

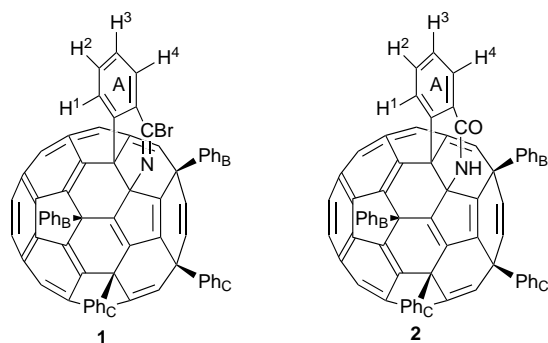
Novel formation of a phenylated isoquinolino[3',4':1,2][60]fullerene

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Reaction of $C_{60}Ph_5Cl$ with cyanogen bromide results in replacement of the chlorine by $BrCN$ and ring closure between the addend and an adjacent phenyl ring, giving a 1-bromoisoquinoline derivative of [60]fullerene; this readily undergoes nucleophilic replacement of Br by OH to give the corresponding 1-isoquinolone derivative.

Recently we described a novel spontaneous oxidation of $C_{60}Ph_5X$ ($X = H, Cl$) into a benzo[*b*]furan derivative of [60]fullerene, whereby oxygen forms a bridge between the cage and one of the phenyl rings.¹ We now report a related ring closure whereby reaction of $BrCN$ with the above chloro precursor results in chlorine loss, and formation of a bromine-substituted CN bridge between the cage and the *ortho* position of the adjacent phenyl ring. This product is a 1-bromoisoquinoline derivative of [60]fullerene **1**. The resulting product then undergoes nucleophilic substitution of the bromine by hydroxide followed by tautomerism to give the isoquinolone derivative **2**, the spectroscopic data for which further confirm the precursor structure.



Cyanogen bromide (660 mg) and $FeCl_3$ (106 mg) were added to a solution of $C_{60}Ph_5Cl$ (52 mg) in dry benzene (50 cm^3). The mixture was heated under reflux for 4 h, during which time it was monitored by TLC. After *ca.* 45 min an orange microcrystalline solid began to form. The reaction mixture was cooled to room temperature, and the solvent removed under reduced pressure to give a dark residue which was washed with Et_2O to remove $FeCl_3$ and $CNBr$. The remaining orange-red solid was dissolved in CCl_4 (this can be helped by sonication) and then column chromatographed (SiO_2, CCl_4) to remove a small amount of $C_{60}Ph_5Cl$, giving a single orange fraction which, after solvent removal, produced an orange crystalline solid (80%). Washing the column with CH_2Cl_2 yielded a second orange fraction which, after solvent removal, was allowed to crystallise from benzene.

The FAB mass spectrum showed the parent ion at 1211 amu, which indicated overall replacement of Cl by $CNBr$. The IR spectrum showed a strong peak at 1646 cm^{-1} indicative of a $C=N$ stretch and a band at 616 cm^{-1} attributable to a $C-Br$ stretch (Fig. 1). This strongly suggests the presence of a $C(Br)=N$ group in the molecule, and NMR spectroscopic analysis revealed the compound to be **1**.

The ^{13}C NMR spectrum shows **1** to have C_s symmetry, with four peaks in the sp^3 region for the cage carbons appearing at δ

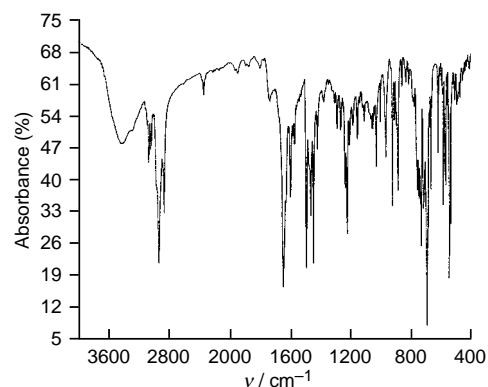


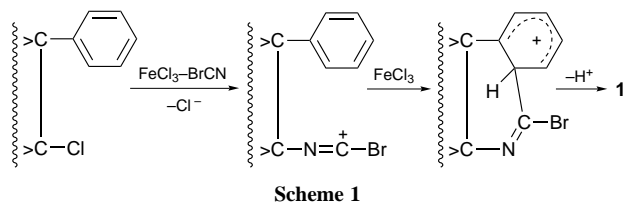
Fig. 1 IR spectrum (KBr) for $C_{91}H_{24}NBr$ (**1**)

