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Chemical Effects of the Nuclear Reaction $N^{14}(n,p)C^{14}$
In Various Nitrogenous Compounds

by

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This progress report is divisible into two parts, the hot atom chemistry of C^{14} and the kinetics of deuteration of aromatic heterocycles.

I. HOT ATOM CHEMISTRY OF CARBON-14

A. Background and Scope of the Research

When compounds containing nitrogen are subjected to thermal neutron irradiation, the following nuclear reaction occurs:

The recoil energy of the product C^{14} atom is 40 Kev., about 10^4 times chemical bond energies. This large recoil ensures rupture of all residual chemical bonds, i.e., chemical bonds originally attached to N^{14} . The recoiling C^{14} atom may then enter chemical combination after dissipating most of its kinetic energy through collisional interactions with atoms, ions, or molecules of the target material. This nuclear reaction and others that produce radioactive carbon provide unique ways to study the chemistry of atomic carbon under varying environmental conditions. The possible chemical combinations of the recoil atom depend initially and principally upon the atomic and molecular constitution of the target and its state of aggregation.^{1,2,3} The ultimate distribution of labeled products may depend as well upon concomitant radiation during the neutron irradiation and upon post-irradiation treatment of the target, such as the dissolution of solid targets in solvents.^{2,3}

Carbon hot atom chemistry has been studied by nuclear reactions that produce C^{11} and C^{14} . Wolf and co-workers^{4,5,6} at Brookhaven determined the distribution of labeled carbon compounds in ammonia using the reactions $N^{14}(p,\alpha)C^{11}$ and $N^{14}(n,p)C^{14}$. C^{14} has a very long half-life (5600 years) and C^{11} a very short one (20 minutes). Consequently, the time required for irradiation of the targets is many times greater for the (n,p) than the (p, α) reaction, in order that sufficient radioactive product be produced. The extraneous radiation is therefore always large for (n,p) irradiations but can be varied from small to large for the (p, α) process, depending upon the proton flux. Cacace and Wolf⁶ subjected gaseous, liquid, and solid ammonia to varying proton flux. The carbon-11 products were methylamine, methyleneimine, and methane. Increases in radiation dose was attended by a decrease in methylamine and a corresponding increase in methane production. Under comparable proton flux, the ratio of methylamine and methane was larger in liquid and solid ammonia than in gaseous ammonia, suggesting that the radiolytic conversion of methylamine to methane is diffusion controlled. In pile irradiated gaseous ammonia, Yang and Wolf⁴ found mainly $C^{14}H_4$ and

small amounts of $C^{14}H_3NH_2$, indicating that the large gamma and x-ray flux attending the pile irradiation affected the conversion of methylamine to methane.² Cacace and Wolf concluded that methylamine and methyleneimine are produced by hot reactions in ammonia, and that methane is produced primarily in thermal reactions and secondarily in radiolytic reactions.

Yankwich and Vaughan² studied the chemistry of C^{14} produced in crystalline ammonium bromide. The distribution of labeled products provides an interesting parallel with that of C^{11} in low dose proton irradiated solid ammonia.⁶ The yields of methylamine were 79% and 75% in ammonium bromide and solid ammonia, respectively, and the yields of methane were 7.5% and 9% for these targets, respectively. In addition, formaldehyde was found when the crystalline ammonium bromide was dissolved in water, which suggests that methyleneimine could have been the precursor in the crystals prior to their dissolution.² This parallel supports the contention that the radiolytic effect upon the distribution of labeled products is diffusion controlled, and that this diffusion is of negligible consequence in high melting ionic salts.

