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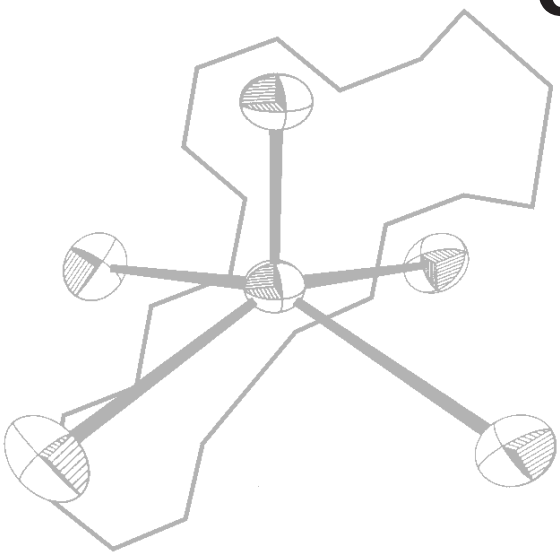

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Reaction of Imidazoles with Cyanogen Bromide: Cyanation at N 1 or Bromination at C 2?

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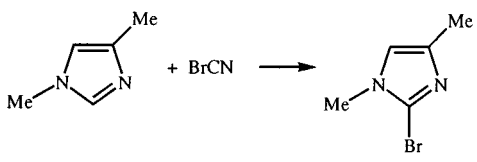
The reaction in acetonitrile solution of a number of imidazoles (1*H*-, 1-methyl-, 2-methyl-, 4-methyl-, 1,2-, 1,4- and 1,5-dimethyl-, 1-ethyl-, 1-benzyl- and 1-butyl-imidazole) and imidazole complexes ($[Co(NH_3)_5(imH)](ClO_4)_3$, $[Co(NH_3)_5(im)](ClO_4)_2$ and $[Co(NH_3)_5(1\text{-Meim})](ClO_4)_3$) with BrCN has been studied. Those imidazoles bearing an *N*-alkyl substituent and having a hydrogen at C 2 react to give the 2-bromo products, while the N–H imidazoles react to give *N*-cyano derivatives. The product(s) from the reaction of 1,2-dimethylimidazole with BrCN could not be characterized. Of the complexes, only $[Co(NH_3)_5(im)](ClO_4)_2$ reacts, giving the 2-bromo product. Our observations suggest a lone pair on a ring nitrogen atom is necessary for an imidazole to react with BrCN, and a possible mechanism is suggested. The X-ray structure of 2-methylimidazole-1-carbonitrile is reported. Crystal data (−143°C) for $C_5H_5N_3$: monoclinic, $P\,2_1/c$, a 10·201(5), b 7·110(3), c 7·227(3) Å, β 100·47(2)°, V 515·4(4) Å^3, Z 4, d_{calcd} 1·380 g cm^{-3}. Refinement of the structure converged with R_1 0·0444 for 1183 reflections with $F_o > 4F(F_o)$ and wR_2 0·1259 for all 1278 data.

Introduction

The reaction of imidazoles with bromine in aqueous and non-aqueous solution usually proceeds rapidly to give bromination at all available carbon sites.[1] Studies of such reactions have shown that the 2-position is invariably the least reactive towards bromine (and other electrophilic brominating reagents) and, indeed, electrophilic bromination at C 2 without concomitant bromination at the other carbon sites is impossible.[2] This usually necessitates the use of indirect methods to prepare 2-bromoimidazoles.[3] Given the current interest in the synthesis of 2-substituted imidazoles[4] and the use of 2-bromoimidazoles as starting materials in the synthesis of such compounds,[5] it is surprising that the early (1928) work of Langenbeck concerning the reaction of imidazoles with cyanogen bromide (BrCN) has not received further attention. He reported that 1,4-dimethylimidazole reacted with BrCN to give 2-bromo-1,4-dimethylimidazole (Scheme 1) while both pilocarpine and isopilocarpine reacted similarly to give the 2-bromo derivatives.[6] However, the few subsequent studies of reactions of imidazoles with BrCN have given somewhat conflicting results. Giesemann showed that both imidazole and 4-methylimidazole reacted with BrCN in ether to give respectively 1-cyanoimidazole* and a mixture of 1-cyano-4-methylimidazole and 1-cyano-5-methylimidazole,[7] while Purygin and Pan'kov recently reported the synthesis of 1-cyano-2-methylimidazole from the reaction of 2-methylimidazole with BrCN in refluxing benzene.[8] Although *N*-cyanoazoles are relatively rare, they are currently of interest due to their capacity to act as CN^+ transfer agents[9] and as reagents for non-enzymic ligation of double-helical DNA,[10] and new routes to the synthesis of such compounds are being sought.[11,12] To date, no *N*-cyanoazoles have been structurally characterized. Recently, it was reported that reaction of imidazole with BrCN gave diimidazole imine



Scheme 1

* Under IUPAC recommendation R-4.1, the systematic name should be imidazole-1-carbonitrile. Such names will be used in the Experimental section.

