JOC Article

A Ceric Ammonium Nitrate N-Dearylation of *N*-*p*-Anisylazoles Applied to Pyrazole, Triazole, Tetrazole, and Pentazole Rings: Release of Parent Azoles. Generation of Unstable Pentazole, HN_5/N_5^-, in Solution

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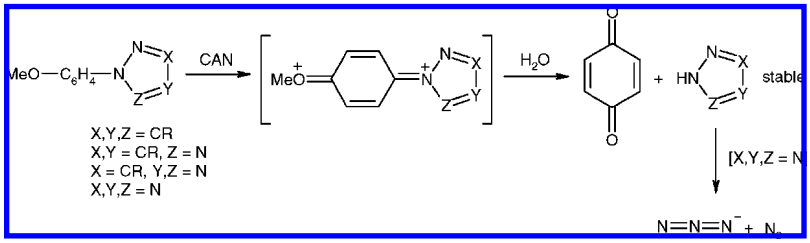
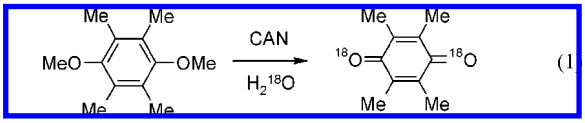


The reaction of cerium(IV) ammonium nitrate (CAN) with a range of *N*-(*p*-anisyl)azoles in acetonitrile or methanol solvents leads to N-dearylation releasing the parent NH-azole and *p*-benzoquinone in comparable yields. The scope and limitations of the reaction are explored. It was successful with 1-(*p*-anisyl)pyrazoles, 2-(*p*-anisyl)-1,2,3-triazoles, 2-(*p*-anisyl)-2*H*-tetrazoles, and 1-(*p*-anisyl)pentazole. The dearylation renders the *p*-anisyl group as a potentially useful N-protecting group in azole chemistry. The azole released in solution from 1-(*p*-anisyl)pentazole is unstable HN_5, the long-sought parent pentazolic acid. *p*-Anisylpentazole samples were synthesized with combinations of one, two, and three ^{15}N atoms at all positions of the pentazole ring. The unstable HN_5/N_5^- produced at −40 °C did not build up in the solution but degraded to azide ion and nitrogen gas with a short lifetime. The ^{15}N-labeling of the N_3^- ion obtained from all samples proved unequivocally that it came from the degradation of HN_5 (tautomeric forms) and/or its anion N_5^- in the solution.

Introduction

The strong aryl−oxygen and aryl−nitrogen bonds are difficult to cleave. The ubiquitous alkyl−oxygen cleavage of alkyl aryl ethers with hydrogen iodide is the basis of the classical Zeisel methoxy analysis[1] for estimating the number of methoxy groups bound to aryl rings. Because of our interest in seeking a mild method of breaking aryl−nitrogen bonds in *N*-arylazoles, with a view to applying it to arylpentazoles, some years ago we were attracted to the reaction (eq 1) reported by Jacob et al.[2] which clearly involved an aryl−oxygen bond cleavage by cerium(IV) ammonium nitrate (CAN).



(1)

Since the report by Jacob et al.,[2] the CAN dearylation has been developed as a deprotecting reaction for many *p*-anisylamino-type systems including azetidines,[3] *p*-anisylamines,[4] and amino acid precursors.[5,6] It has not been applied to aromatic

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TABLE 1. CAN Dearylations of *N-p*-Anisylpyrazoles (Scheme 1)

substrate				conditions				products				
entry	compd	R_1	R_2	reagent	solvent	*T* (°C)	time (h)		yield (%)	mp (°C)		yield (%)
1	**1a**	Me	Me	CAN (3.0 equiv)	MeCN/H_2O (4.75:1 v/v)	rt	1	**2a**	47	107−108[a]	**3**	41
2	**1b**	Ph	Ph	CAN (3.0 equiv)	MeCN/H_2O (4.75:1 v/v)	rt	1	**2b**	30	201−202[b]	**3**	30
3	**1b**	Ph	Ph	CAN (3.0 equiv)	MeCN/H_2O (4.75:1 v/v)	−10	72	**2b**	30		**3**	53
4	**1c**	Me	Ph	CAN (3.0 equiv)	MeCN/H_2O (4.75:1 v/v)	rt	1	**2c**	57	124−125[c]	**3**	53
5	**1c**	Me	Ph	CAN (3.0 equiv)	MeCN/H_2O (4.75:1 v/v)	−10	72	**2c**	70		**3**	76
6	**1c**	Me	Ph	CAN (3.0 equiv)	MeOH:H_2O (10:1 v/v)	−40	168	**2c**	40		**3**	48
7	**1c**	Me	Ph	CAN (3.0 equiv)	MeOH/H_2O (4:1 v/v)	rt	1	**2c**	52		**3**	57
8	**1c**	Me	Ph	CAN (3.0 equiv)	MeCN/CH_2Cl_2/H_2O (5:5:1 v/v)	rt	1	**2c**	43		**3**	71

[a] Lit.[15] mp 107−109 °C. [b] Lit.[16] mp 201 °C. [c] Lit.[17] mp 125−126 °C.

TABLE 2. CAN Dearylations of *N-p*-Anisyl-1,2,3-triazoles and -tetrazoles

substrate			conditions				products				
entry	compd	R	reagent	solvent	*T* (°C)	time		yield (%)	mp (°C)		yield (%)
1	**4a**	H	CAN (2.7 eq.)	MeCN/H_2O (10:1 v/v)	rt	24 h	**5a**	44[a]	130−131[b]	**3**	39
2	**4a**	H	CAN (5.0 eq.)	MeCN/H_2O (10:1 v/v)	rt	4 days	**5a**	36[c]		**3**	37
3	**4a**	H	CAN (2.7 eq.)	MeCN/H_2O (10:1 v/v)	−10	7 days	**5a**	67[d]		**3**	46
4	**4a**	H	CAN (2.7 eq.)	MeCN/H_2O (20:1 v/v)	−40	7 days	**5a**	15[e]		**3**	15
5	**4a**	H	CAN (2.7 eq.)	MeCN/CH_2Cl_2/H_2O (10:10:1 v/v)	rt	24 h	**5a**	52[f]		**3**	69
6	**4a**	H	$Ce(OH)_4$ (2.7 eq.), HCl	MeCN/H_2O (10:1 v/v)	rt	6 days	**5a**	11			
7	**4a**	H	CAS (2.1 eq.), HCl	MeOH/H_2O (6:1 v/v)	rt	24 h	**5a**	19			
8	**4b**	Me	CAN (2.7 eq.)	MeCN/H_2O (10:1 v/v)	rt	24 h	**5b**	52[g]	156−157	**3**	55
9	**4c**	OMe	CAN (2.7 eq.)	MeCN/H_2O (10:1 v/v)	rt	24 h	**5c**	20[h]	169−170	**3**	29
10	**6a**	H	CAN (3.0 eq.)	MeCN/H_2O (10.8:1 v/v)	rt[i]	142 h	**7a**	15	216−217[j]	**3**	15[k]
11	**6b**	Me	CAN (3.0 eq.)	MeCN/H_2O (8.8:1 v/v)	rt[l]	105 h	**7b**	6	252−253[m]	**3**	6[k]

[a] 2-(3′-Nitro-4′-methoxyphenyl)-4,5-diphenyl-1,2,3-triazole (7%) also obtained. [b] Lit.[19] mp 134−135 °C. [c] 2-(3′-Nitro-4′-methoxyphenyl)-4,5-diphenyl-1,2,3-triazole (17%) also obtained. [d] 2-(3′-Nitro-4′-methoxyphenyl)-4,5-diphenyl-1,2,3-triazole (4%) also obtained. [e] No nitrated products encountered. [f] 2-(3′-Nitro-4′-methoxyphenyl)-4,5-diphenyl-1,2,3-triazole (13%) also obtained. [g] 2-(3′-Nitro-4′-methoxyphenyl)-4,5-di(*p*-tolyl)-1,2,3-triazole (8%) also obtained. [h] No 2-(3′-nitro-4′-methoxyphenyl)-4,5-di(*p*-anisyl)-1,2,3-triazole could be isolated. [i] Reaction initiated at −10 °C (4 h), temperature then raised to 0 °C (45 h), rt (45 h), 40 °C (28 h), and 60 °C (20 h). [j] Lit.[20] mp 215−216 °C. [k] Estimated yield from ^{1}H NMR analysis. [l] Reaction initiated at −10 °C (4 h), temperature then raised to 0 °C (6 h), rt (19 h), 40 °C (19 h), 60 °C (57 h). [m] Lit.[21] mp 252 °C.

azole molecules. In 2003, we made a preliminary report[7] of the successful application of CAN dearylation to *N-p*-anisylpyrazoles and *p*-anisylpentazole following the discovery of N_5^+.[8] Having reviewed pentazole chemistry,[9] we have reported on the mechanisms of the formation[10] of the pentazole ring and its thermal degradation,[11] as well as basicity and protonation.[12] Herein we describe fully our work on the N-dearylation of *N-p*-anisylazoles including *p*-anisylpentazole. Our preliminary report[7] on pyrazoles and pentazoles in 2003 drew a challenge,[13] part of which was correct, and we will respond to that also herein.

