Articles

Quinol N-Acyl and Quinol Ether Imines via Anodic Oxidation of Para-Substituted Anilide Derivatives

John S. Swenton,* Timothy N. Biggs, and William M. Clark

Department of Chemistry, The Ohio State University, 140 West 18th Avenue, Columbus, Ohio 43210

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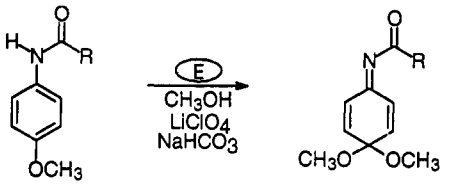
Anodic oxidation of *N*-benzoyl-4-methylaniline in 5% aqueous methanol in the presence of sodium bicarbonate affords two major products: 4-methoxy-4-methylbenzoquinol *N*-benzoylimine, **8a**, and a dimer, 4-[*N*-benzoyl-*N*-(4-methylphenyl)amino]-4-methylbenzoquinol *N*-benzoylimine, **9**. The ratio of these two products was temperature dependent, and conditions were developed for preparing **8a** and **9** in good yield. Using the conditions developed for **8a**, the anodic methoxylation of *N*-benzoyl and acetyl derivatives of 4-ethyl- and 4-*sec*-butyl-4-phenylaniline and 2-aminofluorene derivatives was performed. The yields of the *N*-benzoyl derivatives of the 4-methoxy-4-substituted-benzoquinol imines were 46–80%, while the *N*-acetyl derivatives gave lower yields. When the anodic oxidation was performed using 30% water/acetonitrile or 10% water/tetrahydrofuran, the 4-alkylbenzoquinol *N*-benzoylimine derivatives were obtained. The yields of these anodic hydroxylation reactions were lower than those of the corresponding methoxylations for all systems studied. In addition, the 4-alkylbenzoquinol *N*-benzoylimine derivatives were much more labile. Two methods were developed for conversion of the 4-methoxy-4-substituted-benzoquinol *N*-acylimines to the 4-methoxy-4-substituted-benzoquinol *N*-alkylimines. Finally, the especially labile 4-hydroxy-4-phenylbenzoquinol *N*-acetylimine was prepared for the first time from the readily available *N*-benzoyl derivative.

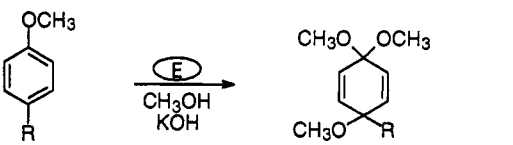
Anodic oxidation of *p*-methoxyanilide derivatives serves as a versatile route to quinone *N*-acylimine ketals (e.g., **1** → **2**).[1,2] The extension of this anodic oxidation chemistry



1 **2** (60-80%)

to *p*-alkylanilides would afford a one-step route to various *N*-acyl quinol and quinol ether derivatives, compounds for which no feasible general route is available.[3] In addition to the synthetic use of these compounds in the preparation of functionalized aromatic amines,[1b] certain quinol derivatives are of special interest since they are intermediates in the metabolic oxidation of aromatic amines.[4] We report herein a study of the anodic oxidation of *p*-alkyl-substituted anilide derivatives. Conditions have been developed for preparing certain quinol *N*-acylimines and their ethers in one step from readily available precursors. In addition, the conversion of these quinol imine derivatives to quinol *N*-acyl- and *N*-alkylimines not directly available via the electrochemical oxidation has been studied.

Anodic Methoxylation Reactions of *p*-Alkylanilide Derivatives. Although anodic oxidation of *p*-alkylanilide derivatives would appear to be a logical extension of the **1** → **2** reaction, we were quite concerned that side-chain oxidation might be competing with ring oxidation. Thus, when the high-yield anodic oxidation of 1,4-dimethoxybenzene (**3** → **4**) was extended to *p*-methoxytoluene (**5** → **6**), nuclear anodic addition was a very minor product.[5] In addition, earlier studies on anilide oxidation had demonstrated a high propensity for anodic dimerization reactions.[6] Although the quinol ether derivative from oxidation of *N*-benzoyltoluidine, **7a**, was not a high priority synthetic target, this compound was studied first. The *N*-benzoylimine formed in the reaction would be less subject to hydrolysis to the carbonyl compound than the corresponding acetyl derivative. In addition, isolation and



3 R = OCH_3
5 R = CH_3

4 R = OCH_3 (> 90%)
6 R = CH_3 (≅ 8%)

• Abstract published in *Advance ACS Abstracts*, September 1, 1993.

(1) (a) Chen, C.-P.; Chou, C.-T.; Swenton, J. S. *J. Am. Chem. Soc.* **1987**, *109*, 946. (b) Swenton, J. S.; Bonke, B. R.; Chen, C.-P.; Chou, C.-T. *J. Org. Chem.* **1989**, *54*, 51.

(2) The anodic methoxylation and hydroxylation of 4-phenylbenzanilide has been reported: Novak, M.; Helmick, J. S.; Oberlies, N.; Rangappa, K. S.; Clark, W. M.; Swenton, J. S. *J. Org. Chem.* **1993**, *58*, 867.

(3) For the preparation of *N*-acetyl-4-methyl-4-methoxy-*p*-benzoquinol imine and a study of some of its chemistry, see: Gassman, P. G.; Granrud, J. E. *J. Am. Chem. Soc.* **1984**, *106*, 2448–2449 and references cited therein.

(4) For a general discussion, see: Lenk, W.; Rosenbauer-Thilmann, R. *Microsomes, Drug Oxidations, and Chemical Carcinogenesis*; Academic Press: New York, 1980; Vol. II.

(5) For leading references and a discussion of this chemistry, see: Capparelli, M. P.; DeSchepper, R. E.; Swenton, J. S. *J. Org. Chem.* **1987**, *52*, 4953.

(6) (a) Ueda, C.; Ohmori, H.; Ueno, K.; Hamada, Y.; Tatsumi, S.; Masui, M. *Chem. Pharm. Bull.* **1985**, *33*, 1407 and references cited therein. (b) For leading references to earlier work on anilide oxidation, see ref 1b.

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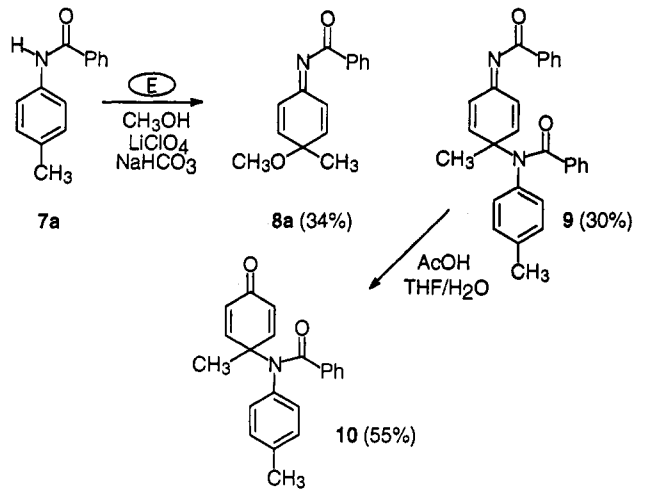
Table I. Anodic Oxidation of 7a in Methanol/Water[a]

entry	T (°C)	7a (M)	mA	% yield 8a	% yield 9
1	25	0.005	150	34	30
2	0	0.005	150	48	13
3	-15	0.005	150	60	
4	0	0.025	150	31	37
5	0	0.050	150	28	34
6	0	0.125	150	33	30
7	0	0.025	1000	52	9
8	0	0.050	1000	37	12
9	40	0.025	150	17	53

[a] All oxidations were conducted using 2% by weight of lithium perchlorate except for the 1-A runs which employed 10% of supporting electrolyte. The yields were obtained by isolation via column chromatograpy.

identification of the major side products formed in the reaction would be simplified for this system. The anodic oxidation of **7a** in 5% H_2O/CH_3OH solution using 2% $LiClO_4$–$3H_2O$ as electrolyte gave the desired **8a** in low yield. Attempts to further isolate and characterize the complex mixture of side products were unsuccessful. However, electrochemical oxidation of **7a** with addition of $NaHCO_3$ to the reaction medium gave a higher yield of **8a** (34%) in addition to a dimeric product identified as **9** (30%).