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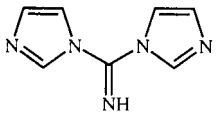
(1)[13] and 1-carbamoylimidazole,[14] presumably via the intermediacy of 1-cyanoimidazole, while Whitten and coworkers showed that treatment of a number of imidazoles with a mixture of BrCN/dimethylaminopyridine gave the corresponding 2-cyanoimidazoles.[15] During our studies of the bromination of cobalt(III)-coordinated imidazoles,[16] we became interested in the mechanism of the reaction of BrCN with imidazoles, as the variety of products and the orientation of bromination preclude a simple electrophilic mechanism. In this paper, we report the results of our studies of the reaction of a number of imidazoles with BrCN to give both *C*-brominated and *N*-cyanated products, and present a reaction mechanism which accounts for the observed experimental data. We also report the crystal structure of 1-cyano-2-methylimidazole, the first structurally characterized 1-cyanoazole.



(1)

Results and Discussion

Synthesis and Characterization

Reactions of imidazoles with excess BrCN were carried out in acetonitrile solution at room temperature in the absence of light for times ranging from 3 h to 3 days. Workup procedures differed depending on the nature of the products. 1-Cyanoimidazoles were found to hydrolyse in aqueous solution and therefore non-aqueous conditions were used to isolate these following removal of solvent under reduced pressure. 1-Cyanoimidazole was crystallized from $CHCl_3$ while 1-cyano-2-methylimidazole was isolated by vacuum sublimation following chromatography on neutral alumina. Although the products of the reaction of 4-methylimidazole and BrCN could not be separated, the ^{1}H n.m.r. spectrum of the crude reaction mixture was consistent with the presence of both 1-cyano-4-methylimidazole and 1-cyano-5-methylimidazole. The brominated imidazoles were isolated by extraction of an aqueous solution of the crude material with $CHCl_3$, with those requiring further purification being distilled under reduced pressure and/or chromatographed on neutral alumina using $CHCl_3$ as eluent. The brominated complex $[Co(NH_3)_5(2\text{-BrimH})]Br_3$ was purified by column chromatography on Dowex 50W×2 cation exchange resin and was crystallized as the bromide salt.

Characterization of the products was achieved in the first instance by ^{1}H and ^{13}C n.m.r. spectroscopy. Bromination at C 2 was accompanied by loss of the lowest field proton signal in the ^{1}H n.m.r. spectrum, while in the ^{13}C n.m.r. spectrum the peak in the starting material corresponding to C 2 was found to decrease in intensity and move 10–20 ppm upfield in the spectrum of the brominated product. N.O.e. and HETCOR data were also used to characterize the product of the reaction of 1,4-dimethylimidazole with BrCN, in order to confirm unequivocally Langenbeck's original assignment of this as 2-bromo-1,4-dimethylimidazole.[6] The ^{1}H n.m.r. spectrum of the product showed only one signal in the aromatic region at 6·67 ppm, irradiation of which resulted in enhancement of both methyl signals at 3·55 and 2·17 ppm. The signal at 6·67 ppm must therefore be due to H 5 and this requires substitution at C 2. *N*-Cyanation of imidazole and 2-methylimidazole resulted in loss of symmetry and resulted in three and two peaks respectively in the aromatic region of the ^{1}H n.m.r. spectrum. The ^{1}H n.m.r. spectrum of 1-cyanoimidazole is worthy of note, comprising a broad singlet (7·98 ppm, H 2), triplet (7·33 ppm) and broad doublet (7·18 ppm). Homonuclear decoupling experiments show that H 2 is coupled to both H 4 and H 5, but this coupling is unresolved, presumably due to the two adjacent quadrupolar nitrogen atoms. The ^{13}C n.m.r. spectrum of both 1-cyanoimidazoles showed the cyano carbon resonance at *c.* 105 ppm. *N*-Cyanation of imidazole and 2-methylimidazole was also confirmed by the appearance of a C≡N band in the i.r. spectrum at approximately 2250 cm^{-1}.