Considerable insight into the mechanisms of carbon atom reactions has been provided by the gas phase studies of Wolfgang, MacKay, and co-workers,⁵ using the nuclear reaction $C^{12}(\gamma, n)C^{11}$ in hydrocarbon targets. Labeled products were attributed to addition (to multiple bonds), insertion into single bonds, and abstraction reactions.^{5,8}

The chemistry of recoil C^{14} in high melting crystalline targets is complicated by the necessity to dissolve the target in a suitable solvent in order to release the labeled products. The identity of the entrapped primary recoil product is masked by the possibility of secondary reactions between these products and the solvent. Thus, neutron-irradiated crystalline Be_3N_2 ⁹ dissolved in aqueous sulfuric acid yielded significant proportions of labeled methane, carbon dioxide, formic acid, formaldehyde, hydrogen cyanide, cyanamide, guanidine, urea, and methylamine, each of which was a secondary product of the reaction of crystal-entrapped precursors and the solvent. The presence of guanidine and urea among the post-solution products indicated the existence of surprisingly stable polyatomic precursors,⁹ which are

probably pi stabilized.

The spectrum of carbon-14 products of neutron irradiated crystalline nitrogeneous targets (aqueous dissolution) depends

markedly upon the specific chemical natures of the targets. In ammonium sulfate,¹⁰ the main products were methylamine, formic acid, formaldehyde, and methane. In hydrazine sulfate ($\text{N}_2\text{H}_6\text{SO}_4$),³ these products plus large yields of guanidine, urea, cyanamide, methylene diamine, and formamidine were found. The richer spectrum of nitrogen compounds produced in hydrazine sulfate is attributable to the weak N-N link in the $\text{N}_2\text{H}_6^{++}$ ion and to the possible carbon atom insertion in N-H or N-N bonds in $\text{N}_2\text{H}_6^{++}$.

The research described in this report is concerned with uncovering the detailed chemistry of recoil carbon-14 produced by pile irradiation of crystalline compounds containing nitrogen. Of chief interest in this research are the alkali azides (NaN_3 , KN_3 , and CsN_3); potassium azide has been the subject of study during the past year and is being studied currently. The alkali azides are particularly interesting targets for the following reasons: (1) The recoil C^{14} atom is limited to reactions with but two elements, nitrogen and alkali metal. Inasmuch as the distribution of labeled products is often quite complex¹⁻³, it is important to minimize this complexity in order to facilitate interpretation of the results. (2) The radiation chemistry of both sodium and potassium azides has been studied in thermal columns of nuclear reactors¹¹; it therefore becomes possible to estimate the effect of concomitant radiation upon the radiocarbon compound distribution in alkali azide targets. (3) Alkali azides are highly soluble in a number of solvents. Thus, the crystal-entrapped labeled products can be released by dissolution in non-aqueous solvents in addition to water. (4) These azides have relatively low decomposition temperatures for ionic solids (e.g., KN_3 decomposes $\sim 350^\circ\text{C}$). Thermal decomposition provides an alternative to solvent dissolution as a means to release crystal-entrapped products. In addition to the alkali azides, other targets being studied are hydrazinium dihydrochloride and solid five-member aromatic heterocycles.

B. Experimental Section

Sample Preparation and Irradiation

1. Potassium Azide. Distillation Products Industries practical grade KN_3 was recrystallized three times from water-ethanol solvent, then dried 12 hours at 120°C . Ten grams of the purified KN_3 was loaded in a quartz ampoule which was held at a reduced pressure of 10^{-5} torr at $\sim 56^\circ\text{C}$ for 96 hours. The ampoule was sealed off under vacuum, then irradiated in the thermal column of the Los Alamos Omega West reactor for 120 hours in a flux of about $10^{12}\text{n, cm}^{-2}, \text{sec}^{-1}$. The reactor ambient temperature was about 90°C . The ampoule was opened in a dry box with helium atmosphere 86 days after irradiation, then ground to uniform size, and stored in a desiccator in the dry box. Subsequent weighings of samples and handling of the irradiated KN_3 was done in the dry box.

2. Hydrazine Dihydrochloride. Fisher Certified Reagent $\text{N}_2\text{H}_6\text{Cl}_2$ was ground finely in a mortar under helium in the dry box, transferred to a quartz ampoule, then vacuum dried ($\sim 10^{-5}$ torr) with infrared heating for eight days. The irradiation and post-irradiation treatment was identical to that of the potassium azide. A 10 g specimen was irradiated.

