Bromoiodinanes with an I(III)–Br bond: preparation, X-ray crystallography and reactivity as electrophilic brominating agents†

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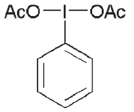
Bromoiodinanes—conveniently and directly prepared from iodobenzenecarbinols and *N*-bromosuccinimide, and characterised for the first time crystallographically—act as electrophilic bromine donors.

The use of hypervalent iodine reagents in synthetic organic chemistry is a field of much current interest,[1,2] exemplified by the Dess–Martin periodinane[3] and IBX[4] reagents. We have recently described the use of stoichiometric quantities of di(acetoxy)iodobenzene "DIB" (**1**) in combination with stoichiometric quantities of lithium bromide to generate an electrophilic source of bromine for the electrophilic monobromination of electron rich aromatics and heteroaromatics, and for the dibromination of alkenes when an additional equivalent of LiBr is present.[5] We postulated that the *de facto* reactive reagent in the mixture was hypervalent iodine compound **2**, with an I(III)–Br bond, but were unable to isolate such a species. Previous combinations of DIB **1** with bromide sources: TMSBr,[6] Bu_4NBr[7] and Et_4NBr[8] have been suggested to give rise to molecular bromine, AcOBr and $Br(OAc)_2$ as the actual electrophilic bromine sources, respectively.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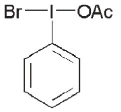
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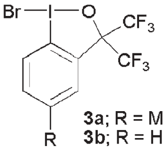
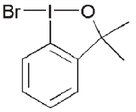

3a; R = Me
3b; R = H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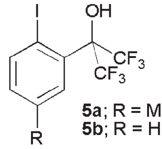
There is only one report in the literature of isolated hypervalent iodine compounds with an I(III)–Br bond *viz.* trigonal bipyramidal bromoiodinanes **3a** and **4**, where two sets of lone pairs on iodine occupy equatorial positions.[9] The authors attributed their ability to isolate these compounds to the inclusion of the hypervalent iodine atom in a five-membered ring, the Thorpe–Ingold effect of the *gem*-dialkyl groups and the inclusion of an additional (other than bromine) stabilising electronegative atom (oxygen) at the other apical position on iodine. By consideration of this latter factor, the *gem*-trifluoromethyl compound **3a** was expected to be more stable than *gem*-dimethyliodinane **4**. This was found to be the case, as witnessed by the stability of **3a** to aqueous KOH, where under similar conditions **4** was completely hydrolysed. Iodinanes **3a** and **4** were found to act as efficient free-radical bromination reagents of benzylic and allylic substrates upon irradiation. Their structural similarity to our proposed brominating agent **2** in the DIB–LiBr system is striking. However, there was no report on their ability to act as electrophilic bromine sources. Guided by Amey and Martin's work,[9] we have now prepared **3b** and **4**. Our aim was to characterise the I(III)–Br bond in these systems and to examine their propensity to act as electrophilic bromine sources. Herein we report a novel single-step preparation of **3b** and **4**, the first X-ray crystal structures of bromoiodinanes, thereby allowing the determination of I(III)–Br bond lengths, and on the ability of **3b** and **4** to act as electrophilic sources of bromine.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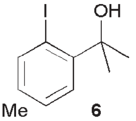
5b; R = H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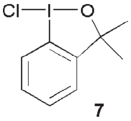
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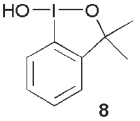
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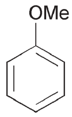
Amey and Martin prepared **3a** *via* direct treatment of alcohol **5a** with potassium hydride and molecular bromine, but this approach for **6** to **4** failed.[9] Instead, they treated alcohol **6** with *tert*-butyl hypochlorite to give the chloroiodinane **7**, which was hydrolysed to hydroxyiodinane **8** and then treated with HBr in the presence of P_2O_5 to generate **4**. We elected to pursue a one-step synthesis of both **3b** and **4** from the corresponding alcohols **5b**[10] and **6**[9], respectively. After some experimentation, it was discovered that stoichiometric *N*-bromosuccinimide (NBS) is a suitable reagent for such a transformation, directly delivering **3b** and **4** in 56%‡ and 60%§ yields, respectively, after recrystallisation. The side-product from these reactions is succinimide.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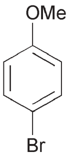
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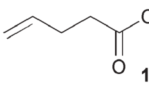
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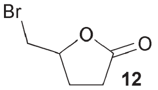
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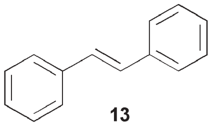
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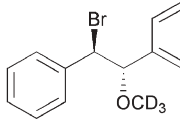
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Compounds **3b** and **4** were tested as stoichiometric sources of electrophilic bromine for the electrophilic aromatic substitution

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† Electronic Supplementary Information (ESI) available: Full crystallographic data for compounds **3b** and **4**. See DOI: 10.1039/b600455e

