Reactions of 5-, 6-, 7-, 8-Hydroxyquinolines and 5-Hydroxyisoquinoline with Benzene and Cyclohexane in Superacids[1]

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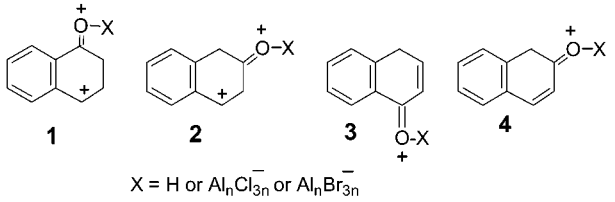
Isomeric 5-, 6-, 7-hydroxyquinolines (**11**−**13**) and 5-hydroxyisoquinoline (**14**) gave N,C-diprotonated dications in $CF_3SO_3H-SbF_5$ superacid medium. Compounds **11**, **13**, **14**, and 8-hydroxyquinoline (**5**) underwent selective ionic hydrogenation with cyclohexane in the presence of aluminum chloride. Compounds **11** and **14** condense with benzene in the presence of aluminum halides. The detailed mechanism of reactions, which involves superelectrophilic dicationic intermediates, is discussed.

Introduction

Naphthols and their derivatives are known to react with benzene, nonactivated arenes, and alkanes in superacids or in the presence of an excess of aluminum halides to give the corresponding aryltetralones[2] and tetralones.[3] It is also recognized that the key intermediates of these reactions are C,C-diprotonated dications of naphthols, (structures **1**, **2**) while the corresponding monocationic forms (**3**, **4**) are inert.[4]



Recently, one of us has found that 8-hydroxyquinoline (**5**) gives the N,C-diprotonated form **6** in superacid $CF_3SO_3H-SbF_5$ and it reacts with cyclohexane and condenses with benzene in the presence of aluminum halides (Schemes 1 and 2).[5] The reason for the dramatic difference in reactivity of dication **6** and monoprotonated nonreactive ion **3** was explained by the increased electrophilic activation by the protonated nitrogen in **6**. Given the tendency of hydroxyquinoline **5** to form the reactive electrophile **6** in strong acids, it seemed likely that isomeric hydroxyquinolines (hydroxyisoquinolines), containing a nitrogen atom and hydroxy group in different rings of the quinoline (isoquinoline) system, would also exibit similar properties. We now report a study on the superelectrophilic[6] activation of 5-, 6-, 7-hydroxyquinolines (**11**−**13**) and 5-hydroxyisoquinoline (**14**) with their reaction with benzene and cyclohexane.

Results and Discussion

NMR Study of Protonation of 11−14. Initially, we examined the process of protonation of **11**−**14** in protonic acids such as CF_3CO_2H ($H_o = -2.7$), CF_3SO_3H (triflic acid, $H_o = -14.1$), and $CF_3SO_3H-SbF_5$ acid system at room temperature by means of ^1H and ^{13}C NMR spectroscopy. Experimentally obtained results are summarized in Table 1. The spectral characteristics of generated ions are given in Table 2. As expected, in the weakest trifluoroacetic acid only the N-monoprotonation of precursors was observed. In the stronger triflic acid the compounds **11**, **12**, and **14** gave a mixture of the corresponding N-protonated forms **11a**, **12a**, **14a**, along with additional ions **11b**, **12b**, and **14b**, which are probably dicationic species, undergoing to rapid proton exchange with the acid.[7] When dissolved in the $CF_3SO_3H-SbF_5$ system, compounds **11**−**14** gave N,C-diprotonated forms **15**−**18**, respectively. The NMR spectra of the dications **15**−**18** contain the signal of the CH_2 group around δ ^1H 4 in the proton NMR and δ ^{13}C 40 in the carbon NMR. At the same time, the proton spectra contains the signal of the hydrogen bound to nitrogen at δ ^1H 11−13.

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(7) The nature of these ions will be discussed elsewhere.

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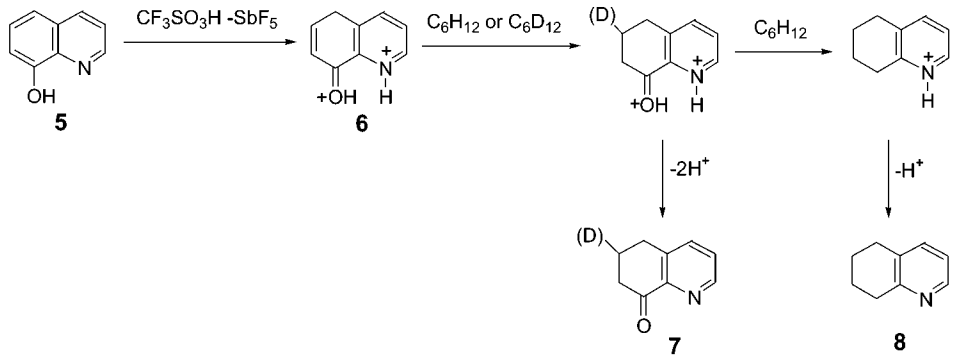
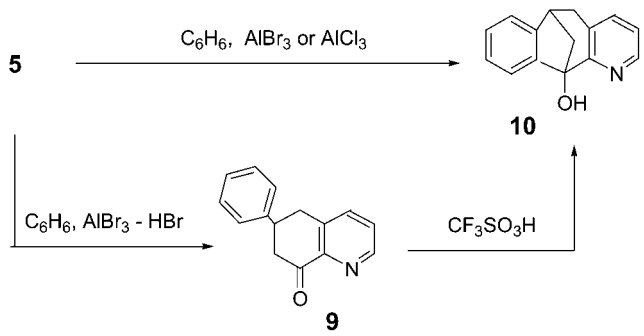
Scheme 1