The structure assignment of **9**[6] is strongly supported by spectroscopic and analytical data; the salient features are discussed below. The formula for **9** was established as $C_{28}H_{24}O_2N_2$ by exact mass measurement. The ^1H NMR (500 MHz) spectrum showed: δ 7.9 (d, J = 7.0 Hz, 2 H), 7.5 (t, J = 7.0 Hz, 1 H), 7.4 (t, J = 8.0 Hz, 2 H), 7.25 (d, J = 7.0 Hz, 2 H), 7.2–7.1 (m, 3 H), 6.9 (AB q, $\Delta\nu$ = 27 Hz, J = 8.0 Hz, 4 H), 6.6 (AB q, $\Delta\nu$ = 82 Hz, J = 10 Hz, 4 H), 2.2 (s, 3 H), and 1.6 (s, 3 H). The two AB quartets at δ 6.9 and 6.6 support the symmetrical structure assigned to **9**. Hydrolysis of the imine moiety of **9** with 5% aqueous AcOH/THF at room temperature gave the dienone **10** (55%). The dienone **10** had a mp and showed spectroscopic properties in agreement with a product isolated from electrolysis of **7a** in acetonitrile[6] containing DBU. Undoubtedly, **9** was formed in this reaction as well but underwent hydrolysis to **10** in the workup or isolation steps.

The effects of temperature, concentration of starting amide, and current density on the product ratios were studied in an attempt to maximize the yield of **8a**. As shown in Table I, the oxidation conditions have an effect on the relative product yield of imine **8a** and dimer **9**. Entries 1–3 best illustrate the effect of temperature on the product ratio. The anodic oxidation performed at 25 °C gave the products **8a** (34%) and **9** (30%). However, lowering the reaction temperature increased the selectivity for imine formation, and at -15 °C the dimer **9** was not isolated (entries 1–3). Increasing the concentration of the starting amide in a 0 °C oxidation initially increased the yield of dimer, but this effect leveled off (entries 2, 4–6). Although the effect of current density on yield was not extensively studied, preparative runs can be performed at 1 A. For these reactions the supporting electrolyte ($LiClO_4$) was also increased since this was convenient in maintaining the temperature of the solution at 0 °C during the electrolysis. Under these conditions (compare entry 4 versus 7; 5 versus 8), the yield of **8a** increased at the expense of **9**.

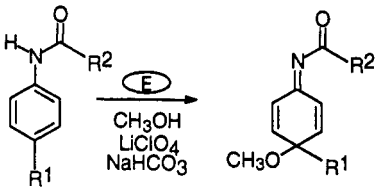
The effects of $NaHCO_3$ concentration and the percentage of water in the methanolic solution were not investigated since these parameters were optimized in an earlier study[1b] involving the preparation of quinone *N*-acylimine ketals. All oxidations reported here were performed in the presence of a 10-fold excess of $NaHCO_3$ by weight relative to the starting amide in 5% H_2O/CH_3OH solution. Although an extensive study of reaction variables on the yield of **8a** was not performed, these results emphasize the importance of temperature and concentration on the yield of products akin to **8a**. In summary, the maximum yield of imine **8a** is obtained by performing the anodic oxidation at lower temperatures (preferably at -15 °C) with a starting amide concentration of 5×10^{-3} M using a constant current of 0.15 A.[7] However, when higher concentrations of starting amide are desirable, an increase in current density is suggested for comparable yields of product. For preparative runs, incremental addition of the amide to the oxidation cell is more convenient than using large volumes of solvent. This method was utilized in the preparative-scale 1 → 2 reactions. It appears that the major side reaction in the amide oxidations is dimerization; however, since all of the starting material was not accounted for in these reactions, side-chain oxidation could also be a competing reaction.

The anodic methoxylations listed in Table II were performed using the optimal conditions developed for **7a**. The yields of the *p*-benzoquinol ether imines ranged from 17% (entry 1) to 80% yield (entry 5). Typically, lower yields were obtained with the *N*-acetyl derivatives, and this is partly due to the ease of hydrolysis of the *N*-acetylamine linkage during the workup and isolation; as previously discussed,[2] the *N*-benzoyl analogues are considerably more stable. Because of the sensitivity of the *N*-acetyl derivatives, absorption chromatography on silica gel and neutral alumina gave appreciable amounts of hydrolysis to the corresponding dienone. Although the best conditions for adsorption chromatography depend on the difficulty of the separation, Florisil and base-washed silica gel are the preferred adsorbents (see Experimental Section). The former appears to cause less hydrolysis, but the latter often effected better separations.

The structures for these compounds were assigned on the basis of exact mass analysis, IR, ^1H NMR, and ^{13}C NMR spectroscopy. The IR spectrum for the *N*-acyl quinol ethers showed strong bands at 1670–1650 cm^{-1}, the

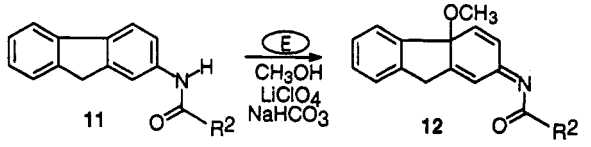
(7) A cylindrical 50-mesh screen platinum cathode (5-cm × 3.5-cm diameter) and a 8- × 8-mm platinum sheet cathode was employed in all oxidations. The estimated surface area of the anode is 80 cm^2.

Table II. Anodic Methoxylation of Para-Substituted Anilides[a]



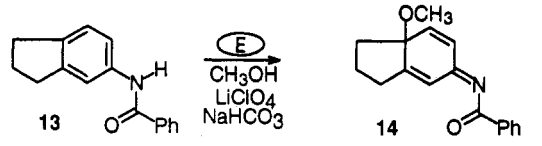
7 8

entry	R^1	R^2	% yield
1	CH_3	CH_3	**8b** (17)
2	CH_3	OCH_3	**8c** (46)
3	CH_3CH_2	Ph	**8d** (58)
4	$CH_3CH_2CH(CH_3)$	Ph	**8e** (46)
5	Ph	Ph	**8f** (80)[b]
6	Ph	CH_3	**8g** (48)[b]



11 12

7		Ph	**12a** (72)
8		CH_3	**12b** (43)[c]



13 14

9 **14** (45)

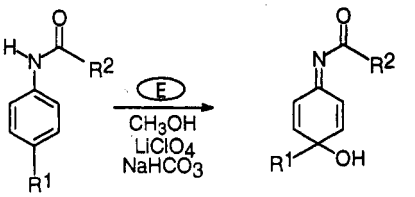
[a] The anodic oxidations were conducted with a constant current of 0.15 A at −15 °C using 5.0 mM concentration of starting amide in 5% H_2O/CH_3OH solution with $NaHCO_3$. [b] This oxidation was reported in ref 2 and is included here for completeness. [c] A 10% yield of the dienone obtained via hydrolysis of **12b** was also isolated.

