615 g, 3.2 mmol, internal standard) in acetic acid (20 mL) was prepared under argon and kept in a thermostatic bath at 80 °C for 10 min. After anhydrous manganese(III) acetate (4.64 g, 20 mmol) was added at once under magnetic stirring, 0.5-mL aliquots were withdrawn directly from the reaction mixture at various times and poured into a stirred mixture of 0.47 M $TiCl_3$ solution (1 mL) and diethyl ether (2 mL). After 15 min, the excess of $TiCl_3$ was titrated against 0.1 N Ce(IV) solution to determine the content of Mn(III) in the sample. The organic phase was dried with sodium sulfate and directly analyzed by capillary GC (column 1) for conversion and yield determination. The results obtained are reported in Figure 1.

Manganese(III) Acetate Oxidation of 1a in the Presence of Styrene and 2a. A solution of **1a** (20 mmol), **2a** (20 mmol), and styrene (10–40 mmol) in acetic acid (100 mL) was thermostated at 70 °C for 5 min. After manganese(III) acetate (3 mmol) was added, the reaction was continued for 3 h. The separation procedure was carried out as above and the extracts were directly, analyzed by GC (column 2) after addition of diphenyl as internal standard. The results are plotted in Figure 3 as ratio *R* of product concentrations against the ratio of starting aromatic concentrations. In a parallel experiment, in the absence of **2a**, the addition products of **1a** to styrene (**10** and **11**, 44 and 38% yield, respectively) were similarly isolated along with minor amounts of the elimination product ($PhCH{=}CHC(Me)(COOEt)_2$, 12% yield).

Diethyl α-[1-(2-Methoxynaphthyl)]-α-methylmalonate (3a). ^1H NMR: 1.2 (t, 6 H, OCH_2Me), 1.98 (s, 3 H, *Me*), 3.87 (s, 3 H, O*Me*), 4.24 (q, 4 H, OCH_2Me), 7.28 (d, 1 H, H_3, $J(H_3–H_4)$ = 9.0 Hz), 7.30 (m, 1 H, H_7, $J(H_7–H_8)$ = 7.4 Hz, $J(H_7–H_5)$ = 1.0 Hz, $J(H_7–H_6)$ = 6.6 Hz), 7.4 (m, 1 H, H_6, $J(H_6–H_5)$ = 7.75 Hz, $J(H_6–H_8)$ = 1.5 Hz), 7.7 (d, 1 H, H_4), 7.85 (dd, 1 H, H_8). MS: *m/e* (M^+) calcd 330.1467, obsd 330.1467 ± 0.0011.

Diethyl α-[8-(2-Methoxynaphthyl)]-α-methylmalonate (3a′). ^1H NMR: 1.20 (t, 6 H, OCH_2Me), 2.10 (s, 3 H, *Me*), 3.90 (s, 3 H, O*Me*), 4.28 (q, 4 H, OCH_2Me), 7.12 (, 1 H, H_3, $J(H_1–H_3)$ = 2 Hz, $J(H_3–H_4)$ = 9 Hz), 7.14 (bs, 1 H, H_1), 7.27 (t, 1 H, H_6, $J(H_6–H_7)$ = $J(H_6H_5)$ = 7.7 Hz), 7.36 (dd, 1 H, H_7, $J(H_7–H_6)$ = 7.7 Hz, $J(H_7–H_5)$ = 1.4 Hz), 7.71 (b, dd, 1 H, H_5), 7.73 (b, dd, 1 H, H_4, J(H4–H3) = 9 Hz, J(H4–H5) = 1.6 Hz). MS: *m/e* (relative intensity) 330 ($M^{\bullet+}$, 85), 257 (71), 229 (22), 212 (11), 211 (15), 183 (100), 168 (2), 153 (11), 43 (30).

Diethyl α-[1-(4-Methoxynaphthyl)]-α-methylmalonate (3b). ^1H NMR: 1.20 (t, 6 H, OCH_2Me), 1.98 (s, 3 H, *Me*), 3.70 (s, 3 H, O*Me*), 4.0 (q, 4 H, CH_2Me), 6.35 (d, 1 H, H_3), 6.94 (d, 1 H, H_2), 7.00–7.20 (m, 2 H, $H_{6,7}$), 7.47 (dd, 1 H, H_8), 7.98 (dd, 1 H, H_5). MS: *m/e* (relative intensity) 330 ($M^{\bullet+}$, 39), 257 (90), 229 (12), 183 (100), 141 (28), 115 (30), 43 (32).

