Ozone-mediated Nitration of Aromatic Ketones and Related Compounds with Nitrogen Dioxide

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Alkyl aryl ketones react smoothly with nitrogen dioxide at low temperatures in the presence of ozone to give *ortho*- and *meta*-nitro derivatives as the principal products, the former usually being predominant (*ortho*:*meta* = 1.1–3.8:1.0). No attack was observed on the alkyl side chains.

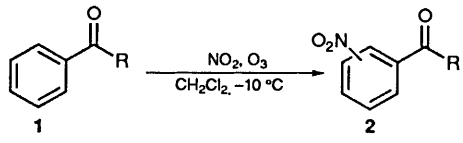
The strong deactivating effect of a carbonyl group on an aromatic ring as a result of inductive and mesomeric electron withdrawal directs an entering electrophile predominantly to the *meta* position. *ortho*-Substitution usually accompanies the reaction but *para*-substitution is insignificant. This general trend of electrophilic aromatic substitutions holds quite well for classical aromatic nitration where nitric acid alone, or in admixture with sulfuric acid, is commonly used as the nitrating agent.

In extensive studies on the nitration of aromatic carbonyl compounds, acetophenone **1a**,[1–4] propiophenone **1b**,[5–7] benzophenone **3a**[8–10] and other ketones[7,11–18] were nitrated with concentrated nitric acid at varying temperatures to give mainly *meta*-nitro derivatives (60–70%), together with a smaller proportion of *ortho*- and *para*-nitro compounds (~ 30%). In a strong protic acid medium, the oxygen atom of the carbonyl group tends to be protonated to form an oxonium species which, in turn, increases the positive charge on the carbonyl carbon atom and thus enhances its *meta*-directing power. Thus, when the ketone **1a** is nitrated with nitric acid in the presence of concentrated sulfuric acid below 0 °C, the yield of *meta*-substitution product often exceeds 80%, a proportion which increases with higher acidity.[4] The accompanying *ortho*- and *para*-nitro isomers are usually difficult to isolate from the reaction mixture in acceptable yield or in a satisfactory state of purity. Accordingly, these compounds are prepared by the indirect routes involving the acetoacetic ester synthesis,[19] malonic ester synthesis[20] or nitration of α-phenylalkyl acetates.[21]

We have recently observed that nitrogen dioxide acts as a powerful nitrating agent in the presence of ozone for aromatic systems, converting nonactivated and even deactivated arenes into the corresponding mononitro or polynitro derivatives in good to excellent yields.[22] When this novel methodology was applied to aromatic carbonyl compounds, we were surprised to observe a remarkably high proportion of *ortho*-substitution. As part of our continuing study on the ozone-mediated nitration of arenes with the lower oxides of nitrogen (kyodai nitration),† we report some new features of the nitration of aromatic ketones and related compounds.

Results and Discussion

The aromatic ketones **1a–g** when treated with nitrogen dioxide in dichloromethane in the presence of ozone (Scheme 1) underwent easy nitration on the ring to give *ortho*- and *meta*-nitro derivatives **2** in good yields (see Table 1). The reaction was clean, no attack being observed on the alkyl portion of the ketones. In the absence of ozone, the nitration did not proceed.



1 2

a R = Me **f** R = $CHCl_2$
b R = Et **g** R = CF_3
c R = Pr^i **h** R = H
d R = Bu^t **i** R = Cl
e R = CH_2Cl

Scheme 1

The reaction of acetophenone **1a** with nitrogen dioxide was almost complete within 4 h, giving a mixture of *ortho*- and *meta*-nitroacetophenones in a ratio of 54:46. The nitration of the acetophenone **1a** with nitric acid was previously examined in detail by Moodie *et al.*,[4] who observed a dominant *ortho*/*meta* orientation and also a considerable increase in *meta*-substitution when highly acidic nitrating systems were employed. In 80% sulfuric acid at 25 °C, the *ortho*/*meta* ratio was 0.37, while in 98% sulfuric acid at the same temperature, the ratio decreased to 0.25. This decrease has been ascribed to an increasing contribution of the conjugate acid of acetophenone **1a** formed by protonation of the carbonyl oxygen atom. However, the ketone itself is known to be nitrated mostly as the free base up to acidities at least as high as 90% sulfuric acid. As compared with the early result,[4] the present nitration produces a remarkably high proportion of *ortho*-nitro compound (*ortho*/*meta* = 1.10).

Some information is available about the nitration of other alkyl aryl ketones,[5–18] but it is mostly of little quantitative significance. The general phenomenon of *ortho*/*meta*-substitution into the aromatic ring is also shown by the nitration of propiophenone **1b**[6] with fuming nitric acid (*d* 1.5), where the *ortho*/*meta* ratio of the nitration product was found to increase with higher temperatures. However, the reported values *ortho*/*meta* = 0.50–0.95) are again much lower over a wide temperature range as compared with our result (*ortho*/*meta* = 1.38). HPLC analysis showed no detectable amount of *para*-substitution in the nitration of the ketones **1a** and **1b**.