3. Imidazole. Aldrich Chemical Company Imidazole was recrystallized three times from benzene, air dried, then stored in a desiccator for several days. Ten grams of the imidazole was subjected to high vacuum (10^{-5} torr) for one hour at 0°C , then sublimed into a quartz ampoule, which was sealed off under vacuum. The target was irradiated in the Omega West reactor for 120 hours at reactor ambient temperature below the crystal melting point of 90°C .

Specific Activity of Potassium Azide.

A weighed sample of the target ($\sim .01$ g.) was mixed with a weighed sample of oxalic acid and burned in a tube furnace containing copper oxide at 800°C . The oxalic acid served as a source of carbon dioxide, which in turn provided a carrier for radioactive carbon dioxide produced by the target combustion. The furnace was continuously swept with oxygen; carbon dioxide was recovered in a tower containing aqueous NaOH and converted to BaCO_3 for weighing and handling.

Thermal Decomposition of KN_3 Target.

A weighed sample of the target was placed in a closed end glass tube 3 mm. x 50 mm.; dry KCN was placed above the KN_3 in the tube and covered with "Pyrex" wool. The sample tube was inserted into a larger closed end glass tube which was attached to the vacuum system through a U-tube trap. The entire system was blanketed with dry nitrogen, the U-tube cooled to 195°C and the outer tube containing the sample tube immersed in a sand bath held at 400°C . After two hours, the U-tube was removed from the system and analyzed for volatile radiocarbon components. The sample tube was removed, crushed under distilled water, and the filtered solution analyzed for cyanide and cyanamide radioactivity. Cyanide and cyanamide activities were determined by the following procedures. An aliquot taken from the target solution was acidified with sulfuric acid, heated to near boiling, and the generated HCN swept into a tower containing AgNO_3 . The resulting AgCN was converted to BaCO_3 by combustion in a CuO -filled furnace at 800°C , followed by precipitation with BaCl_2 . Cyanamide was added to a second aliquot, aqueous ammonia was added, then silver cyanamide (Ag_2CN_2) precipitated. The recovered solid was dissolved in sulfuric acid, then precipitated again by ammoniacal AgNO_3 . This precipitate was oxidized to carbonate in the same way as AgCN .

The trap was analyzed for total volatile activity by combustion of its contents, or for hydrogen cyanide, or for carbon dioxide.

Aqueous Dissolution of KN_3 .

The procedure used for aqueous dissolution of target samples and subsequent separation of possible labeled products has been described in detail elsewhere (see references 2,3,9, and 10). Altogether, analyses were carried out for twelve one-carbon species.

Thermal Anneal of KN_3 Target.

A weighed sample of KN_3 was sealed under vacuum into a 3 mm. x 50 mm. glass tube, then heated at 195°C for 160 minutes. The tubes were cooled to room temperature, then broken in an aqueous solution containing cyanide and cyanamide carriers. This solution was analyzed for cyanide, cyanamide, hydrolyzable (to carbonate), and total non-volatile carbon. The hydrolyzable fraction was obtained by attaching an aqueous NaOH tower directly after the AgNO_3 tower in the cyanide analysis. A known quantity of gaseous CO_2 was swept through the target solution to provide weighable carbonate. The total non-volatile carbon was determined by alkaline permanganate oxidation of an aliquot of the target solution^{2,3}.

Radioactivity Determinations.

All radioactivity measurements were made on gaseous CO_2 evolves from various BaCO_3 specimens using the Cary model 31 vibrating reed electrometer².

C. Results and Discussion

1. Potassium Azide

In all cases, samples of irradiated target were dissolved in water prior to analysis for labeled products. Three sets of results were obtained: (1) Untreated samples of target dissolved in water, (2) Thermally annealed samples of target dissolved in water, and (3) Thermally decomposed residues of samples dissolved in water. These results are given in Tables I, II, and III, respectively. Percent activities were based upon target specific activity of $35,760 \pm 700$ cps/g.-target, the average of three determinations of target specific activity. In Table I, labeled compounds are separated into two categories, depending upon the relative reproducibility of the analyses. In Category 1, uncertainties are represented by average deviation from the mean. In Category 2, reproducibility was poor, and uncertainties are represented by the range of percent activity of each compound in the category.