^1H NMR spectrum showed the vinyl hydrogens as a AB q ($\Delta\nu$ = 13–29 Hz, J = 10 Hz) centered at δ 6.2–6.5, and the ^{13}C NMR spectrum showed absorptions for the carbonyl and imine carbon at ca. δ 180 and 155–160, respectively. In the absence of moisture, acid, and oxygen, the quinol ethers should be indefinitely stable. But in practice they have a short shelf life, probably due to adventitious acid/water and are best prepared as needed. For example, **12b** experienced considerable degradation when stored under nitrogen for 1 week at −20 °C. The preparation of **12b** in 44% yield is especially noteworthy since this is the methyl ether analogue of what is thought to be the active metabolite from biological oxidation of the carcinogenic *N*-acetyl-2-aminofluorene.[8]

Anodic Hydroxylation Reactions of *p*-Alkylanilide Derivatives. Having developed a successful synthesis of the *N*-acetylated *p*-benzoquinol ether imines, the anodic oxidation of these compounds in aqueous solvents was studied. Trapping of the anodically generated electrophile from anilide oxidation with water would furnish benzoquinol *N*-acylimines. These compounds were of major interest since quinol derivatives, not quinol ethers, are the products from biological oxidation of anilide derivatives. Initial studies were done with *N*-benzoyl-*p*-toluidine, **7a**, utilizing a number of water/solvent (CH_3CN, DMF, THF) combinations (see Table I of the supplementary material). The anodic oxidation of **7a** gave a

(8) (a) Panda, M.; Novak, M.; Magonski, J. *J. Am. Chem. Soc.* **1989**, *111*, 4524. (b) Novak, M.; Roy, A. K. *J. Org. Chem.* **1985**, *50*, 571. (c) Scribner, J. D. *J. Am. Chem. Soc.* **1977**, *99*, 7383.

Table III. Anodic Hydroxylation of Para-Substituted Anilides



7 15

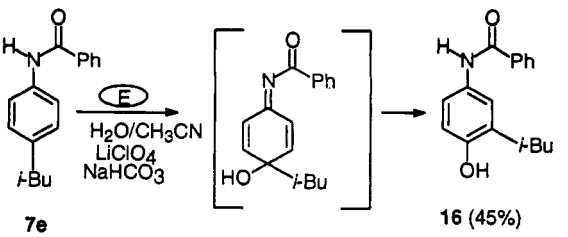
entry	R^1	R^2	solvent	T (°C)	% yield
1	CH_3	Ph	H_2O/CH_3CN (3:7)	25	**15a**[a] (44)
2	CH_3	OCH_3	H_2O/CH_3CN (3:7)	25	**15c**[a] (38)
3	CH_3CH_2	Ph	H_2O/CH_3CN (3:7)	25	**15d**[a] (30)
4	Ph	Ph	H_2O/CH_3CN (3:7)	25	**15f** (30)
5	Ph	Ph	H_2O/THF (1:10)	25	**15f**[b] (53)

[a] These compounds are >95% pure by ^1H NMR spectroscopy, being contaminated with small amounts of dienone side product inseparable by column chromatography. [b] This is an improvement over that reported earlier.[2]

mixture of **9** and the anodic hydroxylation product **15a**. However, in contrast to the results described earlier for the anodic methoxylation reaction, the product ratio of **15a** to **9** was not very dependent upon reaction temperature, concentration, or current density.

The best solvent mixture for the anodic addition reaction depends upon the particular system. For most of the compounds studied, 30% H_2O/CH_3CN was used. However, for the **7d** → **15f** (entry 5) conversion, 10% H_2O/THF gave the better results. The general conditions were as follows: 30% H_2O/CH_3CN as solvent; ca. 25 °C reaction temperature; 2% $LiClO_4$ as supporting electrolyte; 10–15 equiv of $NaHCO_3$ as base; and a current of 0.15 A. As shown in Table III, 30–53% yields of the *p*-benzoquinol *N*-benzoylimines were obtained. These are 20–30% lower than the yields of the corresponding methyl ether derivatives (see Table II). In addition, attempts to oxidize the *N*-acetylanilides under these conditions resulted in complex reaction mixtures. As noted earlier, the lability of the *N*-acetylimine linkage in the product is probably responsible for these failures.

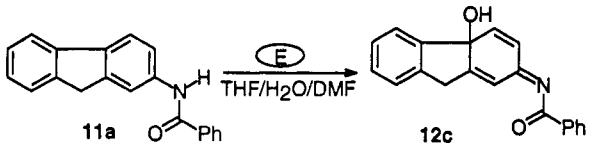
In addition to lower isolated yields for the oxidation of *N*-acylated anilides in aqueous media, the *p*-benzoquinol imines exhibited a tendency for dienone–phenol rearrangement relative to their methyl ether counterparts. This not only complicated their isolation but in some cases even prevented the isolation of the product. For example, anodic oxidation of *N*-benzoyl-4-*sec*-butylaniline, **7e**, afforded the rearrangement product **16** (45%) whose structure was confirmed by synthesis of an authentic sample (see supplementary section). Thus, migration of even alkyl groups can be a competing reaction in this chemistry; such migrations have been noted for aryl groups in *N*-acylated quinol imines.[2]



7e **16** (45%)

The preparation of the quinol imine **12c**, the benzoyl analogue of the postulated metabolite of *N*-acetyl-2-

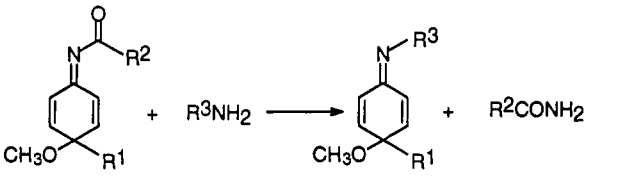
aminofluorene, was initially very difficult via the anodic hydroxylation reaction. The anodic oxidation of **11a** in a single cell apparatus with 10% H_2O/CH_3CN at room temperature gave a complex mixture of products. Attempts to obtain **12c** by lowering the reaction temperature, increasing the water content, or adding DMF to the reaction solvent to increase solubility also proved unsuccessful. However, anodic oxidation of **11a** in a divided cell using a 1:1:8 ratio of $H_2O/DMF/CH_3CN$ as a solvent system in the presence of a 20-fold excess of $NaHCO_3$ at 0 °C formed **12c** (20%). The instability of the product made its isolation and handling very difficult and prevented its complete characterization. However, when the solvent system was changed to 10% H_2O/THF, the single cell constant current oxidation gave **12c** as a light yellow oil in 51% yield (>90% pure). Exact mass analysis established a formula of $C_{20}H_{15}NO_2$; the IR spectrum showed strong absorption at 1661 cm^{-1} characteristic of quinol *N*-benzoylimines; the ^1H NMR (DMSO-d_6) spectrum showed the two vinyl hydrogens adjacent to the imine carbon at δ 6.45 (dd, J = 9.7, 1.7 Hz, 1H) and 6.20 (br s, 1H), and the ^{13}C NMR (DMSO-d_6) spectrum exhibited the expected 18 signals with the characteristic absorptions for the carbonyl and imine carbon at δ 179.4 and 161.7, respectively (see Experimental Section and supplementary material for full details). In spite of extensive efforts, we were never able to obtain even trace amounts of the *N*-acetyl derivative of **12c**. Perhaps this is not surprising since this important metabolite of (*N*-acetylamino)-fluorene, which has never been isolated, has an estimated half-life of minutes in aqueous solution.[8a]



Selected Chemistry of *N*-Acyl Quinol Derivatives. Relatively little is known concerning the preparative chemistry of *N*-acyl quinol derivatives. Since this chemistry could be useful for preparing compounds not available from the anodic oxidation, some exploratory chemistry of the imine linkage was examined. The reaction investigated most thoroughly was the conversion of the quinol *N*-acylimine ether to a simple imine derivative. This conversion can be conducted in two ways. Reaction of the quinol *N*-acylimine ether with strong base leads to deacylation, and the resulting imine is then reacted in situ with an amine (method A). Alternatively, the quinol *N*-acylimine ether can be reacted directly with the amine via an exchange reaction (method B). These reactions were performed with both benzoquinol *N*-acetyl- and *N*-benzoylimine ether derivatives (Table IV). These products were obtained in >95% purity (see ^1H NMR data in supplementary material), and their structures were assigned on the basis of their ^1H NMR and ^{13}C NMR spectra.