74.84 (1 C), 59.77 (2 C), 57.77 (2 C) and 57.36 (1 C) [*cf.* 75.91 (1 C), 60.39 (2 C), 57.72 (2 C) and 62.98 (1 C) for the chloro precursor].² Previously we assigned the most downfield resonance to C-2 from a comparison of the resonance changes on replacing Cl by H (which causes an upfield shift of $\delta 17.5$). The results suggest that the bromocyno group is likewise attached to C-2, and *via nitrogen*. For the cage the required 28 lines for sp^2 carbons ($2 \times 1\text{ C}, 26 \times 2\text{ C}$) appear (all 2 C except where indicated) at $\delta 161.10, 154.21, 151.81, 148.65, 148.21, 148.16, 148.10, 148.04, 147.94, 147.76$ (1 C), $147.64, 147.20, 146.86$ (1 C), $146.82, 146.54, 146.42, 145.0, 144.74, 144.14$ (4 C), $143.99, 143.67$ (4 C), $143.48, 143.37, 143.26, 142.74$ and 142.17 . The spectrum also shows two *ortho* (4 C) peaks at $\delta 128.36/127.33$, two *meta* (4 C) peaks at $\delta 127.81/127.24$, two *para* (2 C) peaks at $\delta 127.33$ (coincident)/ 126.87 , four ipso peaks at $\delta 146.55$ (1 C), 139.18 (2 C), 136.88 (2 C) and 132.07 (1 C) and five other peaks (all 1 C) at $\delta 131.49, 130.81, 127.04, 124.77$ and 124.22 (one of this group being the carbon of the $C(Br)N$ group). This shows that one phenyl ring has *two* substituents attached, namely the fullerene cage and the $C(Br)N$ group.

The 1H NMR spectrum is assigned as follows (aryl ring notation as in **1**): (i) rings B, $\delta 7.61-7.59$ (4 H, dd, *o*-H), $7.34-7.31$ (2 H, m, *p*-H), $7.26-7.22$ (4 H, m, *m*-H); (ii) rings C, $\delta 7.21-7.19$ (4 H, dd, *o*-H), $7.075-7.055$ (2 H, m, *p*-H), $7.00-6.96$ (4 H, m, *m*-H); (iii) ring A, $\delta 7.91$ (1 H, dd, H^4), 7.79 (1 H dd H^1), 7.20 (1 H, dd, H^3), 7.17 (1 H dd, H^2); the couplings were approximately 7.5 and 1.5 Hz, but could not in some cases be accurately given because of peak coincidences.

The locations of the hydrogens in ring A were determined by 2D-COSY and NOE analysis, which showed interaction between H^1 and the *ortho* hydrogens of rings B. The downfield resonance for h^1 is consistent with our previous observation that resonances for hydrogens pointing towards the cage are shifted downfield,³ whilst that for H^4 is attributable to the adjacent $C-Br$ substituent.

The mechanism proposed (Scheme 1) is supported by the following: (i) reaction will not occur with the corresponding 4-fluoro derivative [$C_{60}(4-FC_6H_4)_5Cl$] and (ii) no reaction takes place in the absence of $FeCl_3$. If nucleophilic substitution by the nitrogen of the $BrCN$ group were to take place on the aryl



Scheme 1

addend (giving, ultimately, a quinoline derivative), this would be enhanced in the fluorophenyl compound and would occur *meta* to fluorine, *i.e.* *ortho* to the fullerene cage, which is the site required for the subsequent ring closure. Since reaction does not occur, electrophilic substitution by the carbon of the BrCN group into the aryl ring (giving an isoquinoline derivative) is indicated. However, this is unlikely to occur as a first step since substitution would in general take place at the more accessible position *para* to the cage. It is probable therefore that the initial step involves nucleophilic replacement of the cage-attached chlorine by BrCN, giving an intermediate fullerene- $\text{N}=\text{C}^+\text{-Br}$ moiety, followed by electrophilic substitution by the imino carbocation of this group into the phenyl ring; FeCl_3 will aid polarisation of the cage-Cl bond just as it does in nucleophilic replacement of cage chlorines by phenyl groups.² Electrophilic substitution in aryl rings attached to fullerenes is normally difficult owing to the very strong electron withdrawal by the cage. However, the above intermediate will be strongly electrophilic, and the electrophilicity may be increased further through polarisation of the C-Br bond by FeCl_3 . A related Lewis acid-catalysed intramolecular electrophilic aromatic substitution of isocyanide dihalides has also been described recently.⁴ It is probable that the present reaction is synchronous and synergistic, since C_{60}Cl_6 itself does not react with cyanogen bromide- FeCl_3 .

Confirmation of the structure comes from nucleophilic replacement of the bromine by hydroxide to give **2**, which has the low solubility typical of amides, obtained as orange-red plates from benzene. This occurs both on standing in air and was observed to result from reaction with either Zn-AcOH or HCl-AcOH . (Zinc accelerates the reaction, although the reason for this is unclear.) The mass spectrum of **2** gives the parent ion at the required 1148 amu. The IR spectrum (Fig. 2) shows a new C=O band at 1669 cm^{-1} , an N-H stretch at 3368 cm^{-1} and no C-Br stretch. The correct location of the carbon and nitrogen of the bridge with respect to the cage and phenylene group are confirmed by both the ^{13}C and ^1H NMR spectra.