Diethyl α-[1-(4-Methoxynaphthyl)]-α-ethylmalonate (3bb): mp 123–4 °C. ^1H NMR: 0.75 (t, 3 H, CH_2Me), 1.2 (t, 6 H, OCH_2Me) 2.6 (q, 2 H, CH_2Me), 3.8 (s, 3 H, O*Me*), 4.0–4.5 (m, 4 H, OCH_2Me), 7.2–7.6 (m, 4 H, Ar), 7.7–7.9 (m, 2 H, Ar). MS: *m/e* (relative intensity) 344 ($M^{\bullet+}$, 54), 271 (5), 225 (30), 211 (8), 197 (100), 183 (16), 182 (18), 141 (12), 57 (18).

Diethyl α-[1-(4-Methoxynaphthyl)]-α-butylmalonate (3cb). ^1H NMR: 0.85 (t, 3 H, $(CH_2)_3Me$), 1.15 (t, 6 H, OCH_2Me), 1.20–1.40 (m, 4 H, CH_2CH_2Me), 2.49 (m, 2 H, CH_2Pr), 4.0 (s, 3 H, O*Me*), 4.16 (q, 4 H, OCH_2Me), 6.76 (d, 1 H, H_3, $J(H_3–H_2)$ = 8.3 Hz), 7.38 (d, 1 H, H_2), 7.44 (m, 2 H, $H_{6,7}$, AA′BB′ pattern), 7.88 (m, 1 H, H_5 or H_8, AA′BB′ pattern), 8.32 (m, 1 H, H_8 or H_5, AA′BB′ pattern). MS: *m/e* (relative intensity) 372 ($M^{\bullet+}$, 82), 327 (1), 315 (8), 299 (51), 243 (36), 225 (100).

Diethyl α-[1-Naphthyl]-α-acetoxymalonate (17hc). ^1H NMR: 1.20 (t, 6 H, OCH_2Me), 2.20 (s, 3 H, $OCOCH_3$), 3.90 (m, 4 H, OCH_2), 7.2–7.8 (m, 6 H, Ar). MS: *m/e* (relative intensity) 344 ($M^{\bullet+}$, 17), 271 (2), 229 (42), 155 (100), 127 (18), 43 (45).

Diethyl α-[1-(2-Methoxynaphthyl)]-α-acetoxymalonate (17ha). ^1H NMR: 1.24 (t, 6 H, OCH_2Me), 2.15 (s, 3 H, $OCOCH_3$), 3.88 (s, 3 H, O*Me*), 4.15–4.40 (m, 4 H, OCH_2Me), 7.25 (d, 1 H,

(41) Heiba, E. I.; Dessau, R. M.; Williams, A. L.; Rodewald, P. G. *Org. Synth.* **1983**, *61*, 22.

(42) Lux, H. In *Handbook of Preparative Inorganic Chemistry*; Brauer, G., Ed.; Academic Press: New York, 1965; p 1470.

(43) (a) Philip, A.; Carrol, F. I. *Org. Prep. Proc. Int.* **1975**, *7*, 117; (b) *J. am. Chem. Soc.* **1941**, *63*, 2056.

(44) Oommen, P. K. *Aust. J. Chem.* **1975**, *28*, 2095.

H_3, $J(H_3-H_4)$ = 8.4 Hz), 7.37 (m, 1 H, H_6, $J(H_6-H_7)$ = 7.6 Hz, $J(H_6-H_5)$ = 6.8 Hz, $J(H_6-H_8)$ = 1.1 Hz), 7.46 (m, 1 H, H_7, $J(H_7-H_5)$ = 1.5 Hz, $J(H_7-H_8)$ = 6.1 Hz), 7.79 (dd, 1 H, H_5), 7.88 (d, 1 H, H_4), 8.1 (dd, 1 H, H_8). MS: *m/e* (relative intensity) 374 ($M^{\bullet+}$, 7), 259 (24), 185 (100), 159 (5), 142 (6), 127 (7), 43 (50).