The success of the exchange reactions noted in Table IV prompted us to apply this chemistry to quinol derivatives **12d** and **15g**, compounds which could not be prepared via anodic oxidation chemistry. Reaction of **15f** with sodium methoxide in methanol followed by reaction of the crude product with acetyl chloride and triethylamine gave **15g** (33%). This material was obtained as a 4:1 mixture of **15g** and the respective dienone. All attempts

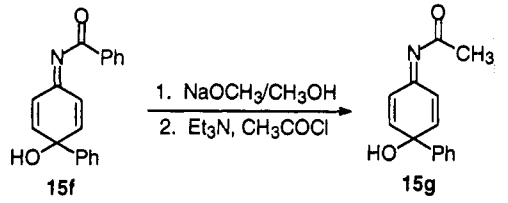
Table IV. Exchange Reactions of *N*-Acylated Quinol Imine and Quinone Imine Ketals

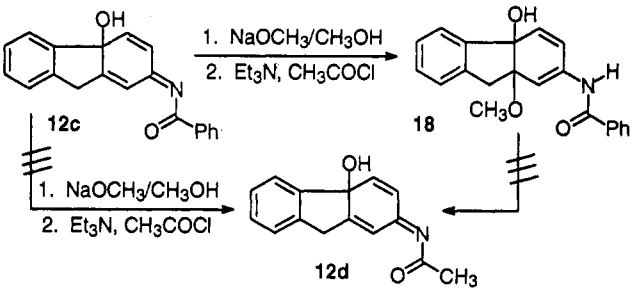


entry	R^1	R^2	R^3	method	% yield
1	Ph	CH_3	$PhCH_2$	A[a]	**17a** (65)
2	Ph	CH_3	$PhCH_2$	B[b]	**17a** (77)
3	Ph	CH_3	4-PhC_6H_4	B[b]	**17b** (45)
4	Ph	CH_3	4-*t*-BuC_6H_4	B[b]	**17c** (69)
5	Ph	CH_3		B[b]	**17d** (82)
6	OCH_3	CH_3		B[b]	**17e** (64)
7	OCH_3	Ph		A[a]	**17f** (55)
8	Ph	CH_3	CH_3CH_2	B[b]	**17g** (68)

[a] The quinol *N*-acylimine ether was deacylated with base, and the product imine was reacted with the amine. [b] The quinol *N*-acylimine ether was reacted directly with the amine. [c] The amine was 3,4-dimethoxyphenethylamine. [d] The amine was (+)-α-methylbenzylamine.

to purify the compound by either HPLC or adsorption chromatography led to further hydrolysis to the dienone as well as other decomposition products. However, its ^1H NMR spectrum, taking into account the dienone peaks, strongly supports the structure **15g**. This extremely labile compound has been detected[2] but has never been isolated previously.

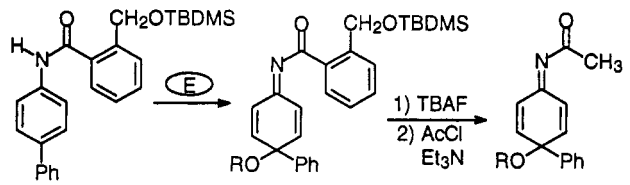




Reaction of **12c** in a manner analogous to that above afforded **18** (55%) as the only isolable product. Under a variety of conditions, no product lacking the benzoyl group could be isolated. An exact mass measurement of **18** gave the formula $C_{21}H_{19}O_3N$, and the structure of **18** was based on its IR, ^1H NMR, and ^{13}C NMR spectra. The most diagnostic features of the ^1H NMR (250 MHz) spectrum were the three vinyl hydrogens occurring at δ 6.59 (d, J = 1.5 Hz, 1 H), 6.48 (d, J = 9.9 Hz, 1 H), 5.95 (dd, J = 9.9, 1.8 Hz, 1 H), the saturated methoxyl group at δ 3.46 (s, 3 H), and the methylene group as an AB centered at δ 3.34 ($\Delta\nu$ = 69 Hz, J = 18.5 Hz, 2 H). The *cis*-stereochemistry has been assigned for the hydroxyl and methoxyl groups as models which suggest the *trans*-molecule is considerably more strained and coordination of the methoxide to the hydroxyl group may be assisting the addition; however, this assignment is tentative. Interestingly, no product

could be isolated from addition to the other β-carbon of the *N*-acylimine system.

Since the Michael addition of methoxide was competing with the deacylation process for **12c**, an internal pathway for the deacylation was examined. Compound **19** was obtained by reaction of 4-aminobiphenyl with phthalide followed by silylation in the standard fashion. Anodic oxidation of **19** under the usual conditions gave **20** (45%). Reaction of **20** with tetrabutylammonium fluoride and then addition of acetyl chloride/triethylamine to the imine generated in situ gave **8g** (35%). Having demonstrated the viability of this strategy for preparation of the quinol ether **8g**, the same chemistry was applied to **21** prepared from **19** in 42% yield via anodic oxidation. However, reaction of **21** with tetrabutylammonium fluoride followed by acetyl chloride/triethylamine gave complex reaction mixtures by TLC and ^{1}H NMR analysis. Since this route was unsuccessful for obtaining isolable amounts of **15g**, further efforts to prepare the fluorene quinol imine **12d** were abandoned.



19 20 R = CH_3 (45%) 21 R = OH (42%) 8g (35%) 15g ----

Summary. Quinol *N*-acylimines are highly reactive intermediates formed from *in vivo* oxidation of acylated aromatic amines. Because of the high reactivity of these compounds toward water and other nucleophiles, there has been no general method for their preparation. The anodic oxidation chemistry reported here makes available a variety of quinol *N*-acylimines and their ethers in one moderate-yield step from the readily available *N*-acylamines. The products are sufficiently pure (>95%) for most synthetic transformations as well as product and kinetic studies. However, the lability of the *N*-acyl quinols dictates that they should not be stored for extended periods and are best prepared as needed. Although the chemistry of these compounds has not been extensively studied, the facile preparation of ethers of quinol imines and quinone imine ketals has been demonstrated via exchange chemistry. In addition, many of the functionalization reactions reported for quinone *N*-acylimine ketals[1b] should be applicable to quinol *N*-acylimines and their ethers.