Results and Discussion

Part I: C,N-Azoles. When the prospective CAN dearylation for *N-p*-anisylazoles was attempted with *N-p*-anisylpyrazoles, 2-*N-p*-anisyl-1,2,3-triazoles, and 2-*N-p*-anisyl-1,2,3,4-tetrazoles, an N-dearylation was achieved which regenerated the parent NH-azole along with *p*-benzoquinone. The yields of *p*-benzoquinone were generally comparable to the yields of the regenerated parent NH-azoles (apart from a few cases of workup difficulties where some *p*-benzoquinone can be lost), and the presence of *p*-benzoquinone, detectable by TLC, was an easy indicator of the successful dearylation. In these reactions, a clear *solution* of the *N-p*-anisyl azole in acetonitrile or methanol was treated dropwise with a 2.7−3 M quantity of CAN, dissolved in water, and stirred at the temperature indicated for the time shown in the tables. The product solution was distributed between dichloromethane and water and the residue from the dichloromethane extract was chromatographed through a column of silica gel to give the products shown in Tables 1 and 2. In each case, the parent N−H azole was identified by comparison of its IR and proton and carbon-13 NMR spectra with authentic samples and also by mixture melting points.

(i) *N-p*-Anisylpyrazoles (Table 1). The results for the CAN dearylations of a number of *N-p*-anisylpyrazoles under a range of conditions are shown in Scheme 1 and Table 1. The overall solvent is the final composition arising from the dropwise addition of the aqueous CAN solution into the solution of the starting pyrazole in the organic solvent. Good results were obtained at ambient temperature, but better results were at lower temperatures (Table 1, entries 3, 5, and 6). Compound **2a** was rearylated back to **1a** in 80% yield by using *p*-anisylboronic acid following a protocol similar to that of Lam et al.[14] (Scheme 1).

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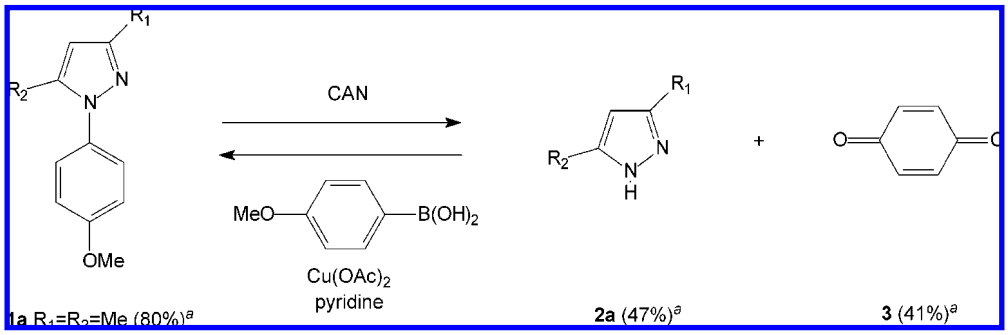
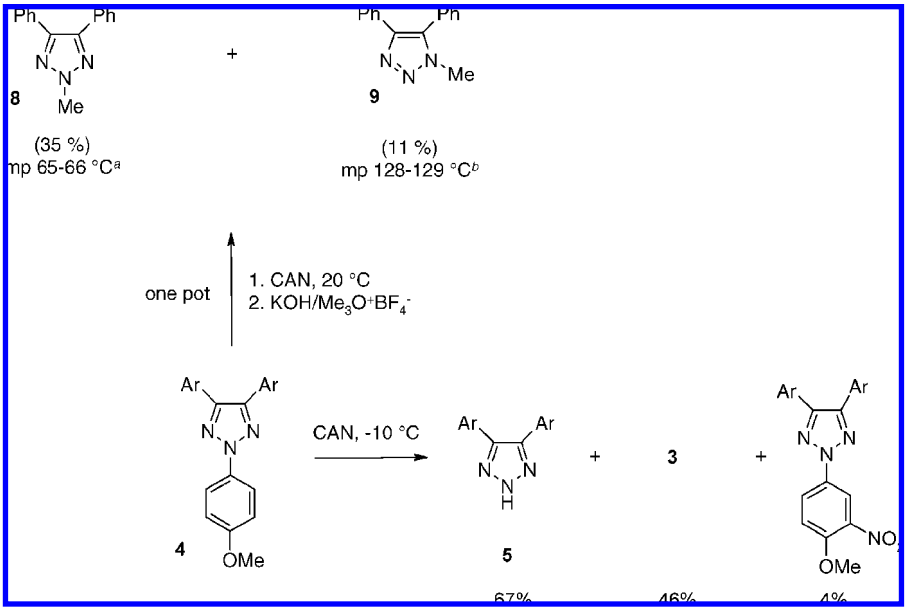
SCHEME 1. CAN Dearylation and Reanisylation of 1-*N*-*p*-Anisylpyrazoles



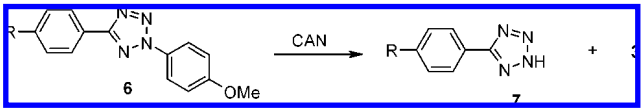
[a] Isolated yield at ambient temperature.

SCHEME 2. CAN Dearylation and One-Pot Dearylation−Alkylation of 2-*N*-(*p*-Anisyl)-4,5-diaryl-1,2,3-triazoles (Ar = *p*-RC$_6$H$_4$−)



[a] Lit.[18] mp 61−63 °C. [b] Lit.[18] mp 129−130 °C.

SCHEME 3. CAN Dearylations of 2-*N*-(*p*-Anisyl)-5-aryltetrazoles



(ii) 2-*N*-*p*-anisyl-1,2,3-triazoles and -1,2,3,4-tetrazoles (Table 2). The N-dearylation reaction was successful with 2-*p*-anisyl-1,2,3-triazoles and -tetrazoles. The results for reactions of CAN with some 2-*p*-anisyl-4,5-diaryl-1,2,3-triazoles **4** and 2-*p*-anisyl-5-aryltetrazoles **6** are shown in Schemes 2 and 3 and Table 2. The growing presence of *p*-benzoquinone in the solution again indicated the progress of N-dearylation. Control reactions with the substrate **4a** in which quantities of *p*-benzoquinone were added to the triazole solution prior to the dropwise addition of the CAN solution showed no detrimental effect on the yield of **5a** regenerated. In order to assess any effects of the presence of HNO_3 in the CAN reaction other Ce^{IV} salts such as the sulfate (CAS) and hydroxide (both with necessary added HCl) were also examined (Table 2, entries 6, 7). Both gave low yields of parent NH-1,2,3-triazole **5a**. No *p*-benzoquinone was detected in these reactions and overall they were less effective than the CAN procedure. The detrimental effects of the low pH, due to HNO_3, in CAN dearylations of *p*-anisylamines has led to the development of alternative nonmetallic oxidative organic N-dearylating agents including trichloroisocyanuric acid (TCCA).[5] When attempted dearylation reactions were carried out with the triazole **4a** using TCCA, tetracyanoethylene (TCNE) and 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ), no dearylations occurred and no traces of *p*-benzoquinone or the parent NH-1,2,3-triazoles were detected. The presence of nitric acid in the CAN dearylation medium resulted in some competitive nitration of the 2-*N*-*p*-anisyl ring of the 1,2,3-triazole substrates (Scheme 2, Table 2, footnotes). This was reduced by using lower temperatures for the dearylation reaction (Table 2, entry 2 versus entries 3 and 4).

4,5-Diphenyl-1,2,3-triazole **5a** has previously been synthesized in 37% yield from the reaction of potassium *tert*-butoxide with benzaldehyde azine by Grundon and Khan.[19] Samples of

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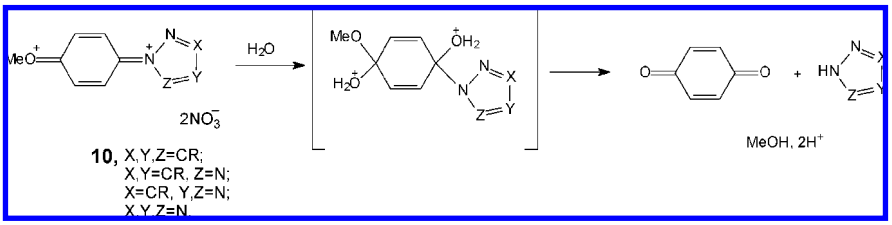
SCHEME 4. Proposed Mechanism of Azole N-Dearylation



compound **5a** from the dearylation reaction were identical to samples prepared by this method.[19] The dearylation route is somewhat more convenient since 2-*N*-*p*-anisyl-1,2,3-triazoles **5** are readily available from benzil bis-*p*-methoxyphenylhydrazones.[22] In the CAN reaction with the substrate **4c**, 2,4,5-tri-(*p*-anisyl)-1,2,3-triazole, only the 2-*N*-*p*-anisyl group was oxidatively removed, and the C-*p*-anisyl groups at the triazole positions 4- and 5- were not affected. The 2-*p*-anisyl-5-aryltetrazoles **6** were dearylated by CAN giving low yields of 5-aryltetrazoles **7** along with comparable quantities of *p*-benzoquinone (Table 2, Scheme 3).