The most striking feature of the nitration of aromatic ketones with nitrogen dioxide is a remarkable enhancement of the *ortho*-substitution as compared with the classical nitration (Table 1). The proportion of the *ortho*-isomer relative to two others increased with the increasing steric bulkiness of the alkyl moiety in ketone **1**, from 1.1 for the ketone **1a** up to 3.8 for the ketone

† This process will be referred to as the kyodai-nitration, hereafter. The nitration of arenes with the lower oxides of nitrogen using a combination of ozonized air and some third substance as the promoter is now subject to industrially based research to circumvent the problems arising from the classical methodologies based on the use of nitric–sulfuric acid. The prefix kyodai is the Japanese abbreviation of Kyoto University, where the initial fundamental research was carried out.

Table 1 Isomer distributions and yields of the nitration products from aromatic carbonyl compounds **1a–i**[a]

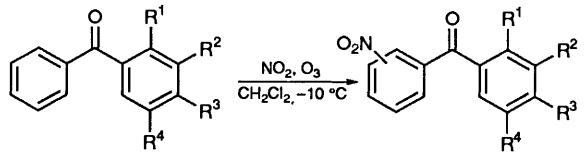
Substrate	GLC yield (%)	Reaction time (h)	Isomer distribution (%)[b] *ortho*	*meta*	*para*	*ortho*:*meta* ratio
1a	99	4	52	48	—[c]	1.08
1a[d]	100	3	47	53	—[c]	0.89
1b	100	6	55	40	5	1.38
1c	100	5	59	38	3	1.55
1d	99	3	68	18	14	3.78
1e	100	4	44	56	—[c]	0.79
1f	100	6	17	83	—[c]	0.21
1g[d]	100	3	< 1	> 99	—[c]	0
1h[d]	> 99	3	32	64	4	0.50
1i	99	3	1	99	—[c]	0.01

[a] All reactions were carried out using a substrate (10 mmol) in dichloromethane (50 cm^3) at −10 °C. Ozone was fed continuously at a rate of 10 mmol h^{-1}. [b] Product compositions were determined by GLC. [c] Not detected. [d] Methanesulfonic acid (0.5 equiv.) was added as catalyst.

Table 2 Isomer distributions and yields of the nitration products from benzophenone **3a** and the nitrobenzophenones **3b–e**[a]

Substrate	GLC yield (%)	Reaction time (h)	Isomer distribution (%)[b] *ortho*:*meta*:*para*	*ortho*:*meta* ratio
3a	99	2	42:36:22	1.17
3b	99	3	60:32:8	1.88
3c	99	3	41:49:10	0.84
3d	99	3	47:46:7	1.02
3e	99	3	37:59:4	0.63

[a] As for reaction conditions, see *a* in Table 1. [b] Product compositions were determined by GLC. Isomer distributions from substrates **3b–3d** and **3e** refer to those of dinitro- and trinitro-benzophenones, respectively, in which the additional nitro group substituted onto the unsubstituted ring.



3 4

	R^1	R^2	R^3	R^4
a	H	H	H	H
b	NO_2	H	H	H
c	H	NO_2	H	H
b	H	H	NO_2	H
e	H	NO_2	H	NO_2

Scheme 2

1d. The increase of the *ortho*/*meta* values is accompanied by an increase in *para*-substitution, suggesting the decrease of the conjugative electron withdrawal by the bulky acyl substituent. As far as judged from Table 1, the pivaloyl group may be classified as *ortho*/*para*-directing rather than *meta*-directing, which stands in marked contrast to the result obtained by ordinary nitration using mixed acid.[17]

Stepwise substitution of one, two or three halogen atoms into the acetyl group in acetophenone **1a** resulted in a gradual change-over in orientation from predominantly *ortho*/*meta* for 2-chloroacetophenone **1e** to predominantly *meta* for 2,2-dichloroacetophenone **1f** and finally exclusively *meta* for 2,2,2-trifluoroacetophenone **1g**. The ketone **1g** is appreciably deactivated and so the addition of methanesulfonic acid as catalyst was necessary for the reaction to proceed at convenient rate.

