

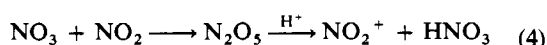
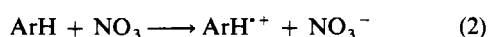
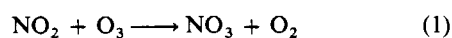
## Nitration of Nonactivated Arenes with a Ternary System NO–NO<sub>2</sub>–O<sub>2</sub>. Mechanistic Implications of the Kyodai-nitration

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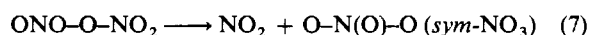
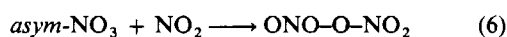
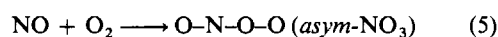
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The ternary mixture NO–NO<sub>2</sub>–O<sub>2</sub> has been found to be more effective than the binary mixture NO<sub>2</sub>–O<sub>2</sub> as a nitrating agent for nonactivated arenes, such as toluene and chlorobenzene; the results may be rationalized in terms of an initial electron transfer mechanism in which nitrogen trioxide, formed from nitrogen monoxide and dioxygen, oxidizes the arene to its radical cation.

Many aromatic compounds that display a wide range of reactivity, can be smoothly nitrated with nitrogen dioxide in the presence of ozone at room temperature or below, to give the corresponding nitro derivatives in high yields (kyodai-nitration).<sup>1</sup> For this novel type of aromatic nitration, we have recently proposed a mechanism in which the reaction proceeds in a dual mode, depending on the oxidation potential of aromatic substrate;<sup>2</sup> nitrogen dioxide can react with ozone to give nitrogen trioxide [eqn. (1)]<sup>3</sup> that then oxidizes the aromatic substrate (ArH) to form a radical cation (ArH<sup>•+</sup>) [eqn. (2)], which is an intermediate in the ring substitution [eqn. (3)]. In the absence of an appropriate oxidizable substrate, the nitrogen trioxide is trapped by another molecule of nitrogen dioxide to form dinitrogen pentaoxide, which itself is a powerful nitrating agent in the presence of an acid catalyst [eqn. (4)].



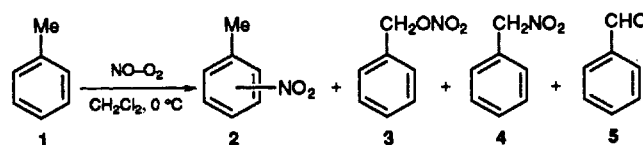
If we assume that nitrogen trioxide is the initial electrophile for the kyodai-nitration, then the reaction of both nonactivated and weakly deactivated aromatic compounds with the ternary mixture of NO–NO<sub>2</sub>–O<sub>2</sub> would be of special interest, since the gas phase oxidation of nitrogen monoxide to dioxide is known to involve two isomeric, unstable intermediates, the asymmetric (O–N–O–O) and the symmetric [O–N(O)–O] nitrogen trioxides [eqns. (5)–(7)].<sup>4a</sup>



Nonactivated and weakly deactivated arenes are inert towards nitrogen monoxide, but they slowly react with nitrogen dioxide under ambient conditions. Therefore, the observation that the ternary mixture of the nitrogen mono- and di-oxides with dioxygen is more effective for nitrating aromatic substrate than the binary mixture of nitrogen dioxide and dioxygen may endorse a possible role of nitrogen trioxide as the initial electrophile in the kyodai-nitration. This communication presents the results of the ternary kyodai-nitration.<sup>5</sup>

The typical experimental procedure is as follows. A solution of toluene **1** (20 mmol dm<sup>-3</sup>) in dry dichloromethane (50 cm<sup>3</sup>) was stirred vigorously at 0 °C while nitrogen monoxide (5 cm<sup>3</sup> min<sup>-1</sup>) and dioxygen (100 cm<sup>3</sup> min<sup>-1</sup>) were introduced as fine bubbles from a glass ball filter (Kinoshita, No. 2). The reaction mixture immediately turned yellow by the *in situ* generated nitrogen dioxide. The progress of the reaction was monitored by GLC. Since the escaping gas removed the volatile solvent, it was necessary to supply fresh portions of dichloromethane intermittently in order to keep the volume of the reaction mixture fairly constant, especially when the reaction was performed over a prolonged time. After 3–5 h, the reaction was quenched by the addition of water and the mixture was extracted with dichloromethane (2 × 10 cm<sup>3</sup>). The combined extracts were evaporated under reduced pressure to leave a product mixture as an oily residue. The results are summarized in Tables 1 and 2.

Toluene **1** was inert towards nitrogen monoxide alone, but in the presence of dioxygen it slowly underwent both ring nitration and side-chain oxidation, giving a mixture of the nitrotoluenes **2**, benzyl nitrate **3**, phenylnitromethane **4** and benzaldehyde **5** (Scheme 1). Upon admixture with insufficient dioxygen,



Scheme 1

nitrogen monoxide was rapidly converted into an equilibrium mixture of the nitrogen mono- and di-oxides and the dinitrogen tri- and tetra-oxides. This mixture was found to show a weak nitrating ability towards toluene, the preferred reaction mode being the oxidation of the alkyl side-chain. However, when this gaseous mixture was passed into a solution of toluene in dichloromethane containing an excess of nitrogen dioxide at 0 °C, the reaction was appreciably enhanced and the relative yield of the nitrotoluenes increased remarkably at the expense of side-chain oxidation products. The reaction of toluene with nitrogen dioxide alone in the presence of dioxygen was sluggish and the relative proportion of ring substitution products was much less as compared with that obtained from the reaction carried out in the presence of nitrogen monoxide. Thus it was apparent that nitrogen monoxide facilitates the reaction between toluene and nitrogen dioxide appreciably in the presence of dioxygen, favouring ring substitution over side-chain oxidation. As expected, the added ozone rapidly completed the reaction, the side-chain oxidation becoming negligible (Table 2).

**Table 1** Nitration of toluene **1** with nitrogen monoxide and dioxygen<sup>a</sup>

Flow rate (cm <sup>3</sup> min <sup>-1</sup> )		Conditions			Relative yield (%) <sup>b</sup>
NO	O <sub>2</sub>	Reaction time (h)	Temp. (°C)	Conversion (%) <sup>b</sup>	
2 ( <i>ortho:meta:para</i> ):3:4:5					
5	5	10	0	34	53 (64:5:31):35:9:3
5	10	10	0	58	81 (61:6:33):9:3:7
5	100	5	0	98	35 (56:12:32):42:8:15
5	100	5	-25	90	49 (54:6:40):43:2:6

<sup>a</sup> All reactions were performed using a mixture of toluene (20 mmol dm<sup>-3</sup>) and dichloromethane (50 cm<sup>3</sup>). <sup>b</sup> Determined by GLC for compounds **1** and **2** and by <sup>1</sup>H NMR for compounds **3–5**.

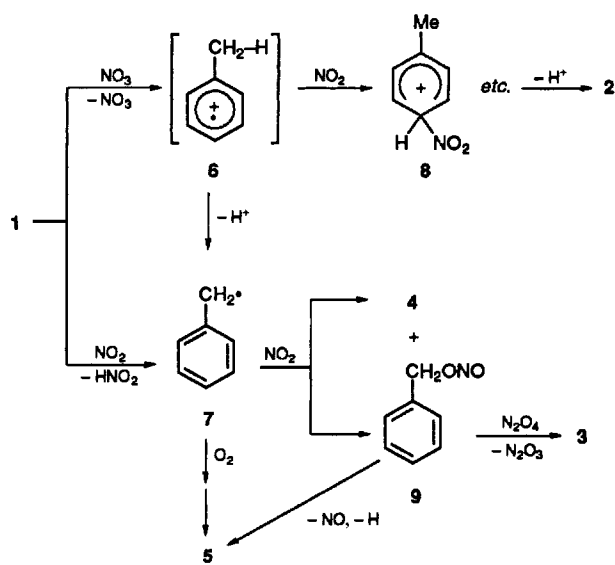
**Table 2** Nitration of toluene **1** with lower nitrogen oxides and dioxygen<sup>a</sup>

Nitrating agent <sup>b</sup>	Reaction time (h)	Product distribution (%) <sup>c</sup>	
		1:2 ( <i>ortho:meta:para</i> ):3:4:5	Conversion <sup>d</sup> (%)
NO + O <sub>2</sub>	5	2:34 (56:12:32):41:8:15	29
NO + NO <sub>2</sub> + O <sub>2</sub>	3	3:60 (62:3:35):26:8:3	81
NO <sub>2</sub> + O <sub>2</sub>	3	19:46 (63:3:34):21:6:8	53
NO <sub>2</sub> + O <sub>3</sub> + O <sub>2</sub> <sup>e</sup>	0.5	1: >95 (61:2:37): <1: <2: <2	>99 <sup>h</sup>
NO <sub>2</sub> <sup>f</sup>	72	>94: <1 (58:4:38): <1: <1:— <sup>g</sup>	<1 <sup>h</sup>
NO <sub>2</sub> + hν <sup>f</sup>	5	>90:3 (39:3:58): <1: <1:— <sup>g</sup>	2 <sup>h</sup>

<sup>a</sup> All reactions were performed using a mixture of toluene (20 mmol dm<sup>-3</sup>) and dichloromethane (50 cm<sup>3</sup>) at 0 °C, unless indicated otherwise.

<sup>b</sup> Nitrogen monoxide and dioxygen were introduced at rates of 5 and 100 cm<sup>3</sup> min<sup>-1</sup>, respectively. Before the reaction started, liquid nitrogen dioxide (1 cm<sup>3</sup>) was mixed with the solvent. <sup>c</sup> See footnote *b* in Table 1. <sup>d</sup> Conversion after 1 h, based on the substrate **1**. <sup>e</sup> Ozone was introduced at a rate of 10 mmol h<sup>-1</sup> (oxygen flow was 170 cm<sup>3</sup> min<sup>-1</sup>) into a mixture of nitrogen dioxide and dichloromethane (v:v = 1:50) containing toluene (0.10 mol dm<sup>-3</sup>). See also ref. 1(a). <sup>f</sup> From ref. 8(a). <sup>g</sup> Not reported. <sup>h</sup> Estimated from the total conversion and reaction time.

The side-chain oxidation products **3–5** were no doubt derived from the capture of the benzyl radical **7** by dioxygen and nitrogen dioxide (Scheme 2). The latter radical species is known

**Scheme 2**

to trap the benzyl radical more effectively than dioxygen.<sup>6</sup> Benzaldehyde probably arose from the decomposition of benzyl peroxide radical, but it may in part be derived from the degradation of unstable benzyl nitrite.<sup>7</sup>

Under the same conditions, the nitration of chlorobenzene with the present ternary system was quite slow and even after 10 h, most of the substrate (>90%) was recovered intact. However, the chloronitrobenzenes obtained in low yield (ca. 6%) showed an unusually high content of the *meta* isomer

(*ortho:meta:para*, 22:67:11). This observation was in accordance with our recent finding,<sup>2a</sup> where the unusual isomer composition was explained by assuming the one-electron oxidation of the arene by nitrogen trioxide, followed by the addition–elimination sequence.