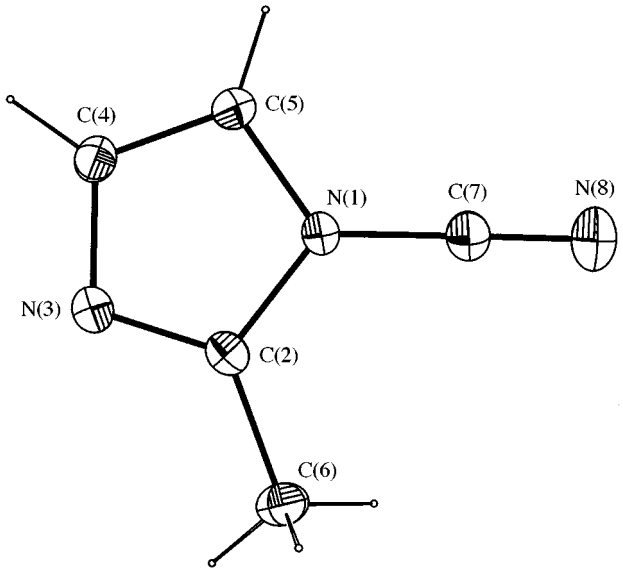


Fig. 1. ORTEP diagram of 1-cyano-2-methylimidazole, with thermal ellipsoids drawn at the 50% probability level.

Table 1. Bond lengths and angles for 1-cyano-2-methylimidazole

Distances (Å)		Angles (degrees)	
N(1)–C(7)	1·3367(18)	C(7)–N(1)–C(2)	126·71(13)
N(1)–C(2)	1·3858(19)	C(7)–N(1)–C(5)	125·69(13)
N(1)–C(5)	1·3908(19)	C(2)–N(1)–C(5)	107·56(12)
C(6)–C(2)	1·472(2)	N(3)–C(2)–N(1)	109·74(14)
C(2)–N(3)	1·2892(19)	N(3)–C(2)–C(6)	128·00(14)
N(3)–C(4)	1·381(2)	N(1)–C(2)–C(6)	122·26(13)
C(4)–C(5)	1·339(2)	C(2)–N(3)–C(4)	106·98(12)
N(8)–C(7)	1·137(2)	C(5)–C(4)–N(3)	111·12(13)
		C(4)–C(5)–N(1)	104·60(12)
		N(8)–C(7)–N(1)	179·30(16)

Crystal Structure of 1-Cyano-2-methylimidazole

Fig. 1 shows a representation of the molecule, while Table 1 gives bond lengths and angles. The imidazole ring is essentially planar, with the mean deviation of the ring atoms from the plane defined by N(1)–C(2)–N(3)–C(4)–C(5) being 0·001 Å. Cyanation of N 1 appears to influence the bond lengths within the imidazole ring, with the N(1)–C(2) and N(1)–C(5) bonds being most affected. The N(1)–C(2) and N(1)–C(5) bond distances of 1·3858(19) and 1·3908(19) Å respectively are slightly longer than the analogous distances in other structurally characterized 1,2-disubstituted imidazoles,[17] while the N(1)–C(7) bond (1·3367(18) Å) is very short for a formal single bond. We believe that these observations are indicative of π-electron donation from the imidazole ring to the cyano group, thus lengthening the ring bonds adjacent to the *N*-cyano substituent and resulting in significant multiple-bond character for the N(1)–C(7) bond. Similarly short N–C 'single' bonds have also been observed in structurally characterized *N*-cyanoindole derivatives.[18]

1-Cyano-2-methylimidazole crystallizes as layers of infinite two-dimensional sheets, with the individual molecules within these sheets held in close proximity by extensive hydrogen bonding interactions. Fig. 2 shows the hydrogen bonds which occur between H(5) and N(8) (2·542 Å) and H(4) and N(3) (2·527 Å) of adjacent molecules in these sheets. The methyl group is not involved in any hydrogen bonding. The intersheet distance of approximately 3·35 Å suggests that there may be π-type interactions between the sheets, and this is further supported by the observation that individual molecules in adjacent sheets do not lie directly above one another, but are instead offset by approximately 1·5 Å with respect to one another. Such an offset has been suggested to be indicative of π-stacking interactions.[19]

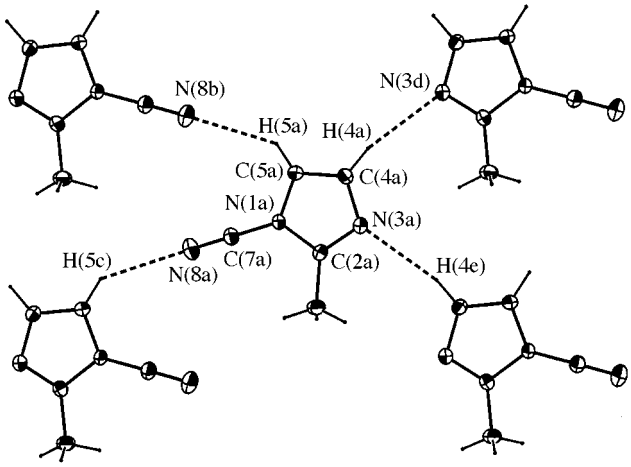
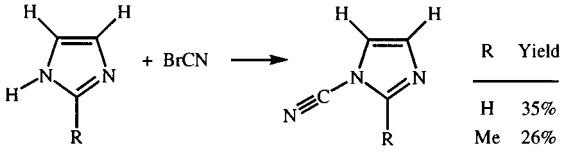


Fig. 2. Hydrogen-bonding interactions between adjacent 1-cyano-2-methylimidazole molecules. N(8)–H(5) 2·542 Å, N(3)–H(4) 2·527 Å.