Preference for *ortho* substitution was also seen in the case of the chloro ketone **1e**, which was readily converted into a mixture of mononitro derivatives **2e** (*ortho*- 44%, *meta*- 56%) in the absence of acid catalyst. *para*-Substitution was not detected. The nitration of the chloro ketone **1e** with fuming nitric acid (*d* 1.50) in 96% sulfuric acid at −20 °C is reported to give 68.5% of *meta*- and 31.5% of combined *ortho*- and *para*-nitro derivatives in 98.5% yield.[13] Change of the directing effect of the acyl group from *ortho*/*meta* to exclusively *meta* according to the increase in the number of halogen atoms attached may reflect the importance of the electron density in the carbonyl function, suggesting that the reaction would proceed through the initial interaction of an attacking species with the carbonyl oxygen atom. In support of this view, benzoyl chloride **1i**, an extreme case where the carbonyl function is directly attached to the electronegative chlorine atom, underwent almost exclusive *meta*-substitution.

Benzaldehyde **1h** was easily oxidized by the nitrogen dioxide–ozone system to produce acidic products, but in the presence of methanesulfonic acid as catalyst, it was smoothly nitrated to give a mixture of *ortho*-, *meta*- and *para*-nitrobenzaldehydes in a ratio of 32:64:4 in 99% yield. The steady increase of the *ortho*/*meta* ratios from compound **1h** to **1a** to **1d** is in accord with the electron-releasing ability and steric bulkiness of the R group in ketone **1** in the order H < Me < Et < Pr^i < Bu^t.

Because of its symmetrical nature, benzophenone **3a** is an excellent substrate for estimating the directing effect of a carbonyl function on an entering nitro group. The ozone-mediated nitration of benzophenone **3a** with nitrogen dioxide was found to be non-regioselective, giving three isomeric nitro ketones **4a** in a ratio close to statistical *ortho*:*meta*:*para* = 2:2:1 (Table 2). If it is assumed that the increase in electron density on the carbonyl oxygen will favour its interaction with the attacking species to lead to the preferential *ortho*-substitution, the introduction of the nitro group onto the *ortho* or *para* position of benzophenone **3a** should counteract this because of its strong electron-withdrawing effect. Correspondingly, a considerable decrease in *para*-substitution was observed for all four nitro ketones **3b–e**. Contrary to our expectation, however, *ortho* enhancement was significant for the nitro ketone **3b** and also appreciable for **3d**. In the case of the ketone **3b**, the electron release from the neighbouring nitro group to the

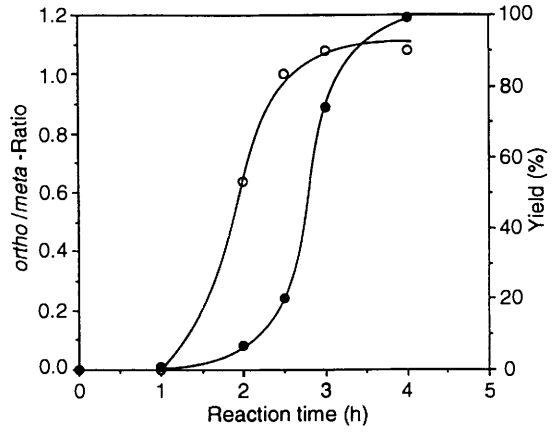


Fig. 1 Variations with reaction time of the yield and *ortho*/*meta* ratio of nitration product **2a**[a]
[a] Solid and empty circles denote the yield and the *ortho*/*meta*-ratio, respectively. For reaction conditions, see *a* in Table 1.

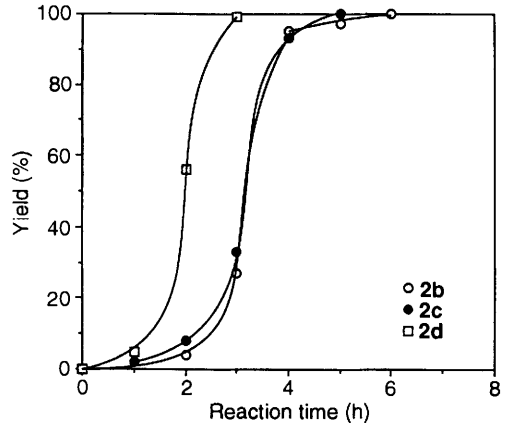


Fig. 2 Yield *vs.* reaction time for the nitro ketones **2b–d**[a]
[a] For reaction conditions, see *a* in Table 1.

carbonyl carbon atom, as has been suggested by Onopchenko *et al.*,[10] may be responsible to some extent. However, such an argument fails for the ketone **3d**.

An additional feature of the nitration of aromatic ketones with nitrogen dioxide is the manifestation of the induction period, as revealed by GLC (Fig. 1). The reaction started only after the amount of ozone introduced had reached 1.0–1.5 mol equiv. with respect to the substrate. Once started, however, the reaction proceeded at an increasingly rapid rate and was soon complete. Other alkyl aryl ketones **1b–1d** behaved similarly (Figs. 2 and 3). Contrary to our expectation, the addition of a Lewis acid catalyst, such as boron trifluoride-diethyl ether or titanium tetrachloride, resulted only in the prolongation of the induction period. Methanesulfonic acid was found to be a good catalyst for the present nitration, while the initial addition of small amounts of nitric acid showed little catalytic effect. The induction period was observed for several solvent systems of varying polarity.