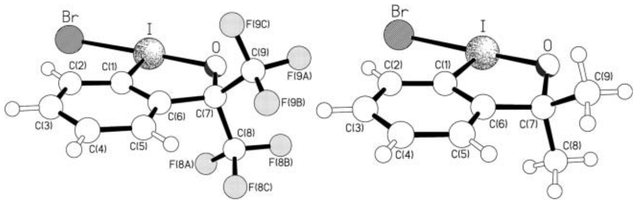

Fig. 1 The molecular structures of **3b** (left) and **4** (right).

of anisole (**9**) to give bromoanisole **10**, for the bromolactonisation of 4-pentenoic acid (**11**) into bromolactone **12**, and the intermolecular bromoetherification with (deuterated) methanol of *trans*-stilbene (**13**) into (±)-1,2-bromoether **14**. Bromoiodinane **3b** gave a 7% conversion of **11** into **12** ($CDCl_3$, 24 h, r.t.). In contrast, the more reactive bromoiodinane **4** gave quantitative conversion of **9** into **10**[5] ($CDCl_3$, 15 h, r.t.), **11** into **12**[5] ($CDCl_3$, 15 h, r.t.) and **13** into **14**[11] ($CDCl_3$, 18 h, r.t.). In all cases, carbinol **6** was the sole side-product. It is of interest to note that, in direct contrast to the use of iodinane **4**, attempted bromolactonisation of **11** with molecular bromine gives significant competitive 1,2-dibromination of the olefin.[5] This suggests that molecular bromine is not generated in this system. Bromolactonisation of **11** is therefore suggested to proceed *via* a bromonium ion by direct electrophilic bromine transfer from the iodinane. A bromonium ion is also implicated as the intermediate in the transformation of **13** into bromoether **14**. The observed *para*-substitution of **9** is also consistent with the expected directing group effect of an electrophilic substitution reaction.

The X-ray analyses (Fig. 1, Table 1) of crystals of **3b**[12] and **4** show that both iodine centres adopt a planar T-geometry (*i.e.* a trigonal bipyramid shape overall), as expected. The five-membered C_3OI rings have an envelope conformation, with the oxygen atom lying *ca.* 0.23 Å (for **3b**) and *ca.* 0.44 Å (for **4**) out of the C_3I plane. This distortion in the position of the oxygen atoms manifests itself as a twisting about the I–C(1) bond so that the bromine is moved to the other side of the plane (see Fig. S2 and Fig. S5 in the ESI†); the torsion angle about the I–C(1) bond is *ca.* 7° for **3b** and *ca.* 9° for **4**. In both cases, the closest intermolecular approach to the iodine centre is from the oxygen of a centrosymmetrically related counterpart at *ca.* 3.03 Å (**3b**) and *ca.* 2.94 Å (**4**), forming discrete dimer pairs (see Fig. S3 and Fig. S6 in the ESI†). Most notably, whilst the I–C(1) bond length is essentially constant (2.120(8) Å in **3b** and 2.112(7) Å in **4**), the I–O and I–Br bond lengths vary considerably in **3b** and **4**, presumably due to the effect of the electron withdrawing *gem*-trifluoromethyl groups on the three centre-four electron O–I(III)–Br bond. The I–O bond length is *ca.* 2.12 Å in **3b** and *ca.* 2.05 Å in **4**. The I(III)–Br bond lengths are *ca.* 2.59 Å and *ca.* 2.69 Å, respectively. To the best of our knowledge, these bond lengths are the first to be obtained for I(III)–Br bonds. These compare with bond lengths of 2.29 Å, 2.47 Å and 2.66 Å for molecular Br_2, Br–I and I_2 bonds, respectively.[13]

Table 1 Comparative selected bond lengths (Å) and angles (°) for **3b** and **4**

	3b	**4**		**3b**	**4**
I–Br	2.5945(11)	2.6927(8)	I–O	2.118(6)	2.050(5)
I–C(1)	2.120(8)	2.112(7)			
Br–I–O	172.80(17)	172.46(16)	Br–I–C(1)	94.1(2)	93.25(18)
O–I–C(1)	79.0(3)	80.3(2)	I–O–C(7)	116.1(5)	114.5(4)

In conclusion, we have demonstrated that bromoiodinanes with an I(III)–Br bond act as sources of electrophilic bromine. They are prepared in a novel one step procedure from iodobenzenecarbinols with NBS, allowing the characterisation of I(III)–Br bond lengths by X-ray crystallography. These results also support the proposition that the actual brominating agent in the DIB–LiBr system[5] is hypervalent iodine compound **2**, containing an I(III)–Br bond.