Experimental Section

General Procedures. Melting points were determined in capillaries and are uncorrected. Unless noted otherwise, the ^{1}H NMR spectra were measured at 200 MHz using deteriochloroform as solvent and residual chloroform as standard. ^{13}C NMR spectra were determined at 50 MHz in deuteriochloroform unless otherwise noted. All reagents or compounds not explicitly referenced were obtained commercially. For chromatography silica gel (Kieselgel 60 230–400 mesh) and Florisil (100–200 mesh) were employed. For acid-sensitive compounds, Florisil columns were eluted with solvent containing the indicated amount of triethylamine prior to addition of the compound. Base-washed silica gel was prepared by washing silica gel with 5% NH_4OH/CH_3OH and then drying the material under vacuum at 60 °C. Thin-layer chromatography was done using silica gel 60 F_{254} precoated aluminum-backed plates, 0.2-mm thickness. Visualization was by UV or by spraying with 5% ethanolic phosphomolybdic acid and then heating. Tetrahydrofuran was purified by distillation from benzophenone ketyl. Throughout the Experimental Section the following abbreviations are used: petroleum ether, bp 35–60 °C (PE), hexanes, bp 68–69 °C (H), ethyl acetate (EtOAc), tetrahydrofuran (THF), *p*-toluenesulfonic acid (*p*-TsOH), and thin layer chromatography (TLC). Extractive workup refers to extraction of the material into the indicated solvent, washing the organic layer with brine solution, drying over Drierite ($CaSO_4$), concentration in vacuo, and drying to constant weight under vacuum (1–2 Torr). Unless noted otherwise, all preparative anodic oxidations were performed under constant current conditions in a single-cell apparatus in reagent-grade methanol, acetonitrile, and water, using a cylindrical platinum anode (5-cm × 3.5-cm diameter, 50 mesh screen), a rectangular platinum sheet cathode (8 × 8 mm), and a Kepco JQE 36-3 M power supply. Divided cell oxidations were performed in a H-type divided cell apparatus using a cylindrical platinum anode (5-cm × 2.5-cm diameter) and a platinum wire cathode. The starting amides were known and were prepared via acylation reactions of the commercially available amines.

Anodic Oxidation of *N*-Acylaniline Derivatives. Several representative procedures are described here. For the remaining examples, only the spectroscopic data are given since the yields are listed in the text and full experimental description is given in the supplementary materials.

4-*O*-Methyl-4-Methyl-*p*-benzoquinol *N*-Benzoylimine (8a). 4-(*N*-benzoylamino)toluene (**7a**) (215 mg, 1.0 mmol) in 5% H_2O/CH_3OH (200 mL) was cooled to −15 °C. $LiClO_4 \cdot 3H_2O$ (4.0 g) and freshly ground $NaHCO_3$ (6.0 g) were added, and the mixture was anodically oxidized at a constant current of 0.15 A. The reaction was monitored by TLC (2% EtOAc/CH_2Cl_2) and was complete after 35 min. After filtration of the $NaHCO_3$ and addition of H_2O (100 mL), extractive workup with CH_2Cl_2 (3 × 50 mL) gave the crude product as a yellow oil (230 mg). Chromatography (Florisil, 10-cm × 1-cm column, 15% EtOAc/H as eluant) gave **8a** (R_f = 0.54, 2% EtOAc/CH_2Cl_2) as a light yellow oil (144 mg, 60% yield, >99% pure): IR (KBr) 1653, 1599, 1246, 1092, 1060, 716 cm^{-1}; ^{1}H NMR δ 7.9 (d, J = 8.0 Hz, 2 H), 7.5–7.3 (m, 3 H), 6.4 (s, 4 H), 3.1 (s, 3 H), 1.4 (s, 3 H); ^{13}C NMR δ 181.9, 156.7, 148.2, 134.4, 134.3, 130.5, 129.6, 127.8, 73.5, 54.0, 27.8; HRMS calcd for $C_{15}H_{15}O_2N$ m/z 251.1103, obsd 251.1106.

4-[*N*-Benzoyl-*N*-(4-methylphenyl)amino]-4-methyl-2,5-cyclohexadienone *N*-Benzoylimine (9). *N*-Benzoyl-4-aminotoluene (1.06 g, 5.0 mmol) in 5% H_2O/CH_3OH (200 mL) was warmed to 40 °C. $LiClO_4 \cdot 3H_2O$ (4.0 g) and freshly ground $NaHCO_3$ (6.0 g) were added, and the mixture was anodically oxidized at a constant current of 0.15 A. The reaction was monitored by TLC (2% EtOAc/CH_2Cl_2) and was completed in 2.5 h. After filtration of the $NaHCO_3$ and addition of H_2O (100 mL), extractive workup with CH_2Cl_2 (3 × 100 mL) gave a yellow oil (1.2 g). Chromatography (Florisil, 15-cm × 2-cm column, 25% EtOAc/H as eluant) gave first the imine **8a** as a light yellow oil (200 mg, 17% yield), followed by the dimer **9** (R_f = 0.45, 40% EtOAc/H) as a yellow oil (562 mg, 53% yield) with >95% purity: IR (neat) 1653, 1598, 1247 cm^{-1}; ^{1}H NMR (500 MHz) δ 7.9 (d, J = 7.0 Hz, 2 H), 7.5 (t, J = 7.0 Hz, 1 H), 7.4 (t, J = 8.0 Hz, 2 H), 7.25 (d, J = 7.0 Hz, 2 H), 7.2–7.1 (m, 3 H), 6.9 (AB q, Δν = 27 Hz, J = 8.0 Hz, 4 H), 6.6 (AB q, Δν = 82 Hz, J = 10.0 Hz, 4 H), 2.2 (s, 3 H), 1.6 (s, 3 H); HRMS calcd for $C_{28}H_{24}O_2N_2$ m/z 420.1832, obsd 420.1836.

4-[*N*-Benzoyl-*N*-(4-methylphenyl)amino]-4-methyl-2,5-cyclohexadienone (10). The dimer **9** (125 mg, 0.3 mmol), acetone (5 mL), H_2O (1 mL), and CH_3CO_2H (1 mL) were stirred at rt, and the reaction was complete after 10 h (TLC, 40% EtOAc/H). Saturated $NaHCO_3$ (5 mL) was added, and extractive workup with CH_2Cl_2 (2 × 10 mL) gave a brown oily solid (125 mg) which was purified by chromatography (silica gel, 10 cm × 1 cm, 230–400 mesh, 20% EtOAc/H as eluant) to give **10** (R_f = 0.39, 40% EtOAc/H) as a pale white solid (48 mg, 53% yield), mp 150.0–152.0 °C. Two recrystallizations from Et_2O/H gave analytically pure material: mp 156.0–157.0 °C (lit.[6a] mp 154.5–155.5 °C); IR (KBr) 1661, 1643, 1623, 1349, 858 cm^{-1}; ^{1}H NMR δ 7.3–7.2 (m, 7 H), 7.1–6.9 (AB q, Δν = 11 Hz, J = 8 Hz, 4 H), 6.2 (d, J = 10 Hz, 2 H), 2.2 (s, 3 H), 1.6 (s, 3 H); ^{13}C NMR δ 185.2, 172.2, 151.4, 138.4, 137.7, 136.6, 130.7, 129.6, 129.4, 128.1, 127.6, 127.3, 59.6,

26.9, 21.0. Anal. Calcd for $C_{21}H_{19}O_2N$: C, 79.47; H, 6.03. Found: C, 79.48; H, 6.01.

4-*O*-Methyl-4-methyl-*p*-benzoquinol *N*-Acetylimine (8b). For additional data, see reference 3: ^{1}H NMR δ 6.4 (AB q, $\Delta\nu$ = 23 Hz, J = 10 Hz, 4 H), 3.1 (s, 3 H), 2.2 (s, 3 H), 1.3 (s, 3 H).