The isomer distribution varied considerably during the course of the reaction (Fig. 1). At the initiation stage, the orientation was almost completely *meta*, but as the reaction proceeded, it rapidly changed to both *ortho* and *meta*, reaching a value of *ortho*/*meta* around 1.1. Addition of a further portion of substrate to the reaction mixture at an intermediate stage (approximately 20% conversion) brought a sharp drop in the value of the *ortho*/*meta* ratio from 1.0 to 0.35, but as the reaction was allowed to proceed, the value slowly increased to 0.5–0.6.

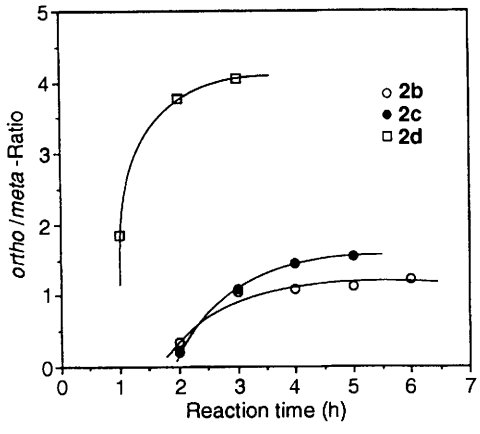


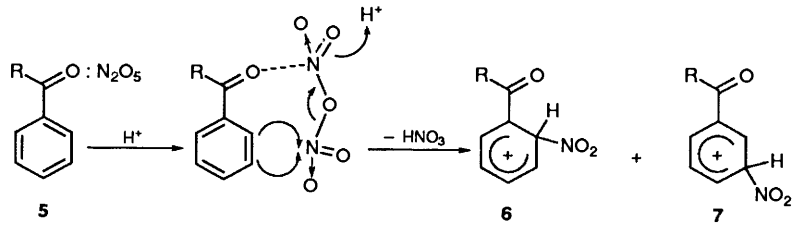
Fig. 3 Variations with reaction time of the *ortho*/*meta* ratios of nitration products **2b–d**[a]
[a] For reaction conditions, see *a* in Table 1.

In the preceding paper,[23] we suggested a single-electron transfer mechanism for the nitration of alkylbenzenes with nitrogen dioxide in the presence of ozone. Nitrogen dioxide reacts rapidly with ozone to give nitrogen trioxide, which is usually trapped by a further molecule of nitrogen dioxide to form dinitrogen pentaoxide.[24] Electron-rich substrates such as alkylbenzenes would readily suffer a single-electron oxidation by nitrogen trioxide to give a radical cation, which would subsequently undergo a coupling reaction with nitrogen dioxide to furnish the ordinary arenium intermediate.

In the reaction of aromatic carbonyl compounds, however, it is unlikely for the ketone **1** to be oxidized by nitrogen trioxide to form a cation radical and so dinitrogen pentaoxide is the likely reagent for the present nitration. Indeed, the action of a large excess of dinitrogen pentaoxide on ketone **1a** led to a mixture of the nitro ketones **2a** (*ortho*:*meta*:*para* = 52–56:48–44:0), an isomeric composition of which is quite close to that obtained by the kyodai nitration.

In a recent paper,[25] Moodie *et al.* reported the rapid, reversible formation of 4-(dinitratomethyl)nitrobenzene from 4-nitrobenzaldehyde and dinitrogen pentaoxide in a concentrated nitric acid solution. However, similar adduct formation from the aromatic ketones and dinitrogen pentaoxide was readily discounted, since the ^{13}C NMR inspection of a mixture of acetophenone **1a** and dinitrogen pentaoxide in dichloromethane at −50 °C revealed no peak in the expected region of the spectra. The ^{13}C resonance due to the carbonyl group appeared at δ 201.7, appreciably downfield from the original signal (δ 198.1), but the resonances for other carbon atoms remained almost unchanged, indicating the operation of a strong, but rather localized interaction between the carbonyl group and dinitrogen pentaoxide. An equimolar solution of acetophenone **1a** and dinitrogen pentaoxide in dichloromethane was kept at −10 °C in the presence of an excess of nitrogen dioxide both with and without 1 mol equiv. of methanesulfonic acid. However, the ketone was recovered unchanged after 3 h in both cases.