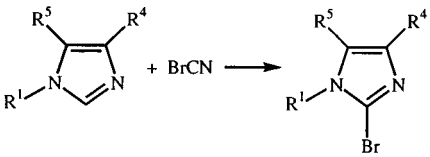
Bromination or Cyanation? The Reaction Mechanism

The imidazoles in this study were found to undergo one of two reactions with BrCN in acetonitrile solution, with the reactivity of the imidazoles apparently dictated by the nature of the substituent at N 1. Imidazoles protonated at N 1 gave the *N*-cyano derivatives (Scheme 2), while *N*-alkylimidazoles having a hydrogen at C 2 gave the 2-bromo derivatives (Scheme 3). Thus reaction of N–H imidazoles with BrCN allows facile synthesis of the novel *N*-cyanoimidazoles in a one-step procedure and, while other syntheses involving ring contraction of pyrazines and tetrazolopyrimidines, and reaction of an α-cyaniminocarbene with acetonitrile, have been reported,[12] this should be considered the method of choice for the preparation of such compounds. The reaction of *N*-alkylimidazoles with BrCN similarly allows a one-step synthesis of 2-bromo-*N*-alkylimidazoles which hitherto have been prepared by alkylation of 2-bromoimidazole (itself prepared by a multistep synthesis[20]) or by lithiation of the *N*-alkylimidazole followed by treatment with Br_2 [21] or 1,2-dibromoethane.[5] Bromination at C 2 does not occur on treatment of 1,2-dimethylimidazole with BrCN as such a reaction would necessarily involve loss of the methyl group at C 2. We believe that some conjugated ring-opened product may have formed, as evidenced by the deeply coloured products. Such ring-opening reactions are well known for pyridine and its derivatives.[22]



R	Yield
H	35%
Me	26%

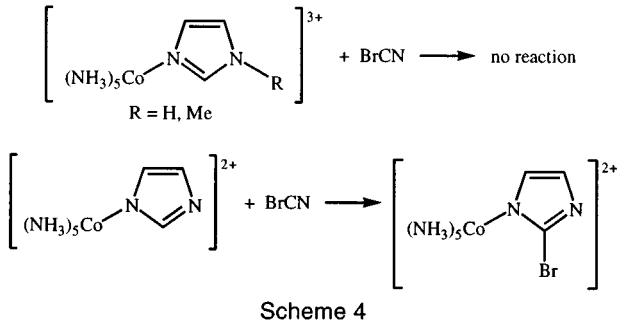
Scheme 2



R^1	R^4	R^5	Yield
Me	H	H	64%
Me	Me	H	29%
Me	H	Me	27%
Et	H	H	34%
$PhCH_2$	H	H	39%
Bu	H	H	24%

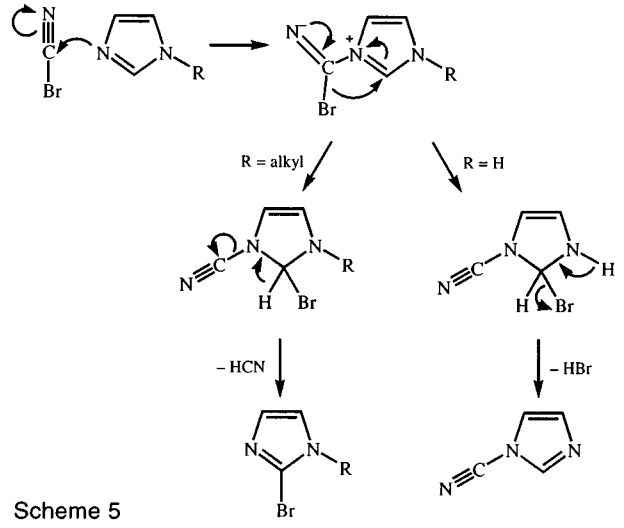
Scheme 3

Coordination of both imidazole (imH) and *N*-methylimidazole (*N*-Meim) to $Co(NH_3)_5^{3+}$ markedly changes their reactivity towards BrCN (Scheme 4). While imidazole and *N*-methylimidazole gave *N*-cyanoimidazole and 2-bromo-*N*-methylimidazole respectively on treatment with BrCN, the corresponding complexes $[Co(NH_3)_5(imH)](ClO_4)_3$ and $[Co(NH_3)_5(N\text{-}Meim)](ClO_4)_3$ were unreactive towards BrCN. In these complexes, the imidazole ligands are bound to the metal ion via the lone pair on N 3, thus removing the ability of this lone pair to act as a nucleophile. How-



