In a similar pyrolysis of unlabelled **2c** (450 mg) the yield of 2-phenylbenzimidazole-1-carbonitrile was 99.9%; m.p. 110° (sharp); subl. 60° (0.001 Torr); very soluble in ether.

$C_{14}H_9N_3$ (219.09) Calc. C 76.7 H 4.14 N 19.18% Found C 76.8 H 4.30 N 19.16%

2-Phenyl-[1(3)-^{15}N]-benzimidazole (**4c**) was obtained in quantitative yield after heating **3c** (30 mg) with 5 ml 1N NaOH at 100° for 3 h. The product, extracted with ethyl acetate, had m.p. 305° (45 atom-% ^{15}N). An unlabelled specimen prepared similarly was identical with an authentic sample [8].

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30. Tetrazoloazines. ^{15}N Nuclear Magnetic Resonance and Infrared Absorption Spectroscopy

by **Célestin Thétaz**[1], **F.W.Wehrli**[2]) and **Curt Wentrup**[3])

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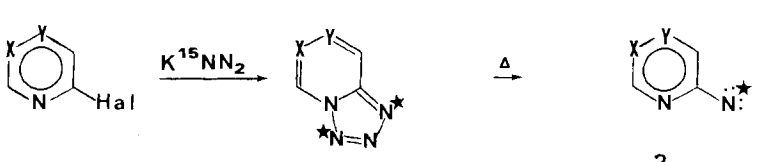
(17. XII. 75)

Summary. The reaction of 4-chloro-2-phenylquinazoline with $K^{15}NN_2$ has been studied by ^{15}N-NMR. spectroscopy. ^{15}N-chemical shifts in 5-phenyl-1(3)-[^{15}N]-tetrazolo[1,5-*c*]quinazoline and -$N_\alpha(N_\gamma)$-[^{15}N]-4-azido-2-phenylquinazoline are reported. The characteristic IR. absorption frequencies of the tetrazole group have been determined in a series of annelated ^{15}N-labelled compounds. From these studies and the chemistry of the labelled tetrazoles, it is concluded that all haloazines examined react with KN_3 by the direct nucleophilic substitution mechanism. An addition of nucleophile-ring opening-ring closure (ANRORC) mechanism was not observed. The synthesis of several ^{15}N-labelled tetrazoloazines is described.

The ready availability of ^{15}N-labelled potassium azide [1] has allowed the synthesis of a number of labelled tetrazoloazines with the general formula **1**.



1 **2**

X and Y = CH or N; ★ = $^1/_2$ ^{15}N

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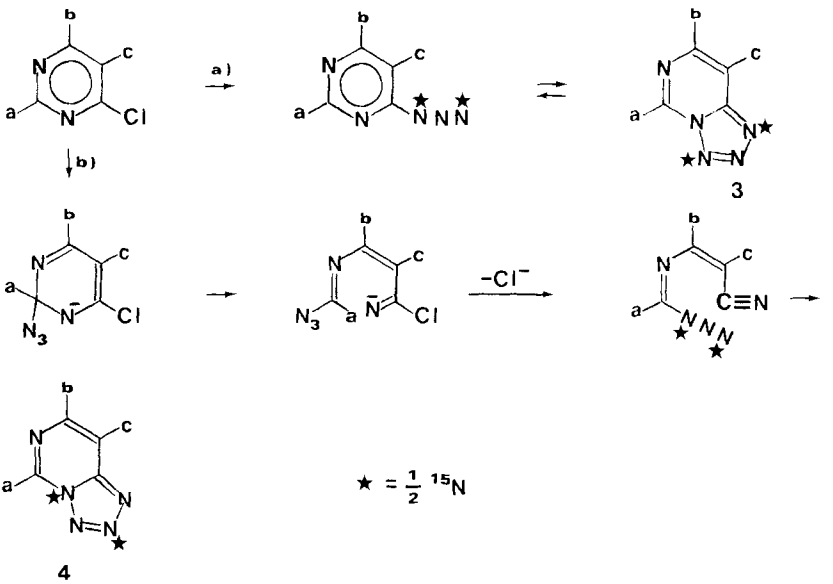
[3]) To whom correspondence should be addressed at the University of Lausanne.