The above findings are highly suggestive of the formation of a Lewis acid–base complex **5** (R = Me) as an intermediate as illustrated in Scheme 3. The above-mentioned induction period may then be attributed to the accumulation of this complex in the reaction system. During this period, free acetophenone **1a** in equilibrium with the complex **5** reacts slowly with the nitronium ion derived from the ionic form of dinitrogen pentaoxide, giving predominantly the *meta* isomer. The complex **5** itself may also act as the nitrating agent for acetophenone **1a**. As the reaction proceeded, however, nitric acid formed would facilitate the



Scheme 3

heterolytic collapse of the complex **5**, leading to the usual intermediates (**6** and **7**) in *ortho*- and *meta*-nitration.

In view of the versatility of *o*-nitro ketones as the precursor for a variety of heterocyclic compounds, the present finding is of considerable synthetic importance and the mechanism for the enhancement in *ortho*-substitution needs to be clarified.

Experimental

General Experimental Details.—All m.p.s were determined on a Yanagimoto hot-stage apparatus and are uncorrected. IR spectra were recorded as KBr pellets on a Shimadzu FT–IR DR 8000/8100 IR spectrophotometer. ^{1}H NMR spectra were obtained with a Varian Gemini-200 spectrometer for solutions in $CDCl_3$ with tetramethylsilane as internal standard. Coupling constants J are given in Hz. Mass spectra were recorded on a Shimadzu GCMS QP-2000A spectrometer at an ionization potential of 70 eV. GLC analyses were performed on a Shimadzu GC-14A gas chromatograph, using a CBP1-M25-025 column [25 m × 0.2 mm (i.d.)]. Merck precoated silica gel sheets 60F-254 were used for TLC. Silica gel column chromatography was performed on a Wakogel 200 (100–200 mesh) support with hexane–ethyl acetate as eluent. An apparatus (Nippon Ozone Co. Ltd., type ON-1-2) was used for the generation of ozone at a rate of 10 mmol h^{-1}, with an oxygen flow of 10 dm^3 h^{-1} and an applied voltage of 80 V. Calibration of the ozone generator was made by iodometric titration. Products were identified by IR, ^{1}H NMR, MS and elemental analysis, or by direct comparison with the authentic specimens.

Reagents and Solvents.—All reagents and solvents used were reagent-grade commercial products. Dichloromethane was distilled from calcium hydride. Liquid aromatic carbonyl compounds such as acetophenone and benzaldehyde were distilled prior to use. Nitrogen dioxide [99% purity; impurities involve nitrogen monoxide and small amounts of nitrogen] was used from commercial cylinders, purchased from the Sumitomo Seika Co. Ltd. Dinitrogen pentaoxide was prepared by the literature procedure.[26]

Nitration of Aromatic Ketones: Typical Procedure.—(*a*) *With nitrogen dioxide–ozone.* A solution of acetophenone **1a** (10 mmol) in freshly distilled dichloromethane (50 cm^3) was placed in a three-necked 50 cm^3 flask fitted with two gas inlet tubes and a vent, and cooled to −10 °C by an external ice–salt bath, while a stream of ozonized oxygen was introduced through one of the gas inlet tubes, which was submerged below the surface of the liquid. A stream of nitrogen dioxide was also slowly introduced through the other inlet tube, which opened just above the surface of the liquid. Throughout the reaction, both ozonized oxygen and nitrogen dioxide were fed continuously at a low flow rate. It was necessary to carry out the reaction in the presence of excess of nitrogen dioxide, otherwise the nitration was quite slow and incomplete. Within 4 h, the mononitration was complete and the reaction mixture was quenched by the addition of aqueous sodium hydrogen carbonate. The organic phase was separated, washed with water, dried (Na_2SO_4), and evaporated under reduced pressure to leave a mixture of nitroacetophenones **2a** in nearly quantitative yield.

(*b*) *With dinitrogen pentaoxide.* To a stirred solution of acetophenone **1a** (10 mmol) in dry dichloromethane (50 cm^3) cooled to −10 °C was added a solution of dinitrogen pentaoxide (40 mmol) in the same solvent (40 cm^3) in four portions at hourly intervals. An aliquot (0.1 cm^3) was withdrawn at an appropriate interval and analysed by GLC.

Kyodai Nitration of Benzaldehyde **1h**.—Into a solution of benzaldehyde (10 mmol) and methanesulfonic acid (5 mmol) in dry dichloromethane (50 cm^3) kept at < 0 °C was slowly introduced streams of ozonized oxygen and nitrogen dioxide as described for method (*a*). The progress of the reaction was monitored by TLC. After 3 h, the reaction was complete and the mixture was worked up to give a mixture of nitrobenzaldehydes **2h** as an oily mass in almost quantitative yield. In the absence of methanesulfonic acid, extensive oxidation occurred concurrently to yield a mixture of benzoic and nitrobenzoic acids as the major products.