Table I

Distribution of Activity: Aqueous Dissolution of Untreated Potassium Azide Target

Category 1

Compound	Number of Separate Determinations	Percent Activity
CO ₂	3	2.2 ± 0.0
CO/CH ₄	3	0.7 ± 0.7
HCN	4	31.4 ± 3.2
CNNH ₂	3	12.8 ± 0.2
HCHO	2	4.0 ± 0.1
CH ₃ NH ₂	3	12.1 ± 0.2
Sub-Total		63.6 ± 0.2

Category 2

Compound	Number of Separate Determinations	Percent Activity	Range of Percent Activity
HCOOH	7	5.8	4.3 - 7.8
CO(NH ₂) ₂	5	4.3	2.9 - 5.4
CNH(NH ₂) ₂	4	7.9	1.9 - 14.8
CH ₃ NHNH ₃	3	6.8	3.9 - 10.6
CH ₃ OH	2	1.4	0.5 - 2.3
Hydrolyzable	2	6.6	2.0 - 11.1
Sub-Total		32.8	15.5 - 52.0
Grand Total		96.4	79 - 106

Table II

Distribution of Activity: Aqueous Dissolution of Thermally Annealed Potassium Azide Target

Source	Number of Separate Determinations	Percent Activity
HCN	2	41 $\pm$ 1
CNNH ₂	2	5 $\pm$ 1
Hydrolyzable	2	32.5 $\pm$ 0.5
Total Non-Volatile Carbon	2	94.5 $\pm$ 3.5

Table III

Distribution of Activity: Aqueous Dissolution of Thermally Decomposed Potassium Azide Target Residue (400°C, 2 hours)

Experiment	Percent Activity Recovered	Percent Activity ^a and Percent Of Recovered Activity ^b		
		Trap	HCN	CNNH ₂
D1	97.8	1.96 (2.0)	36.7 (37.5)	59.2 (60.5)
D2	92.4	1.85 (2.0)	33.9 (36.7)	56.6 (61.3)
D3	97.3	1.94 (2.0)	37.0 (38.0)	58.4 (60.0)
D4	68.3	3.55 (5.2)	23.4 (34.2)	41.4 (60.6)

- a. Based upon target specific activity of 35.760 ± 700 cps/g. - target
- b. Based upon the specific activity recovered in the given experiment

The scatter in the results in Table I warrants consideration. The results in Category 1 are probably quite reliable. Precipitation procedures, such as those used for the cyanide and cyanamide determinations, are subject to large errors arising from foreign activities carried on the surfaces of these precipitates. Precautions have been taken to avoid these errors; in the case of cyanide, hydrogen cyanide is swept out of the solution containing high concentrations of foreign Cl^{4} activity. In the case of cyanamide, the silver precipitate is purified by dissolving it in excess acid and then precipitating anew. The procedures for methylamine and formaldehyde were shown by Marteney to be reliable by comparing them with carrier-free gas chromatographic methods¹². The considerable scatter exhibited by the results in Category 2 could be due to the hydrolyzable fraction. The component(s) making up this fraction have not been identified as yet, and could be separated with carriers of other components as trace impurities. The hydrolyzable activity ranged from 2% to 32% (Tables I and II), and accordingly could introduce large errors.