The tetrazoles **1** are useful starting materials for the generation of nitrenes **2**, the rearrangements of which have been extensively studied [2–4]. In order to deduce any mechanistic details from the observed positions of the ^{15}N-label in the products derived from **2**, it is obviously necessary to know the positions of label in the tetrazoles **1**.

The problem is of considerable interest, especially in the pyrimidine derivatives, since it is known that haloazines can react with nucleophiles (alkali amides) by two distinct mechanisms: a) direct nucleophilic substitution; and b) Addition of Nucleophile-Ring Opening-Ring Closure (ANRORC-mechanism) [5]. Thus, the reaction of halopyrimidines with labelled azide anion could *a priori* give two differently labelled products, *e.g.* **3** and **4**, as described in *Scheme 1*.

Scheme 1

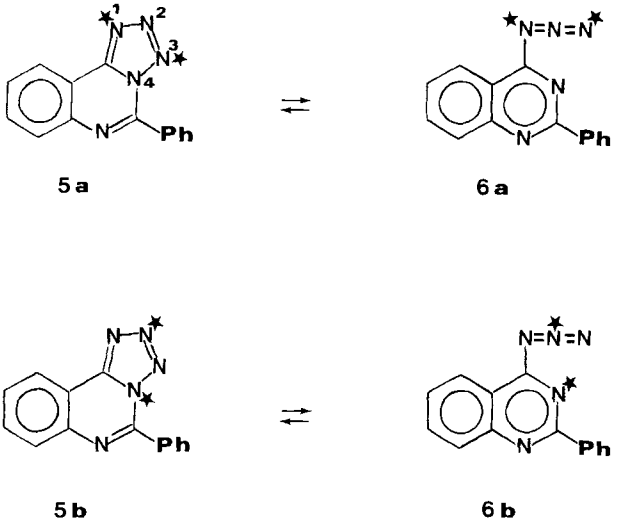


The position of label was determined by ^{15}N-NMR. spectroscopy of 5-phenyltetrazolo[1,5-*c*]quinazoline (**5**).

^{15}N Nuclear Magnetic Resonance. – The dynamic azido/tetrazoloazine valence tautomerism [6] (*Scheme 2*) allows a double identification of the labelled nitrogen atoms.

In trifluoroacetic acid (TFA) solution the azide tautomers **6a** resp. **6b** are exclusively present, while in dimethylsulfoxide (DMSO) solution only the tetrazoles **5a** resp. **5b** are detectable [7]. The ^{15}N-NMR. chemical shifts measured for the two solutions are reported in Table 1. Comparison with known ^{15}N shieldings in aryl azides [8], quinazoline [8], and tetrazoles [9] conclusively proves that the compound is labelled as in **5a** and **6a** (*Scheme 2*). The chemical shifts of N(1) and N(3) in **5a** are in excellent agreement with values reported for other annelated tetrazoles [9]. In the

Scheme 2

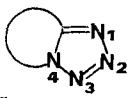
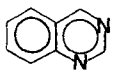


5a **6a**

5b **6b**

azide **6a** the N_α-signal was broadened relative to the N_γ-signal, due to coupling with remote protons. The N_α-signal disappeared altogether in the proton-decoupled spectrum. This is due to the negative magnetogyric ratio of ^{15}N, which, in this particular case, results in a partial negative nuclear *Overhauser* effect (NOE), which just cancels the signal. In order to circumvent this problem, trisacetylacetonato-chromium ($Cr(acac)_3$) was added to the solution with the purpose of quenching the NOE by short-circuiting the dipolar relaxation path. A further benefit of this method [10] is the concomitant shortening of spin-lattice relaxation times which considerably enhances the sensitivity.

Table 1. *^{15}N-Chemical shifts*

Azides	δ [a]			
R—N_α—N_β—N_γ	N_α	N_β	N_γ	
Ph—N_3 [8]	286	135	194	
6a	250.8	–	128.8	
Tetrazoles	N(1)	N(2)	N(3)	N(4)
 [9]	75	0	25	135
5a	71.0	–	30.4	–
 [8]	90	90		

[a] Chemical shift δ in ppm relative to CH_3NO_2.