The product mixtures were subjected to HPLC separation to obtain major nitro isomers for spectral identification. Some physical data of less common products are given below:

2′-*Nitropropiophenone* **2b**. Oil (lit.,[27] b.p. 144–145 °C/8 mmHg); ν_{max}(neat)/cm^{-1} 1704, 1531, 1348, 1243, 855, 790, 751 and 701; δ_H 1.24 (3 H, t, J 7.3), 2.82 (2 H, q, J 7.3), 7.43 (1 H, dd, J 1.6 and 7.4), 7.62 (1 H, dt, J 1.8 and 7.8), 7.75 (1 H, dt, J 1.5 and 7.3) and 8.09 (1 H, dd, J 1.1 and 8.1); m/z 179 (1.6%, M^+), 150 (100), 104 (18) and 76 (31).

3′-*Nitropropiophenone* **2b**. M.p. 97–100 °C (lit.,[11] 98–99 °C); ν_{max}(KBr)/cm^{-1} 1692, 1619, 1530, 1351, 1253, 1109 and 744; δ_H 1.16 (3 H, t, J 7.2), 3.01 (2 H, q, J 7.2), 7.62 (1 H, t, J 8.1), 8.25 (2 H, m) and 8.64 (1 H, s); m/z 179 (4%, M^+), 150 (100), 104 (35) and 76 (29).

2-*Methyl*-2′-*nitropropiophenone* **2c**. M.p. 45–47 °C (lit.,[28] 46–47 °C); ν_{max}(KBr)/cm^{-1} 1704, 1530, 1350, 1245, 855, 788, 751 and 700; δ_H 1.10 (6 H, d, J 6.9), 2.89 (1 H, sept, J 6.9), 7.30 (1 H, dd, J 1.5 and 7.3), 7.52 (1 H, dt, J 1.5 and 7.8), 7.65 (1 H, dt, J 1.4 and 7.5) and 8.00 (1 H, dd, J 1.2 and 8.2); m/z 193 (4%, M^+), 151 (46), 150 (100), 121 (44), 104 (28), 93 (22) and 76 (36).

2-*Methyl*-3′-*nitropropiophenone* **2c**. M.p. 36–37 °C (lit.,[14] 37 °C); ν_{max}(KBr)/cm^{-1} 1692, 1618, 1530, 1351, 1252, 1111, 745 and 666; δ_H 1.14 (6 H, d, J 6.9), 3.53 (1 H, sept, J 6.9), 7.63 (1 H, t, J 8.1), 8.24 (2 H, m) and 8.62 (1 H, s); m/z 193 (4.6%, M^+), 150 (100), 104 (27) and 76 (24).

2,2-*Dimethyl*-2′-*nitropropiophenone* **2d**. Oil; ν_{max}(neat)/cm^{-1} 1698, 1520, 1363 and 853; δ_H 1.25 (9 H, s), 7.31 (1 H, dd, J 1.4 and 7.6), 7.58 (1 H, dt, J 1.5 and 7.5), 7.74 (1 H, dt, J 1.3 and 7.5) and 8.18 (1 H, dd, J 1.4 and 8.4); m/z 207 (0.9%, M^+), 151 (53), 121 (49) and 57 (100).

2,2-*Dimethyl*-3′-*nitropropiophenone* **2d**. M.p. 43–45 °C (lit.,[17] 45–46 °C); ν_{max}(KBr)/cm^{-1} 1679, 1613, 1526, 1370, 1108 and 881; δ_H 1.39 (9 H, s), 7.65 (1 H, t, J 7.8), 8.04 (1 H, d, J 7.8), 8.34 (1 H, d, J 7.9) and 8.54 (1 H, s); m/z 207 (1.3%, M^+), 151 (15), 76 (20) and 57 (100).

2,2-*Dimethyl*-4-*nitropropiophenone* **2d**. M.p. 62–65 °C (lit.,[17] 62–64 °C); ν_{max}(KBr)/cm^{-1} 1683, 1605, 1527, 1360, 1260, 1010 and 856; δ_H 1.35 (9 H, s), 7.76 (2 H, d, *J* 8.9) and 8.27 (2 H, d, *J* 8.8); *m*/*z* 207 (2.2%, M$^+$), 151 (18) and 57 (100).

2-*Chloro*-2′-*nitroacetophenone* **2e**. M.p. 66–67 °C; ν_{max}(KBr)/cm^{-1} 1727, 1530, 1348, 1208, 791, 739 and 700; δ_H 4.47 (2 H, s), 7.45 (1 H, dd, *J* 1.5 and 7.3), 7.68 (1 H, dt, *J* 1.6 and 7.6), 7.80 (1 H, dt, *J* 1.4 and 7.5) and 8.23 (1 H, dd, *J* 1.3 and 8.1); *m*/*z* 150 (100), 104 (14), 76 (40), 51 (57) and 50 (36) (Found: C, 47.4; H, 3.0; N, 7.2. $C_8H_6ClNO_3$ requires C, 48.1; H, 3.1; N, 7.0%).