Dimethyl α-[1-(2-methoxynaphthyl)]-α-acetoxymalonate (17ia): mp 197–8 °C. ^{1}H NMR: 2.20 (s, 3 H, OCO*CH*$_3$), 3.82 (s, 6 H, COO*Me*), 3.91 (s, 3 H, O*Me*), 7.25 (d, 1 H, H_3), 7.2–7.5 (m, 2 H, $H_{6,7}$), 7.78 (dd, 1 H, H_5), 7.84 (d, 1 H, H_4), 8.1 (dd 1 H, H_8). MS: *m/e* (M^+) calcd 346.1052, obsd 346.1059 ± 0.0018.

Diethyl α-[1-(4-Methoxynaphthyl)]-α-acetoxymalonate (17hb). ^{1}H NMR: 1.07 (t, 6 H, OCH$_2$*Me*), 2.02 (s, 3 H, OCO*CH*$_3$), 3.60 (s, 3 H, O*Me*), 3.71–4.16 (m, 4 H, O*CH*$_2$Me), 6.48 (d, 1 H, H_3), 6.55 (dd, 1 H, H_2), 6.70–6.80 (m, 2 H, $H_{6,7}$), 7.28–7.55 (m, 2 H, $H_{5,8}$). MS: *m/e* (relative intensity) 374 ($M^{\bullet+}$, 28), 314 (3), 285 (8), 259 (66), 185 (100), 157 (7), 127 (4), 43 (28).

3-(Methoxycarbonyl)-3-acetoxy-2(3*H*)-naphtho[4,5-*b*]-furanone (18): mp 153–4 °C. ^{1}H NMR: 2.19 (s, 3 H, OCO*CH*$_3$), 3.77 (s, 3 H, COO*Me*), 7.4 (d, 1 H, H_3, $J(H_3-H_4)$ = 9.0 Hz), 7.47 (m, 1 H, H_6, $J(H_6-H_7)$ = 8.3 Hz, $J(H_6-H_5)$ = 6.9 Hz, $J(H_6-H_8)$ = 1.04 Hz), 7.59 (m, 1 H, H_7, $J(H_7-H_8)$ = 7.0 Hz), 7.91 (m, 2 H, H_5 + H_8), 7.98 (d, 1 H, H_4). MS: *m/e* (relative intensity) 300 ($M^{\bullet+}$, 21), 258 (1), 256 (1), 241 (2), 214 (20), 199 (83), 71 (28), 59 (3), 43 (100). IR: (max, cm^{-1}, Nujol) 1810, 1750, 1730.

1-[Bis(methoxycarbonyl)methylene]-1,2-naphthoquinone (19): mp 93–4 °C. ^{1}H NMR: 3.90 (s, 3 H, COO*Me*), 3.97 (s, 3 H, COO*Me*), 6.26 (d, 1 H, H_3, $J(H_3-H_4)$ = 7.5 Hz), 7.4 (d, 1 H, H_4), 7.2–7.6 (m, 4 H, Ar). MS: *m/e* (relative intensity) 272 ($M^{\bullet+}$, 58), 241 (27), 229 (14), 213 (100), 185 (12), 170 (10), 154 (11), 145 (17), 126 (30), 115 (10), 114 (13).

Diethyl α-[1-(3,4-Dimethoxyphenyl)]-α-acetoxymalonate (17hg). ^{1}H NMR: 1.24 (t, 6 H, OCH$_2$*Me*), 2.29 (s, 3 H, OCO*Me*), 3.88 (s, 3 H, O*Me*), 3.90 (s, 3 H, O*Me*), 4.25 (q, 4 H, O*CH*$_2$Me), 6.84 (d, 1 H, H_6), 7.05–7.26 (m, 2 H, $H_{2,5}$). MS: *m/e* (relative intensity) 354 ($M^{\bullet+}$, 29), 239 (74), 165 (100), 43 (11).