4-*O*-Methoyl-4-methyl-*p*-benzoquinol *N*-(Methoxycarbonyl)imine (8c). 4-[*N*-(Methoxycarbonyl)amino]toluene (165 mg, 1.0 mmol, R_f = 0.83, 4% EtOAc/CH_2Cl_2) in 5% H_2O/CH_3OH (200 mL) was cooled to −15 °C. $LiClO_4$·$3H_2O$ (4.0 g) and freshly ground $NaHCO_3$ (6.0 g) were added, and the mixture was anodically oxidized at a constant current of 0.15 A. The reaction was monitored by TLC (4% EtOAc/CH_2Cl_2) and was complete after 35 min. After filtration of the $NaHCO_3$ and addition of H_2O (200 mL), extractive workup with CH_2Cl_2 (3 × 50 mL) gave a yellow oil (175 mg). Chromatography (Florisil, 8-cm × 2-cm column, 10% EtOAc/H as eluant) gave **8c** (R_f = 0.61, 4% EtOAc/CH_2Cl_2) as a white solid (90 mg, 46% yield): mp 70.0–71.5 °C; IR (KBr) 1720, 1650, 1590, 1230, 1110, 1080, 840 cm^{-1}; ^{1}H NMR δ 6.4 (AB q, $\Delta\nu$ = 16 Hz, J = 10 Hz, 4 H), 3.8 (s, 3 H), 3.1 (s, 3 H), 1.4 (s, 3 H); ^{13}C NMR δ 163.4, 158.9, 148.0 (2C), 72.4, 53.6, 53.4, 26.9; HRMS calcd for $C_{10}H_{13}O_3N$ m/z 195.0892, obsd 195.0941.

4-*O*-Methyl-4-ethyl-*p*-benzoquinol *N*-benzoylimine (8d): IR (neat) 1670, 1654, 1599, 1246, 1075, 715 cm^{-1}; ^{1}H NMR δ 7.9 (d, J = 8.0 Hz, 2 H), 7.5–7.3 (m, 3 H), 6.4 (AB q, $\Delta\nu$ = 23 Hz, J = 10 Hz, 4 H), 3.1 (s, 3 H), 1.7 (q, J = 7 Hz, 2 H), 0.8 (t, J = 7.0 Hz, 3 H); ^{13}C NMR δ 180.3, 155.8, 146.4, 133.1, 129.4, 128.5, 127.8, 127.0, 76.2, 52.9, 32.6, 7.8; HRMS calcd for $C_{16}H_{17}O_2N$ m/z 255.1255, obsd 255.1231.

4-*O*-Methyl-4-*sec*-butyl-*p*-benzoquinol *N*-benzoylimine (8e): IR (neat) 1655, 1599, 1247, 1075, 715 cm^{-1}; ^{1}H NMR δ 7.9 (d, J = 8.0 Hz, 2 H), 7.5–7.3 (m, 3 H), 6.4 (AB q with the lower field component further coupled, $\Delta\nu$ = 29 Hz, J = 10 Hz, 4 H), 3.1 (s, 3 H), 1.6–1.5 (m, 1 H), 0.9–0.8 (m, 8 H); ^{13}C NMR δ 180.3, 156.0, 145.9, 145.5, 133.2, 129.3, 128.5, 128.0, 78.4, 52.7, 43.9, 23.6, 13.3, 12.4; HRMS calcd for $C_{18}H_{21}O_2N$ m/z 283.1567, obsd 283.1586.

Anodic Oxidation of *N*-Benzoyl-2-aminofluorene (11a). The title compound (250 mg, 0.793 mmol, R_f = 0.54, 2% EtOAc/CH_2Cl_2) was added to 5% H_2O/CH_3OH (200 mL) and stirred vigorously for 10 min at rt. $LiClO_4$·$3H_2O$ (2.0 g) and $NaHCO_3$ (2.0 g) were added, and the reaction mixture was anodically oxidized with a constant current of 0.15 A at rt. The reaction was followed by TLC (2% EtOAc/CH_2Cl_2) and was judged to be complete after 25 min (70% current efficiency). After filtration of the $NaHCO_3$ and addition of H_2O (50 mL), extractive workup with CH_2Cl_2 (2 × 75 mL) gave a viscous yellow oil (270 mg). Rapid chromatography (Florisil, 10-cm × 1-cm column, 20% EtOAc/H as eluant) on a column pretreated with Et_3N (1 mL) gave **12a** contaminated with some starting material. Trituration of the resulting oil with cold ether gave a yellow solid (15 mg), mp 198–201 °C, that was identical to starting material by TLC. The mother liquors were combined to give a yellow oil (196 mg, 71%) which was characterized as **12a** (R_f = 0.45, 2% EtOAc/CH_2Cl_2) of >95% purity by ^{1}H NMR: IR (neat) 1655, 1590, 1240, 1040 cm^{-1}; ^{1}H NMR δ 7.9 (dd, J = 8, 1.5 Hz, 2H), 7.6–7.3 (m, 7H), 6.9 (d, J = 10 Hz, 1H), 6.6 (dd, J = 10, 2 Hz, 1H), 6.4 (m, 1 H), 4.0 (dd, J = 18, 2 Hz, 1H), 3.4 (d, J = 18 Hz, 1H), 3.2 (s, 3H); ^{13}C NMR δ 180.3, 157.1, 156.8, 141.7, 141.3, 137.8, 133.3, 133.1, 130.0, 129.7, 129.5, 128.6, 127.5, 125.3, 123.2, 78.4, 52.1, 35.9 (one C missing); HRMS calcd for $C_{21}H_{17}O_2N$ m/z 315.1255, obsd 315.1238.

Anodic Oxidation of *N*-Acetyl-2-aminofluorene (11b). The title compound (0.2 g, 0.790 mmol, R_f = 0.23, 40% EtOAc/H) and $LiClO_4$ (2.0 g) in 5% H_2O/CH_3OH (200 mL) were cooled to 0 °C. After addition of $NaHCO_3$ (2.0 g), the mixture was anodically oxidized at a constant current of 0.3 A. The reaction was followed by TLC (40% EtOAc/H) and found to be complete after 0.5 h (60% current efficiency). After filtration of the $NaHCO_3$ and addition of H_2O (100 mL), extractive workup with CH_2Cl_2 (3 × 70 mL) gave a yellow-brown oil (215 mg). Rapid chromatography (Florisil, 10-cm × 2-cm column, 25% EtOAc/H as eluant) on a column pretreated with Et_3N (1 mL) gave a light yellow solid (20 mg, 12% yield), mp 99.0–102.0 °C, identified as the dienone derived from hydrolysis: mp 102.1–103.5 °C; IR (KBr) 1669, 1640, 1608, 1473, 1462, 1387, 1282, 1088, 1076, 1051, 949, 925, 810, 762, 716 cm^{-1}; ^{1}H NMR δ 7.5–7.3 (m, 4 H), 7.2 (d, J = 10 Hz, 1 H), 6.47 (dd, J = 10, 2 Hz, 1 H), 6.3 (d, J = 2 Hz, 1 H), 4.05 (dd, J = 20, 1.5 Hz, 1 H), 3.3 (d, J = 20 Hz, 1 H), 3.2 (s, 3 H); HRMS calcd for $C_{13}H_{12}O$ m/z 181.0651, obsd 181.0647.

Compound **12b** (R_f = 0.51, 40% EtOAc/H) was isolated as a yellow oil (97 mg, 43% yield) which was >95% pure by ^{1}H NMR: IR (neat) 1695, 1670, 1605, 1220, 1045, 750 cm^{-1}; ^{1}H NMR δ 7.43–7.33 (m, 1 H), 7.32–7.26 (m, 3 H), 6.93 (d, J = 10 Hz, 1 H), 6.52 (dd, J = 10, 2 Hz, 1 H), 6.35 (d, J = 2 Hz, 1 H), 3.98 (dd, J = 18, 2 Hz, 1 H), 3.45 (d, J = 18 Hz, 1 H), 3.12 (s, 3 H), 2.23 (s, 3 H); HRMS calcd for $C_{16}H_{15}O_2N$ m/z 253.1099, obsd 253.1068.