Two preliminary thermal decomposition experiments were run to determine if the trap held labeled carbon dioxide. None was detected. In experiment D3 (Table III), the trap was analyzed for HCN; the 2% activity recorded for the trap is due solely to HCN in this case, and probably in cases D1, D2, and D4 as well. The thermal decomposition experiments indicate the residue to contain potassium cyanide and potassium cyanamide (K_2CN_2); a trace of water impurity in the target could lead to the evolution of HCN during the decomposition. The large percent activity recovered (D1, D2, D3) reveal that the thermal decomposition products consist essentially only of CN^- and CN_2^- in the ratio 2 to 3. Since CN^- is found in large yield irrespective of the pre-solution treatment of the target, this product is probably present as such in the target. Cyanide activity has been conspicuously rare in other ionic crystalline targets, despite the strength of the C,N triple bond. The largest previous yield of CN^- reported was 6% in beryllium nitride⁹. The ~60% yield of cyanamide attending thermal decomposition contrasts sharply with the 12% yield in the dissolution of untreated target. An attractive hypothesis is that all the radio-carbon in the target is present as KCN and K_2CN_2 , held in the crystal structure under strain. Upon dissolution of the untreated target, the ions would be released with activation proportional to the strain, which could lead to the various one-carbon products in Table I. The cyanide ions having stronger C,N bonds than cyanamide ions would undergo less extensive reaction with water. The hypothesis is weakened by the results of the thermal anneal experiments. One would expect that heating to 195° for longer than two hours could cause at least partial relaxation of internal strain, and then accordingly the CN_2^- yield would increase. Actually, the yield of CN_2^- decreased (Table II). Despite the results of thermal anneal, it seems likely that CN_2^- and some of the other labeled products in

Table I have a common crystal precursor, which may or may not be CN_2^- . One clear example is that of urea, which is a known hydrolytic product of cyanamide.

Clearly, more experimental work is required to resolve the problems raised by the present results. The work will include detailed thermal anneal studies ranging to temperatures near the decomposition temperature of KN_3 , and will emphasize carrier-free methods of analysis of the labeled products (see the attached renewal proposal for details).

Cunningham's study of the pile radiolysis of KN_3 revealed that an integrated thermal flux of $10^{18} \text{ n, cm}^{-2}, \text{ sec}^{-1}$ led to $\sim 0.003\%$ decomposition of the target. Accordingly the probability that C^{14} recoil atoms be affected by radiolysis products (K and N_2) or by the ionizing radiation is sufficiently small to be neglected.

2. Other Targets.

Preliminary experiments on hydrazine dihydrochloride indicate the radiocarbon distribution to be qualitatively similar to that of hydrazine sulfate³. The source of oxygen in such species as formaldehyde and formic acid remains to be ascertained.

Imidazole has been irradiated, but analyses on this target have not been started.

II. KINETICS OF DEUTERATION OF FIVE-MEMBER AROMATIC HETEROCYCLES

A. Background and Scope of the Research

In recent years, considerable attention has been focussed upon the relative electrophilic reactivities of various ring sites in aromatic heterocyclic compounds^{13,14}. The electrophilic reactivities depend upon the nature of the substrate and the nature of the electrophile. Theoretical interpretations of the relative reactivities of ring sites have been hindered by the dearth of rate studies upon these systems. In order that different positions of a given substrate be compared for the same or different electrophilic reagents, it is important that the kinetics of substitution for each site and each reaction be known. From the observed rate laws, one may formulate compatible mechanisms, which in turn serve as guides in comparisons of reactivity. For example, kinetic data may often indicate the form of the substrate (i.e., whether the free molecule or its conjugate acid or base) and the form of the electrophile involved in a given reaction¹⁵.

Deuteration and tritiation are particularly useful reactions for reactivity comparisons for the following reasons: (1) It is possible to study essentially all sites in substrates so that a very large spectrum of reactivities of sites in various molecules may be obtained. (2) Isotope effects, if present, are large. (3) The substituting group (D or T) and the leaving group (H) are isotopes, so that models of the transition state that include the electrophile are comparatively simple. This report describes studies in progress of the kinetics of deuteration of pyrazole (I), imidazole (II), 1,2,4-triazole III, and tetrazole (IV).