The ^{13}C NMR spectrum shows the product to have C_s symmetry, the four peaks in the sp^3 region appearing at δ 65.56 (1 C), 60.74 (1 C), 60.57 (2 C) and 58.30 (2 C). Thus, whereas the ring carbons bearing the two pairs of phenyl rings have very similar shifts to those in the precursor, one of the two unique carbons has shifted markedly upfield whilst the other has shifted downfield (and to a smaller extent). This is entirely consistent with the proposed structure of **2** compared to that of **1**. The sp^2 -hybridised nitrogen on the cage has changed to sp^3 hybridisation (thereby resulting in a marked upfield shift of the attached carbon), whereas the phenyl group now has an electron-withdrawing CO group attached, so that the fullerene carbon attached to this ring experiences a downfield shift. Since the electron withdrawing CO moiety is more remote than the electron-withdrawing -N= moiety, the downfield shift should be smaller than the upfield one, as observed.

For the cage, the required 28 lines for sp^2 carbons ($2 \times 1\text{ C}$, $26 \times 2\text{ C}$) appear (all 2 C except where indicated) at δ 160.86, 154.22, 152.10, 148.62, 148.52 (4 C), 148.36, 148.22, 148.04 (1 C), 147.94, 147.84, 147.48, 147.35 (1 C), 147.01, 148.86, 146.77, 145.43, 144.79, 144.46, 144.38, 144.21, 143.99, 143.93, 143.90, 143.77, 143.17, 142.83 and 142.53; the resonance for the C=O group appears at δ 161.34. The ipso peaks appear at δ 133.78 (1 C), 139.42 (2 C), 136.99 (2 C) and 132.08 (1 C), and it can be seen that the last three values are

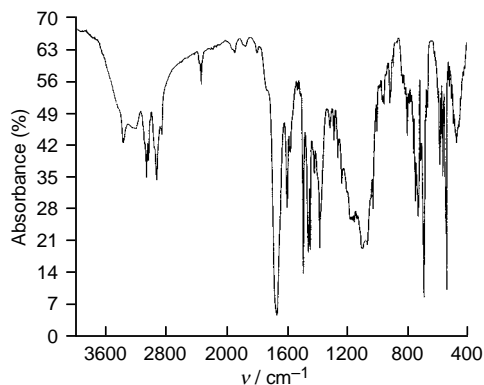


Fig. 2 IR spectrum (KBr) for $\text{C}_{91}\text{H}_{25}\text{NO}$ (**2**)

almost identical to those in the precursor **1**. The first value can be assigned to the aryl ring carbon which is adjacent to the C-Br group in **1** and the C=O group in **2**. The normally stronger electron withdrawing effect of the carbonyl group⁵ is evidently moderated through resonance with the adjacent nitrogen lone pair.

The ^1H NMR spectrum is assigned as follows, the hydrogen locations being identified by 2D-COSY and NOE analysis. Ring notations are as in **2**; couplings are not given due to peak coincidences, and splitting could not be resolved for H^3 and H^2 : (i) rings B, δ 7.66–7.64 (4 H, d, *o*-H), 7.36–7.33 (2 H, t, *p*-H), 7.29–7.25 (4 H, t, *m*-H); (ii) rings C, δ 7.27–7.25 (4 H, d, *o*-H), 7.09–7.06 (2 H, t, *p*-H), 7.01–6.98 (4 H, t, *m*-H); (iii) ring A, δ 8.12 (1 H, dd, H^4), 7.92 (1 H, dd, H^1), 7.28 (1 H, H^2), 7.23 (1 H, H^3); (iv) δ 7.03, (1 H, s, -NH-).

This identification for H^1 was confirmed by NOE enhancement (4.1%) of the signal for the *ortho* hydrogens of ring B. The resonances for hydrogens in ring A are all shifted downfield relative to those in the precursor, which is consistent with CO being substituted on this ring, but not with -N= being attached originally to this ring and then converted to -NH- on hydrolysis. The relatively greater downfield shift in **2** compared to **1** of the resonance for H^1 relative to that of H^3 (both positions being *meta* to the substituent) is consistent with C-N bond lengthening in the quinolone relative to the quinoline, forcing H^1 slightly nearer to the cage. AM1 calculations indicate that the cage- H^1 distance is reduced from 2.634 Å in the bromoisoquinoline to 2.61 Å in the isoquinolone. Similarly, the greater downfield shift for H^4 (*ortho*) relative to H^2 (*para*) is consistent with the calculated $\text{H}^4\text{-O}$ distance (2.49 Å) in **2** compared to the $\text{H}^4\text{-Br}$ distance (2.63 Å) in **1**.

Notes and References

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