Anodic oxidation of *N*-benzoyl-2-aminoindan (13), formation 14: IR (neat) 1660, 1598, 1246, 1173, 1111, 1090, 1056 cm^{-1}; ^{1}H NMR δ 7.9 (d, J = 8.0 Hz, 2 H), 7.6–7.4 (m, 3 H), 6.5 (AB q, with higher field component further coupled, $\Delta\nu$ = 13 Hz, J = 10, 1.5 Hz, 2 H), 6.3 (d, J = 1.5 Hz, 1 H), 3.0 (s, 3 H), 2.5 (m, 2 H), 2.2 (m, 2 H), 1.7 (m, 2 H); ^{13}C NMR δ 180.5, 161.5, 157.0, 141.3, 133.3, 133.2, 129.4, 128.8, 128.5, 120.3, 78.7, 51.3, 35.9, 28.6, 21.1; HRMS calcd for $C_{17}H_{17}O_2N$ m/z 267.1255, obsd 267.1295.

4-Methyl-*p*-benzoquinol *N*-Benzoylimine (15a). *N*-Benzoyl-4-aminotoluene (216 mg, 1.0 mmol) was dissolved in 30% H_2O/CH_3CN (200 mL), and freshly ground $NaHCO_3$ (6.0 g) and $LiClO_4$·$3H_2O$ (4.0 g) were added. The mixture was anodically oxidized at a constant current of 0.15 A at rt, and the reaction was complete after 35 min by TLC (40% EtOAc/H). After filtration of the $NaHCO_3$ and addition of H_2O (200 mL), extractive workup with CH_2Cl_2 (2 × 75 mL) gave a yellow oil (220 mg). Chromatography (Florisil, 10-cm × 1-cm column, 25% EtOAc/H as eluant) gave a light yellow oil (100 mg, 44% yield) of >95% purity: IR (neat) 3388, 1653, 1599, 1580, 1449, 1313, 1248, 1079, 1063, 838, 724 cm^{-1}; ^{1}H NMR δ 7.9 (d, J = 8.0 Hz, 2 H), 7.5–7.3 (m, 3 H), 6.3 (AB q, $\Delta\nu$ = 77 Hz, J = 10 Hz, 4 H), 3.5 (br s, 1 H), 1.4 (s, 3 H); ^{13}C NMR δ 180.6, 155.8, 148.2, 133.3, 132.8, 129.4, 128.5, 122.9, 66.8, 27.1; HRMS calcd for $C_{14}H_{13}O_2N$ m/z 227.0943, obsd 227.0937.

4-Methyl-*p*-benzoquinol *N*-methoxycarbonylimine (15c): IR (neat) 3322, 1706, 1542, 1515, 1456, 1275, 1240 cm^{-1}; ^{1}H NMR δ 6.4 (AB q, $\Delta\nu$ = 78 Hz, J = 10 Hz, 4 H), 3.8 (s, 3 H), 2.3 (br s, 1 H), 1.4 (s, 3 H); HRMS calcd for $C_9H_{11}O_3N$ m/z 181.0736, obsd 181.0744.

4-Ethyl-*p*-benzoquinol *N*-benzoylimine (15d): IR (neat) 3385, 1643, 1599, 1313, 1257, 1062, 1023, 718 cm^{-1}; ^{1}H NMR δ 7.9 (d, J = 8.0 Hz, 2 H), 7.5–7.3 (m, 3 H), 6.4 (AB q, $\Delta\nu$ = 43 Hz, J = 10 Hz, 4 H), 1.7 (q, J = 7.0 Hz, 2 H), 0.9 (t, J = 7.0 Hz, 3 H); ^{13}C NMR δ 180.5, 155.9, 146.9, 133.3, 132.9, 129.4, 128.5, 124.6, 70.2, 33.0, 7.9; HRMS calcd for $C_{15}H_{15}O_2N$ m/z 241.1099, obsd 241.1103.

***N*-Benzoyl 4-hydroxy-3-*sec*-butylaniline (16):** IR (neat) 3313, 1643, 1612, 1544, 1507, 1430, 1265 cm^{-1}; ^{1}H NMR δ 8.1 (s, 1 H), 7.8 (d, J = 8.0 Hz, 2 H), 7.5–7.2 (m, 5 H), 6.7 (d, J = 8.0 Hz, 1 H), 3.0 (sextet, J = 7.0 Hz, 1 H), 1.5 (pentet, J = 7.0 Hz, 2 H), 1.2 (d, J = 7.0 Hz, 3 H), 0.9 (t, J = 7.0 Hz, 3 H); HRMS calcd for $C_{17}H_{19}O_2N$ m/z 269.1411, obsd 269.1414.

4-Phenyl-*p*-benzoquinol *N*-Benzoylimine (15f). This is an improved procedure over that previously reported.[2] A solution of *N*-benzoyl-4-aminobiphenyl (249 mg, 0.91 mmol) in 10% H_2O/THF (150 mL) with $LiClO_4$ (2 g) was stirred at 25 °C. After addition of crushed $NaHCO_3$ (2 g), the mixture was anodically oxidized at 0.2 A for 2 h, after which time TLC (60% EtOAc/H) indicated complete reaction. Addition of H_2O (100 mL) and extractive workup with CH_2Cl_2 (3 × 75 mL) gave a dark yellow oil which was chromatographed (Florisil, 2.5 × 15 cm, 25% EtOAc/H) to give **15f** as a yellow oil (160 mg, 61% yield). The oil was triturated with cold Et_2O to give a yellow solid, which was recrystallized from Et_2O/H to yield a white solid (140 mg, 53%), mp 118–119.0 °C (lit.[2] mp 118.5–119 °C).

Anodic Oxidation of *N*-Benzoyl-2-aminofluorene (11a). A solution of *N*-benzoyl-2-aminofluorene (245 mg, 0.9 mmol) in 10% H_2O/THF (200 mL) and DMF (8 mL) with $LiClO_4$ (2 g) was cooled to 0 °C. After addition of crushed $NaHCO_3$ (2 g), the mixture was anodically oxidized at 0.2 A for 2 h, after which time the reaction was complete by TLC (60% EtOAc/H). After addition of H_2O (100 mL), extractive workup with CH_2Cl_2 (3 × 75 mL) gave a dark yellow oil. Chromatography (Florisil, 2.5 × 15 cm, 25% EtOAc/H as eluant) gave a yellow oil identified as **12c** (140 mg, 51% yield), which was 90% pure by ^{1}H NMR: IR

(neat) 3316, 2956, 1661, 1070 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 7.84 (d, J = 7 Hz, 2 H), 7.65–7.45 (m, 4 H), 7.45–7.2 (m, 4 H), 6.45 (dd, J = 9.7, 1.7 Hz, 1 H), 6.2 (s, 1 H), 4.0 (d, J = 18.4 Hz, 1 H), 3.52 (d, J = 18.6 Hz, 1 H); ^{13}C NMR (DMSO-d_6) δ 179.4, 161.7, 156.8, 142.8, 141.2, 133.4, 132.8, 129.2, 128.9, 128.8, 128.3, 127.5, 127.0, 125.0, 123.3, 116.8, 72.0, 35.2; HRMS calcd for $C_{20}H_{15}O_2N$ m/z 301.1104, obsd 301.1109.