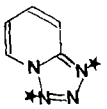
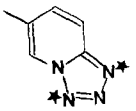
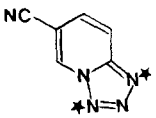
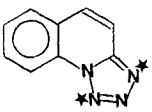
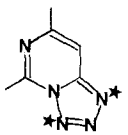
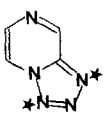
Infrared spectroscopy. – Partial IR. spectra of labelled and unlabelled tetrazole derivatives of pyridines, quinoline, pyrimidine, quinazoline, and pyrazine are reported in Table 2. *Lieber* [11] has assigned two principal absorptions to the tetrazole ring:

ca. 1335–1270 cm^{-1} (cyclic N–N=N), and

ca. 1100–980 cm^{-1} (up to three bands; skeletal vibrations of the tetrazole ring).

The isotopic shifts observed in our spectra (Table 2) confirm this assignment and also show that some bands at intermediate frequencies (1195–1260 cm^{-1}) in the tetra-

Table 2. *Infrared frequency displacements in ^{15}N-labelled tetrazoles*

Compound (★ = $^1/_2$ ^{15}N)	Absorption frequency (cm^{-1})	
	unlabelled compound	labelled compound
	1330 1240 1100 1020 700	1323 1230 1090 1010 693
	1330 1195 1005	a) 1185 990
	1340 1262 1210 1070 995	1330 1255 1200 1060 975
	1315 1080 990 690	1307 1070 980 685
	1100 1078	1090 1068
5a	1270 1100 990	1260 1090 975
	1090 1000	1080 990

a) Too weak to measure.

zolopyridines must be ascribed to the tetrazole ring. The occational bands noted by *Lieber* [11] at 740–760 cm^{-1} were not displaced in our spectra. However, in two cases bands at 690–700 cm^{-1} were shifted in the labelled compounds (tetrazolopyridine and tetrazoloquinoline). The fact that all the tetrazoles exhibit very similar shifts of the principal frequencies due to isotopic substitution indicates that they are all labelled as in **5a**. At any rate, having established the positions of label in **5a**, an alternative assignment for the other tetrazoles can be excluded on chemical grounds [4].

We conclude, therefore, that all haloazines examined react with alkali azide by the direct nucleophilic substitution mechanism.

Experimental Part

^{15}N-NMR. spectra were recorded on a *Varian* XL-100 instrument at 10.14 MHz in the pulsed mode. The spectrum of 4-azido-2-phenylquinazoline (**6a**) was obtained on a trifluoroacetic acid solution containing 10% acetone-d_6 for field/frequency lock. Nitromethane served as an external reference. 5-Phenyltetrazolo[1,5-*c*]quinazoline (**5a**) was measured in hexadeuteriodimethylsulfoxide with some Cr(acac)$_3$ being added. This spectrum was referenced to nitromethane.

IR. spectra were recorded on KBr discs using a *Beckmann* IR-20A spectrophotometer.

^{15}N-labelled potassium azide was prepared as described previously [1]. Melting points are corrected. Microanalyses were performed by *E. Thommen*, Mikrolabor, 4000 Basle.

*1(3)-[^{15}N]-Tetrazolo[1,5-*a*]pyridine.* A mixture of 2-bromopyridine (71 mg; 0.449 mmol), K^{15}NN$_2$ (50 atom-% ^{15}N; 34 mg; 0.417 mmol), and 10% aqueous ethanol (0.5 ml) containing 78 mmol HCl per 100 ml, was stirred in a closed vessel at 45–47° for 7 days, then heated to 60°, cooled slowly to 20°, and allowed to stand at 0° overnight. The long needles which separated were filtered without suction, washed with precooled (–10°) 10% ethanol, and dried in a desiccator. Yield: 25.1 mg (50%), m.p. 160–161°. The unlabelled compound [12] had m.p. 159–160°.

The remaining 50% of [^{15}N]-hydrazoic acid, which was still present in the filtrate from above, was distilled with the aid of a vacuum line into a solution of NaOMe in methanol/ether. Na^{15}NN$_2$ precipitated and was recovered by filtration.