Scheme 4

ever, deprotonation of $[Co(NH_3)_5(imH)]^{3+}$ at N 1 gave the conjugate base $[Co(NH_3)_5(im)]^{2+}$, which reacted with BrCN to give the 2-bromo product $[Co(NH_3)_5(2\text{-}BrimH)](ClO_4)_3$. These observations suggest that the presence of a lone pair on an imidazole ring nitrogen is essential for any reaction to occur and plays a vital role in the reaction mechanism. Scheme 5 gives a possible mechanism for the reaction which explains both the fact that the substituent on N 1 determines the product, and that a nitrogen lone pair is required for reaction to occur. The initial step is nucleophilic attack of the imidazole on the carbon atom of BrCN, via the nitrogen lone pair, to form an imidazolium cation which then undergoes bromination at C 2. The difference in products comes about as a consequence of the different mechanisms of rearomatization available to the N–H and N–R species. Imidazoles having an ionizable N–H proton can rearomatize by loss of HBr to give the *N*-cyano product. Such a pathway is not available to either the *N*-alkylated and *N*-metallated imidazoles, and these must rearomatize by loss of HCN to give the 2-bromo products.



Scheme 5

In conclusion, we have shown that BrCN is an effective reagent for the one-pot synthesis of otherwise difficult-to-prepare 2-bromoimidazoles, while it can also be used with similar ease to prepare the rare *N*-cyanoimidazoles, with the course of the reaction being determined by the nature of the substituent on N 1. We are currently investigating the reactivity of *N*-cyanoimidazoles as CN^+ transfer agents.

Experimental

All reagents were L.R. or A.R. grade. Cyanogen bromide (5·0 M in acetonitrile, Aldrich) was used as received. ^{1}H and ^{13}C n.m.r. spectra were recorded on a Varian VXR 300 spectrometer or a Gemini 200 spectrometer in $CDCl_3$ or D_2O at 25°C. Chemical shifts (δ) are reported in ppm using tetramethylsilane (^{1}H, 0·00 ppm) and $CDCl_3$ (^{13}C, 77·08 ppm) or sodium 3-(trimethylsilyl)(2,2,3,3-D_4)propionate (^{1}H, 0·00 ppm) and 1,4-dioxan (^{13}C, 67·8 ppm) as internal reference standards for solutions prepared in $CDCl_3$ or D_2O respectively. Microanalyses were performed by the Campbell Microanalytical Laboratory, University of Otago.

Table 2. Atomic coordinates and equivalent isotropic displacement parameters for 2-methylimidazole-1-carbonitrile (1-cyano-2-methylimidazole)

U_{eq} is defined as one-third of the trace of the orthogonalized U_{ij} tensor

Atom	10^4x	10^4y	10^4z	10^3U_{eq} (Å^2)
N(1)	2059(1)	2620(2)	4720(2)	17(1)
C(6)	2996(2)	5856(2)	5369(2)	22(1)
C(2)	3096(1)	3794(2)	5509(2)	17(1)
N(3)	4085(1)	2802(2)	6350(2)	18(1)
C(4)	3711(1)	938(2)	6114(2)	18(1)
N(8)	−98(1)	3596(2)	2817(2)	31(1)
C(5)	2472(1)	777(2)	5122(2)	18(1)
C(7)	890(1)	3142(2)	3698(2)	20(1)

X-Ray Structure of 2-Methylimidazole-1-carbonitrile

X-Ray structural data for 2-methylimidazole-1-carbonitrile were collected at −143(2)°C on a Seimens P4 diffractometer with graphite-monochromatized Mo Kα radiation (0·71073 Å). The crystal (0·50 by 0·30 by 0·24 mm) of 2-methylimidazole-1-carbonitrile used for data collection was obtained from vacuum sublimation of impure material (0·5 mmHg, room temperature) onto a cold finger. Data were processed and empirical absorption corrections (Ψ-scans) applied using programs from the SHELXTL package.[23] The unit cell dimensions and orientation matrices were obtained from 24 accurately centred reflections. Systematic absences were consistent with the monoclinic space group $P2_1/c$ and this was confirmed by subsequent solution and refinement of the structure. The structure was solved by direct methods with the TREF option in SHELXS-97[24] with the resulting Fourier map revealing the location of all non-hydrogen atoms. Weighted full-matrix refinement on F^2 was carried out using SHELXL-97[25] with all non-hydrogen atoms being refined with anisotropic displacement parameters. Hydrogen atoms were included in calculated positions and refined as riding atoms with individual (or group if appropriate) isotropic displacement parameters. Final residuals were R_1 0·0444 and wR_2 0·1193 for 1183 reflections with $F_o > 4F(F_o)$, and R_1 0·0536 and wR_2 0·1259 for all 1278 data, where $R_1 = \Sigma||F_o| - |F_c||/\Sigma|F_o|$ and $wR_2 = [\Sigma\{(wF_o{}^2 - F_c{}^2)^2\}/\Sigma\{w(F_o{}^2)^2\}]^{1/2}$ with $w = 1/[\sigma^2(F_o{}^2)+(0·0651P)^2+0·3348P]$ and $P = (F_o{}^2+2F_c{}^2)/3$. The goodness of fit was 1·038. A final difference-Fourier map showed the highest peak to be 0·329 e Å^{-3} (hole −0·338 e Å^{-3}). Further details of the crystals, data collection and structure refinement are as follows: empirical formula $C_5H_5N_3$; formula weight 107·12; unit cell dimensions a 10·201(5), b 7·110(3), c 7·227(3) Å, α 90, β 100·47(2), γ 90°; volume 515·4(4) Å^3; Z 4; calculated density 1·380 g cm^{-3}; absorption