(iii) One-Pot N-Dearylation−Methylation Protocol. The 2-*p*-anisyl-1,2,3-triazole substrate was explored further as a model system. A one-pot dearylation−methylation protocol was developed (Scheme 2), which involved raising the pH of the completed CAN dearylation reaction mixture to 10 with KOH followed by introduction of the super alkylating Meerwein reagent trimethyloxonium tetrafluoroborate. This allowed a one-pot conversion of an *N*-arylazole to an *N*-methylazole in reasonable yields (Scheme 2). The 2- and 1-methyl-1,2,3-triazole isomers **8** and **9** were identical with authentic samples. The in situ methylation of the regenerated **5a** was also carried out on the acidic CAN dearylation solution, without basification to pH 10. In this case, the yields of the *N*-methyl isomers **8** (3%) and **9** (7%) were significantly lower and reversed in relative magnitude. These trends were also observed in separate independent methylations of compound **5a** distinct from those carried out in situ on **5a** regenerated by CAN dearylation of **4a**.

(iv) Mechanism, Limitations, and Selectivity of CAN Azole N-Dearylations. The CAN dearylation process renders the *p*-anisyl substituent as a potential aryl protecting group in the chemistry of *N*-arylpyrazoles and 2-aryl-1,2,3-triazoles and -tetrazoles. Since many triazole and tetrazole derivatives display biological activity, a reviewer has pointed out that the reaction may prove useful for deprotecting *N*-aryl-bearing products of click reactions. In this context, we feel that the use of the sulfate salt CAS merits further exploration in order to avoid the nitric acid environment which may be detrimental to some structures linked by click reactions. The reaction was not effective with *N*-*p*-anisylimidazoles, *N*-*p*-anisyl-1,2,4-triazoles, and 1-*p*-anisyl-1,2,3-triazoles. For a range of these cases studied, no benzoquinone was produced and the parent N−H azole was not regenerated. Ce(IV) is a one-electron oxidizing agent, and by analogy with the proposed literature mechanism[2,3,23−25] for the oxidation of alkyl aryl ethers to *p*-benzoquinone, we expect that successive one-electron oxidations give rise to the dicationic species **10** which undergoes hydrolytic degradation to the parent N−H azole and *p*-benzoquinone (Scheme 4).

Theoretical calculations[26] suggest that the species **10** is considerably stabilized by ion-pairing, and when the two NO_3^- anions are included above and below the plane of the benzene ring in B3LYP/3-611+G(d) geometry optimizations for X,Y, Z = N the bond lengths resemble much more a neutral aromatic system than a quinone structure.[26] The benzene 1- and 4-carbons remain positive enough to still favor nucleophilic H_2O addition which facilitates the separation of the aromatic rings.

The *N*-*p*-anisylazoles which have been dearylated have characteristically weak basicities possessing basic pK_a values (pK_a of conjugate acid) less than 0.5. Thus, 1-phenylpyrazole has a basic pK_a of 0.43, while 1-phenylimidazole has basic pK_a 5.1.[27] In the triazole series, the N-substituted derivatives for which basic pK_a values are available, such as 1- and 4-methyl-1,2,4-triazoles, display pK_a values of 3.2 and 3.4, respectively, while 1-methyl-1,2,3-triazole has a basic pK_a of 1.23.[27] Only the 2-substituted 1,2,3-triazoles are well-known as exceptionally weak bases, with the pK_a for 2-methyl-1,2,3-triazole being as low as −3.25.[27] The reported *N*-aryl- and *N*-alkyltetrazoles have low basic pK_a values in the range −1.96 to −3.25.[27] In agreement with the mechanism of Scheme 4, only azoles which are unprotonated in the strongly acidic conditions of aqueous CAN solutions are expected to be oxidized by Ce^{IV}. For 4-*p*-anisyl-1,2,4-triazole, the CAN solution in CD_3OD-D_2O showed deshielding of the 3-CH/5-CH proton from δ 8.9 to 9.6 as expected for protonation of the molecule. The results suggest that the reaction is limited to substrates with basic pK_a values lower than ca. 0.5 because of prior protonation, which then requires oxidative electron extraction from a cation. Arylpentazoles are exceptionally weak bases.[28−31] A basic pK_a value of −8.9 has been theoretically estimated for 1-methylpentazole.[30,31] Arylpentazoles are not protonated by trifluoroacetic acid but in the superacid, chlorosulfonic acid, *p*-anisylpentazole was fully protonated at N-3 (rather than the ethereal oxygen) and this pentazole derivative has a basic pK_a of ca. −8.[12] Hence,

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1-*p*-anisylpentazole should be a good candidate for CAN dearylation. The results in Table 1 (entry 6) and Table 2 (entry 4) confirmed that CAN dearylations are successful at −40 °C, well below the thermal degradation temperature of arylpentazoles.

Part II: Pentazoles. The arylpentazole system, ArN_5, was discovered by Huisgen and Ugi[32] in Munich and Clusius and Hürzeler[33] in Zurich. Its dimensions,[34] spectral effects,[35] basicity, and protonation site[12] place the pentazole ring firmly as the highest nitrogen member of the azoles. A potentially viable route to HN_5 of ozonolytic degradation of the aryl ring was attempted by Ugi[36] and recently repeated with necessary gentler more controlled conditions by Kaszynski and co-workers.[37] However, while no indication of HN_5 was found, compelling theoretical studies in 1992 by Bartlett's group[38] determined activation barriers for the decomposition pathways for HN_5 and predicted that both it and its pentazolate anion N_5^- should be viable entities under appropriate conditions.

Schleyer et al.[39] and Nguyen et al.[40] have theoretically illustrated that the most stable all-nitrogen systems, after N_2, are pentazolic units and that HN_5 and N_5^- should be comparable in aromaticity to furan and pyrrole. Two groups[41,42] have detected N_5^- in the gas phase from high-energy mass spectrometric degradation of aryl pentazoles. A theoretical assessment of the acidity of HN_5 concluded that it may be a stronger acid than HNO_3,[43] and hence, if generated in an aqueous nitrate salt environment it could form a metallic salt. A range of theoretical studies[26,44] have suggested that metallic salts of N_5^- should be stable entities. But which metal cations should be chosen? The low-temperature solution chemistry of pentazoles is difficult and not suitable for a wide variety approach. Following our own theoretical assessment[26] of the relative stability of pentazole counterions, we initially chose Zn^{2+} due to the higher covalent character of the M−N compared to group I and II counterions. (However, adding Zn^{2+} ion was discontinued as it proved ineffective.) Subsequent theoretical work[45] showed that the presence of counterions such as Fe^{2+} changes the nature of the ground state $Fe^{2+}\cdot 2N_5^-$ complex from a singlet to a quintet, lowering the barrier to N_5^- decomposition. Interestingly, a computational study by the Klapötke group[46] has predicted methyl pentazole, MeN_5, to be among the most stable pentazole derivatives, and this prompted our development of the one-pot dearylation-methylation protocol for *N*-*p*-anisylazoles (part I). Methylation of N_5^-, if possible, would be a prime route to MeN_5.

(i) *p*-Anisylazide: ^{15}N Signal Intensities and Control Reactions with CAN. In a linear chain of three nitrogen atoms ($-N_3$) containing one ^{15}N atom the intensity of the ^{15}N NMR signal of the central ^{15}N atom (which will be doubly bound to two ^{14}N atoms) will be much stronger than either of the terminal ^{15}N atoms (which will be doubly bound to only one ^{14}N atom) due to more efficient relaxation of the central ^{15}N atom.[47] In the Supporting Information (S5), we show the natural abundance ^{15}N NMR spectrum of *p*-anisylazide, where the central $^{15}N_\beta$ signal at −134.3 ppm is much more intense than that of N_γ (−146.1 ppm) or N_α (−290.0 ppm) as expected.

Since arylpentazole samples may contain various levels of aryl azide impurities, it was necessary to examine the reactions of *p*-anisylazide with CAN to (a) eliminate any possible reaction of CAN with arylazide impurity and (b) ensure that the reaction of CAN with *p*-anisylpentazole did not begin with pentazole ring destruction to *p*-anisylazide. This was confirmed by proton NMR spectra of the products from the reaction of CAN with *p*-anisylazide at −40 °C showing a very weak signal for *p*-benzoquinone (maximum isolated yield 5−6%) as against the comparable NMR spectra from the reaction of CAN with *p*-anisylpentazole at −40 °C, showing a much stronger *p*-benzoquinone signal (maximum isolated yield 34%) (S6).

The reaction of CAN with *p*-anisylazide is more rapid than with the pentazole, and pentazole samples containing a significant arylazide impurity will show no reaction with CAN because the arylazide will consume much of the CAN reagent. With such cases it is necessary to introduce a second charge of CAN to achieve the pentazole dearylation and this procedure may also be used to clean up a poor pentazole sample. One of the early products of the reaction of CAN with *p*-anisylazide at −40 °C is N_3^-. In these solutions, the ^{15}N NMR shifts of N_3^- are $^{15}N_{\alpha,\gamma}$,-281 ± 2 ppm and $^{15}N_\beta$, −144 ± 3 ppm. In the ^{15}N NMR spectrum of fully labeled $^{15}N_3^-$ ($Na^{15}N_3$) in CD_3OD-D_2O, the shifts are $^{15}N_{\alpha,\gamma}$ −280 to −281 ppm (d) and $^{15}N_\beta$ −131 ppm (t) (with N_β again more intense than the combined $N_{\alpha,\gamma}$ signal) (S7). When this fully labeled N_3^- is added to the product solution from CAN dearylation of the pyrazole **1c** (Table 1) (after first adding unlabeled N_3^- to consume any remaining Ce^{IV} since azide ion is oxidized by Ce^{IV} above 0 °C), the ^{15}N NMR spectrum now shows three N_β signals for the labeled azide ion, at −129.4 ppm (t) (uncomplexed $^{15}N_3^-$), −132 ppm, and −143 ppm (S8). The latter signals are from metal complexed azide ions. The presence of azide ion in three different environments is further confirmed by three separate signals also for the $N_{\alpha,\gamma}$ atoms of the azide ion between −290 and −293 ppm. Each of

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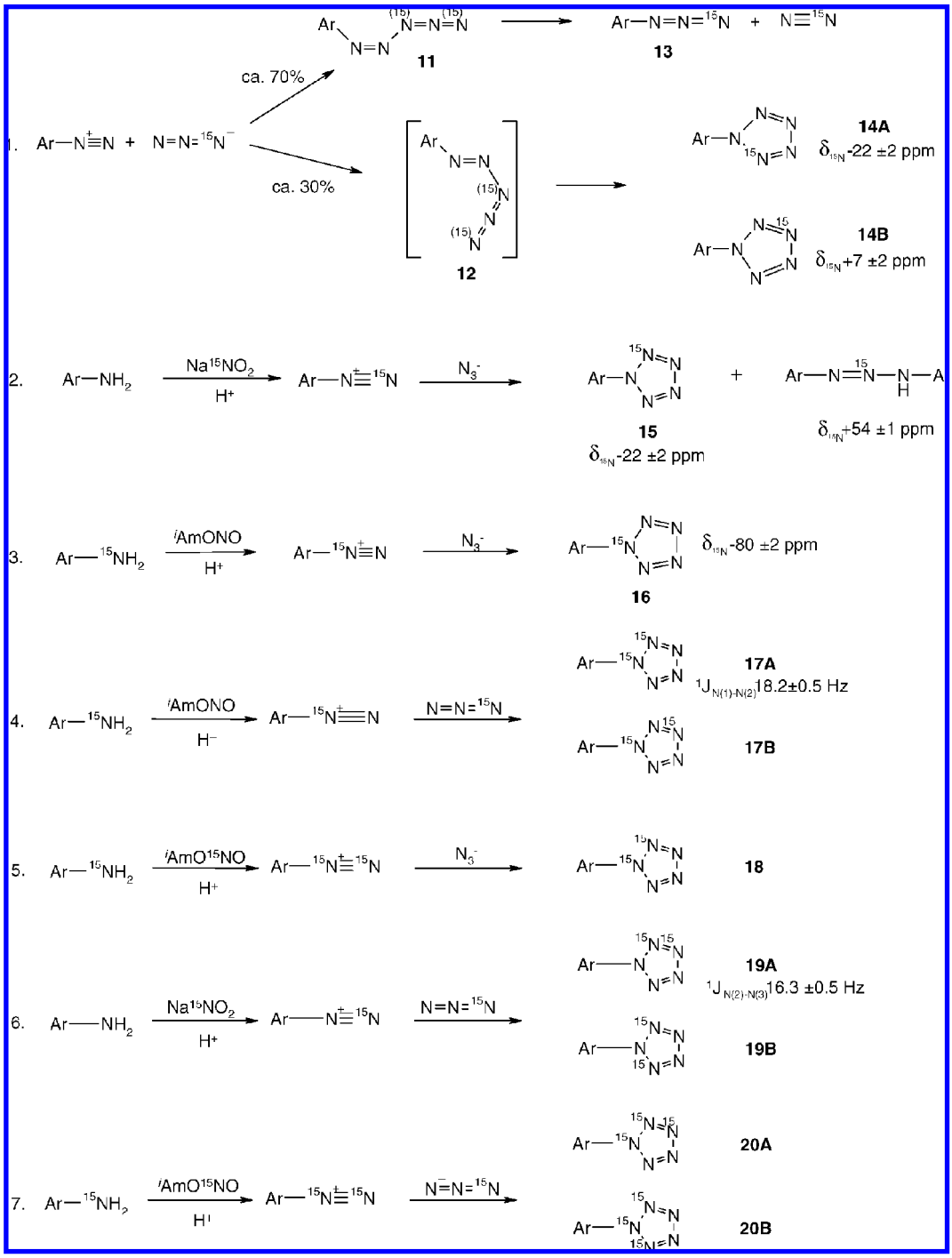
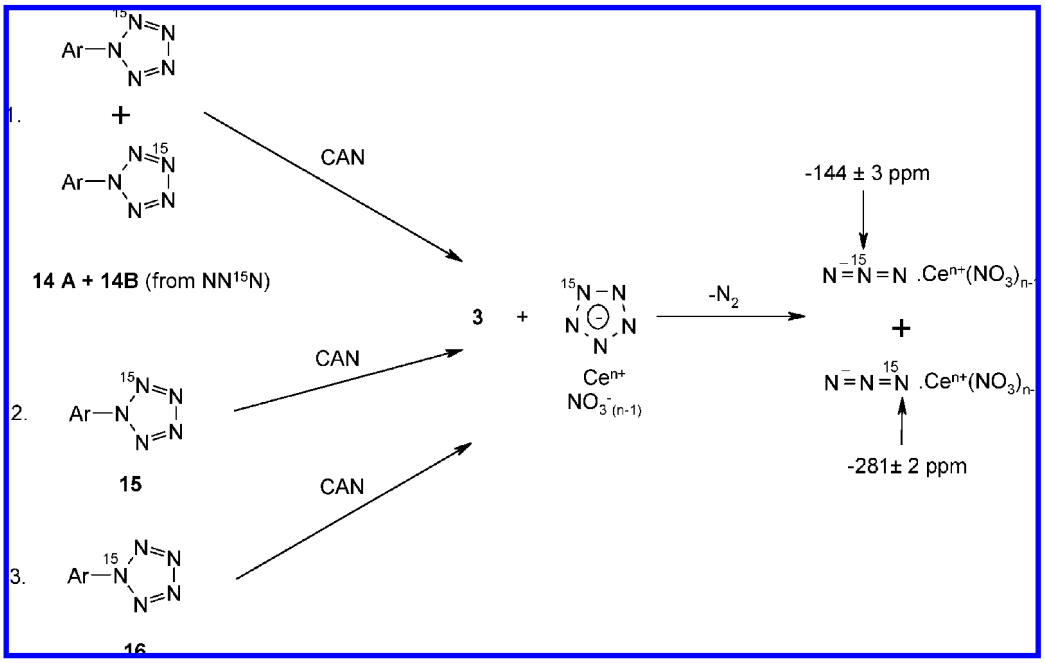
SCHEME 5. Preparation of ^{15}N-Labeled *p*-Anisyl Pentazoles (Ar = *p*-MeOC$_6$H$_4$)



these is a doublet split by the azide ion N_β (Supporting Information, S8). The strongest signals are from uncomplexed $^{15}N_3^-$ where N_α and N_γ are identical. The appearance of the azide ion $^{15}N_\beta$ signal at ca. −143 ppm is probably due to Ce^{III} complexation. The ^{15}N NMR signal of N_β for the azide ion formed by decomposition of HN_5/N_5^-, produced by CAN dearylation of *p*-anisylpentazole, appears at the same chemical shift, 144 ± 3 ppm. The spectra (Supporting Information, S8) also illustrate a feature of the metal complexed azide ions in these solutions where despite ^{15}N labels at both N_α and N_γ sites the combined terminal $N_{\alpha,\gamma}$ signal is exceptionally weak relative to that of N_β, possibly due to Ce^{III} complexation. In such cases the $N_{\alpha,\gamma}$ signal for a single label may be lost in the baseline, but its splitting effect on the adjacent strong N_β signal is readily detected.

(ii) CAN Dearylation of *p*-Anisylpentazole: Generation of HN_5/N_5^- in Solution. A suite of ^{15}N-labeled pentazoles was prepared (Scheme 5). The series **14A** + **14B**, **15**, and **16** carry a single ^{15}N atom located at each position of the pentazole ring, namely N-1, N-2, and N-3. The series **17A** + **17B**, **18**, and **19A** + **19B** contain two ^{15}N atoms in each pentazole molecule (Scheme 5, nos. 4−6). The compounds **20A** + **20B** contain three ^{15}N atoms in each pentazole ring. The reactions of each of these with CAN were examined. Those molecules with more

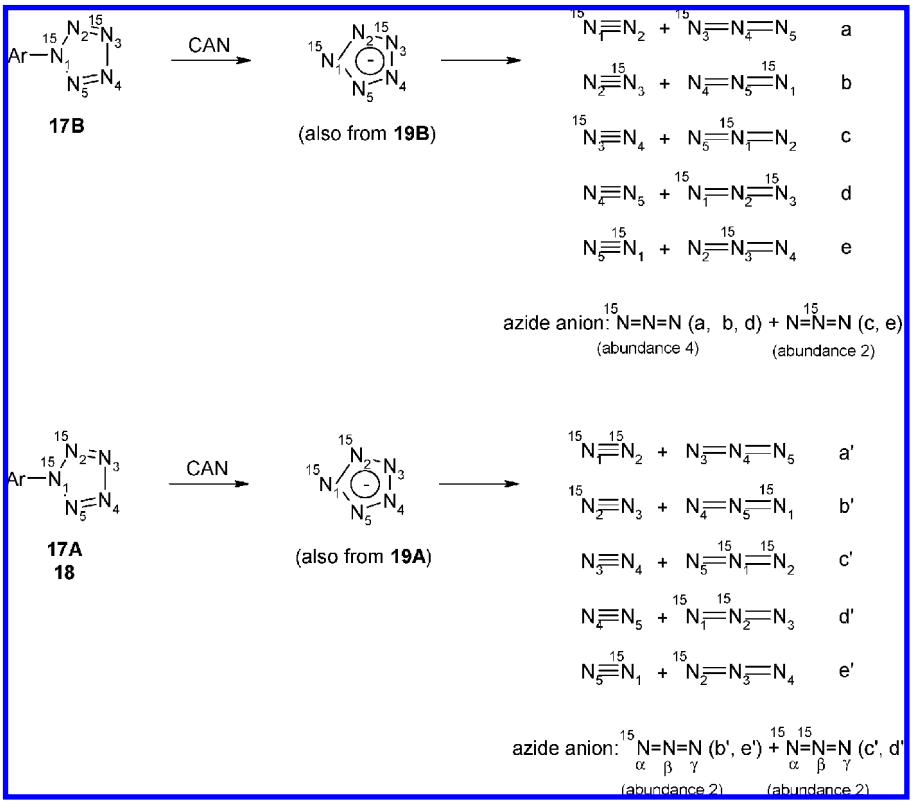
SCHEME 6. CAN Dearylation of Singly ^{15}N-Labeled *p*-Anisylpentazoles



than one ^{15}N atom allow splitting effects as well as chemical shifts to be used for analysis. In preparing these pentazoles, inorganic nitrite salts were avoided where possible and isoamyl nitrite was used as the preferred diazotization reagent, as in our preliminary report.[7] It was found that the level of *p*-anisyl azide impurity present in pentazoles prepared by using inorganic nitrite salts in the diazotization step was often unacceptably high, and a second impurity, 1,3-di-*p*-anisyltriazene, was also present in significant quantity. (Separate reactions of CAN with the diaryl triazene produced aryl diazonium ion). The only case where these impurities could not be fully avoided was for reaction no. 2 (Scheme 5) in which the ^{15}N label was placed exclusively at the pentazole N-2 in compound **15**. However, this problem was somewhat alleviated in cases 5 and 7 by in situ generation of ^{15}N-labeled isoamyl nitrite, and for case 6 the triazene and most of the aryl azide was removed by cleaning using CAN (see the Supporting Information). The label was placed exclusively at the pentazole N-1 in compound **16**, by using ^{15}N-labeled *p*-anisidine. This was synthesized by nitrating chlorobenzene with $H^{15}NO_3$, carrying out an S_NAr displacement of chloride with MeO^- on the isolated *p*-$ClC_6H_4{}^{15}NO_2$ isomer, and subsequently reducing the nitro group. This synthesis was experimentally not trivial. In the preliminary account of this work[7] the pentazole substrate used was a 1:1 mixture of **14A** and **14B** which was reacted with one charge of CAN. The spectra obtained are in the literature.[7] In Scheme 5, reaction 1, the mechanism[11,32] of the reaction of N_3^- with aryldiazonium ion is summarized. When mono-^{15}N-labeled azide anion is used the ^{15}N label at the terminal position of the azide anion is focused heavily into the γ-position of the main *p*-anisyl azide product. This is the arylazide impurity which will contaminate the arylpentazole. The ^{15}N label can only make its way into the β-position of *p*-anisyl azide via thermal degradation of the pentazole which is a minor part of the overall reaction of an aryl diazonium salt with azide ion.[11,32]

(a) Pentazole Samples with One ^{15}N Atom (Scheme 6). When a solution of the pentazole **14A** + **14B** (Scheme 5) in CD_3OD at −40 °C was treated by dropwise addition of a cooled solution of CAN in D_2O with stirring and the mixture stirred at −40 °C for several days *p*-benzoquinone was produced (Supporting Information, S6). NMR samples were withdrawn and ^{15}N NMR spectra were measured at −40 °C and again at −20 °C. This work was described in the preliminary communication.[7] The spectra, which have been published,[7] showed the presence of NO_3^- (correctly reassigned by Schroer et al.[13]), unreacted **14**, and a mixture of azide ions labeled at $N_{\alpha/\gamma}$ and N_β, $^{15}N_\alpha{=}N{=}N^-$ and $N{=}{}^{15}N_\beta{=}N^-$. The signal for $N_{\alpha,\gamma}$-labeled N_3^- was at −281 ± 2 ppm and that for N_β-labeled N_3^- was at −144 ± 3 ppm (Scheme 6). These results showed that N_5^- had been present in the solution. Schroer et al.,[13] however, disputed that these signals were from azide ion labeled at $N_{\alpha/\gamma}$ and N_β but significantly acknowledged that if they were azide signals they would constitute strong evidence for the formation of an intermediate N_5^- anion in which all nitrogens had become equivalent. They interpreted the signal at −283 ppm as N_α of singly labeled azide anion impurity carried invisibly through all of the ^{15}N NMR spectra from the pentazole synthesis but reappearing in the last spectrum from the CAN reaction. The signal at −147 ppm was ascribed to N_γ of *p*-anisyl azide (from decomposition of compound **14A** + **14B**) but in which N_β of the *p*-anisyl azide was not visible because its signal was too weak. However, the natural abundance ^{15}N NMR spectrum of *p*-anisyl azide shows the supposedly invisible N_β signal to be much more intense than that of N_γ. Schroer et al.[13] show a ^{15}N NMR spectrum of *p*-anisyl azide where the signal for N_γ is twice as intense as N_β from a sample which is claimed to have equal labels at N_β and N_γ. However, the spectrum shown by Schroer et al.[13] is a sample of the aryl azide heavily contaminated with compound **13** (Scheme 5, reaction 1) in which the ^{15}N label has been bonded exclusively at N_γ, a consequence of the mechanism of the reaction. Compound **13** is the main product of the reaction of aryl diazonium ions with terminally ^{15}N-labeled azide ion.[11,32] If the sample of the arylpentazole used to produce aryl azide is contaminated by the aryl azide **13** false

SCHEME 7. Expected Azide Anion ^{15}N Multiplicities and Intensities from Di-^{15}N-Labeled Pentazoles (Ar = *p*-$MeOC_6H_4$−)



relative intensities will be observed for the N_β and N_γ signals, with N_γ appearing much more intense.

The issue was further resolved by placing a single ^{15}N label at the N-1 and N-2 pentazole positions as in structures **15** and **16**. When these singly ^{15}N-labeled pentazoles **15** and **16** were similarly treated with CAN the results obtained were the same as those for **14**, namely *p*-benzoquinone and metal-complexed ^{15}N-labeled azide ions with a strong label at the important N_β position were produced (Scheme 6, reactions 2 and 3) (Supporting Information, S9−S10). The azide ion had the same chemical shifts as those from reaction 1, Scheme 6. Raising the temperature of the reaction to −20 °C, or introducing a second charge of CAN, increased the intensity of the azide ion signals and significantly reduced the amount of unreacted pentazole (spectra in the Supporting Information). No ^{15}N-labeled azide ion was used in the synthesis of the starting pentazoles **15** and **16**, and neither of these can decompose to a $^{15}N_\gamma$-labeled arylazide. These results show that ceric ammonium nitrate has dearylated *p*-anisylpentazole just as it did the other azoles in part I. The reaction has produced *p*-benzoquinone and HN_5/N_5^- in which a single ^{15}N label at any position in the starting pentazole has been scrambled to produce ^{15}N-labeled azide ion with ^{15}N atoms at $N_{\alpha/\gamma}$ and N_β as shown in reactions 1−3, Scheme 6. Because of the difficulties already mentioned concerning the synthesis of the N-2-labeled pentazole **15**, S10 (Supporting Information) also shows the presence of *β*-labeled aryldiazonium ion [Ar−N^+≡^{15}N] from CAN degradation of the diaryltriazene contaminant.

(b) Pentazole Samples with Two ^{15}N Atoms (Scheme 7). When the starting arylpentazole contains two ^{15}N labels located at positions 1 and 3 and at positions 1 and 2, as in structures **17A** + **17B** and **18** (Scheme 7), the azide anion expected from degradation of HN_5/N_5^- will have a combination of special intensities and splitting patterns for the ^{15}N-labeled N_β and $N_{\alpha,\gamma}$ positions as illustrated in Scheme 7. The key central $^{15}N_\beta$ signal of the azide ion at 144 ± 3 ppm is particularly significant. From the equimolar mixture **17A** + **17B** it will be an overlapping strong singlet (c + e) and a weaker doublet (c′ + d′). For N_5^- from substrate **18** the azide anion N_β signal will be a strong doublet (c′ + d′, Scheme 7). Both of these expectations were borne out in the $^{15}N_\beta$ signal at −144 ± 3 ppm which appears in the solutions from the separate dearylations of substrates **17A** + **17B** and **18** with CAN at −40 °C (Supporting Information, S11−S12). The strong singlet azide ion N_β signal (Supporting Information, S11) is particularly significant. It can only arise for N_3^- from HN_5 or N_5^- since the only possible aryl azides from fragmentation of **17A** + **17B** are Ar−^{15}N═N_β═^{15}N and Ar−^{15}N═$^{15}N_\beta$═N, neither of which can produce azide anion with an $^{15}N_\beta$ singlet signal. The expected strong doublet azide ion N_β signal (split by a single ^{15}N labeled $N_{\alpha,\gamma}$) is also obtained from degradation of HN_5/N_5^- generated by dearylation of pentazole **18** (c′, d′, Scheme 7) (S12). The sample of HN_5/N_5^- produced from dearylation of the *p*-anisyl pentazoles **19A** + **19B** (with different initial labels) will have the same distribution of ^{15}N labels as that from **17A** + **17B** (Scheme 7). As expected the azide ion produced from its degradation again showed the $^{15}N_\beta$ signal as a strong singlet overlapping a weaker doublet (Supporting Information, S13). These results combined with those of the singly labeled pentazoles above are unequivocal. They confirm the formation of N_3^- by degradation of HN_5/N_5^- in these solutions. The azide anion $N_{\alpha,\gamma}$ signals, which are much weaker than N_β, also have significant characteristics. In

some cases, the weak azide ion $N_{\alpha,\gamma}$ signal itself is not visible in the low-temperature ^{15}N spectra above the level of noise; its presence is confirmed by its splitting effect on the N_β signal in cases where the decomposition of N_5^- can give an azide ion with two ^{15}N labels, at both $N_{\alpha,\gamma}$ and N_β, as in S12(Supporting Information). Samples of **20A** + **20B** were treated with CAN at −40 °C, and recording of ^{15}N NMR spectra was started within 20 min of the CAN addition, examined every 500 scans (49 min) for up to 14 h, and accumulated accordingly (Supporting Information, S57−S62). The weak $N_{\alpha,\gamma}$ signal at −280 ppm began to appear after 2000 scans, and as it grew it displayed the expected doublet character split by $^{15}N_\beta$. Since the azide ion used for the synthesis of **20A** + **20B** contained only a single terminal $^{15}N_\alpha$ atom, the doublet $N_{\alpha,\gamma}$ signal for the azide ion from **20A** + **20B** again shows that it now possesses an $^{15}N_\beta$ atom and that it came from degradation of N_5^- and is not a leftover from the synthesis of **20A** + **20B**. In this case, the azide N_β signal is a multiplet of overlapping doublets and triplets.

(iii) *p*-Benzoquinone. *p*-Benzoquinone was produced in the CAN reactions carried out with the pentazole samples, as for the other azoles. It could be observed in low-temperature proton NMR spectra for both unlabeled and ^{15}N-labeled pentazole samples (Supporting Information, S13). It was isolated by partitioning the CAN solution between dichloromethane and water, evaporation of the dichloromethane extract and chromatographic separation of the residue on a silica gel column. The *p*-benzoquinone could also be sublimed out of the dichloromethane residue onto a cold finger. Because of the large number of *p*-benzoquinone isolations, a rapid proton NMR estimation method was developed from a plot of standard *p*-benzoquinone−methyl iodide mixtures in CD_2Cl_2 whereby a proton NMR spectrum of a CD_2Cl_2 extract containing a known quantity of added MeI gave an estimated % yield of *p*-benzoquinone (Supporting Information, S47−S49). All yields quoted are isolated values unless specifically designated as estimated. Both methods were in agreement within experimental error. The yields of *p*-benzoquinone from the CAN dearylation of *p*-$MeOC_6H_4N_5$ were 23−34%. By analogy with the other azoles this implied that a comparable quantity of HN_5 should have been produced alongside. Schroer et al.[13] state that there was no reaction between CAN and *p*-anisylpentazole and no "evidence of N_5^-, N_3^- or benzoquinone" formation "under the reported conditions", but the conditions used were quite different to our reported conditions[7] and the reaction could not have been observed (Supporting Information, S49).

(iv) Search for N_5^-. In the preliminary communication,[7] we reported a ^{15}N signal at −10 ± 2 ppm which agreed with the expected position for N_5^- with one ^{15}N atom. This signal can appear anywhere between −5 and −17 ppm as seen in the wider range of spectra herein, and its variability combined with an intensity comparable to the signals obtained from ^{15}N labeled samples proved misleading. The reassignment of the signal as a natural abundance NO_3^- by Schroer et al.[13] means that N_5^- has not been directly seen. One purpose of putting three ^{15}N atoms into the aryl pentazoles **20A** + **20B** was to increase the intensity of the possible signal from HN_5/N_5^- where each molecule would have three equivalent ^{15}N atoms. Samples of **20A** + **20B** were treated with CAN at −40 °C as described. Recording of ^{15}N NMR spectra was started within 20 min of the CAN addition, and spectra were examined and accumulated every 500 scans (49 min) for up to 14 h (Supporting Information, S57−S62), but no signals were detected anywhere in the range expected for HN_5/N_5^-, from −20 to 50 ppm. The results were the same in the presence and absence of Zn^{2+} ions. Extensive attempts were also made to trap HN_5/N_5^- by in situ methylation of a number of ^{15}N-labeled samples for both the normal acidic and basified solutions from CAN dearylations using the procedures established with the triazole **5a**. Calculated ^{15}N NMR shifts have been published[46] for methyl pentazole and if a second pentazole molecule had appeared in these solutions its set of signals would have been easily detected in the NMR spectra. However, methyl pentazole was not detected. Hence, we conclude that the species HN_5/N_5^- is unstable and did not build up in the solutions even at −40 °C. If it is ever to be directly detected or isolated it will need to be specially stabilized.

Experimental Section

Details of instrumentation used and all spectral figures are in the Supporting Information.

N-Dearylations of C−N Azoles. Representative Procedure for the Dearylation of *N*-*p*-Anisylpyrazoles: CAN Dearylation of 1a (Table 1, Entry 1). A solution of **1a** (0.27 g, 1.33 mmol) in MeCN (19 mL) was treated dropwise with an aqueous solution (4 mL) of CAN (2.19 g, 3.99 mmol) and stirred at ambient temperature for 1 h. The reaction mixture was then diluted with water (30 mL) and the MeCN removed under reduced pressure. The remaining aqueous solution was extracted with CH_2Cl_2 (4 × 20 mL). The combined organic extracts were washed with saturated aqueous $NaHCO_3$ solution (4 × 20 mL) and dried over $MgSO_4$, and the solvent was removed under reduced pressure. The residue (in 3 mL of CH_2Cl_2), was placed on a column of silica gel (230−400 mesh ASTM) and eluted with a gradient mixture of petroleum spirit (bp 40−60 °C)−CH_2Cl_2 (1:0 to 0:1 v/v using a 5% v/v changing gradient) to give **3** (0.06 g, 41%) and with a gradient mixture of CH_2Cl_2−Et_2O (1:0 to 0:1 v/v using a 2.5% v/v changing gradient) followed by Et_2O−MeOH (1:0 to 19:1 v/v) to give **2a** (0.06 g, 47%). **Compound 2a:** mp 107−108 °C (from petroleum spirit (bp 80−100 °C)) (lit.[15] mp 107−109 °C); ^1H NMR (400 MHz, $CDCl_3$) δ 2.31 (s, 6H, CH_3), 5.81 (s, 1H, 4-CH), 12.18 (br s, 1H, NH); ^{13}C NMR ($CDCl_3$) δ 12.3 (3-CH_3/5-CH_3) 104.0 (C-4), 144.3 (C-3/C-5); IR (mull, cm^{-1}) ν_{max} 3108 (NH), 1595 (C═N). Anal. Calcd for $C_5H_8N_2$: C, 62.5; H, 8.4; N, 29.1. Found: C, 62.3; H, 8.7; N, 29.0. **Compound 3:** mp 109−110 °C (from petroleum spirit (bp 40−60 °C) (lit.[2] mp 111.5−112.5 °C); ^1H NMR (400 MHz, $CDCl_3$) δ 6.78 (4H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 136.6 (C-2/C-3/C-5/C-6), 187.3 (C-1/C-4).

Representative Procedure for the Dearylation of 2-*N*-*p*-Anisyl-1,2,3-triazoles: CAN Dearylation of 4a (Table 2, Entry 1). A solution of **4a** (0.40 g, 1.2 mmol) in MeCN (18 mL) was treated dropwise with an aqueous solution (1.8 mL) of CAN (1.75 g, 3.2 mmol) and stirred at ambient temperature for 24 h. The reaction mixture was diluted with water (10 mL) and the MeCN removed under reduced pressure. The aqueous solution remaining was extracted with CH_2Cl_2 (4 × 10 mL). The combined extracts were dried over $MgSO_4$, and the solvent was removed under reduced pressure. The residue (in 3 mL of CH_2Cl_2) was placed on a column of silica gel (230−400 mesh ASTM) and eluted with a gradient mixture of petroleum spirit (bp 40−60 °C)−CH_2Cl_2 (9:1 to 0:1 v/v using a 5% v/v changing gradient) followed by CH_2Cl_2−Et_2O (1:0 to 4:1 v/v using a 2.5% v/v changing gradient). The products eluted from the column were isolated in the following order: 2-(3′-nitro-4′-methoxyphenyl)-4,5-diphenyl-1,2,3-triazole (0.03 g, 7%); **3** (0.05 g, 39%); **5a** (0.12 g, 44%). **Compound 5a:** mp 130−131 °C (from toluene) (lit.[19] mp 134−135 °C); ^1H NMR (400 MHz, $CDCl_3$) δ 7.31−7.33 (m, 6H, H_m, H_p, phenyl), 7.52−7.54 (m, 4H, H_o, phenyl), 13.97 (s, 1H, NH); ^{13}C NMR (100 MHz, $CDCl_3$) δ 130.0, 128.2, 128.6, 128.5 (C-1′, C-2′, C-3′, C-4′ respectively, phenyl rings), 142.3 (C-4/C-5); IR (mull, cm^{-1}) ν_{max} 3065 (NH), 1584 (C═N). Anal. Calcd for $C_{14}H_{11}N_3$: C, 76.0; H,

5.0; N, 19.0. Found: C, 76.1; H, 4.6; N, 19.0. 2-(3′-Nitro-4′-methoxyphenyl)-4,5-diphenyl-1,2,3-triazole: mp 176−178 °C (from CH_2Cl_2−hexane 2:1 v/v); ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.03 (s, 3H, OCH_3), 7.20−7.22 (d, 1H, $J_{6'-5'}$ 9.0 Hz, 5′-CH of 3′-NO_2-4′-$OCH_3C_6H_3$−), 7.40−7.41 (m, 6H, phenyl), 7.62−7.63 (m, 4H, phenyl), 8.33−8.36 (dd, 1H, $J_{6'-5'}$ 9.0 Hz, $J_{6'-2'}$ 3.0 Hz, 6′-CH of 3′-NO_2-4′-$OCH_3C_6H_3$−), 8.67−8.68 (d, 1H, 2′-CH of 3′-NO_2-4′-$OCH_3C_6H_3$−); ^{13}C NMR (100 MHz, $CDCl_3$) δ 56.9 (OCH_3), 132.7, 116.2, 139.7, 151.8, 114.2, 123.7 (C-1′, C-2′, C-3′, C-4′, C-5′, C-6′ respectively, 3′-NO_2-4′-$OCH_3C_6H_3$-), 146.5 (C-4/C-5), 128.4, 128.7, 128.9 (phenyls), 130.3 (C-1′, phenyl). Anal. Calcd for $C_{21}H_{16}N_4O_3$: C, 67.7; H, 4.3; N, 15.1. Found: C, 67.3; H, 4.3; N, 15.4.

Representative Procedure for the Dearylation of 2-*N*-*p*-Anisyl-1,2,3,4-tetrazoles: CAN Dearylation of 6a (Table 2, Entry 10). A suspension of **6a** (0.20 g, 0.79 mmol) in MeCN (27 mL) at −10 °C was treated dropwise with an aqueous solution (2.5 mL) of CAN (1.30 g, 2.37 mmol) and stirred at this temperature for 4 h. The temperature was raised to 0 °C for 45 h, then to ambient temperature for 45 h, 40 °C for 28 h, and finally 60 °C for 20 h. The reaction mixture was diluted with MeCN (30 mL) and brought to pH 10 using 0.1 M aqueous NaOH. The precipitate was filtered and washed with water (10 mL). The combined filtrate and water washings were extracted with Et_2O (3 × 30 mL) and the aqueous layer acidified to pH 3.5 with concd HCl. The acidified aqueous layer was extracted with CH_2Cl_2 (4 × 20 mL). The combined organic extracts were dried over $MgSO_4$ and evaporated under reduced pressure to give **7a** (0.017 g, 15%). Further workup resulted in the isolation of unreacted starting material and gums. **Compound 7a:** mp 216−217 °C (from EtOH) (lit.[20] mp 215−216 °C); ^{1}H NMR (400 MHz, CD_3OD) δ 7.57−7.59 (m, 3H, $H_{m,p}$, 5-CC_6H_5), 8.01−8.30 (m, 2H, H_o, 5-CC_6H_5); ^{13}C NMR (100 MHz, CD_3OD) δ 125.4, 132.7, 130.6, 128.3 (C-1′, C-2′, C-3′, C-4′, respectively, 5-C-C_6H_5), 157.5 (tetrazole C-5); IR (mull, cm^{-1}) ν_{max} 3141 (NH), 1613 (C═N). Anal. Calcd for $C_7H_6N_4$: C, 57.5; H, 4.1; N, 38.3. Found: C, 57.5; H, 4.0; N, 38.1.

One-Pot Dearylation−Alkylation of 4a: Basic Conditions. A solution of **4a** (1.00 g, 3.05 mmol) in MeOH (45 mL) was treated dropwise with an aqueous solution (4.5 mL) of CAN (4.74 g, 8.65 mmol) and stirred at ambient temperature for 24 h. The reaction mixture was then adjusted to pH 10 with dropwise addition of a solution of KOH in MeOH. Trimethyloxonium tetrafluoroborate (2.26 g, 15.28 mmol) was added, and the mixture was stirred for a further 24 h at ambient temperature. The reaction mixture was then diluted with water (40 mL) and the MeOH evaporated under reduced pressure. The resulting aqueous mixture was extracted with CH_2Cl_2 (4 × 20 mL). The combined organic extracts were dried over $MgSO_4$ and evaporated under reduced pressure, and the residue (in 8 mL CH_2Cl_2) was placed on a column of silica gel (230−400 mesh ASTM) and eluted using a gradient mixture of petroleum spirit (bp 40−60 °C)−CH_2Cl_2 (1:0 to 0:1 v/v using a 5% v/v changing gradient), followed by a gradient mixture of CH_2Cl_2−Et_2O (1:0 to 3:2 v/v using a 2.5% v/v changing gradient) to give **8** (0.25 g, 35%) and **9** (0.08 g, 11%). **Compound 8:** mp 65−66 °C (from petroleum spirit (bp 40−60 °C)) (lit.[18] mp 60−61 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.26 (s, 3H, CH_3), 7.34−7.36 (m, 6H, $H_{m,p}$, phenyl), 7.53−7.55 (m, 4H, H_o, phenyl); ^{13}C NMR (100 MHz, $CDCl_3$) δ41.8 (CH_3), 131.1 (C-1′, phenyl), 128.3, 128.4 (C-2′/C-3′, phenyl), 128.7 (C-4′, phenyl), 144.6 (C-4/C-5, triazole). Anal. Calcd for $C_{15}H_{13}N_3$: C, 76.6; H, 5.6; N, 17.9. Found: C, 76.5; H, 5.8; N, 17.6. **Compound 9:** mp 128−129 °C (from EtOAc−petroleum spirit (bp 40−60 °C)) (lit.[18] mp 129−130 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.92 (s, 3H, CH_3), 7.24−7.34 (m, 5H, phenyl), 7.49−7.55 (m, 5H, phenyl); ^{13}C NMR (100 MHz, $CDCl_3$) δ 35.4 (CH_3), 131.0, 128.0, 129.8, 127.8, 127.0, 128.7, 129.5, 129.9 (phenyl), 134.2 (C-5, triazole), 144.4 (C-4, triazole). Anal. Calcd for $C_{15}H_{13}N_3$: C, 76.6; H, 5.6; N, 17.9. Found: C, 76.5; H, 5.7; N, 18.0.

Synthesis and Dearylation of *N*-*p*-Anisylpentazoles (Schemes 5 and 6). *Unstable p-anisylpentazole samples, unlike the stable lower azole samples, cannot be stored and weighed for separate dearylation reactions. Hence, all pentazole samples, once prepared and isolated at −40 °C, were immediately reacted with CAN.*

Representative Procedure for the Synthesis of Arylpentazoles. Synthesis of Unlabeled 1-(*p*-Anisyl)pentazole. A solution of *p*-anisidine (1.61 g, 13.1 mmol) in MeOH (8.2 mL) at 0−2 °C was treated dropwise with concd HCl (2.1 mL) followed by isoamyl nitrite (1.9 mL, 1.66 g, 14.2 mmol). The mixture was allowed to stand for 20 min at 0−2 °C and then diluted with a MeOH−H_2O mixture (1:1 v/v) (22.4 mL) and covered with a layer of petroleum spirit (bp 40−60 °C) (120 mL). The mixture was cooled to −35 °C, and a cooled solution of sodium azide (0.85 g, 13.1 mmol) in MeOH−H_2O (3:2 v/v) (6.95 mL) was injected into the lower, aqueous layer. A solid mixture of products separated and was isolated by filtration through a sintered glass funnel with a cooling jacket at −40 °C. The solid was repeatedly washed with a MeOH−H_2O mixture (3:2 v/v), cooled below −55 °C, to give 1-(*p*-anisyl)-pentazole containing a small quantity of *p*-anisyl azide impurity (max 12−16% by ^{1}H NMR): ^{1}H NMR (400 MHz, CD_3OD−CD_2Cl_2 (1:1 v/v), −40 °C) δ 3.96 (s, 3H, OCH_3), 7.22−7.25 (d, 2H, H_m, AA′BB′, $NC_6H_4OCH_3$-*p*, AA′BB′ J_{AB} 9.1 Hz), 8.15−8.17 (d, 2H, H_o, AA′BB′, $NC_6H_4OCH_3$-*p*); ^{13}C NMR (100 MHz, $CDCl_3$, −40 °C) δ 56.1 (OCH_3), 126.7, 122.6, 115.3, 161.4 (C-1′, C-2′, C-3′, C-4′ respectively, $NC_6H_4OCH_3$-*p*).

^{15}N-Labeled 1-(*p*-anisyl)pentazole samples **14A** + **14B**, **15**, **16**, **17A** + **17B**, **18**, **19A** + **19B** and **20A** + **20B** were prepared in a similar manner using ^{15}N-labeled *p*-anisidine to introduce an isotope label at N-1, ^{15}N-labeled sodium nitrite to introduce an isotope label at N-2, terminally ^{15}N-labeled sodium azide to introduce an isotope label at N-2 or N-3, and combinations of these for the di- and tri-^{15}N-labeled pentazole samples (experimental details in the Supporting Information).

CAN Dearylation of Unlabeled 1-(*p*-Anisyl)pentazole. Isolation of *p*-Benzoquinone 3. 1-(*p*-Anisyl)pentazole (1.09 mmol, see below) was dissolved in MeOH (32 mL) at −40 °C in a jacketed reaction flask. The solution was treated dropwise with a cooled aqueous solution (4.2 mL) of CAN (4.93 g, 9.0 mmol). The reaction mixture was allowed to stir for 6 days at −40 °C, followed by warming to ambient temperature, dilution with water (30 mL), and extraction with CH_2Cl_2 (5 × 20 mL). The combined extracts were dried over $MgSO_4$ and evaporated under reduced pressure. The residue (in 5 mL of CH_2Cl_2) was placed on a column of silica gel (230−400 mesh ASTM) and eluted using a gradient mixture of petroleum spirit (bp 40−60 °C)−CH_2Cl_2 (1:0 to 0:1 v/v) to give **3** (0.04 g, 34%).

To precisely estimate the molar amount of 1-(*p*-anisyl)pentazole present as starting material, the above procedure was repeated to the point where the solution of the pentazole in MeOH at −40 °C was prepared. This solution was allowed to warm to ambient temperature, and evaporated under reduced pressure, giving a residue of *p*-anisylazide (0.19 g, 1.27 mmol). The original 1-(*p*-anisyl)-pentazole was shown by ^{1}H NMR to contain 14% *p*-anisylazide; the molar amount of pentazole present was therefore estimated to be 1.09 mmol, giving a yield of *p*-benzoquinone of 34%. In repeated isolations and ^{1}H NMR estimations of *p*-benzoquinone from such reactions the yield of **3** ranged from 23 to 34%. Compound **3** was also directly detected in these solutions at −40 °C by proton NMR before its isolation (Supporting Information, S6 and S13).

CAN Dearylation of 16 (Scheme 6, Reaction 3). A sample of **16** prepared as described was dissolved in CD_3OD (2.5 mL) at −40 °C and treated dropwise with a solution of $Zn(NO_3)_2 \cdot 6H_2O$ (0.32 g, 1.08 mmol) in D_2O (0.125 mL), followed by a solution of CAN (0.59 g, 1.08 mmol) in D_2O (0.50 mL). The reaction mixture was stirred at −40 °C for 24 h. A sample was then withdrawn and analyzed by ^{1}H and ^{15}N NMR at −41 °C. The ^{1}H NMR signals (400 MHz, CD_3OD−D_2O (4:1 v/v), −41 °C) included: δ 3.84 (s, OCH_3, **16**), 6.73 (**3**), 7.16−7.19 (d, H_o, AA′BB′ spectrum, **16**),

8.04−8.06 (d, H_m, AA′BB′ spectrum, **16**); ^{15}N NMR (40 MHz, CD_3OD-D_2O (4:1 v/v), −41 °C, 6.892 scans) δ −7.1 (NO_3^-), −80.2 (N-1, **16**), (−140.3)−(−147.3) ($^{15}N_\beta$, azide ion) (Supporting Information, S9). Repetition of the procedure without addition of $Zn(NO_3)_2 \cdot 6H_2O$ gave the same results.

CAN Dearylation of 15 (Scheme 6, Reaction 2). A sample of **15** prepared as described was dissolved in CD_3OD (4.0 mL) at −40 °C and treated dropwise with a cooled solution of CAN (1.23 g, 2.24 mmol) in D_2O (1.0 mL). A sample was withdrawn from the reaction after ca. 5 min and analyzed by ^{15}N NMR (40 MHz, CD_3OD-D_2O (4:1 v/v), −41 °C, 1,160 scans). Signals attributable to NO_3^- (−12.3 ppm), remaining **15** (−23.3 ppm), N-2-labeled *p*-anisyldiazonium ion (−56.3 ppm), N-2-labeled *p*-anisylazide (−133.7 ppm), and N_β-labeled azide ion ((−143.2)-(−143.6) ppm) were visible.

The reaction mixture was allowed to stir at −40 °C for 3 days, after which time a further sample was withdrawn and analyzed by NMR at −41 °C. The ^{1}H NMR spectrum (400 MHz, CD_3OD-D_2O (4:1 v/v), −41 °C) shows a significant peak attributable to **3** (δ 6.76 ppm). The ^{15}N NMR spectrum (40 MHz, CD_3OD-D_2O (4:1 v/v), −37.4 °C, 3758 scans) shows peaks attributable to NO_3^- (−16.6 ppm), remaining **15** (−23.2 ppm), N-2-labeled *p*-anisyldiazonium ion (−56.4 ppm), N-2-labeled *p*-anisylazide (−133.8 ppm), and N_β-labeled azide ion ((−143.0)-(−143.6) ppm) (Supporting Information, S10).

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Supporting Information Available: Key figures directly mentioned in the text (S5−S13); **s**ynthetic details for all substrates and products not included in Experimental Section (S14−S26); further experimental procedures for azole dearylations (S27−S32); further experimental details for anisylation and alkylation of parent azoles (S32−S33); experimental procedures for substrates giving unsuccessful dearylation reactions (S34−S38); detailed experimental procedures for synthesis of labeled pentazole samples (S39−S44); further experimental procedures for dearylation of labeled pentazole samples (S45−S46); details of NMR quantification of *p*-benzoquinone yields (S47−S49); additional ^{15}N NMR spectra for pentazole dearylation reactions (S50−S62); NMR spectra for previously unknown compounds **4b**,**c** and **5b**,**c** (S63−S70). This material is available free of charge via the Internet at http://pubs.acs.org.

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