The nitration of polymethylbenzenes with nitrogen dioxide has recently been suggested by Bosch and Kochi to proceed by a thermal or a photochemical charge-transfer activation of the donor–acceptor complex, such as [ArH,NO<sup>+</sup>]NO<sub>3</sub><sup>-</sup>.<sup>8</sup> They claimed that the nitration of arenes with nitrogen dioxide was retarded by the presence of nitrogen monoxide;<sup>8a</sup> however, this is contrary to our results. The reaction of nonactivated arenes with nitrogen dioxide in the presence of dioxygen is moderately facilitated by the additional presence of nitrogen monoxide, where the ring nitration is greatly favoured over the oxidation of the alkyl side-chain. A recent report by the same authors described that the reaction between toluene and nitrosonium tetrafluoroborate in acetonitrile at room temperature gave nitrotoluenes only in a low yield (3% after 24 h),<sup>9</sup> which ruled out a possible intervention of the nuclear nitrosation followed by oxidation in our case.

#### Acknowledgements

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#### References

- (a) H. Suzuki, T. Murashima, I. Kozai and T. Mori, *J. Chem. Soc., Perkin Trans. 1*, 1993, 1591; (b) H. Suzuki and T. Mori, *J. Chem. Soc., Perkin Trans. 2*, 1994, 479; (c) H. Suzuki and T. Murashima, *J. Chem. Soc., Perkin Trans. 1*, 1994, 903; (d) H. Suzuki, T. Mori and K. Maeda, *Synthesis*, 1994, 841; (e) H. Suzuki, S. Yonezawa, T. Mori and K. Maeda, *J. Chem. Soc., Perkin Trans. 1*, 1994, 1367.
- (a) H. Suzuki, T. Murashima and T. Mori, *J. Chem. Soc., Chem.*

- Commun.*, 1994, 1443; (b) H. Suzuki, A. Tatsumi, T. Ishibashi and T. Mori, *J. Chem. Soc., Perkin Trans. 1*, 1995, 339.
- 3 H. J. Schumacher, *Z. Anorg. Allg. Chem.*, 1937, **233**, 47; R. A. Graham and H. S. Johnston, *J. Phys. Chem.*, 1978, **82**, 254; D. N. Mitchell, R. P. Wayne, P. J. Allen, R. P. Harrison and R. J. Twin, *J. Chem. Soc., Faraday Trans. 2*, 1980, **76**, 785. For a review, see R. P. Wayne, I. Barnes, P. Briggs, J. P. Burrows, C. E. Canosa-Mas, J. Hjorth, G. Le Bras, C. K. Moortgat, D. Perner, G. Poulet, G. Restelli and H. Sidebottom, *Atmos. Environ.*, 1991, **25A**, 1.
- 4 (a) J. Hecklen and N. Cohen, *Adv. Photochem.*, 1968, **5**, 157; (b) F. B. Brown and R. H. Crist, *J. Chem. Phys.*, 1941, **9**, 840.
- 5 T. Mori and H. Suzuki, Presented at the 6th International Kyoto Conference on New Aspects of Organic Chemistry (IKCOC-6), 1994, Kyoto, Japan.
- 6 A. Goumri, L. Elmaimouni, J. P. Sawerysyn and P. Devolder, *J. Phys. Chem.*, 1992, **96**, 5395.
- 7 H. Suzuki, K. Nakano, T. Mishina and T. Hanafusa, *Nippon Kagaku Kaishi*, 1978, 1049; Y. Ogata, Y. Sawaki, F. Matsunaga and H. Tezuka, *Tetrahedron*, 1966, **22**, 2655. Also see P. Gray, P. Rathbone and A. Williams, *J. Chem. Soc.*, 1960, 3932.
- 8 (a) E. Bosch and J. K. Kochi, *J. Org. Chem.*, 1994, **59**, 3314; (b) also see E. K. Kim and J. K. Kochi, *J. Org. Chem.*, 1989, **54**, 1692; (c) for a review, see J. K. Kochi, *Adv. Phys. Org. Chem.*, 1994, **29**, 185.
- 9 E. Bosch and J. K. Kochi, *J. Org. Chem.*, 1994, **59**, 5573.

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