I

II

III

IV

B. Experimental Section

1. Materials. Pyrazole, imidazole, 1,2,4-triazole, and tetrazole were each recrystallized thrice from the appropriate solvent (either cyclohexane or benzene). Deuterium chloride (38% in D₂O), sodium deuterioxide (40% in D₂O), and heavy water (99.75%) were obtained from Merck, Sharpe, and Dohme of Canada, Ltd.

2. Kinetic Runs. All kinetic runs were made in heavy water solutions adjusted to constant ionic strength of 1.00M by measured addition of NaCl. In the case of imidazole, DCl was added to control the buffer ratio (B.R.), defined as the ratio of the concentration of conjugate acid and the neutral base molecule. For the other substrates, all very weak bases, either ND_4^+ , ND_3 or pyridinium- d_6 , pyridine- d_5 were added to buffer the solutions. Eight 1.0 ml aliquots were prepared for each run; each aliquot was sealed in a 3.0 ml thick wall pyrex tube. Seven of the tubes were then plunged into an oil bath set at an appropriate elevated temperature, before being removed at intervals and quenched in cold water. Samples taken from the tubes were analyzed with the Varian A-60-A nuclear magnetic spectrometer. Proton peak areas were determined by the cut and weigh method. The same proton peak area observed in a sample from the eighth (unheated) aliquot was used as a reference. Pseudo-first order rate constants were obtained from plots of log (per cent area) vs. time; linear plots were obtained for exchange reactions proceeding to 60% completion. Rate constants were reproducible to within $\pm 15\%$.

3. Uncertainties in Concentrations of Reactants. The largest uncertainty in the kinetic data was that arising from changes in the concentrations of reagents in high temperature runs. Accurate calculation of these concentrations at say 200°C would require consideration of the thermal expansion of the sealed glass ampoules, knowledge of the partial molar volumes of all solutes and the solvent at 200°C , and also the extent of vaporization of solvent and possibly some substrate at this temperature. A rough calculation that utilized the ideal gas law, the vapor pressure and the density of liquid water at 200° indicated a 15% increase in the volume of liquid water attending the change in temperature from 25° to 200° . This change in volume would introduce corresponding changes in the concentrations of reagents. Accurate calculation of the change in concentration was not feasible. Since the ionic strength was adjusted to a constant changes would be determinate in principle if not in practice. Accordingly, all concentrations used in analyzing reaction orders were room temperature values. This procedure would in effect lead to a lateral shift in the concentration coordinate of the plotted data, which alone would introduce no error in the slopes of log (rate) vs. log(concentration) plots.

C. Results and Discussion

Imidazole

In aqueous solution, imidazole (II) has two isotopic exchange sites. The 2 position lies between the ring nitrogen atoms; the

4 and 5 positions are equivalent and indistinguishable because of the rapid tautomeric exchange of a proton (or deuteron) between the two nitrogens. Deuteration of the 2 position was studied at 65°C and 70°C, while that at the 4(5) position required temperatures of 180°C and 190°C. The reactions were examined over a wide range of pD values, from acidic to basic solutions. Figure I gives log k_1 vs. pD for the 2 position at 65° and the 4(5) position at 180°; the corresponding curves for 70° and 190° are similar in form to these. k_1 values corresponding to pD values less than 2 and greater than 12 emphasize the flattening indicated in Figure I. pD values were controlled by addition of excess DCl or NaOD for the acid and base regions, with addition of smaller quantities of DCl in the buffer region (pD 6 to 9) (see Experimental Section). The following points are of interest: (1) Deuteration is first order in imidazole for both positions, which indicates that the reaction is not self-base catalyzed. This result is opposite that found in iodination¹⁵. (2) The dependence of the pseudo-first order rate constant upon pD for both positions is qualitatively similar to that observed for protonation of the 2 position of 1-methylimidazole by Randall and Harris¹⁶. This result indicates that the conjugate base of imidazole

is probably not the nucleophile involved in the exchange. (3) The 2 position is more reactive to the deuterium electrophile than the 4(5) position. The opposite appears to be true for the iodine electrophile¹⁷. (4) The rate law may be expressed