coefficient 0·093 mm^{-1}; $F(000)$ 224; θ range for data collection 2·03–27·50°; index ranges $-13 < h < 13$, $-9 < k < 0$, $0 < l < 9$; reflections collected 1278; independent reflections 1183 ($R_{int} = 0·0164$); data/restraints/parameters 1183/0/75; extinction coefficient 0·052(9). Atomic coordinates are given in Table 2 and bond lengths and angles are given in Table 1. An Accessory Publication (anisotropic displacement parameters, hydrogen atom parameters and a list of structure factors) is available, until 31 December 2004, from the Australian Journal of Chemistry, P.O. Box 1139, Collingwood, Vic. 3066.

Syntheses

Caution

Cyanogen bromide is highly toxic. All work with BrCN was carried out in an efficient fume hood. Removal of solvent from these reaction mixtures was carried out so that all vapours passed through an aqueous base trap to destroy any excess BrCN.

All reactions were carried out in the absence of light, as some 1-cyanoimidazoles were found to be photosensitive.

Imidazole-1-carbonitrile

To a solution of imidazole (0·68 g) dissolved in acetonitrile (30 ml) was added BrCN in acetonitrile (5 M, 2 ml) and the solution was stirred at room temperature for 3 h. Removal of solvent under vacuum gave a dark yellow solid. The solid was extracted with 3×50 ml aliquots of chloroform and the extracts were concentrated under vacuum to yield white needle-like crystals (0·33 g, 35%). The product decomposed on exposure to light. M.p. 60°C (lit.[7] 59·5–60·5°C). ^{1}H n.m.r. ($CDCl_3$): δ 7·98, br s, $W_{h/2}$ 2·8 Hz, 1H; 7·33, t, J 1·4 Hz, 1H; 7·18, d, J 1 Hz, 1H. ^{13}C n.m.r. ($CDCl_3$): δ 138·9, 129·8, 119·8, 104·4. $\nu_{C\equiv N}$ (Nujol) 2259 cm^{-1}.

2-Methylimidazole-1-carbonitrile

To a solution of 2-methylimidazole (0·82 g) dissolved in acetonitrile (40 ml) was added BrCN in acetonitrile (5 M, 2 ml) and the solution was stirred at room temperature overnight. Removal of solvent under vacuum gave a dark yellow oil that solidified on standing. The solid was dissolved in chloroform and the solution loaded onto an alumina column. The product was eluted with chloroform and the eluate was concentrated to give a light yellow solid which was purified by vacuum sublimation (0·5 mmHg, room temperature) onto a water-cooled cold finger. Large clear cubic *crystals* suitable for X-ray structural analysis were formed (0·28 g, 26%) over 2–3 h, m.p. 60–62°C (Found: C, 56·1; H, 4·6; N, 39·2. $C_5H_5N_3$ requires C, 56·1; H, 4·7; N, 39·2%). ^{1}H n.m.r. ($CDCl_3$): δ 7·17, d, J 1·7 Hz, 1H; 6·97, d, J 1·7 Hz, 1H; 2·61, s, 3H. ^{13}C n.m.r. ($CDCl_3$): δ 149·0, 129·7, 119·6, 105·1, 13·3. $\nu_{C\equiv N}$ (Nujol) 2256 cm^{-1}.

2-Bromo-1-methylimidazole

To a solution of 1-methylimidazole (0·82 g) dissolved in acetonitrile (40 ml) was added BrCN in acetonitrile (5 M, 2 ml) and the solution was stirred at room temperature for 3 h. Distilled water (60 ml) was then added, and the solution was concentrated under vacuum to about half the original volume and then extracted with 3×20 ml aliquots of chloroform. The combined extracts were dried over $MgSO_4$ and concentrated under vacuum to give the product as a pale yellow *oil* (1·03 g, 64%) (Found: C, 29·8; H, 2·9; Br, 49·5; N, 17·1. $C_4H_5BrN_2$ requires C, 29·8; H, 3·1; Br, 49·6; N, 17·4%). ^{1}H n.m.r. ($CDCl_3$): δ 6·98, s, 1H; 6·96, s, 1H; 3·61, s, 3H. ^{13}C n.m.r. ($CDCl_3$): δ 129·6, 123·0, 120·0, 34·5.

2-Bromo-1,4-dimethylimidazole

To a solution of 1,4-dimethylimidazole (1·02 g) in acetonitrile (40 ml) was added BrCN in acetonitrile (5 M, 2 ml) and the mixture was stirred at room temperature overnight. The yellow solution was reduced to dryness, the residue was dissolved in water (20 ml) and the resulting solution was made basic by addition of solid sodium carbonate. This was extracted with $CHCl_3$ (4×20 ml), the combined extracts were dried over $MgSO_4$, filtered and reduced to dryness. The crude product was distilled (Kugelrohr, 65°C/0·3 mmHg) to give the pure product as a colourless oil which slowly solidified on standing (0·54 g, 29%), m.p. 52°C (lit.[6] 51–52°C). The product could also be purified by column chromatography on neutral alumina with $CHCl_3$ as eluent (Found: C, 34·5; H, 4·1; Br, 45·4; N, 16·0. Calc. for $C_5H_7BrN_2$: C, 34·3; H, 4·0; Br, 45·7; N, 16·0%). ^{1}H n.m.r. ($CDCl_3$): δ 6·67, s, 1H; 3·55, s, 3H; 2·17, s, 3H. ^{13}C n.m.r. ($CDCl_3$): δ 121·4, 119·5, 118·5, 34·3, 13·7. N.O.e. enhancement of both 3·55 and 2·17 when 6·67 irradiated, no enhancement of 2·17 by irradiation at 3·55. HETCOR: 6·67–119·5; 3·54–34·3; 2·17–13·7.

2-Bromo-1,5-dimethylimidazole

To a solution of 1,5-dimethylimidazole (0·87 g) in acetonitrile (40 ml) was added BrCN in acetonitrile (5 M, 2 ml) and the mixture was stirred at room temperature overnight. The yellow solution was reduced to dryness, the residue was dissolved in water (20 ml) and the resulting solution made basic by addition of solid sodium carbonate. This was extracted with $CHCl_3$ (4×20 ml), the combined extracts were dried over $MgSO_4$, filtered and reduced to dryness. The crude product was distilled (Kugelrohr, 78°C/0·2 mmHg) to give the pure product as a colourless oil which slowly solidified on standing (0·42 g, 27%), m.p. 46–47°C. The *product* could also be purified by column chromatography on neutral alumina with $CHCl_3$ as eluent (Found: C, 34·7; H, 4·0; Br, 45·9; N, 16·0. $C_5H_7BrN_2$ requires C, 34·3; H, 4·0; Br, 45·7; N, 16·0%). ^{1}H n.m.r. ($CDCl_3$): δ 6·74, d, J 1 Hz, 1H; 3·48, s, 3H; 2·21, d, J 1 Hz, 3H. ^{13}C n.m.r. ($CDCl_3$): δ 130·4, 126·9, 118·6, 31·7, 10·4.

2-Bromo-1-ethylimidazole

To a solution of 1-ethylimidazole (0·92 g) in acetonitrile (30 ml) was added BrCN in acetonitrile (5 M, 2 ml) and the solution was stirred at room temperature for 3 days. Distilled water (40 ml) was then added and the solution was concentrated under vacuum to half its original volume. The aqueous solution was extracted with chloroform (3×30 ml) and concentration of the combined extracts under vacuum gave the product as a colourless *oil* (0·57 g, 34%) (Found: C, 34·0; H, 4·2; Br, 45·9; N, 15·6. $C_5H_7BrN_2$ requires C, 34·3; H, 4·0; Br, 45·7; N, 16·0%). ^{1}H n.m.r. ($CDCl_3$): δ 6·93, s, 2H; 3·90, q, J 7·2 Hz, 2H; 1·32, t, J 7·2 Hz, 3H. ^{13}C n.m.r. ($CDCl_3$): δ 129·7, 121·1, 118·7, 42·6, 15·5.