*1(3)-[^{15}N]-6-Methyltetrazolo[1,5-*a*]pyridine.* A mixture of 2-bromo-5-methylpyridine (150 mg; 0.87 mmol), K^{15}NN$_2$ (96 atom-% ^{15}N; 79 mg; 0.96 mmol), and 10% aqueous ethanol (1.5 ml) containing 78 mmol HCl per 100 ml was stirred in a closed flask at 80° for 5 days. After cooling, a first crop (70 mg) separated as colourless prisms, m.p. 139–141°. The remaining solution was evaporated to dryness, and the residue was chromatographed on a 20 × 1.5 cm column of Al_2O_3 (standard; activity II-III), eluting with CH_2Cl_2. The first 70 ml eluate contained a little starting material; the next 100 ml contained the product (30 mg), m.p. 139–141°. The unlabelled compound [13] had m.p. 138–139°. The total yield was 85%.

*1(3)-[^{15}N]-Tetrazolo[1,5-*a*]pyridine-6-carbonitrile.* A mixture of 2-chloropyridine-5-carbonitrile (200 mg; 1.44 mmol), K^{15}NN$_2$ (96 atom-% ^{15}N; 132 mg; 1.60 mmol), and 7 ml of abs. dimethylformamide was stirred in a closed flask at 80° for 24 h. The solvent was evaporated *in vacuo* at 50°, leaving a brown oil which was taken up in $CHCl_3$ and filtered. Evaporation and freezing of the residue yielded 170 mg of crystals (80%), m.p. 90°. A similarly prepared unlabeled sample was subjected to elemental analysis.

$C_6H_3N_5$ (145) Calc. C 49.66 H 2.07 N 48.28% Found C 49.67 H 2.12 N 48.47%

*1(3)-[^{15}N]-Tetrazolo[1,5-*a*]quinoline.* 2-Chloroquinoline (19.3 mg; 0.118 mmol) and K^{15}NN$_2$ (50 atom-% ^{15}N; 10.4 mg; 0.127 mmol) was dissolved in 1 ml of 50% ethanol, and two drops of 10% ethanol containing 78 mmol HCl per 100 ml was added. The solution was stirred in a closed flask at 100° for 24 h, and, after cooling, the white needles (14 mg; 70%) were collected: m.p. 155–156° (lit. for unlabelled compound: 153–154° [14]).

*1(3)-[^{15}N]-Tetrazolo[1,5-*a*]pyrazine.* 2-Chloropyrazine (231.4 mg; 2.02 mmol) and K^{15}NN$_2$ (50 atom-% ^{15}N; 165 mg; 2.02 mmol) in 20 ml of dry dimethylformamide was stirred in a closed vessel at 80° for 3 days. Evaporation of the solvent left a black oil which was extracted with boiling toluene. Evaporation of the extract furnished a solid product which was recrystallized

from cyclohexane to colourless prisms (168 mg; 68.5%), m.p. 90–91° (Lit. for unlabeled compound: 90.8–91.5° [15]). The compound sublimed at 60°/0.1 Torr.

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31. The Derivation of Inductive Substituent Constants from pK_a Values of 4-Substituted Quinuclidines. Polar Effects. Part I

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(29. X. 75)

Summary. Thermodynamic pK_a-values have been determined for 38 4-substituted quinuclidinium perchlorates. They are remarkably sensitive to the polar effect of the substituent and cover a range of 3.63 pK_a units. Furthermore, they vary linearly and almost equally with temperature since the contribution of the $T\Delta S°$ term to the free energy of ionization is relatively small and constant. The magnitude of the polar effect of the 4-cyano group varies with the solvent and appears to depend on its ability to form hydrogen bonds to the substituent rather than its dielectric constant.

New inductive substituent constants σ_I^q are derived from the pK_a values. Their correlation with known inductive constants is only fair or unsatisfactory, especially as regards the relative order of hydrogen and the alkyl groups. The discrepancies can be ascribed mainly to the different models used to derive the substituent constants.

Several methods have been developed for the quantitative determination of polar substituent effects on the reactivity (rates and equilibria) at a non-conjugating reaction center.