Diethyl α-[1-(2-Methoxyphenyl)]-α-acetoxymalonate (17hf). ^{1}H NMR: 1.18 (t, 6 H, OCH$_2$*Me*), 2.18 (s, 3 H, OCO*Me*), 3.7 (s, 3 H, O*Me*), 4.1 (q, 4 H, O*CH*$_2$Me), 6.7 (d, 2 H, $H_{2,6}$), 7.3 (d, 2 H, $H_{3,5}$). MS: *m/e* (relative intensity) 324 ($M^{\bullet+}$, 31), 282 (5), 209 (100), 135 (100), 118 (14), 57 (19), 43 (25).

Diethyl α-[1-(2-Methoxyphenyl)-α-methylmalonate (3af). ^{1}H NMR: 1.25 (t, 6 H, OCH$_2$*Me*), 1.82 (s, 3 H, *Me*), 3.77 (s, 3 H, O*Me*), 4.23 (m, 4 H, O*CH*$_2$Me), 6.87–6.96 (m, 2 H), 7.10 (dd, 1 H), 7.27 (dt, 1 H). MS: *m/e* (relative intensity) 280 (M, 53), 234 (3), 208 (13), 207 (48), 162 (47), 161 (100), 133 (78), 119 (10), 105 (26), 91 (11), 59 (17).

Diethyl α-[1-(2,5-Dimethoxyphenyl)]-α-methylmalonate (3ah). ^{1}H NMR: 1.20 (t, 6 H, OCH$_2$*Me*), 1.88 (s, 3 H, *Me*), 3.91 (s, 6 H, O*Me*), 4.24 (m, 4 H, O*CH*$_2$Me), 6.85–7.05 (m, 3 H, Ar). MS: *m/e* (relative intensity) 310 ($M^{\bullet+}$, 66), 237 (22), 191 (59), 177 (44), 163 (100), 149 (10), 135 (20), 59 (70).

Diethyl α-[1-(3,4-Dimethoxyphenyl)]-α-methylmalonate (3aq). ^{1}H NMR 1.30 (t, 6 H, OCH$_2$*Me*), 1.86 (s, 3 H, *Me*), 3.90 (s, 6 H, O*Me*), 4.20 (q, 4 H, O*CH*$_2$Me), 6.8–7.0 (m, 3 H, Ar). MS: *m/e* (relative intensity) 310 ($M^{\bullet+}$, 41), 237 (20), 203 (11), 191 (40), 177 (20), 163 (100), 149 (26), 135 (11), 59 (50), 43 (30).

Ethyl 2-(2-Methoxy-1-naphthyl)propionate (21ga). ^{1}H NMR: 2.10 (t, 3 H, OCH$_2$*Me*), 2.52 (d, 3 H, *Me*), 3.88 (s, 3 H, O*Me*), 4.12 (q, 2 H, O*CH*$_2$Me), 4.50 (q, 1 H, CH$_3$*CH*), 7.14–7.58 (m, 3 H, Ar), 7.68–7.96 (m, 3 H, Ar). MS: *m/e* (relative intensity) 258 ($M^{\bullet+}$, 26), 185 (100), 170 (13).

Ethyl 2-Acetoxy-2-(4-methoxy-1-naphthyl)propionate (23gb). ^{1}H NMR: 1.15 (t, 3 H, OCH$_2$*Me*), 2.12 (s, 3 H, *Me*), 2.24 (s, 3 H, OCO*Me*) 3.98 (s, 3 H, O*Me*), 4.20 (q, 2 H, O*CH*$_2$Me), 6.75 (d, 1 H, Ar), 7.40–7.62 (m, 3 H, Ar), 8.24–8.42 (m, 2 H, Ar). MS: *m/e* (relative intensity) 316 ($M^{\bullet+}$, 5), 256 (21), 227 (12), 201 (72), 183 (96), 168 (30), 139 (22), 43 (100).