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Notes and references

‡ 1-Bromo-3,3-bis-trifluoromethyl-1,3-dihydro-1λ^3-benzo[*d*][1,2]iodoxole (**3b**; R = H): To a solution of crude 1,1,1,3,3,3-hexafluoro-2-(2-iodophenyl)-propan-2-ol (**5**; R = H, 1.5 g, 4.1 mmol) stirring in $CHCl_3$ (16 mL) at room temperature was added portion-wise NBS (721 mg, 4.1 mmol). The reaction mixture was stirred for 18 h, diluted with further $CHCl_3$ (24 mL), washed with water (2 × 40 mL) and brine (50 mL), dried over $MgSO_4$ and concentrated to give a sticky orange solid. Recrystallisation (EtOAc/hexane) yielded **3b** (1.00 g, 56%) as shiny yellow plates: m.p. 190–191 °C; R_f 0.77 (CH_2Cl_2); FT-IR (NaCl/$CDCl_3$) ν_{max} 1587, 1559, 1457, 1437, 1265, 1193 and 1103 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 8.03 (dd, *J* = 8.3, 1.1 Hz, 1 H, Ar-*H*), 7.80 (dt, *J* = 7.1, 1.5 Hz, 1 H, Ar-*H*), 7.74 (dt, *J* = 6.9, 0.8 Hz, 1 H, Ar-*H*) and 7.66 (br-d, *J* = 7.1 Hz, 1 H, Ar-*H*); ^{13}C NMR (68 MHz, $CDCl_3$) δ 133.8, 132.5, 131.9, 130.0, 129.7 (septet, *J* = 3 Hz), 122.8 (q, *J* = 289 Hz), 109.9 and 84.2 (septet, *J* = 33 Hz); MS (EI^+) 450, 448 (M^+), 381, 379 ($M - CF_3^+$) and 269 ($M - Br^+$); HRMS calc. for $C_9H_4{}^{79}BrF_6IO$ 447.8394 and $C_9H_4{}^{81}BrF_6IO$ 449.8374, found 447.8396 and 449.8380, respectively; anal. calc. for $C_9H_4BrF_6IO$: C 24.08, H 0.90; found: C 23.91, H 0.86. *Crystal data*: $C_9H_4BrF_6IO$, *M* = 448.93, orthorhombic, *Pbca* (no. 61), *a* = 9.663(3), *b* = 14.7448(17), *c* = 16.435(3) Å, *V* = 2341.6(8) $Å^3$, *Z* = 8, D_c = 2.547 g cm^{-3}, μ(Mo-K_α) = 6.210 mm^{-1}, *T* = 203 K, yellow tablets; 2056 independent measured reflections, R_{int} 0.00%, F^2 refinement, R_1 = 0.045, wR_2 = 0.100, 1493 independent observed absorption-corrected reflections [$|F_o| > 4\sigma(|F_o|)$, $2\theta_{max}$ = 50°], 164 parameters. CCDC 259288. For crystallographic data in CIF or other electronic format see DOI: 10.1039/b600455e

§ 1-Bromo-3,3-dimethyl-1,3-dihydro-1λ^3-benzo[*d*][1,2]iodoxole (**4**): To a solution of crude 2-(2-iodo-phenyl)propan-2-ol (**6**; 3.00 g, 11.5 mmol) stirring in $CHCl_3$ (30 mL) at room temperature was added portion-wise NBS (2.45 g, 13.7 mmol). The reaction mixture was stirred for 18 h, diluted with further $CHCl_3$ (30 mL), washed with water (2 × 50 mL) and brine (50 mL), dried over $MgSO_4$ and concentrated to give a yellow solid. Recrystallisation (EtOAc/hexane) yielded **4** (2.34 g, 60%) as shiny yellow crystals: m.p. 126–128 °C [lit.,[8] 98–100 °C]; FT-IR (NaCl/$CDCl_3$) ν_{max} 3076, 3053, 3005, 2980, 2924, 2860, 1589, 1560, 1460, 1435, 1377, 1362, 1215, 1153, 1109, 995, 939 and 860 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 7.97 (m, 1 H, Ar-*H*), 7.55–7.49 (m, 2 H, Ar-*H*), 7.13 (m, 1 H, Ar-*H*) and 1.54 (s, 6 H, CH_3); ^{13}C NMR (68 MHz, $CDCl_3$) δ 149.9, 131.2, 130.5, 129.4, 126.0, 112.1, 84.3 and 29.3; MS (EI^+) 342, 340 (M^+), 327, 325 ($M - CH_3^+$) and 262 ($M - Br^+$); HRMS calc. for $C_9H_{10}{}^{79}BrIO$ 339.8960 and $C_9H_{10}{}^{81}BrIO$ 341.8939, found 339.8959 and 341.8938, respectively; anal. calc. for $C_9H_{10}BrIO$: C 31.70, H 2.96; found: C 31.86, H 2.99. *Crystal data*: $C_9H_{10}BrIO$, *M* = 340.98, triclinic, $P\bar{1}$ (no. 2), *a* = 8.115(2), *b* = 8.2108(17), *c* = 9.1784(19) Å, α = 106.812(12), β = 91.202(18), γ = 114.00(2)°, *V* = 528.1(2) $Å^3$, *Z* = 2, D_c = 2.144 g cm^{-3}, μ(Mo-K_α) = 6.769 mm^{-1}, *T* = 203 K, yellow blocks; 1581 independent measured reflections, R_{int} 2.04%, F^2 refinement, R_1 = 0.044, wR_2 = 0.112, 1496 independent observed absorption-corrected reflections [$|F_o| > 4\sigma(|F_o|)$, $2\theta_{max}$ = 50°], 109 parameters. CCDC 259289. For crystallographic data in CIF or other electronic format see DOI: 10.1039/b600455e

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