Scheme 2



Dications **15** and **18** as well as dication **6** can be regarded as analogues of 4-hydroxy-1-naphthalenonium ion **3**. Dications **16** and **17** are the analogues of 2-hydroxy-1-naphthalenonium ion **4**.

Calculational Study of Electrophilicities. To investigate the relative electrophilicity of generated dications **15**−**18** and to compare it with the electrophilicity of chemically inert monocations **3** and **4** and reactive dications **1**, **2**, and **6**, we calculated the energies of lowest unoccupied molecular orbitals (ϵ_{LUMO}), the square of the coefficients of the carbon atom of the reaction center ($c_{\bullet}^2$) at the LUMO (orbital control of reaction), and atomic charges of the reaction center ($q_{\bullet}$) localized on the carbon atom and pendent hydrogen atom (charge control of reaction). Among other factors, values of $c_{\bullet}^2$ at LUMO and $q_{\bullet}$ are important for predicting the positional selectivity of a reaction, in case the electrophile contains more than one reaction center. For an estimation of "absolute" electrophilicity, the ϵ_{LUMO} and $q_{\bullet}$ of an electrophile are important factors.

Calculations were carried out with the Gaussian 98 program system.[8] The geometry optimizations were performed using the DFT[9] method at the B3LYP[10]/6-31G* level.[11] Vibrational frequencies at the B3LYP/6-31G*// B3LYP/6-31G* level were used to characterize stationary points as minima (number of imaginary frequency (NIMAG) = 0). Atomic charges $q_{\bullet}$ were obtained by using the natural bond orbital analysis[12] (NBO) method. For comparison, the ϵ_{LUMO}s were also calculated by the MNDO[13] method. Results of calculations are presented in Table 3 and show dramatic difference between the ϵ_{LUMO}s of monocations **3** and **4** (∼ −7 eV) and dications **6** and **15**−**18** (∼ −12 eV). The latter are close to ϵ_{LUMO}s of dications **1** and **2**, which means that the conjugation of the protonated nitrogen site activates the hydroxynaphthalenonium ion almost as effectively as an additional C-protonation. According to Table 3, dications **6**, **15**, and **18** have close values of $q_{\bullet}$ (0.34−0.36). For this reason, their relative electrophilicity can be predicted by comparison of corresponding values of ϵ_{LUMO}: **6** > **18** > **15**. The electrophilicity of dication **17** should be close to that of **15** according to their ϵ_{LUMO} data, but a comparison of the localization of positive charge on their reaction centers ($q_{\bullet}$ = 0.3 and 0.34 respectively) shows that **17** must be a weaker electrophile from a kinetic point of view. Thermodynamically, the dication **16** should be as reactive as the dication **6** (ϵ_{LUMO} = −12.201 and −12.263 eV, respectively), but due to the lowest $q_{\bullet}$ value (0.22) among **6** and **15**−**18** dications, **16** is the kinetically weakest electrophile in this group. Summarizing results of calculations, the relative reactivity of the considered electrophiles can be presented as follows: **1** > **2**, **6** > **18** > **15** > **17** > **16** ≫ **4**, **3**.

It is remarkable that the energy levels of LUMO of the all dications are lower than the energy levels of the highest occupied molecular orbital (HOMO) of benzene (−9.782 eV (DFT)), cyclohexane (−9.109 eV, (DFT)), and methylcyclopentane (−8.883 eV (DFT)). This result allows the possibility of one-electron transfer from the nucleophile (benzene or cycloalkane) to the dication (RH_2^{2+}) with the formation of an intimate radical−cation/radical−cation pair, which subsequently recombines to the σ-complex (in case of benzene) or gives the product of ionic hydrogenation (in case of cycloalkane) (Scheme 3). In this case, positional selectivity of reactions would be determined by the spin density distribution in $RH_2^{+\bullet}$, which is described approximately by the c^2 values at the LUMO for dications RH_2^{2+}.

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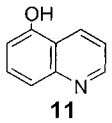
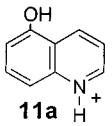
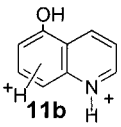
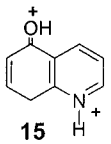
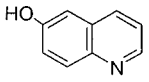
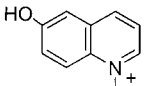
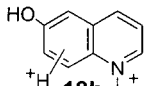
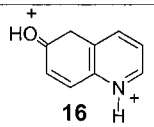
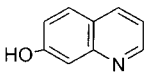
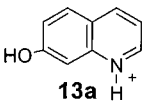
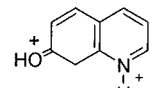
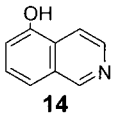
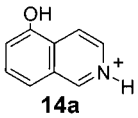
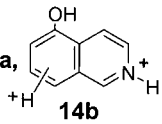
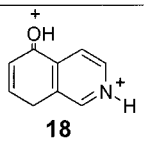
Table 1. Ions, Formed upon Protonation of 11−14

Precursor	CF_3CO_2H	CF_3SO_3H	CF_3SO_3H-SbF_5
 **11**	 **11a**	**11a,**  **11b** 1 : 1[a]	 **15**
 **12**	 **12a**	**12a,**  **12b** 1 : 1[a]	**12b,**  **16** 1.5 : 1[a]
 **13**	 **13a**	**13a**	**13a,**  **17** 1 : 2[a]
 **14**	 **14a**	**14a,**  **14b** 7 : 1[a]	**14a,**  **18** 1 : 10[a]

[a] The equilibrium ratio of ions at 25 °C, according to ^{1}H NMR data.

Table 2. ^{1}H and ^{13}C NMR Data of Mono- and Diprotonated Ions of Compounds 11−14 at 25 °C[a]

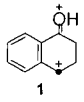
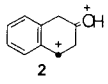
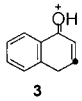
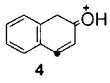
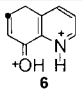
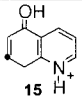
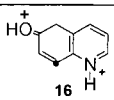
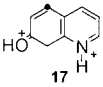
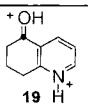
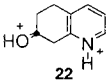
ion	^{1}H NMR signals (*J*, Hz)[b]	^{13}C NMR signals
11a[c]	6.75 d (7.9), 7.09 d (8.6), 7.32 dd (8.3, 5.8), 7.4 t (8.33), 8.31 t (5.8), 8.9 d (8.3), 13.03 br s	110.08, 112.18, 118.7, 121.5, 137.06, 137.69, 142.65, 143.53, 153.35
11b[d,e]	6.49 d (7.8), 7.3 dd (8.5, 5.5), 7.83 d (7.8), 8.27 t (6.8), 8.76 d (8.5), 12.8 br s	111.2, 114.95, 121.28, 121.92, 133.8, 139.76, 145.04, 145.98, 159.75
15[f]	3.65 s 2H, 6.43 d (9.5), 7.2 t (7), 7.64 d (9.5), 7.87 t (6), 8.34 d (7), 11.4 br s	34.78, 119.4, 124.49, 128.18, 148.21, 149.02, 157.46, 174.89, 189.93
12a[c]	6.96 d (2.5), 7.18 dd (9.4, 2.5), 7.28 dd (8.33, 5.6), 7.49 d (9.4), 8.15 t (5.6), 8.24 d (8.33), 13.18 br s	109.8, 120.75, 121.11, 127.67, 130.8, 132.67, 139.87, 145.65, 156.69
12b[d,g]	7.09 d (9.6), 7.45 m, 7.55 d (9.6), 8.12 m, 8.82 d (8.9), 12 br s	111.8, 124.17, 127.04, 128.18, 130.43, 133.25, 141.13, 143.16, 159.3
16[f]	3.8 s 2H, 6.36 d (9.5), 7.1 m, 7.48 d (8.5), 7.53 d (9.5), 7.58 t (6.4), 11 br s	39.06, 117.38, 125.13, 130.65, 136.46, 144.15, 147.03, 155.72, 212.73
13a[c]	6.94 s, 6.96 dd (9, 2.2), 7.14 dd (7.9, 7), 7.49 d (9), 8.14 t (7), 8.27 d (7.9), 12.8 br s	101.33, 117.55, 122.81, 124.7, 130.75, 139.85, 141.56, 146.64, 162.85
17[f]	4.12 s 2H, 6.47 d (10), 7.25 bs, 7.78.1 m 3H, 11.55 br s	38.58, 122.44, 127.61, 128.12, 145.06, 148.64, 150.56, 166.16, 208.04
14a*c*	7.03 dd (7.26, 1.2), 7.29 t (7.26), 7.33 d (7.47), 7.8 t (6), 8.14 d (6.63), 8.8 d (7.26), 12.83 br s	119.8, 121.14, 121.45, 128.13, 128.6, 130.3, 132.62, 145.38, 151.87
14b[d,e]	6.67 d (7.3), 7.69 t (6), 7.71 d (7.6), 8.03 d (6.7), 9.1 d (7.3), 11.85 br s	122.66, 123.93, 124.3, 129.15, 131.93, 132.5, 137.16, 142.89, 157.04
18[f]	3.78 s 2H, 6.68 d (11), 7.8 t (7), 7.86 d (7), 8.11 d (6), 8.14 d (12), 11.8 br s	36.45, 125.12, 126.25, 138.59, 140.42, 143.76, 143.97, 185.1, 189.08

[a] Chemical shifts are given with respect to $(CD_3)_2CO$ as external standard (2.04 and 206 ppm, respectively, in ^{1}H and ^{13}C NMR spectra). [b] Protons bonded to oxygen are not observed, due to rapid proton exchange with the acid. [c] Data for CF_3CO_2H solution. [d] Data for CF_3SO_3H solution. [e] H^8 signal is not observed due to rapid exchange with protons of acid. [f] Data for $CF_3SO_3H-SbF_5$ solution. [g] H^5 signal is not observed, due to rapid proton exchange with the acid.

Reactions with Cyclohexane and Benzene. On the basis of the ease of formation of dications **15**−**18** as long-living species in the explored superacidic systems, we studied their reactions with cyclohexane and benzene in these media.

Hydroxyquinolines **11**−**14** were found to be unreactive with cyclohexane in $CF_3SO_3H-SbF_5$ at room temperature during several hours.[14] This indicates that their corresponding dications **15**−**18** are not as electrophilic as dication **6**, which underwent complete ionic hydrogenation with cyclohexane during a 10 min period under similar conditions.[5] This is in accord with the calculational results. Successful reaction of compounds **11**, **13**, and **14** with cyclohexane occurred, however, by using

Table 3. Energies of the LUMO (ϵ_{LUMO}), the Square of the Coefficiets (c^2) on Carbon Atoms at the LUMO, NBO Charges on CH Groups (q), and ΔH_f of Ions 1−4, 6, 15−20, 22, 23 Calculated by the MNDO and DFT Methods

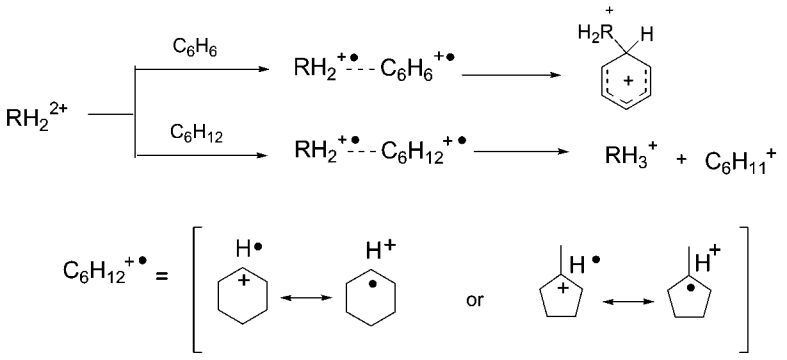
Ion	ΔH_f, kcal/mol (MNDO)	ε_{LUMO}, eV (MNDO)	ε_{LUMO}, eV (DFT)	$c_\bullet^2$ (DFT)	$q_\bullet$ (DFT)
 1	431.91	-11.228	-12.936	0.45	0.46
 2	432.39	-10.617	-12.244	0.64	0.38
 3	155.07	-6.271	-7.277	0.43	0.25
 4	157.06	-6.376	-7.402	0.53	0.26
 6	417.05	-10.831	-12.263	0.34	0.36
 15	412.36	-10.538	-11.988	0.38	0.34
 16	413.66	-10.597	-12.201	0.4	0.22
 17	413.79	-10.455	-12.005	0.46	0.3
 18	413.22	-10.713	-12.157	0.31	0.36
 19	394.16	-10.631	-12.126	0.61	0.68
 20	463.62	-11.432	-13.106	0.68	0.53
 22	392.92	-10.186	-11.52	1.64	0.73
 23	468.61	-11.296	-12.767	1.59	0.62

5−7 molar excess of aluminum chloride at 90 °C.[15] Hydroxyquinoline **11** gave tetrahydroquinoline **8** in 97% yield over a period of 90 h. The probable mechanism of the reaction is shown in Scheme 4. According to the scheme, superelectrophilic dication **15a** undergoes selective ionic hydrogenation with cyclohexane, followed by similar reaction of dications **19** and **20**. The in situ generated intermediate **19** is an example of superelec-

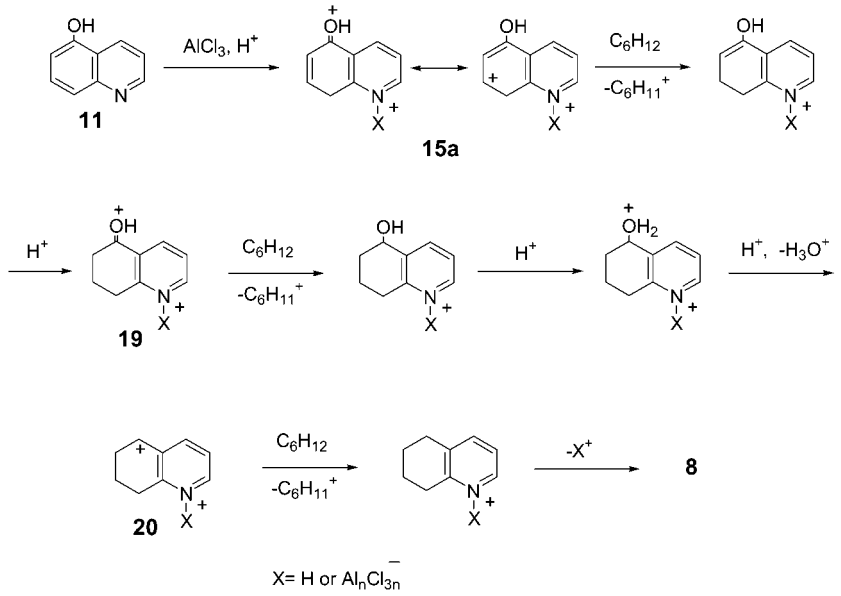
(14) Compound **13**, after 24 h of reaction, gave 30% of **8**. Compound **12** after 48 h gave a product of oxidative dimerization, please see: (a) Chen, Y.-X.; Yang, L.-W.; Li, Y.-M.; Zhou, Z.-Y.; Lam, K.-H., Chan, A. S. C., Kwong, H.-L. *Chirality*. **2000**, *12*, 510. (b) Schmitt, M. M.; Schuler, E.; Braun, M.; Haring, D.; Schreier, P. *Tetrahedron Lett*. **1998**, *39*, 2945.

(15) Under the reaction conditions cyclohexane exists in an equilibrium with methylcyclopentane, see: Nenitzescu, C. D.; Cantuniari, R. *Chem. Ber*. **1933**, *66*, 1097.

Scheme 3



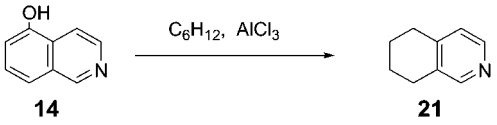
Scheme 4



trophilic activation of ketone by O-monoprotonation and additional protonation (or coordination by Lewis acid) of closely situated nitrogen atom. Recently, a similar type of superelectrophilic activation of carbonyl-containing heterocyclic compounds for reactions with arenes has been demonstrated by Klumpp and co-workers.[16] Dication **20** is an example in which the pyridinum nitrogen dramatically enhances the reactivity of an adjacent carbon electrophilic center. Previously, the possibility of generation of such reactive intermediates was shown by low-temperature NMR for reactions of amino alcohols with benzene in superacids.[17] Calculated ϵ_{LUMO} and $q_{\bullet}$ values of dications **19** and **20** (X = H) show them to be stronger electrophiles than dication **15** (Table 3). This explains the failure to stop the reaction at the stage of either ketone (7,8-dihydro-5(6*H*)-quinolinone) or alcohol (5,6,7,8-tetrahydro-5-quinolinol).

The more reactive hydroxyquinoline **5** was shown to give **8** (yield 95%) over a 15 h period under similar reaction conditions. Hydroxyisoquinoline **14** gave 5,6,7,8-tetrahydroisoquinoline **21** (yield 85%) over 50 h of reaction (Scheme 5). The mechanisms of reaction of compounds **5** and **14** are considered similar to those described in Scheme 4.

Scheme 5



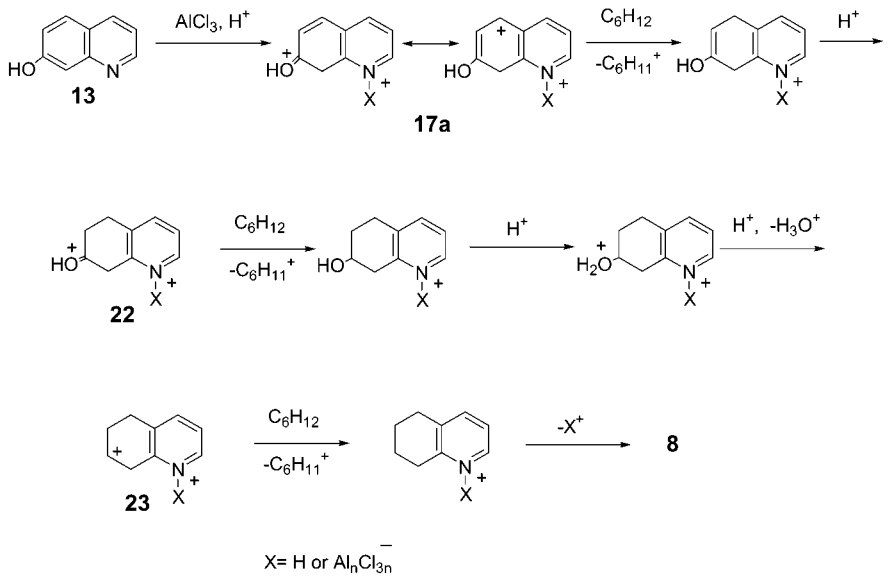
Hydroxyquinoline **12** is, as expected, inert toward cyclohexane. But hydroxyquinoline **13** is slowly converted (50% after 100 h of reaction at 110 °C) to give **8** (Scheme 6). This is in agreement with the higher electrophilicity of dication **17** predicted by calculations. It is remarkable that the C_7 reaction center of intermediates **22** and **23** is not included in the conjugated π-system containing the protonated nitrogen. Nevertheless, it seems to be no obstacle for this site to enhance the reactivity of the reaction center through space at close distance. Results of calculations show the high electrophilicity of dications **22** and **23** (Table 3). Recently, similar superelectrophilic activation has been demonstrated for 4-piperidinone.[16c]

The study of reactivity of compounds **11**−**14** toward benzene showed all of them to be inert in triflic acid or in the presence of aluminum halides under mild conditions. Attempts to obtain condensation products in the CF_3SO_3H−SbF_5 acid system failed because of side reactions. Successful condensations were achieved only by using 5−10 molar excess of aluminum halides at 80−90

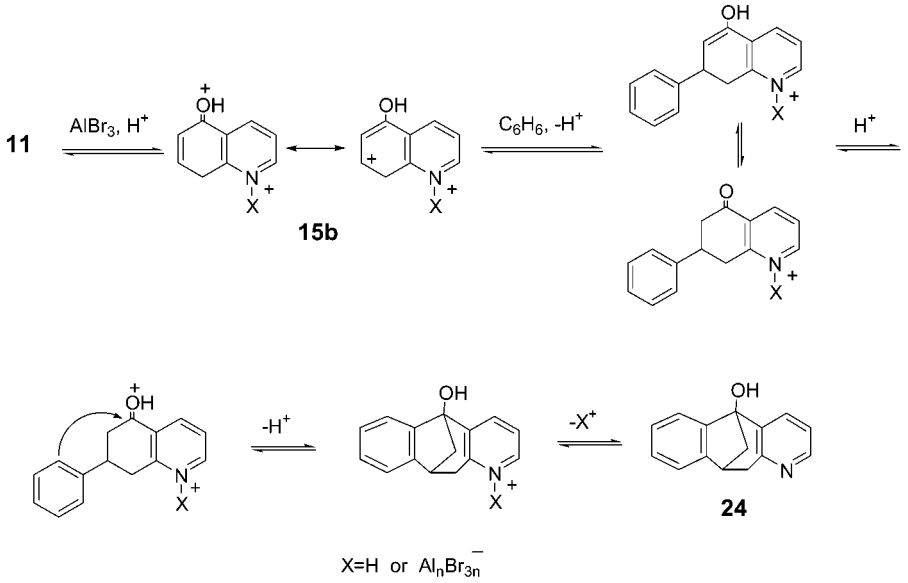
(16) (a) Klumpp, D. A.; Lau, S. L.*J. Org. Chem.* **1999**, *64*, 7309. (b) Klumpp, D. A.; Jones, A.; Lau, S.; DeLeon, S.; Garza, M. *Synthesis.* **2000**, *8*, 1117. (c) Klumpp, D. A.; Garza, M.; Jones, A.; Mendoza, S. *J. Org. Chem.* **1999**, *64*, 6702. (d) Klumpp, D. A.; Garza, M.; Sanchez, G. V.; Lau, S.; DeLeon, S. *J. Org. Chem.* **2000**, *65*, 8997.

(17) Klumpp, D. A.; Aguirre, S. L.; Sanchez, G. V.; DeLeon, S. *Org. Lett.* **2001**, *3*, 2781.

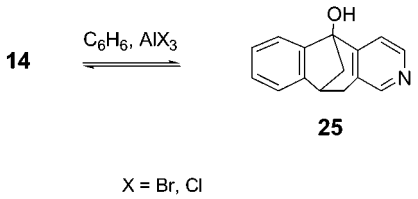
Scheme 6



Scheme 7



Scheme 8



°C. Hydroxyquinoline **11** upon treatment with aluminum bromide gave the condensation product followed by intramolecular cyclization to 5,10-methano-10,11-dihydro-5-hydroxybenzo[4,5]cyclohepta[1,2-*b*]pyridine (**24**) in 15−30% yield (Scheme 7).

Hydroxyisoquinoline (**14**) slowly reacts with benzene and HBr−$AlBr_3$ at room temperature (100−150 h) or in the presence of $AlCl_3$ or $AlBr_3$ at 90 °C for 15 h to give 5,10-methano-10,11-dihydro-5-hydroxybenzo[4,5]-cyclohepta[1,2-*c*]pyridine (**25**) in 25−40% yield (Scheme 8).

Attempts to increase the yield of **24** and **25** by variation of reaction conditions or increasing the reaction time were, however, unsuccessful. In further experiments it was found that the reactions are reversible. Products **24** and **25** gave precursors **11** and **14**, respectively, in ~70% equilibrium concentration under conditions similar to that of condensation. For comparison, more reactive quinoline **5** gave (similarly to **24** and **25**) **10** in higher yield (40−85%), and moreover, it was possible to stop the reaction at the stage of formation of azatetralone **9** (68%) (Scheme 2).[5b]

Hydroxyquinolines **12** and **13** were found to be unreactive toward benzene at 20−120 °C in the presence of aluminum halides. This can be explained by the relatively weak electrophilicity of corresponding intermediate ions **16** and **17** and as a consequence of the shift of their equilibrium reaction with benzene to starting compounds.

Conclusions

In summary, we have found that hydroxyquinolines **11**−**13** and isoquinoline **14** give in CF_3SO_3H−SbF_5 superacidic system N,C-diprotonated dications **15**−**18**, which can be regarded as superelectrophilic intermediates in

their reactions with benzene and cyclohexane. It was shown that the computed values of ϵ_{LUMO} and q_+ of superelectrophiles could be successfully used for estimation of their reactivity. From a synthetic point of view, condensation of hydroxyheteroarenes with benzene offers a new, useful synthetic approach for the preparation of novel heterocycles. Products **24** and **25** formally belong to a class of alkaloids and possess previously unknown carbon skeletons. The reversibility of reactions found can be utilized for the synthesis of quinolines (isoquinolines) from corresponding arylquinolones (isoquinolones). Ionic hydrogenation with cyclohexane was found to be an alternative way of synthesis of hydroquinolines and hydroisoquinolines.

Experimental Section

^{1}H and ^{13}C NMR spectra were recorded on a 300 MHz superconducting NMR spectrometer. High-resolution mass spectra were measured by the Southern California Mass Spectrometry Facility at the University of California at Riverside. Triflic acid, trifluoroacetic acid, aluminum bromide, and aluminum chloride were purchased from suppliers. Antimony pentafluoride was distilled under argon. Compounds **5** and **11**−**14** were purchased and used as received, except **14**, which was recrystallized from ethanol, mp 229−230 °C. High-temperature reactions (>80 °C) were carried out in 15 mL pressure tubes.

General Procedure for the Protonation of 11−**14**. Samples of **11**−**14** (20−30 mg) were dissolved in trifluoroacetic or triflic acid in 5 mm NMR tubes at room temperature. The triflic acid solutions were kept for 5−24 h until a constant ratio of derived ions was obtained. For generation of dications **15**−**18**, SbF_5 was added to the previously prepared solutions of compounds **11**−**14** in triflic acid (molar ratio CF_3SO_3H/SbF_5 = 3:1), the resulting solutions were kept for 2−5 h.

General Procedure for the Reaction of 5, 11, 13, and 14 with Cyclohexane. A 0.1 g portion of the hydroxyheteroarene was added to a suspension of 0.65 g of $AlCl_3$ in 3 mL of cyclohexane. This mixture was stirred at 90 °C (**13** was reacted at 110 °C) for 15−100 h until two distinct layers were formed, followed by cooling of the mixture poured over several grams of ice. The aqueous layer was washed with ether and then made basic with concentrated NaOH and extracted with ether (5 × 6 mL). The organic phase was dried with $MgSO_4$. Careful removal of the solvent under reduced pressure provided the products **8** or **21** as colorless liquids. NMR data of **8**[5b,18] and **21**[19] were comparable to those previously reported.

5,6,7,8-Tetrahydroquinoline (8): ^{1}H NMR ($CDCl_3$) δ 1.7−1.9 (m, 4H), 2.7 (t, *J* 7 Hz, 2H), 2.87 (t, *J* 7.3 Hz, 2H), 6.95 (dd, *J* 8.7, 5.3 Hz, 1H), 7.27 (d, *J* 8.7 Hz, 1H), 8.28 (d, *J* 5.3 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 22.5, 22.88, 28.57, 32.29, 120.69, 132.29, 136.58, 146.53, 157.16.

5,6,7,8-Tetrahydroisoquinoline (21): ^{1}H NMR ($CDCl_3$) δ 1.75−1.85 (m, 4H), 2.7 (br s, 4H), 6.93 (d, *J* 8.3 Hz, 1H), 8.23 (d, *J* 8.3 Hz, 1H), 8.26 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 22.22, 22.43, 26.09, 28.51, 123.78, 132.9, 146.02, 146.2, 150.23.

5,10-Methano-10,11-dihydro-5-hydroxybenzo[4,5]-cyclohepta[1,2-*b*]pyridine (24).

Method a. To a solution of $AlBr_3$ (2.67 g, 10 mmol) in benzene (5 mL) was added hydroxyquinoline **11** (0.145 g, 1 mmol). The resulting mixture was saturated with gaseous HBr (0.33 g, 4 mmol), followed by heating in a flask with a reflux condenser at 80 °C, under stirring for 16 h. Subsequently, the mixture was cooled to room temperature and poured over 20 g of ice. The aqueous layer was washed with ether, made basic with concentrated NaOH and extracted with $CHCl_3$.[20] The organic phase, after washing with H_2O and drying over $MgSO_4$, was concentrated in vacuo to give **24** (65 mg, 29%) as colorless crystalline product: mp 208−209 °C (acetone); ^{1}H NMR ($CDCl_3$) δ 2.34 (d, *J* 9.76 Hz, 1H), 2.55 (ddd, *J* 9.76, 5.37, 1.22 Hz, 1H), 2.89 (d, *J* 17.82 Hz, 1H), 3.05 (br s, 1H), 3.39 (dd, *J* 17.82, 5.13 Hz, 1H), 3.66 (td, *J* 5.13, 1.22 Hz, 1H), 7.06 (dd, *J* 7.81, 4.89 Hz, 1H), 7.1−7.22 (m, 3H), 7.29 (dd, *J* 6.1, 1.5 Hz, 1H), 7.94 (dd, *J* 7.81, 1.7 Hz, 1H), 8.27 (d, *J* 4.8 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 37.9, 37.91, 49.29, 80.12, 119.07, 121.29, 123.72, 127.12, 127.88, 128.65, 140.83, 143.18, 147.86, 149.75, 153.72; HRMS $C_{15}H_{13}NO$ ($M - H^+$) calcd 222.0919, found 222.0925.

Method b. An analogous procedure without saturation of the reaction mixture with HBr gave 33 mg (15%) of **24**.[20]

5,10-Methano-10,11-dihydro-5-hydroxybenzo[4,5]-cyclohepta[1,2-*c*]pyridine (25). Method a. To a solution of $AlBr_3$ (2.67 g, 10 mmol) in benzene (5 mL) was added hydroxyquinoline **14** (0.145 g, 1 mmol). The resulting mixture was saturated with gaseous HBr (0.33 g, 4 mmol), stirred at 25 °C for 150 h, and then poured over 20 g of ice. The aqueous layer was washed with ether, made basic with concentrated NaOH, and extracted with $CHCl_3$.[21] The organic phase after washing with H_2O and drying over $MgSO_4$ was concentrated in vacuo to give **25** (83 mg, 37%) as colorless crystalline product: mp 222−223 °C (acetone); ^{1}H NMR ($CDCl_3$) δ 2.32 (d, *J* 10.01 Hz, 1H), 2.55 (ddd, *J* 10.01, 5.37, 1.22 Hz, 1H), 2.72 (d, *J* 17.09 Hz, 1H), 3.24 (dd, *J* 17.09, 4.88 Hz, 1H), 3.65 (td, *J* 4.88, 1.22 Hz, 1H), 7.11−7.23 (m, 3H), 7.27 (dd, *J* 6.2, 1.7 Hz, 1H), 7.56 (d, *J* 5.13 Hz, 1H), 8.1 (s, 1H), 8.29 (d, *J* 5 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 31.66, 38.5, 48.72, 79.96, 115.53, 119.36, 123.61, 127.22, 128.07, 128.4, 142.97, 147.1, 149.46, 150.01, 153.54; HRMS $C_{15}H_{13}NO$ calcd 223.0997, found 223.0990.

Method b. Heating a similar reaction mixture at 80 °C for 5 h gave 67 mg (30%) of **25**.[21]

Method c. To a suspension of $AlCl_3$ (1.33 g, 10 mmol) in benzene (5 mL) was added hydroxyquinoline **14** (0.145 g, 1 mmol). The resulting mixture was stirred at 90 °C for 15 h and after standard workup gave **25** (54 mg, 24%).[21]

Acknowledgment. Partial support of the work by the National Science Foundation is gratefully acknowledged.

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(19) (a) Boger, D. L.; Panek, J. S.*J. Org. Chem*. **1981**, *46*, 2179. (b) Gribble, G. W.; Barden, T. C.; Johnson, D. A. *Tetrahedron* **1988**, *44*, 3195.

(20) Workup with Na_2CO_3 instead of NaOH gave a mixture of **11** and **24** (molar ratio 2:1 to 5:1).

(21) Workup with Na_2CO_3 instead of NaOH gave a mixture of **14** and **25** (molar ratio 1.5:1 to 3:1).