N- and *C*-Attacks on aromatics of phenylnitrenium ion generated from *N*-phenylhydroxylamine in the presence of trifluoroacetic acid containing polyphosphoric acid or trifluoroacetic anhydride

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A phenylnitrenium ion formed from *N*-phenylhydroxylamine in the presence of trifluoroacetic acid (TFA) containing polyphosphoric acid (PPA) interacts with the counterion $^{-}O_2CCF_3$ and the unshared electron-pair of H_2O, showing Hammett's ρ values −5.2 and −4.0 for *N*- and *C*-attacks on aromatics PhX (X = H, Me, Et, Ph and Cl), respectively. The ratio *N*-/*C*-attack for this nitrenium ion is lower than for the nitrenium ion interacting with only the counterion; the latter nitrenium ion is generated by the use of trifluoroacetic anhydride (TFAA) instead of PPA or by reaction of phenyl azide with aromatics in TFA. The ratio for the former nitrenium ion is affected by the aromatic substituent X: X = Me > X = Et > X = Ph > X = H > X = OMe at 20 and 50 °C. The order for X = Cl is between those of X = H and X = Ph at 20 °C, but highest at 50 °C. The ratio is increased by higher reaction temperature and by decreased concentration of TFA. The results are demonstrated from the mechanistic viewpoint for the nitrenium ions.

Nitrenium ions have been studied from the viewpoint of being reactive metabolites[1] of carcinogens and useful intermediates[2–5] for direct aromatic aminations. Parent nitrenium ion,[2,3] arylnitrenium ion[4] and alkylnitrenium ion[3] generated from *N*-aminopyridinium or *S*-aminosulfonium salt interact with the counterion and the unshared electron-pair of the N- or S-atom while the nitrenium ions[5] formed from azides interact only with the counterion. In this paper, we propose that a phenylnitrenium ion formed from *N*-phenylhydroxylamine using trifluoroacetic acid (TFA) containing polyphosphoric acid (PPA) has a structure interacting with both the counterion and the unshared electron-pair. Further, the reactivity of the nitrenium ion as indicated by Hammett's ρ values for the *N*- and *C*-attacks or the *N*-/*C*-attack on the aromatics is here demonstrated mechanistically.

Results and discussion

Reactions of *N*-phenylhydroxylamine 1a with benzene 2a in the presence of TFA

Reactive intermediate in the presence of TFA containing trifluoroacetic anhydride (TFAA). Reaction of *N*-phenylhydroxylamine **1a** with benzene **2a** using TFA gave diphenylamine **3a** and 2- and 4-phenylanilines **4a** and **5a**, along with azoxybenzene **6** (Table 1). In this case, **3a** or **4a** and **5a** would correspond to *N*- or *C*-attack of a phenylnitrenium ion on **2a**, respectively. Adding TFAA (1.2 mmol) to the reaction of **1a** with **2a** in TFA, we observed an increased total yield of **3a**–**5a** and an enhanced *N*-/*C*-attack ratio, from 2.4 to 4.2 (Table 1); the yields of **3a**–**5a** in the addition of TFAA include the yields of the corresponding trifluoroacetanilides. The result means that the addition of TFAA not only causes dehydration of the solvent but also varies the reactive species. The *N*-/*C*-attack ratio in the reaction of **1a** (1.0 mmol) with **2a** using 1.0 mmol of TFAA at 25 °C for 3 h was the same as that in the reaction of phenyl azide **1b** (1.0 mmol) with **2a** under the same conditions; the *N*-/*C*-attack ratio in the two reactions was 4.6–4.7 or 1.9–2.0 in the presence of 30 or 73% v/v of TFA, respectively (Table 2). This shows that the two reactions proceed *via* a common intermediate, a phenylnitrenium ion **II** interacting only with $^{-}O_2CCF_3$ (Scheme 1). Thus, the reactive species **II** may be formed *via* *O*-trifluoroacetylation of **1a** by TFAA (Scheme 1). The intermediacy of arylnitrenium ions from esters of hydroxylamines has been well established.[6]

Reactive intermediate in the presence of TFA containing PPA. Addition of 100 mg of PPA to this reaction increased the total yield of **3a**–**5a** from 30% to 66%, but scarcely varied the *N*-/*C*-attack ratio on **2a** (Table 1). These results suggest that PPA acts as a dehydration agent towards the solvent to increase the yields without changing the reactive species.

The use of PPA instead of TFAA gives a low *N*-/*C*-attack ratio (Table 1). The more stable nitrenium ion can have a higher contribution of the stable C^{+}-resonance form compared to the unstable N^{+}-resonance form, leading to the lower *N*-/*C*-attack ratio. Thus, the nitrenium ion **I** generated with the use of PPA might be more stabilised by interacting with two species, the counterion and the unshared electron-pair of H_2O, than the nitrenium ion **II** interacting with only the counterion (Scheme 1); the interacting H_2O is not water in the solvent, but interacts with the nitrenium ion just after N–O scission of **1a**. This type of interaction with the counterion and unshared electron-pair of pyridines, quinoline and sulfides corresponds well with our previous results.[2–4]

We could not determine the reaction order for the aromatic compound for the decomposition of **1a** by the usual method because **1a** is unstable on working up the reaction mixture. In fact, **6** was formed from **1a** by post-treatment with aqueous Na_2CO_3 of the reaction mixture. The yield of **6** is lower in the higher conversion of **1a**, as seen in the effect of the reaction time in Table 3 and in the effect of the addition of PPA or TFAA in Table 1. Thus, the yield of **6** is thought to reflect the recovered percent of **1a** in this reaction. The yield of **6** in the reaction of **1a** with **2a** is almost equal to that in the reaction with the more nucleophilic *p*-xylene **2b** in the separate reaction times 1 and 3 h (Table 3). The result indicates that the decomposition of **1a** is insensitive to the nucleophilicity of **2**. Thus, the conjugate acid of **1a** should spontaneously decompose to form the phenylnitrenium ion without being induced by an S_N2 attack on **2** (Scheme 1).