Preparation of 4-*O*-Methyl-4-phenylbenzoquinol *N*-Benzylimine (17a) from 8f via Exchange with Benzylamine. 4-*O*-Methyl-4-phenyl-*p*-benzoquinol *N*-benzoylimine (72 mg, 0.24 mmol) was dissolved in THF (5 mL), benzylamine (0.03 mL, 0.26 mmol) was added, and the solution was stirred at rt. The reaction was monitored by TLC (20% EtOAc/hexanes) and was complete after 2.0 h. The reaction solvent was removed under vacuum, giving a yellow oil (100 mg) which was dissolved in CH_2Cl_2 and impregnated on Florisil (1.5 g). Chromatography on Florisil (10 × 2 cm column, gradient eluted from H to 15% EtOAc/H) was preceded by eluting Et_3N (2 mL) through the column. There was obtained a light yellow oil (56 mg, 82% yield) which was greater than 95% pure by ^{1}H NMR spectroscopy: IR (neat) 2932, 1602, 1583, 1489, 1449, 1069, 823 cm^{-1}; ^{1}H NMR δ 7.5–7.2 (m, 10 H), 6.9 (dd, J = 10, 2 Hz, 1 H), 6.6 (dd, J = 10, 2 Hz, 1 H), 6.3 (dd, J = 10, 2 Hz, 1 H), 6.2 (dd, J = 10, 2 Hz, 1 H), 4.9 (s, 2 H), 3.4 (s, 3 H); ^{13}C NMR δ 157.0, 143.0, 141.3, 139.8, 138.7, 133.6, 128.6, 128.4, 127.9, 127.7, 126.9, 125.7, 118.8, 77.6, 55.0, 52.2; HRMS calcd for $C_{20}H_{19}NO$ m/z 289.1471, obsd 289.1462.

Preparation of 4-*O*-Methyl-4-phenylbenzoquinol *N*-Benzylimine (17a) via Deacylation of 8g and Addition of Benzylamine. To a solution of 4-*O*-methyl-4-phenyl-*p*-benzoquinol *N*-acetylimine (**8g**) (100 mg, 0.41 mmol) in THF (5 mL) was added a 1.0 N NaOH (2 mL) solution, and the heterogeneous mixture was stirred vigorously at rt. After 2 h the reaction was determined to be complete by TLC (20% EtOAc/H). Benzylamine (0.045 mL, 0.41 mmol) was added and the heterogeneous solution then stirred at rt for 6 h. Extractive workup with Et_2O (3 × 25 mL) gave a yellow oil (110 mg) which was chromatographed (Florisil, 15-cm × 1-cm column, gradient eluted with H through 5% EtOAc/H) to give a light yellow oil (78 mg, 65% yield) of >95% purity by ^{1}H NMR spectroscopy.

4-*O*-Methyl-4-phenylbenzoquinol *N*-(4-biphenyl)imine (17b): IR (neat) 2932, 1599, 1581, 1484, 1448, 1070, 757, 696 cm^{-1}; ^{1}H NMR δ 7.6–7.5 (m, 4 H), 7.5–7.2 (m, 8 H), 6.9 (d, J = 8 Hz, 2 H), 6.76 (dd, J = 10, 2 Hz, 1 H), 6.6 (dd, J = 10, 2 Hz, 1 H), 6.43 (dd, J = 10, 2 Hz, 1 H), 6.33 (dd, J = 10, 2 Hz, 1 H), 3.4 (s, 3 H); HRMS calcd for $C_{25}H_{21}ON$ m/z 351.1618, obsd 351.1627.

4-*O*-Methyl-4-phenylbenzoquinol *N*-(4-*tert*-butylphenylimine (17c): IR (neat) 2961, 1601, 1582, 1499, 1488, 1448, 1086, 1071, 1010 cm^{-1}; ^{1}H NMR δ 7.5–7.2 (m, 7 H), 6.82 (d, J = 8 Hz, 2 H), 6.73 (dd, J = 10, 2 Hz, 1 H), 6.6 (dd, J = 10, 2 Hz, 1 H), 6.4 (dd, J = 10, 2 Hz, 1 H), 6.27 (dd, J = 10, 2 Hz, 1 H), 3.4 (s, 3 H), 1.3 (s, 9 H); ^{13}C NMR δ 156.9, 147.2, 147.1, 143.0, 141.2, 141.0, 131.7, 128.5, 127.8, 125.7, 125.6, 121.4, 120.3, 52.2, 34.1, 31.4; HRMS calcd for $C_{23}H_{25}ON$ m/z 331.1930, obsd 331.1967.

4-*O*-Methyl-4-phenylbenzoquinol *N*-(3,4-dimethoxyphenethyl)imine (17d): IR (neat) 2934, 1587, 1516, 1464, 1449, 1262, 1237, 1156, 1140, 1071, 1030 cm^{-1}; ^{1}H NMR δ 7.4–7.2 (m, 5 H), 6.4–6.8 (str m, 5 H), 6.2 (d, J = 10 Hz, 2 H), 3.88 (t, J = 7 Hz, 2 H), 3.85 (s, 3 H), 3.83 (s, 3 H), 3.3 (s, 3 H), 3.0 (t, J = 7 Hz, 2 H); ^{13}C NMR δ 157.0, 148.8, 147.5, 142.3, 138.8, 132.4, 132.2, 128.4, 127.7, 125.6, 120.7, 118.5, 112.3, 111.2, 76.7, 55.9, 55.8, 53.0, 52.1, 36.9; HRMS calcd for $C_{23}H_{25}O_3N$ m/z 363.1828, obsd 363.1833.

4-Methoxy-*O*-methylbenzoquinol *N*-(3,4-dimethoxyphenethyl)imine (17e): IR (neat) 2938, 1588, 1514, 1461, 1262, 1236, 1142, 1106, 1061, 1031 cm^{-1}; ^{1}H NMR δ 6.7–6.6 (m, 3 H), 6.57 (dd, J = 10, 2 Hz, 1 H), 6.44 (dd, J = 10, 2 Hz, 1 H), 6.24 (d, J = 10 Hz, 2 H), 3.81 (s, 3 H), 3.80 (s, 3 H), 3.80 (t, buried under singlet peaks, 2 H), 3.2 (s, 6 H), 2.9 (t, J = 7 Hz, 2 H); ^{13}C NMR δ 156.5, 148.7, 147.4, 135.8, 133.3, 132.5, 132.3, 120.6, 119.0, 112.2, 111.2, 55.8, 55.7, 53.3, 49.9, 36.8; HRMS calcd for $C_{18}H_{23}O_4N$ m/z 317.1621, obsd 317.1613.

4-*O*-Methyl-4-phenylbenzoquinol *N*-(α-methylbenzylimine (17f): $[\alpha]_D$ = +165; IR (neat) 2969, 1585, 1106, 1064, 1039, 956 cm^{-1}; ^{1}H NMR δ 7.4–7.2 (m, 5 H), 6.8 (d, J = 11.0 Hz, 1 H), 6.5 (d, J = 11.0 Hz, 1 H), 6.4 (overlapping dd, J = 11.0, 2.0 Hz, 2 H), 5.0 (d, J = 6.5 Hz, 1 H), 3.4 (s, 3 H), 3.3 (s, 3 H), 1.5 (d, J = 6.5 Hz, 3 H); HRMS calcd for $C_{16}H_{19}O_2N$ m/z 257.1415, obsd 257.1415.

4-Phenylbenzoquinol *N*-Acetylimine (15g). To the quinol **15f** (90 mg, 0.3 mmol) in anhydrous methanol (5 mL) was added NaOMe (8 mg, 0.3 mmol). After the mixture was stirred for 0.5 h at rt, THF (5 mL) was added, followed by addition of Et_3N (150 mg, 1.5 mmol). After an additional 5 min, acetyl chloride (60 mg, 0.8 mmol) was added dropwise. