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The Solid-state Hierarchy and Iodination Potential of \([\text{bis}(3\text{-acetaminopyridine})\text{iodine(I)}]\)PF\(_6\)

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The first iodine(I) complex bearing hydrogen-bond donor and acceptor groups, \([\text{bis}(3\text{-acetaminopyridine})\text{iodine(I)}]\)PF\(_6\) (3), was synthesised, which exhibited two temperature-dependent solid-state connectivities of the hydrogen bonding. Upon reaction of 3 with \(t\text{BuOMe}\), unprecedented iodination of a \(t\text{Bu}\) methyl group proceeded under exceptionally mild conditions in good yield.

Halogen bonding has rapidly matured into one of the most studied intermolecular interactions, and comparisons can be drawn with hydrogen bonding. Hydrogen-bonded networks have a well-established history of practical uses, from body armour to constituting the double helix of our DNA, and whilst not as ubiquitous, the advantages of halogen bonding, like a closely related family of carbonyl or alkyl hypoiodites (R‒OI; R = alkyl or alkanyl), recently demonstrated for the first time to be comparable to halogen-bonded iodine(I) species,\(^5\) are often utilised as in situ generated reagents.\(^6\)\(^,\)\(^7\) The closely related family of carbonyl or alkyl hypohalides (R‒O\(_X\); R = carboxylic or alkyl), recently demonstrated for the first time to be comparable to halogen-bonded iodine(I) species,\(^8\)\(^,\)\(^9\) are often utilised as in situ generated reagents.\(^5\)\(^,\)\(^1\)\(^1\) Alkyl hypohalides such as \(\text{"BuOCl}\)\(^1\)\(^2\)\(^,\)\(^1\)\(^3\) for which the exact reactive species is still under debate,\(^1\)\(^4\) have been reported to perform different synthetic conversions such as the synthesis of neopentyl iodide from unactivated neopentane (Scheme 1).\(^1\)\(^5\) However, iodinations are predominantly limited to substrates which possess sacrificial functional groups (e.g., hydroxyl or carboxylic acids),\(^1\)\(^6\)\(^,\)\(^1\)\(^8\)\(^,\)\(^1\)\(^9\) require exotic reagents or methodologies.\(^2\)\(^1\)\(^,\)\(^2\)\(^2\) and entail multi-step syntheses.\(^2\)\(^1\)\(^,\)\(^2\)\(^2\) Given that the formation of C–I functionalities remains non-trivial, this creates a void in the literature that iodine(I) species might be able to fill with further research, especially as C–I compounds are of great utility and can act as feedstocks in a wide range of synthetic procedures such as Pd-cross coupling reactions.\(^2\)\(^3\)\^-\(^2\)\(^5\)

The concept of hierarchical materials, that is materials with structural elements which themselves have structure,\(^2\)\(^6\) have found success in a variety of fields including bio-inspired and biomimetic materials,\(^2\)\(^7\)\^-\(^2\)\(^8\) as well as toward materials for medical applications.\(^2\)\(^9\)\^-\(^2\)\(^0\) To date, examples of iodine(I) complexes in the solid-state incorporate pyridine,\(^3\)\(^1\) or pyridine derivatives with no secondary functional groups capable of meaningful intermolecular interactions,\(^3\)\(^2\)\^-\(^3\)\(^3\) only with a handful of examples of a single ligand, 4-aminopyridine (4-NH\(_2\)py), capable of enabling strong hydrogen-bonded intermolecular interactions.\(^3\)\(^4\) However, the prior solid-state examples incorporating 4-NH\(_2\)py were all limited to demonstrating ion pair interactions with their halide anions, owing to their direct synthesis from \(I\)\(_2\) or IX (X = Cl, Br).\(^3\)\(^4\) The 3-acetaminopyridine (1) ligand was synthesised according to a literature procedure from 3-aminopyridine,\(^3\)\(^5\) and straightforwardly incorporated into the iodine(I) complex \([I(1)\text{PF}_6] (3)\) in a one-pot reaction via its respective silver(I) complex, \([\text{Ag}(1)\text{PF}_6] (2)\), Scheme 2). The \(^1\)H NMR spectra in CD\(_3\)CN of 1-3 were as expected, showing the single alkyl peak for the acetyl group, and five peaks in the aromatic region for the four distinct aromatic groups and the NH group. The series also clearly showed the trend of moving downfield to higher frequency going from 1 to 3 (Fig. 1), with the largest coordination shift (\(\Delta\delta\)) of 0.52 ppm observed for the aromatic hydrogen atom at the 2-position (H\(_2\) in Fig. 1) of 2 (8.78 ppm).
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Fig. 2

The solid-state packing of four molecules of

Scheme 2 The synthetic procedure to generate the iodine(I) complex 3 from ligand 1 via

the silver(I) complex 2.

and 3 (9.30 ppm). This trend was observed for all

1H NMR peaks except for the aromatic hydrogen atom at the 4-position (H₆ in

Fig. 1) of 1 (8.02 ppm) and 2 (8.02 ppm), which was unaffected

by coordination to the Ag⁺ centre in 2.

The ¹H-¹⁵N HMBC determined ¹⁵N NMR chemical resonances

also demonstrated the same trend of coordination shifts for the

pyridinic peaks of 1 (-63.7 ppm), 2 (-85.8), and 3 (-174.5 ppm),

which has been previously observed for similar systems.⁸,³² The

¹⁵N NMR resonance for 2 (-85.8) was lower than other

analogous bis(substituted pyridine)silver(I) complexes reported

(δ₅ ~110-140), but this is due to the NMR solvent being

CD₃CN,³⁶,³⁷ as opposed to the much more commonly used (and

non-coordinating) solvent CD₂Cl₂.¹³ This was supported by the

single crystal X-ray diffraction (SCXRD) structure of 2 (Fig. S1),

where each Ag⁺ centre was found to be weakly coordinated to

two CH₃CN molecules, with Ag…NCMe distances of 2.722(3)

and 2.756(3) Å. This did not affect the characteristic Ag–N bond

lengths of 2.183(2) and 2.189(2) Å, and a N–Ag–N angle of

174.40(8)°, which agree well with other 2-coordinate silver(I)

complexes incorporating pyridine-based ligands.³¹

Interestingly, two solid-state structures of the same

composition (polymorphs) were observed for 3, viz. 3_1 and

3_2, with 3_2 containing two crystallographically independent

molecules in the asymmetric unit cell (3_1 only has one

molecule in the asymmetric unit). The important structural

features of the two polymorphs both fall within the expected

values for iodine(I) complexes, with I–N bond lengths of

2.237(5)/2.296(5) Å for 3_1, and 2.250(5)/2.251(4) Å and

2.253(4)/2.255(4) Å for the two independent molecules of 3_2,

and N–I–N angles of 175.7(2)° (3_1), 177.2(2)° (3_2), and

177.8(2)° (3_2). Iodine(I) ions, and halogen(I) ions generally,
do not typically demonstrate meaningful intermolecular

interactions in the solid state, though some examples (I"−I", I"…Ag") have been reported.³³,³⁶–⁴⁰ Whilst 3_2 exhibited no

close contacts, with only I"…F–PF₆ interactions of 3.779(4) Å or

longer (cf. van der Waals radii of I + F = 3.45 Å), 3_1 was found

to have close I"…F–PF₆ intermolecular interactions of 3.333(9)

and 3.520(6) Å from two disordered positions of the same PF₆

Fig. 1 The superimposed ¹H NMR spectra in CD₃CN (298 K) of 1 (red), 2 (green), and 3

(blue), annotated with the hydrogen atom assignments, showing the downfield-shifted
trend of coordination shifts going from 1 to 3.

Fig. 2 The solid-state packing of four molecules of 3_1 (top; viewed down the a-axis) showing the 1D chain of hydrogen-bonded iodine(I) cations (hydrogen bonds represented by

red dashed lines), and sideview (bottom).

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definitely confirmed by SCXRD (Fig. 4). The two important routinely used etheric solvents (commonly used as anti-solvents no similar reactivity of iodine(I) complexes reacting with more interestingly, the installation of an iodine atom on a methyl group of that incorporated a unique to an iodine(I) complex incorporating ligand 1, it is also reasonable to propose that the acetylamino substituent facilitates the process in some manner. A straightforward mechanistic explanation for 4 would be the reaction of 'BuOMe with complex 3 as a source of "I"+, generating the reactive hypoiodite species IO Me and 'Bu' (Fig. S7). The 'Bu' would then go on to lose a proton to become 2-methylpropene (isobutene). The alkene group of the 2-methylpropene would in turn react with a source of "I" (either from complex 3 or the in situ generated IO Me) and a molecule of 1 (liberated from 3 to generate the initial reactive source of "I"+, [I(1)])4.4 would act as a nucleophile to form the new pyridinic N-C bond with the newly formed [CMe2(CH2)]I" fragment. Whilst grounded in the literature, this proposed mechanism does not explain why this reactivity is only observed for 3 and has not been reported for other iodine(I) complexes, given that 'BuOMe is a commonly used crystallisation anti-solvent, e.g., [I(quinuclidine)2]ClO4,36 or whilst 'BuOMe was used as the solvent during the iodination of other substrates.45 In conclusion, the first example of a hydrogen-bonded halogen(I) complex, [bis(3-acetaminoypyridine)iodine(I)]PF6 (3), was synthesised from the 3-acetaminopyridine (1) ligand via the analogous silver(I) complex 2. Complex 3 was found to possess all the expected spectroscopic and structural features of an iodine(I) complex, and two temperature-dependent crystallographic polymorphs were observed (3_1 and 3_2) that demonstrated different hydrogen-bonded connectivities between the [(I)I]+ cations of 3. In solution, complex 3 was found to demonstrate never before observed reactivity for an iodine(I) complex, whereupon it reacted with 'BuOMe to give the complex 4 in good yield, which incorporated an iodinated 'Bu substituent. The observation of 4 is highly novel and more extensive studies are currently underway to explore its future utilisation of 3 in organic transformations.

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Conflicts of interest

There are no conflicts to declare.

Notes and references

† The data for 3_2 reported herein was actually collected on crystals grown by MeCN evaporation for reasons of crystal quality, however, the unit cell and packing motif of 3_2 was also identified from crystals grown from CH$_2$Cl$_2$-MeCN (7:1)/pentane.