Partial rate factors k_f for *para*-positions of toluene, ethylbenzene, biphenyl and chlorobenzene **2d**–**g** were determined for the aromatic *N*- or *C*-substitution in the reaction of **1** (1.0 mmol) in TFA (3.0 cm^3)–aromatic substrates (5.0 cm^3) in the presence of

Table 1 Reactions of *N*-phenylhydroxylamine **1a** (1.0 mmol) with benzene **2a** (5.0 cm³) in the presence of TFA (3.0 cm³) containing PPA or TFAA at 20 °C

t/h	PPA/ mg	TFAA/ mmol	Yield[a] (%) **3a**	**4a**	**5a**	**6**	*N*-/*C*- Attack ratio	Total yield of **3**–**5** (%)
3.0	0	0	21	4.2	4.5	13	2.4	30
3.0	50	0	44	8.8	9.5	6.8	2.4	62
3.0	80	0	44	9.5	10	6.1	2.3	64
3.0	100	0	45	9.8	11	5.9	2.2	66
3.0	0	0.4	42	8.5	8.5	3.5	2.5	59
3.0	0	0.8	48	8.8	8.8	2.5	2.7	66
3.0	0	1.0	50	6.4	6.2	2.1	3.9	62
3.0	0	1.2	50	5.6	6.3	2.2	4.2	62

[a] Yields are based on **1a** used, and determined by HPLC analysis. The yields of **3a**, **4a** and **5a** in the addition of TFAA include the yields of the corresponding trifluoroacetanilide derivatives **3a′**, **4a′** and **5a′**, respectively.

Table 2 Reactions of *N*-phenylhydroxylamine **1a** (1.0 mmol) and phenyl azide **1b** (2.5 mmol) with benzene **2a** in the presence of TFA at 25 °C for 3 h

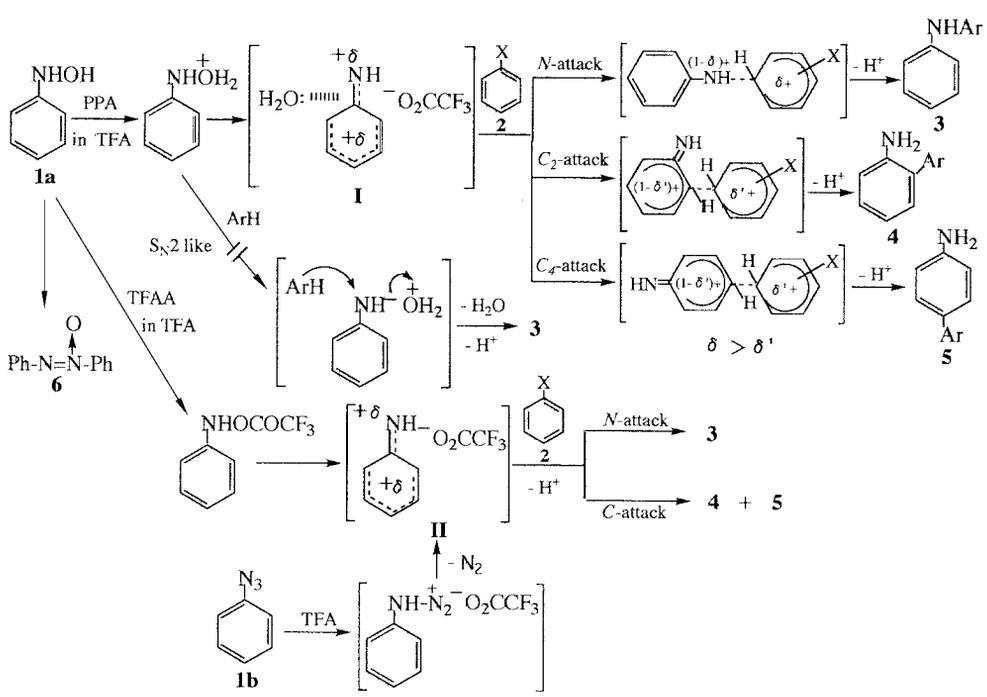
Precursor	Benzene **2a**/cm³	TFA/ cm³	TFAA/ mmol	Yield[a] (%) **3a**	**4a**	**5a**	*N*-/*C*- Attack ratio
1a	5.0	2.1	1.1	45	4.8	4.2	4.6
1b[b]	7.0	3.0	0	66	7.0	7.0	4.7
1a	3.0	8.0	1.1	43.8	10.1	11.0	2.0
1b	3.0	8.0	0	49	9.5	12	1.9

[a] The yields are obtained as shown in Table 1. [b] In this case, the data of ref. 5*c* were used. The yields of **3a**, **4a** and **5a** in the addition of TFAA include the yields of **3a′**, **4a′** and **5a′**, respectively.

Table 3 Reactions of *N*-phenylhydroxylamine **1a** (1.0 mmol) with benzene **2a** (5.0 cm³) and *p*-xylene **2b** (5.0 cm³) in the presence of TFA (3.0 cm³) containing PPA (100 mg) at 20 °C

ArH	*t*/h	PPA/ mg	Yield[a] (%) **3**	**4**	**5**	**6**	*N*-/*C*- Attack ratio	Total yield of **3**–**5** (%)
2a	1.0	100	25	5.6	6.4	15	2.1	37
2b	1.0	100	24	3.0	4.6	16	3.2	32
2a	3.0	100	45	9.8	11	5.9	2.2	66
2b	3.0	100	47	4.3	9.3	5.9	3.3	61

[a] The yields are obtained as indicated in Table 1.



Scheme 1

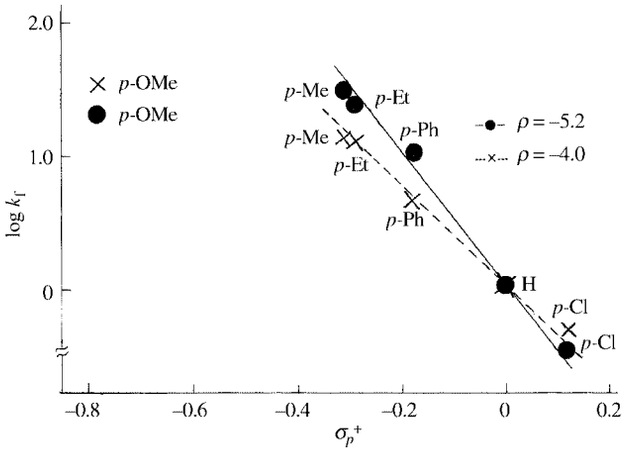


Fig. 1 Hammett plots of σ_p^+ against log k_f for aromatic *N*-substitution (—●—) and *C*-substitution (---×---) in the reaction of *N*-phenylhydroxylamine **1a** with aromatics in the presence of TFA containing PPA at 20 °C.

PPA 100 mg at 20 °C for 0.5 h. The correlation between log k_f and σ_p^+ gives a linear plot with $\rho = -5.2$ or -4.0 for the *N*- or *C*-substitution, respectively (Fig. 1); the *C*-substitution was applied to the attack on the C-4 position (not the C-2 position) of the nitrenium ion. The large negative ρ values support the formation of a cationic intermediate such as the phenylnitrenium ion.

The transition state of the *C*-substitution has lower positive charge on the phenyl ring from **2** than that of the *N*-substitution since the charge in the former transition state is widely dissipated over two phenyl rings whereas that in the latter one is dissipated over one phenyl and one N-atom (see Scheme 1). Thus, the *C*-substitution is less influenced by the substituent than the *N*-substitution, leading to a less negative ρ value. We explain the difference in the ρ values by differing amounts of positive charge in the two transition states (*i.e.* the transition states of the *N*- and *C*-substitutions). It seems that it is equally possible that the two transition states lie at different positions along the reaction coordinate, one being earlier than the other.

We have already reported the Hammett's $\rho = -4.5$ for the *N*-substitution of the nitrenium ion **II** generated from phenyl azide **1b** in TFA (30% v/v)–aromatic substrate (70% v/v) at 25 °C.[5c] If the temperature difference is disregarded, we would consider that the ρ value in TFA (3.0 cm^3)–aromatic substrate (5.0 cm^3) (*i.e.* in the presence of *ca.* 38% v/v of TFA) is less negative than -4.5 for **II**; in the higher concentration of less nucleophilic TFA from 30 to 38% v/v, the nitrenium ion may be more reactive, giving the less negative ρ value due to the lower selectivity for aromatic substrates. Thus, the ρ value -5.2 for the *N*-substitution of **I** would be more negative than that of **II**. This more negative ρ value means that **I** is less reactive (*i.e.* more selective for aromatic substrates) than **II**, strongly supporting the proposal that **I** is more stabilised by interaction with the two species, the counterion and the unshared electron-pair of H_2O, than **II** interacting with only with the counterion.

We did not use k_f for *p*-OMe as the value was abnormally lower than that expected from the Hammett relationship. We suppose that the reaction with anisole **2c** proceeds by a diffusion-controlled process, and is retarded by protonation of the oxygen atom of **2c**; the log k_f values for the *N*- and the *C*-4 substitutions were 1.3 and 1.5, respectively. These values are a little lower and greater than those values (1.5 and 1.1) of the *N*- and *C*-substitutions for *p*-Me, respectively (Fig. 1). The results imply that the faster *N*-substitution compared to the *C*-substitution would be more easily attainable in the diffusion-controlled process in the aromatic compound possessing a less electron-donating group between *p*-OMe and *p*-Me. The slightly low value for the *N*-substitution of *p*-OMe rather than *p*-Me might reflect the protonation of **2c**.

***N*-/*C*-Attack of phenylnitrenium ion I on aromatic compounds.** The ratio *N*-/*C*-attack of the phenylnitrenium ion **I** on aromatic compounds varied with the aromatics as follows: **2d** > **2e** > **2f** > **2a** > **2c** at 20 and 50 °C. The order for **2g** was nearly between those of **2a** and **2f** at 20 °C, and highest at 50 °C (Table 4). In consideration of the charge distribution in the transition state as shown above, the higher electron-donating group can stabilise the transition state (possessing high positive charge) of *N*-substitution more than that (having low positive charge) of the *C*-substitution, leading to the order **2d** > **2e** > **2f** > **2a**. Considering the insolubility of **2f** in TFA, the *N*-/*C*-attack ratio for **2f** was obtained in the reaction in TFA–CH_2Cl_2. No solvent effect by CH_2Cl_2 on the ratio was apparent.

The reaction of the nitrenium ion with the less reactive chlorobenzene **2g** occurs *via* a later transition state with a high positive charge on the phenyl ring from **2g**. Thus, the transition state in the *N*- or *C*-substitution to **2g** is more influenced by the substituent than that for the *N*- or *C*-substitutions to **2a** and **2d**–**f** (in other words, the difference of the positive charge at the transition state between the *N*- and *C*-substitutions to **2g** is greater than that to **2a** and **2d**–**f**), leading to the abnormally high *N*-/*C*-attack ratio for **2g**. The highest order for *N*-/*C*-attack of **2g** at 50 °C may result from the high resonance contribution of the N^+-form of the nitrenium ion compared to the C^+-form at high temperature as shown below. Such a high *N*-/*C*-attack ratio for **2g** at 50 °C is interesting because the phenylnitrenium can selectively react at the *N*-position rather than the *C*-position. As for the reaction with anisole **2c**, the *N*-substitution is less affected by the substituent than the *C*-substitution to give the unusually low *N*-/*C*-attack ratio because the *N*-substitution more easily attains the diffusion-controlled rate in an aromatic substrate with a less electron-donating group than the *C*-substitution as described above.

The total yield for the *N*- and *C*-attacks was less than 100% as seen in Tables 1–4. This reflects unidentified by-products because of the very high reactivity of the nitrenium ion species; in fact, a lot of very small GLC peaks were observed for the reaction mixtures.

Effect of temperature and concentration of TFA. The reaction of **1a** with **2** in the presence of TFA containing PPA gave a higher *N*-/*C*-attack ratio at higher temperature or with lower concentration of TFA (Table 4). At higher temperature, the less stable N^+-form of the nitrenium ion may contribute much more to the resonance than the more stable C^+-form, giving a high *N*-/*C*-attack ratio. A low concentration of TFA (*i.e.* a high concentration of **2**) might increase the proportion of the hard N^+-resonance form, which preferentially makes a tight ion-pair, relative to the soft C^+-resonance form, which preferentially makes a solvent separated ion-pair, since the tight ion-pair can be preferentially formed in a higher concentration of less polar aromatic compound. Thus, a low concentration of TFA leads to a high *N*-/*C*-attack ratio.

Experimental

IR spectra were obtained on a Nipponbunko A-302 spectrometer. ^1H NMR spectra were taken with a Nippondenshi PMX-60SI instrument (*J* values are given in Hz). GLC-MS were recorded with a Shimadzu QP-5000 spectrometer linked to a Shimadzu GC-17A column (15 m × 0.25 mm) coated with DC-1 (0.25 μm film thickness), made by J & W Scientific. HPLC was performed with a Shimadzu LC-6A system (column of YMC-Pack ODS-A A-303 (25 cm × 4.6 mm)) using a mixture of MeCN and H_2O as the solvent. Two runs agreed to within 3% error for the yields of the products which were determined by replicated HPLC analyses.

Benzene **2a**, *p*-xylene **2b**, anisole **2c**, toluene **2d**, ethylbenzene **2e** and chlorobenzene **2g** were purified by standard methods.

Table 4 Reactions of *N*-phenylhydroxylamine **1a** (1.0 mmol) with aromatics **2a** and **2c**–**g** in the presence of TFA containing PPA (100 mg) for 3 h

				Yield[a](%)							
				3		**4**		**5**			
PhX **2**	**2**/cm³	TFA/cm³	*T*/°C	*o*-	*p*-	*o*-	*p*-	*o*-	*p*-	Total yield of **3**–**5** (%)	*N*-/*C*-Attack ratio
a; X = H	5.0	3.0	20	45[b]		9.8[b]		11[b]		66	2.2
a; X = H	5.0	3.0	50	53[b]		4.7[b]		6.5[b]		64	4.6
a; X = H	2.0	6.0	20	39[b]		12[b]		14[b]		65	1.5
a; X = H	2.0	6.0	50	53[b]		7.7[b]		11[b]		71	2.8
c; X = OMe	5.0	3.0	20	16	24	0.1	6.7	2.6	9.9	58	2.1
c; X = OMe	5.0	3.0	50	25	37	0.6	9.5	5.4	12	89	2.3
c; X = OMe	2.0	6.0	20	17	23	0.5	13	5.5	17	76	1.1
c; X = OMe	2.0	6.0	50	20	27	1.3	13	6.0	15	82	1.3
d; X = Me	5.0	3.0	20	20	38	1.4	2.1	3.0	3.2	68	6.0
d; X = Me	5.0	3.0	50	24	44	1.2	2.9	2.1	2.2	76	9.3
d; X = Me	2.0	6.0	20	19	34	2.1	3.2	4.6	4.9	69	3.6
d; X = Me	2.0	6.0	50	24	42	1.1	2.5	4.3	4.4	78	5.4
e; X = Et	5.0	3.0	20	23	35	0.9	5.6	3.3	3.9	71	4.2
e; X = Et	5.0	3.0	50	29	41	0.5	4.0	2.4	3.0	80	7.0
e; X = Et	2.0	6.0	20	23	33	2.3	7.0	4.9	5.8	75	2.8
e; X = Et	2.0	6.0	50	26	36	2.0	5.9	4.0	4.7	59	3.7
f; X = Ph	5.0[c]	3.0	20	17	30	0.3	7.7	2.7	1.2	59	4.0
f; X = Ph	5.0[c]	3.0	35	18	34	0.3	7.1	2.3	0.3	62	5.2
f; X = Ph	2.0[c]	6.0	20	15	26	0.4	13	4.1	0.4	59	2.3
f; X = Ph	2.0[c]	6.0	35	17	31	0.4	13	3.8	0.7	65	2.7
g; X = Cl	5.0	3.0	20	5.6	42	7.5	1.8	5.6	3.7	66	2.6
g; X = Cl	5.0	3.0	50	10	50	1.8	0.8	1.4	1.3	65	12
g; X = Cl	2.0	6.0	20	5.3	40	8.4	1.8	5.5	3.4	64	2.4
g; X = Cl	2.0	6.0	50	9.2	47	2.1	1.1	2.2	1.0	62	8.8

[a] The yields are obtained as shown in Table 1. Product **6** was also formed in low yield (*ca.* 3–6%). [b] The *ortho*-product is the same as the corresponding *para*-product. [c] The reactions were carried out in CH_2Cl_2 (5.0 or 2.0 cm³) containing **2f** (5.0 mmol).

Trifluoroacetic acid (TFA) was purified by distillation of reagent grade materials (Nacalai Tesque). Biphenyl **2f**, polyphosphoric acid (PPA), trifluoroacetic anhydride (TFAA), diphenylamine **3a**, 2-phenylaniline **4a** and azoxybenzene **6a** were reagent grade (Nacalai Tesque), and used without further purification. The following compounds had the same spectral data as those of the compounds synthesized in the previous report:[5c] 4-phenylaniline **5a**, 2- and 4-methyldiphenylamines **3d**$_1$ and **3d**$_2$, 2- and 4-phenyldiphenylamines **3f**$_1$ and **3f**$_2$, 2- and 4-chlorodiphenylamines **3g**$_1$ and **3g**$_2$, and 2,2,2-trifluoro-*N*-phenylacetanilide **3a**′. We could find no *meta*-products by GLC-MS in the reactions of **1a** with **2a**–**g**.

N-Phenylhydroxylamine[7] and phenyl azide[8] were prepared by the methods described in the literature.

Reactions of *N*-phenylhydroxylamine 1a with benzene 2a in the presence of TFA containing PPA or TFAA

The reaction of *N*-phenylhydroxylamine **1a** with benzene **2a** was carried out in the presence of TFA containing PPA or TFAA under the conditions shown in Table 1. After the reactions, aq. Na_2CO_3 was added until the solution reached pH > 7. The organic layer was extracted with CH_2Cl_2, and the yields were determined by HPLC analysis. The products **3a**, **4a**, **5a** and **6** were isolated by thin layer chromatography using silica gel (Merck 60F254) after column chromatography using silica gel (Fujisiriaru Chem. BW-127ZH). The structures of the products were characterised by comparison of their mass spectra and GLC-MS retention times with those of authentic samples. The effect of PPA or TFAA is summarised in Table 1.

Reactions of *N*-phenylhydroxylamine 1a or phenyl azide 1b with benzene 2a in the presence of TFA

The reaction of **1a** or phenyl azide **1b** with **2a** in the presence of TFA was carried out as described in Table 2. The procedures used for isolation and characterisation of the products and the determination of their yields are indicated above. The effect of the precursors **1a** and **1b** is shown in Table 2.

Reactions of *N*-phenylhydroxylamine 1a with benzene 2a or *p*-xylene 2b in the presence of TFA containing PPA

The detailed reaction conditions and the result are indicated in Table 3. Isolation and characterisation of the products **3a**, **4a**, **5a** and **6** and determination of their yields were performed as shown above. The structures of the products **3b**, **4b** and **5b** were confirmed as shown below, and their yields were determined as shown above. The effect of aromatic compounds **2a** and **2b** is indicated in Table 3.

2,5-Dimethyldiphenylamine 3b. Liquid, ν_{max}(neat)/cm^{-1} 3380 (NH), 3012 and 2920 (C–H), 1600 and 1498 (aromatic C=C), 1460 (C–H), 1414, 1313 (C–N), 1240, 1185, 1028, 1035, 1007, 870, 810 (1,2,4-substituted phenyl) and 752 and 700 (monosubstituted phenyl); δ_H ($CDCl_3$) 2.13 (3H, s, Me), 2.23 (3H, s, Me), 4.96–5.36 (1H, br, NH) and 6.50–7.40 (8H, m, phenyl H); *m*/*z* (GLC-MS) 197 (M^+), 182, 167, 165, 120, 97, 90, 77, 65 and 51 (Found: C, 85.06; H, 7.42; N, 7.06. Calc. for $C_{14}H_{15}N$: C, 85.23; H, 7.67; N, 7.10%).

2-(2,5-Dimethylphenyl)aniline 4b. Liquid, ν_{max}(neat)/cm^{-1} 3460 and 3360 (NH_2), 3012 and 2920 (C–H), 1602 and 1495 (aromatic C=C), 1450 (C–H), 1400, 1300 and 1250 (C–N), 1188, 1168, 1150, 1035, 890, 820 (1,2,4-substituted phenyl), 753 (*ortho*-substituted phenyl) and 700; δ_H ($CDCl_3$) 2.10 (3H, s, Me), 2.31 (3H, s, Me), 2.83–4.16 (2H, br, NH_2) and 6.56–7.50 (7H, m, phenyl H); *m*/*z* (GLC-MS) 197 (M^+), 182, 167, 165, 139, 128, 115, 97, 90, 77, 63 and 51 (Found: C, 85.58; H, 7.60; N, 6.82. Calc. for $C_{14}H_{15}N$: C, 85.23; H, 7.67; N, 7.10%).

4-(2,5-Dimethylphenyl)aniline 5b. The brown crystalline product had mp 32.5–33.5 °C; ν_{max}(KBr)/cm^{-1} 3440 and 3380 (NH_2), 3020 and 2920 (C–H), 1620 and 1495 (aromatic C=C), 1450 (C–H), 1265 (C–N), 1090, 1148, 840 (1,2,4-substituted phenyl) and 815 (*para*-substituted phenyl); δ_H ($CDCl_3$) 2.17 (3H, s, Me), 2.27 (3H, s, Me), 3.24–3.64 (2H, br, NH_2) and 6.34–7.27 (7H, m, phenyl H); *m*/*z* (GLC-MS) 197, 181, 167, 165, 141, 128, 115, 97, 90, 77, 65 and 51. The elemental analysis of the

product **5b** was not satisfactory because of the presence of a small amount of impurity probably arising by oxidation.

2,2,2-Trifluoro-2′-phenylacetanilide 4a′. This whitish crystalline compound had mp 95–95.5 °C; ν_{max}(KBr)/cm^{-1} 3250 (NH), 2880 and 3070 (C–H), 1710 (C=O), 1545 and 1485 (aromatic C=C), 1440 (C–H), 1265 (C–N), 1230, 1205, 1187, 1178 and 1162 (C–F), 750 (*ortho*- and monosubstituted phenyl) and 710 (monosubstituted phenyl); δ_H ($CDCl_3$) 7.01–8.41 (10H, m, NH and phenyl H); *m*/*z* (GLC-MS) 265 (M^+), 196, 178, 167, 152, 139, 115, 89, 69, 63 and 51 (Found: C, 63.36; H, 3.93; N, 5.25. Calc. for $C_{14}H_{10}F_3NO$: C, 63.39; H, 3.80; N, 5.28%). This compound was synthesised quantitatively by the reaction of **4a** (3.0 mmol) with TFAA (3.3 mmol) in CH_2Cl_2 (10 cm^3) at 25 °C for 3 h.

2,2,2-Trifluoro-4′-phenylacetanilide 5a′. This white crystalline compound had mp 160.5–161.5 °C; ν_{max}(KBr)/cm^{-1} 3320 (NH), 3120 and 3060 (C–H), 1700 (C=O), 1600, 1580, 1540 and 1490 (aromatic C=C), 1310, 1285 and 1270 (C–N), 1210, 1185 and 1142 (C–F), 845 (*para*-substituted phenyl) and 770 and 700 (monosubstituted phenyl); δ_H ($CDCl_3$–CD_3CN) 7.20–7.95 (9H, m, phenyl H) and 8.76–9.16 (1H, br, NH); *m*/*z* (GLC-MS) 265 (M^+), 195, 168, 152, 141, 115, 98, 84, 70, 69, 63 and 51 (Found: C, 63.27; H, 3.76; N, 5.31. Calc. for $C_{14}H_{10}F_3NO$: C, 63.39; H, 3.80; N, 5.28%). This product was also synthesised quantitatively from **5a** by a method similar to that for the synthesis of **4a′**.

Reactions of *N*-phenylhydroxylamine 1a with various aromatic compounds 2a and 2c–g in the presence of TFA containing PPA at different temperatures and concentrations of TFA

The reaction conditions are shown in Table 4. The effects of aromatics, temperature and reaction time on the yields and the *N*-/*C*-attack ratio are also shown in Table 4. Isolation and characterisation of the products and determination of their yields were by methods similar to those indicated above. However, the structures for the following compounds were confirmed by the spectral data, and their yields were determined as shown below.

2-Methoxydiphenylamine 3c$_1$. The compound was obtained as a mixture containing a small amount of **5**. The ^{1}H NMR was satisfactory after deducting the spectrum of **5** from the total spectrum: δ_H ($CDCl_3$) 3.86 (3H, s, OMe), 5.96–7.81 (1H, br, NH) and 6.65–7.80 (9H, m, phenyl H); *m*/*z* (GLC-MS) 199 (M^+), 184, 167, 166, 156, 154, 129, 128, 100, 92, 77, 65, and 51. The shorter GLC retention time than that for **3c$_2$** and *m*/*z* 167 ($M^+ - MeOH$) and 166 ($M^+ - MeOH_2$) support the *ortho*-structure of **3c$_1$**. The yield was determined by the assumption that the HPLC area-sensitivity for **3c$_1$** is the same as that for **3c$_2$**.

4-Methoxydiphenylamine 3c$_2$. The whitish yellow crystals had mp 105–106 °C; ν_{max}(KBr)/cm^{-1} 3247 (NH), 3000, 2960 and 2832 (C–H), 1597 and 1515 (aromatic C=C), 1443 (C–H), 1318 and 1298 (C–N), 1238, 1250 (C–O), 1193, 1042 (C–O), 852 and 832 (*para*-substituted phenyl) and 758 and 703 (monosubstituted phenyl; δ_H ($CDCl_3$) 3.78 (3H, s, OMe), 5.19–5.84 (1H, br, NH) and 6.66–7.59 (9H, m, phenyl H); *m*/*z* (GLC-MS) 199 (M^+), 184, 167, 154, 129, 128, 99, 83, 77, 65, 64, 63 and 51 (Found: C, 78.65; H, 6.75; N, 7.03. Calc. for $C_{13}H_{13}NO$: C, 78.36; H, 6.56; N, 7.03%).

2-(2-Methoxyphenyl)aniline 4c$_1$. This compound was not isolated, but the structure was confirmed as follows: *m*/*z* (GLC-MS) 199 (M^+), 181, 180, 168 ($M^+ - OMe$), 167, 166, 156, 154, 139, 128, 115, 92, 78, 77, 65, 63 and 51. The shortest GLC retention time among the isomers suggests that this compound has the double *ortho*-form. The yield was obtained by the assumption that the HPLC area-sensitivity for **4c$_1$** is identical with that for **4c$_2$**.

2-(4-Methoxyphenyl)aniline 4c$_2$. This compound was liquid; ν_{max} (neat)/cm^{-1} 3440 and 3352 (NH_2), 3000, 2900 and 2828 (C–H), 1610, 1510 and 1490 (aromatic C=C), 1450 (C–H), 1290 (C–N), 1240 (C–O), 1187 and 1039 (C–O), 835 (*para*-substituted phenyl) and 755 (monosubstituted phenyl); δ_H ($CDCl_3$) 2.93–3.81 (2H, br, NH_2), 3.81 (3H, s, OMe) and 6.60–7.73 (8H, m, phenyl H); *m*/*z* (GLC-MS) 199 (M^+), 184, 166, 156, 139, 128, 115, 99, 84, 79, 77 and 65 (Found: C, 78.42; H, 6.57; N, 6.97. Calc. for $C_{13}H_{13}NO$: C, 78.36; H, 6.56; N, 7.03%).

4-(2- and 4-Methoxyphenyl)anilines 5c$_1$ and 5c$_2$. These products were not isolated. The structure for **5c$_1$** was confirmed by the following spectra: *m*/*z* (GLC-MS) 199 (M^+), 184, 168, 167, 166, 156, 154, 129, 128, 99, 83, 77, 63 and 51. The high relative intensity for *m*/*z* 167 ($M^+ - MeOH$) of **5c$_1$** compared to **4c$_2$** and **5c$_2$** supports the structure of **5c$_1$** has an *ortho*-methoxy group. The product **5c$_2$** had the longest GLC retention time among the isomers, and thus was assigned to the double *para*-form; *m*/*z* (GLC-MS) for **5c$_2$** 199 (M^+), 184, 156, 139, 128, 115, 100, 84, 77 and 65. The yields of **5c$_1$** and **5c$_2$** were also obtained by the assumption that their HPLC area-sensitivities are identical with those of **4c$_1$** and **4c$_2$**, respectively.

2-(2- and 4-Methylphenyl)anilines 4d$_1$ and 4d$_2$. A mixture of these two compounds was obtained; ν_{max}(neat)/cm^{-1} 3432 and 3352 (NH_2), 3008 and 2912 (C–H), 1610 and 1490 (aromatic C=C), 1446 (C–H), 1293 (C–N), 1165, 1110, 825 (*para*-substituted phenyl) and 750 (*ortho*-substituted phenyl) (Found: C, 85.13; H, 6.93; N, 7.94. Calc. for $C_{13}H_{13}N$: C, 85.20; H, 7.15; N, 7.65%); *m*/*z* (GLC-MS) for **4d$_1$** 183 (M^+), 182, 168, 167, 166, 165, 152, 139, 128, 115, 77, 65 and 63; *m*/*z* (GLC-MS) for **4d$_2$** 183 (M^+), 182, 168, 167, 152, 139, 115, 90, 77 and 63. The shortest GLC retention time for **4d$_1$** and *m*/*z* 166 ($M^+ - MeH_2$) suggest that **4d$_1$** corresponds to the double *ortho*-form. The high relative intensity for *m*/*z* 182 supports a methyl substituted phenyl group. These results and the appearance of 825 cm^{-1} (NH_2) for *para*-substitution indicate the structure for **4d$_2$**. The yield for **4d$_1$** and **4d$_2$** is determined by the assumption that their area-sensitivities by HPLC are the same.

4-(2- and 4-Methylphenyl)anilines 5d$_1$ and 5d$_2$. A mixture of these two compounds was obtained; ν_{max}(neat)/cm^{-1} 3440 and 3350 (NH_2), 3004 and 2900 (C–H), 1617, 1503 and 1483 (aromatic C=C), 1450 (C–H), 1276 (C–N), 1190, 1130, 813 (*para*-substituted phenyl) and 765 (*ortho*-substituted phenyl); *m*/*z* (GLC-MS) for **5d$_1$** 183 (M^+), 182, 168, 167, 166, 165, 141, 128, 115, 90, 78, 77 and 65; *m*/*z* (GLC-MS) for **5d$_2$** 183 (M^+), 182, 165, 90, 78, 77 and 65. The peak *m*/*z* 167 ($M^+ - MeH$) suggests the *ortho*-methyl structure. These observations and the presence of the NH_2 group suggest the structure of **5d$_1$**. The GLC retention time for **5d$_2$** is longest among the isomers, so the structure of **5d$_2$** might be the double *para*-form. The yield for **4d$_1$** and **4d$_2$** is also obtained by the assumption that their area-sensitivities by HPLC are the same.

2-Ethyldiphenylamine 3e$_1$. This compound was liquid; ν_{max}(neat)/cm^{-1} 3380 (NH), 3020 and 2960 (C–H), 1595 and 1497 (aromatic C=C), 1450 (C–H), 1413, 1295 (C–N), 1248, 1185, 885, 750 (*ortho*- and monosubstituted phenyls) and 700 (monosubstituted phenyl); δ_H ($CDCl_3$) 1.20 (3H, t, *J* 8.0, Me), 2.57 (2H, q, *J* 8.0, Me*CH*$_2$), 5.00–5.65 (1H, br, NH) and 6.67–7.65 (9H, m, phenyl H); *m*/*z* (GLC-MS) 197 (M^+), 183, 182, 181, 180, 168, 167, 165, 152, 139, 128, 120, 106, 90, 77, 65, 63 and 51 (Found: C, 85.14; H, 7.83; N, 7.05. Calc. for $C_{14}H_{15}N$: C, 85.23; H, 7.67; N, 7.10%).

4-Ethyldiphenylamine 3e$_2$. This was obtained as a mixture with **3e$_1$** and **5**; *m*/*z* (GLC-MS) 197 (M^+), 183, 182, 180, 167, 90, 77, 65 and 51. On the basis of the absence of *m*/*z* 181 ($M^+ - CH_4$) corresponding to an *ortho*-ethyl group, the absorption of 3380 cm^{-1} (NH) and 820 cm^{-1} (*para*-substituted phenyl) for the

mixture and the longer GLC retention time than that for **3e$_1$**, this structure is supported. The yield is determined by the idea that the HPLC area-sensitivity is identical with that of **3e$_1$**.

2-(2- and 4-Ethylphenyl)anilines 4e$_1$ and 4e$_2$ and 4-(2- and 4-ethylphenyl)anilines 5e$_1$ and 5e$_2$. These compounds were not isolated, but their structures were confirmed by the following data: *m*/*z* (GLC-MS) for **4e$_1$** 197 (M^+), 196, 182, 181, 180, 179, 178, 168, 167, 166, 165, 139, 128, 115, 90, 78, 77, 65, 63 and 51; *m*/*z* (GLC-MS) for **4e$_2$** 197 (M^+), 196, 183, 182, 180, 168, 167, 166, 165, 139, 115, 91, 90, 77, 65 , 63 and 51; *m*/*z* (GLC-MS) for **5e$_1$** 197 (M^+), 182, 181, 180, 142, 115, 90, 78, 77, 76, 65, 63 and 51; *m*/*z* (GLC-MS) for **5e$_2$** 197 (M^+), 182, 165, 90, 77 and 65. The relatively high intensity for *m*/*z* 196 ($M^+ - H$) for **4e$_1$** and **4e$_2$** indicates the *ortho*-amino structure. These compounds were determined by the idea that the order for the GLC retention times is **4e$_1$ < 4e$_2$ < 5e$_1$ < 5e$_2$**, considering the following orders for GLC retention times: **4d$_1$ < 4d$_2$ < 5d$_1$ < 5d$_2$** and **4c$_1$ < 4c$_2$ < 5c$_1$ < 5c$_2$**. The yield for these compounds is obtained by the idea that their HPLC area-sensitivities are the same as those for **3e$_1$** and **3e$_2$**.

2-(2- and 4-Aminophenyl)biphenyls 4f$_1$ and 5f$_1$. A mixture of the two compounds was obtained; ν_{max}(KBr)/cm^{-1} 3468 and 3368 (NH_2), 1613, 1585 and 1485 (aromatic C=C), 1453 (C–H), 1398, 1313 (C–N), 1015, 840 (*para*-substituted phenyl) and 709, 752 and 766 (mono- and *ortho*-substituted phenyls); *m*/*z* (GLC-MS) for **4f$_1$** 245 (M^+), 244 ($M^+ - H$), 228 ($M^+ - NH_3$), 217, 202, 168, 167, 122, 121, 115, 114, 113, 101, 94, 77 and 63; *m*/*z* (GLC-MS) for **5f$_1$** 245 (M^+), 244 ($M^+ - H$), 243 ($M^+ - H_2$), 168, 167 ($M^+ - PhH$), 152, 139, 115, 77 and 63. The high relative intensity for *m*/*z* 244 and 228 supports the *ortho*-amino structure for **4f$_1$**. The product **5f$_1$** might show the high relative intensity for *m*/*z* 243 and 167 without giving *m*/*z* 228. The order for the GLC retention times, **4f$_1$ < 4f$_2$ < 5f$_1$ < 5f$_2$**, supports these structures.