1-Benzyl-2-bromoimidazole

To a solution of 1-benzylimidazole (1·59 g) in acetonitrile (30 ml) was added BrCN in acetonitrile (5 M, 2 ml) and the solution was stirred at room temperature for 2 days. The solvent was removed under reduced pressure, the residue suspended in water (20 ml) and the suspension made basic by addition of solid sodium carbonate. This was extracted with $CHCl_3$ (4×20 ml), the combined extracts were dried over $MgSO_4$ and reduced to dryness. The crude material was distilled (Kugelrohr, 170°C/0·3 mmHg) to give a colourless *oil* which was further purified by column chromatography on neutral alumina with $CHCl_3$ as eluent (0·94 g, 39%) (Found: C, 50·7; H, 3·8; Br, 33·7; N, 11·6. $C_{10}H_9BrN_2$ requires C, 50·7; H, 3·8; Br, 33·7; N, 11·8%). ^{1}H n.m.r. ($CDCl_3$): δ 7·36–7·31, m, 3H; 7·18–7·12, m, 2H; 7·04, s, 1H; 6·95, s, 1H; 5·11, s, 2H. ^{13}C n.m.r. ($CDCl_3$): δ 130·2, 129·6, 129·5, 129·0, 128·3, 127·3, 122·2, 51·3.

2-Bromo-1-butylimidazole

To a solution of 1-butylimidazole (1·32 g) in acetonitrile (30 ml) was added BrCN in acetonitrile (5 M, 3 ml) and the solution was stirred at room temperature overnight. To the solution was added distilled water (40 ml) and the resulting solution was evaporated under vacuum to half its original volume. The aqueous solution was extracted with chloroform (3×30 ml) and the combined extracts were concentrated to give the product as a yellow *oil* (0·51 g, 24%) (Found: C, 41·5; H, 5·3; Br, 39·5; N, 13·8. $C_7H_{11}BrN_2$ requires C, 41·4; H, 5·4; Br, 39·3; N, 13·8%). ^{1}H n.m.r. ($CDCl_3$): δ 6·99, d, J 1·4 Hz, 1H; 6·97, d, J 1·4 Hz, 1H; 3·91, t, J 7·2 Hz, 2H; 1·74, quin, J 7·2 Hz, 2H; 1·34, sext, J 7·2 Hz, 2H; 0·94, t, J 7·2 Hz, 3H. ^{13}C n.m.r. ($CDCl_3$): δ 129·7, 121·7, 119·2, 47·4, 32·3, 19·5, 13·5.

[Co(NH$_3$)$_5$(2-BrimH)]Br$_3$.1·5H$_2$O

To a solution of $[Co(NH_3)_5(im)](ClO_4)_2$ [26] (1·89 g) in acetonitrile was added BrCN in acetonitrile (5 M, 1 ml) and the solution was stirred at room temperature for 3 days. The solution was filtered to remove an orange precipitate and the filtrate was evaporated to dryness. The resulting solid was dissolved in water and sorbed onto Dowex 50W×2 cation exchange resin. This was washed with water and 1 M HCl, and elution with 2 M HCl produced two bands. The first band contained starting material while the second contained the brominated product. The eluate containing the second band was evaporated to dryness and the *solid* was twice recrystallized (0·62 g, 24%) from hot water by adding LiBr and cooling in ice (Found: C, 6·5; H, 3·3; Br, 57·6; N, 17·5. $C_3H_{18}Br_4CoN_7.1·5H_2O$ requires C, 6·5; H, 3·8; Br, 57·3; N, 17·6%). ^{1}H n.m.r. (D_2O): δ 7·44, d, 1H; 6·96, d, 1H. ^{13}C n.m.r. (D_2O): δ 131·3, 124·6, 123·2.

Reaction of 4-Methylimidazole with BrCN

To a solution of 4-methylimidazole (0·82 g) dissolved in acetonitrile (40 ml) was added BrCN in acetonitrile (5 M, 2 ml) and the solution was stirred at room temperature for 3 h. The yellow solution was concentrated to a yellow oil which by ^{1}H n.m.r. appeared to be a mixture of two compounds. All attempts to isolate the pure products were unsuccessful.

Reaction of 1,2-Dimethylimidazole with BrCN

To a solution of 1,2-dimethylimidazole (0·82 g) in acetonitrile (30 ml) was added BrCN in acetonitrile (5 M, 2 ml). A rapid colour change to deep orange was observed, and stirring was continued for 1 h. All attempts to isolate pure products from the reaction mixture were unsuccessful.

Attempted Reaction of [Co(NH$_3$)$_5$(imH)](ClO$_4$)$_3$ with BrCN

To a solution of $[Co(NH_3)_5(imH)](ClO_4)_3$ [16] (1·25 g) in acetonitrile was added BrCN in acetonitrile (5 M, 1 ml) and the solution was stirred at room temperature overnight. Following removal of solvent, i.r. and n.m.r. spectra of the solid material were identical to those of starting material.

Attempted Reaction of [Co(NH$_3$)$_5$(1-Meim)](ClO$_4$)$_3$ with BrCN

To a solution of $[Co(NH_3)_5(1\text{-}Meim)](ClO_4)_3$ [16] in acetonitrile was added BrCN in acetonitrile (5 M, 2 ml) and the solution was stirred for 3 days at room temperature. N.m.r. spectroscopy of the solid following removal of solvent showed the presence of starting material only.

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