The addition products of diethyl methylmalonate to phenantrene (approximate yield 10%) were characterized only by GC-MS. Five isomers in relative ratios 42:7.7:1.0:33:6.7 were detected. They present the following MS spectra: (a) *m/e* (relative intensity) 350 ($M^{\bullet+}$, 90), 277 (79), 249 (87), 232 (23), 204 (100), 57 (14), 43 (81); (b) *m/e* (relative intensity) 350 ($M^{\bullet+}$, 69), 277 (45), 249 (36), 232 (23), 203 (91), 57 (9), 43 (100); (c) *m/e* (relative intensity) 350 ($M^{\bullet+}$, 52), 277 (54), 249 (16), 203 (78), 57 (6), 43 (100); (d) *m/e* (relative intensity) 350 ($M^{\bullet+}$, 63), 277 (63), 249 (15), 203 (100), 91 (6), 71 (9), 57 (30), 43 (96); (e) *m/e* (relative intensity) 350 ($M^{\bullet+}$, 36), 277 (80), 249 (85), 203 (60), 57 (16), 43 (100).

Diethyl 2,3-Dimethyl-2,3-dicarbethoxy-1,4-succinate (6). ^{1}H NMR: 1.31 (t, 12 H, OCH$_2$*Me*), 1.79 (s, 6 H, *CH*$_3$), 4.27 (q, 8 H, O*CH*$_2$Me). MS: *m/e* (relative intensity) $M^{\bullet+}$ absent, 301 (M – OEt$^{\bullet+}$, 26), 273 (2), 229 (16), 227 (15), 199 (14), 174 (50), 155 (100), 127 (85), 99 (18).

Diethyl 2-Methyl-2,4-dicarbethoxyglutarate (7). ^{1}H NMR: 1.28 (t, 12 H, OCH$_2$*Me*), 1.3 (t, 3 H, *Me*), 2.55 (d, 2 H, *CH*$_2$CH), 3.52 (t, 1 H, *CH*CH$_2$), 4.19 (q, 4 H, O*CH*$_2$Me), 4.20 (q, 4 H, O*CH*$_2$Me). MS: *m/e* (relative intensity) $M^{\bullet+}$ absent, 301 (M – OEt$^{\bullet+}$, 32), 255 (30), 200 (16), 174 (100), 173 (81), 160 (44), 127 (90), 99 (28), 73 (7), 55 (30), 45 (18).

1,1,2,2-Tetracarbethoxy-1,2-diphenylethane (15). ^{1}H NMR: 1.25 (m, 12 H, OCH$_2$*Me*), 4.3 (m, 8 H, O*CH*$_2$Me), 6.93 (d, 4 H, H ortho), 7.08 (t, 4 H, H meta), 7.21 (t, 2 H, H para). MS: *m/e* (relative intensity) $M^{\bullet+}$ absent, 235 (90), 161 (20), 105 (100), 77 (35), 57 (30), 40 (85).

Registry No. **1a**, 609-08-5; **1b**, 133-13-1; **1c**, 133-08-4; **1d**, 759-36-4; **1e**, 83-13-6; **1f**, 23197-67-3; **1g**, 1071-46-1; **1h**, 105-53-3; **1i**, 108-59-8; **1j**, 2985-33-3; **1k**, 141-82-2; **2a**, 93-04-9; **2b**, 2216-69-5; **2c**, 91-20-3; **2d**, 85-01-8; **2e**, 120-12-7; **2f**, 100-66-3; **2g**, 91-16-7; **2h**, 150-78-7; **2i**, 71-43-2; **3a**, 118647-58-8; **3a′**, 118647-59-9; **3af**, 118657-12-8; **3ag**, 118657-13-9; **3ah**, 83026-47-5; **3b**, 118647-72-6; **3bb**, 118657-04-8; **3cb**, 118657-05-9; **6**, 49846-73-3; **7**, 17696-77-4; **15**, 117720-83-9; **17ha**, 118647-61-3; **17hb**, 118657-08-2; 17hc, 118657-06-0; **17hf**, 117720-82-8; **17hg**, 118657-11-7; **17ia**, 118657-07-1; **18**, 118657-09-3; **19**, 118657-10-6; **21ga**, 1875-53-2; **23gb**, 118657-14-0.

Supplementary Material Available: Figure 4 depicting the dependence of added sodium acetate on **2b** and **5b** formation in Mn(III) acetate oxidation of **1a** in the presence of **2b** and Table V listing the affect of variables on the ortho/para ratio in the reaction of anisole and **1a** (2 pages). Ordering information is given on any current masthead page.