4-(2- and 4-Aminophenyl)biphenyls 4f$_2$ and 5f$_2$. A mixture consisting of the two compounds was obtained; ν_{max}(KBr)/cm^{-1} 3464 and 3376 (NH_2), 1623, 1610 and 1523 (aromatic C=C), 1475, 1450 and 1440 (C–H), 1292 (C–N), 1198, 840 (*para*-substituted phenyl) and 770, 756 and 708 (*ortho*- and monosubstituted phenyls); δ_H ($CDCl_3$) 3.18–4.58 (2H, br, NH_2) and 6.38–7.78 (13H, m, phenyl H) (Found: C, 87.87; H, 6.41; N, 5.71. Calc. for $C_{18}H_{15}N$: C, 88.13; H, 6.16; N, 5.71%); *m*/*z* (GLC-MS) for **4f$_2$** 245 (M^+), 244 ($M^+ - H$), 243, 230, 228 ($M^+ - NH_3$), 227, 226, 217, 216, 215, 202, 189, 122, 121, 115, 114, 113, 108, 107, 94, 80 and 63; *m*/*z* (GLC-MS) for **5f$_2$** 245 (M^+), 226, 215, 202, 152, 123, 109, 94, 77 and 63. The product **4f$_2$** shows the high relative intensity for *m*/*z* 244 and *m*/*z* 228. The compound **5f$_2$** indicates the strong relative intensity for *m*/*z* 245, but the relative intensity for the other mass spectral peaks is very low. These observations and the above order for retention times, **4f$_1$ < 4f$_2$ < 5f$_1$ < 5f$_2$**, support these structures.

2-(2-Chlorophenyl)aniline 4g$_1$. This compound was liquid; ν_{max}(neat)/cm^{-1} 3450 and 3370 (NH_2), 3025 and 3070 (C–H), 1648 and 1500 (aromatic C=C), 1470, 1450 and 1430 (C–H), 1300 (C–N), 1270, 1170, 1080, 1038, 1010 and 767, 750 and 680 (mono- and *ortho*-substituted phenyls); δ_H ($CDCl_3$) 3.03–4.13 (2H, br, NH_2) and 6.61–7.93 (8H, m, phenyl H); *m*/*z* (GLC-MS) 205 and 203 (M^+), 168 ($M^+ - Cl$), 167 ($M^+ - HCl$), 139, 115, 101, 83, 70, 63 and 51. The high relative intensity for *m*/*z* 167 and 168 and the shortest retention times among **4g** and **5g** (*i.e.* **4g$_1$ < 4g$_2$ < 5g$_1$ < 5g$_2$**) support this structure. The elemental analysis was not satisfactory due to the presence of a small amount of impurity.

2-(4-Chlorophenyl)aniline 4g$_2$. This compound was not isolated, but the structure was confirmed by the following data: *m*/*z* (GLC-MS) 205 and 203 (M^+), 204 and 202 ($M^+ - H$), 168, 167, 139, 115, 83, 70, 63 and 57. The appearance of *m*/*z* 204 and 202 indicates the presence of an *ortho*-amino group. The structure was determined by the idea that the order for GLC retention time of the isomers becomes **4g$_1$ < 4g$_2$ < 5g$_1$ < 5g$_2$** as this order is similar to the order in the methoxy, methyl, ethyl and phenyl derivatives.

4-(2- and 4-Chlorophenyl)anilines 5g$_1$ and 5g$_2$. A mixture of these compounds was obtained; ν_{max}(neat)/cm^{-1} 3400, 3340 and 3180 (NH_2), 3020 and 2900 (C–H), 1618 and 1570 (aromatic C=C), 1470 (C–H), 1282 (C–N), 1190, 1134, 1105, 1080, 1040, 1010, 820 (*para*-substituted phenyl) and 760 (*ortho*-substituted phenyl); δ_H ($CDCl_3$) 3.07–4.14 (2H, br, NH_2) and 6.51–7.77 (8H, m, phenyl H) (Found: C, 71.06; H, 4.68; N, 6.86. Calc. for $C_{12}H_{10}NCl$: C, 70.77; H, 4.95; N, 6.88%). The GLC-MS for these compounds are as follows: *m*/*z* for **5g$_1$** 205 and 203 (M^+), 167, 139, 115, 101, 83, 70, 63 and 51; *m*/*z* for **5g$_2$** 205 and 203 (M^+), 167, 139, 115, 101, 83, 70 and 63. The high relative intensity of *m*/*z* 167 ($M^+ - HCl$) for **5g$_1$** compared to **5g$_2$** and the above order for retention time **4g$_1$ < 4g$_2$ < 5g$_1$ < 5g$_2$** support these structures.

Hammett plots

A solution of **1a** (1.0 mmol) in a mixture of TFA (3.0 cm^3) and an aromatic substrate containing benzene (4.0 cm^3) and another aromatic compound (1.0 cm^3) such as toluene **2d**, ethylbenzene **2e**, biphenyl **2f** or chlorobenzene **2g** was allowed to stand in the presence of PPA (100 mg) at 20 °C for 0.5 h. The molar ratio of **1a** to aromatic substrate was less than 1 : 50. After the reaction mixture had been treated as described above, the ratios **3d$_2$/3a**, **3e$_2$/3a**, **3f$_2$/3a**, **3g$_2$/3a**, **5d$_2$/5a**, **5e$_2$/5a**, **5f$_2$/5a** and **5g$_2$/5a** were determined by HPLC. The *N*- and *C*-attacking partial rate factors (k_f) were calculated on the basis of the above ratios, initial concentration of the aromatic compounds and the number of C–H bonds in benzene and *para*-C–H bond of the substituted aromatics; *e.g.* k_f for *N*-substitution of *p*-Me = (**3d$_2$/3a**)(6/1)-[**2a**]$_0$/[**2b**]$_0$. A linear plot with $\rho = -5.2$ for the *N*-attack or $\rho = -4.0$ for the *C*-attack was obtained as shown in Fig. 1. Their correlation coefficients were −0.996.

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