2-*Chloro*-3′-*nitroacetophenone* **2e**. M.p. 102–103 °C (lit.,[13] 100.5–102 °C); ν_{max}(KBr)/cm^{-1} 1705, 1613, 1526, 1393, 1350, 1209, 787, 739 and 683; δ_H 4.75 (2 H, s), 7.76 (1 H, t, *J* 8.3), 8.32 (1 H, d, *J* 7.7), 8.49 (1 H, d, *J* 8.2) and 8.79 (1 H, s); *m*/*z* 150 (100), 104 (38), 76 (35) and 50 (22) (Found: C, 48.1; H, 3.0; N, 7.0. $C_8H_6ClNO_3$ requires C, 48.1; H, 3.1; N, 7.0%).

2,2-*Dichloro*-2′-*nitroacetophenone* **2f**. M.p. 72–73 °C; ν_{max}(KBr)/cm^{-1} 1725, 1528, 1343, 1217, 1198, 798, 741, 702 and 637; δ_H 6.38 (1 H, s), 7.62 (1 H, dd, *J* 1.8 and 7.5), 7.70–7.89 (2 H, m) and 8.29 (1 H, dd, *J* 1.4 and 8.1); *m*/*z* 150 (100), 104 (12), 76 (41), 51 (48) and 50 (34) (Found: C, 41.0; H, 2.1; N, 6.0. $C_8H_5Cl_2NO_3$ requires C, 41.1; H, 2.2; N, 6.0%).

2,2-*Dichloro*-3′-*nitroacetophenone* **2f**. M.p. 57–58 °C; ν_{max}(KBr)/cm^{-1} 1703, 1615, 1526, 1348, 1229, 810, 687 and 671; δ_H 6.66 (1 H, s), 7.79 (1 H, t, *J* 8.1), 8.45–8.55 (2 H, m) and 8.95 (1 H, s); *m*/*z* 150 (100), 104 (33), 76 (39) and 50 (25) (Found: C, 41.0; H, 2.2; N, 6.1. $C_8H_5Cl_2NO_3$ requires C, 41.1; H, 2.2; N, 6.0%).

2,2,2-*Trifluoro*-3′-*nitroacetophenone* **2g**. M.p. 54–55 °C (lit.,[15] 54–55 °C); ν_{max}(KBr)/cm^{-1} 1732, 1705, 1617, 1538, 1352, 1190, 1055 and 712; δ_H 7.93 (1 H, t, *J* 8.1), 8.47 (1 H, d, *J* 7.5), 8.63 (1 H, d, *J* 8.3) and 8.89 (1 H, s); *m*/*z* 150 (100), 104 (42), 76 (45) and 50 (27).

2-*Nitrobenzophenone* **3b**. M.p. 104–106 °C (lit.,[29] 104–106 °C); ν_{max}(KBr)/cm^{-1} 1662, 1595, 1520, 1109 and 735; δ_H 7.41–7.83 (8 H, m) and 8.24 (1 H, d, *J* 8.0); *m*/*z* 227 (5.4%, M$^+$), 134 (64), 105 (100), 77 (71), 76 (26) and 51 (43).

3-*Nitrobenzophenone* **3c**. M.p. 92–94 °C (lit.,[30] 94–95 °C); ν_{max}(KBr)/cm^{-1} 1655, 1596, 1538, 1280, 1086, 975, 738, 705 and 675; δ_H 7.53 (2 H, t, *J* 8.0), 7.64–7.84 (4 H, m), 8.15 (1 H, d, *J* 7.8), 8.45 (1 H, d, *J* 7.8) and 8.62 (1 H, s); *m*/*z* 227 (5.9%, M$^+$), 134 (64), 105 (100), 77 (74), 76 (27), 51 (47) and 50 (22).

4-*Nitrobenzophenone* **3d**. M.p. 138–139 °C (lit.,[29] 135–137 °C); ν_{max}(KBr)/cm^{-1} 1650, 1595, 1513, 1319, 1106, 931, 874, 734 and 706; δ_H 7.52 (2 H, t, *J* 8.0), 7.64 (1 H, d, *J* 7.6), 7.81 (2 H, d, *J* 7.9), 7.94 (2 H, d, *J* 8.4) and 8.35 (2 H, d, *J* 8.4); *m*/*z* 227 (62%, M$^+$), 150 (24), 105 (99), 77 (100), 76 (31), 51 (39) and 50 (28).