$$-\frac{d[\text{Imidazole}]}{dt} = k_1 [\text{Imidazole}]$$

where

$$k_1 = \frac{k}{[\text{D}^+]^n}$$

Here n is 0.1 for the 2 position in the buffer region, 0.2 for the 4(5) position in the buffer region, $n \sim 0$ for both positions for $pD > 10$, and < 0.1 for both positions for $pD < 6$. Such a rate law suggests parallel reactions, with different dependences upon $[\text{D}^+]$. Since n is small (relative to 1) in all cases, the dominant exchange must be independent of $[\text{D}^+]$. The following mechanism¹⁸ is consistent with independence upon $[\text{D}^+]$:

FIG. I: IMIDAZOLE

Here $\text{rate} = k_a [\text{conjugate acid}] [\text{OD}^-]$

$$K_b = \frac{[\text{conjugate acid}] [\text{OD}^-]}{[\text{Imidazole}]}$$

$$\therefore \text{rate} = k_a K_b [\text{Imidazole}]$$

Randall and Harris¹⁶ suggested this same Ylid mechanism for 1-methylimidazole, but failed to point out that it does not account for the dependence of k_1 upon $[\text{D}^+]$ in the buffer region. The attractive feature about the mechanism is that the 2 position in the conjugate acid of imidazole would likely be more acidic than the 4(5) position and hence more reactive¹³. At this point, we have not solved the problem of the pD profile for the entire pD range. Experimental and theoretical work continues. (5) The activation energy for deuteration in the 2 position is much less over the entire pD range than in the 4(5) position (e.g., for pD=7, $E_a(2)=10$ Kcal/mole and $E_a(4(5))=25$ Kcal/mole). Evidently the greater reactivity of the 2 position is an activation energy effect; this observation is consistent with preliminary formation of the Ylid being rate determining.

Pyrazole

In pyrazole (I) isotopic exchange may occur in the 4 position and the equivalent 3 and 5 positions. Deuteration in the 4 position was followed at 202° and in the 3(5) position at 230°. The reactions were buffered by ND_4^+ , ND_3 and also by pyridinium- d_6 , pyridine- d_5 . Figure II illustrates the dependence of the pseudo-first order rate constant upon the buffer concentration for the ammonia buffer. The

FIG. II: PYRAZOLE

chief points of interest for this substrate follow: (1) In ammonia buffer ($pK_a=5.2$) deuteration of the 4 position depends linearly upon $[ND_3]$ but is independent of $[D^+]$. In contrast, deuteration of this position in pyridine buffer ($pK_a=9.3$) depends linearly upon $[pyridine]$ and is dependent (in a direct fashion) upon $[D^+]$. Deuteration of the 3(5) position is independent of both buffer concentration and $[D^+]$ in both cases. Detailed mechanistic interpretation awaits determination of the complete pD profile, now in progress. At this point, it appears that formation of a sigma intermediate may account for deuteration in the 4 position. (2) unlike imidazole, the rate laws for deuteration of the two available sites differ markedly. (3) The activation energy of the deuteration of the 4 position is 23.3 Kcal/mole and that of the 3(5) position is 27.8 Kcal/mole.

Triazole

1,2,4-Triazole (III) may be deuterated in the 3 and 5 positions. Like the 3 and 5 positions of pyrazole, they are equivalent and indistinguishable. Deuteration of triazole is specific acid and specific base catalyzed but exhibits no dependence upon ammonia buffer. Kinetic runs for the 3(5) position are being made at 65°, like the 2 position of imidazole.

Tetrazole

Preliminary experiments indicate tetrazole (IV) undergoes deuteration at 75°, somewhat less rapidly than 1,2,4-triazole. Work on this substrate continues.

Conclusions

The relative rates of deuteration of the substrates studied follow the qualitative order 2-Im $\approx$ 3(5)-Tri > 5-Tet > 4(5)-Im > 4-Py > 3(5)Py. Theoretical interpretation of these relative rates depend upon proper assignment of appropriate nucleophiles and electrophiles in each case.

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