2,2′-*Dinitrobenzophenone* **4b**. M.p. 191–193 °C (lit.,[31] 190–191 °C); ν_{max}(KBr)/cm^{-1} 1686, 1607, 1526, 1352, 1280, 967, 934, 851, 791, 772 and 623; δ_H 7.57–7.63 (2 H, m), 7.67–7.73 (4 H, m) and 7.94–8.00 (2 H, m); *m*/*z* 272 (2.8%, M$^+$), 150 (100), 134 (38), 104 (23), 76 (33) and 51 (20).

2,3′-*Dinitrobenzophenone* **4c**. M.p. 122–125 °C (lit.,[32] 126 °C); ν_{max}(KBr)/cm^{-1} 1687, 1617, 1527, 1439, 1350, 1252, 1075, 972, 814, 797 and 705; δ_H 7.52 (1 H, d, *J* 7.2), 7.64–7.90 (3 H, m), 8.11 (1 H, d, *J* 7.7), 8.31 (1 H, d, *J* 8.0), 8.41–8.47 (1 H, m) and 8.50 (1 H, s); *m*/*z* 272 (2.6%, M$^+$), 150 (100), 134 (66), 104 (29), 76 (36) and 51 (23).

2,4′-*Dinitrobenzophenone* **4d**. M.p. 195–197 °C (lit.,[8] 196–197 °C); ν_{max}(KBr)/cm^{-1} 1686, 1615, 1525, 1350, 1270, 851 and 795; δ_H 7.52 (1 H, d, *J* 7.2), 7.76–7.90 (2 H, m), 7.97 (2 H, d, *J* 8.3), 8.33 (1 H, d, *J* 8.0) and 8.41 (2 H, d, *J* 8.2); *m*/*z* 272 (33%, M$^+$), 150 (100), 104 (30) and 76 (30).

3,3′-*Dinitrobenzophenone* **4c**. M.p. 151–153 °C (lit.,[33] 153.4–153.8 °C); ν_{max}(KBr)/cm^{-1} 1665, 1611, 1525, 1352, 1098, 988, 851 and 702; δ_H 7.77 (2 H, t, *J* 8.1), 8.14 (2 H, d, *J* 7.7), 8.48–8.54 (2 H, m) and 8.63 (2 H, s); *m*/*z* 272 (37%, M$^+$), 150 (100), 104 (27) and 76 (27).

3,4′-*Dinitrobenzophenone* **4d**. M.p. 170–172 °C (lit.,[34] 171.7–173.7 °C); ν_{max}(KBr)/cm^{-1} 1669, 1605, 1525, 1348, 1306, 1264, 851, 820, 781, 720 and 700; δ_H 7.77 (1 H, t, *J* 7.9), 7.97 (2 H, d, *J* 8.3), 8.16 (1 H, d, *J* 7.6), 8.40 (2 H, d, *J* 8.2), 8.49–8.54 (1 H, m) and 8.63 (1 H, s); *m*/*z* 272 (2.9%, M$^+$), 150 (100), 134 (64), 104 (32) and 76 (38).

4,4′-*Dinitrobenzophenone* **4d**. M.p. 190–192 °C (lit.,[34] 192–193 °C); δ_H 7.98 (4 H, d, *J* 8.3) and 8.41 (4 H, d, *J* 8.2); *m*/*z* 272 (35%, M$^+$), 150 (100), 104 (31) and 76 (33).

2,3′,5′-*Trinitrobenzophenone* **4e**. M.p. 159–161 °C; ν_{max}(KBr)/cm^{-1} 1698, 1622, 1549, 1350, 1277, 1076, 986, 731, 718 and 702; δ_H 7.55 (1 H, dd, *J* 1.7 and 7.3), 7.81–7.98 (2 H, m), 8.38 (1 H, dd, *J* 1.5 and 7.9), 8.83 (2 H, d, *J* 2.1) and 9.24 (1 H, t, *J* 2.1); *m*/*z* 195 (100), 150 (59), 75 (25) and 51 (28) (Found: C, 49.1; H, 2.2; N, 13.3. $C_{13}H_7N_3O_7$ requires C, 49.2; H, 2.2; N, 13.3%).

3,3′,5′-*Trinitrobenzophenone* **4e**. M.p. 157–159 °C; ν_{max}(KBr)/cm^{-1} 1680, 1626, 1545, 1350, 1119, 994, 920 and 722; δ_H 7.84 (1 H, t, *J* 7.9), 8.13–8.18 (1 H, m), 8.56–8.66 (2 H, m), 8.94 (2 H, d, *J* 2.2) and 9.31 (1 H, t, *J* 2.2); *m*/*z* 317 (23%, M$^+$), 195 (23), 150 (100), 104 (20), 76 (20) and 75 (24) (Found: C, 49.3; H, 2.2; N, 13.4. $C_{13}H_7N_3O_7$ requires C, 49.2; H, 2.2; N, 13.3%).

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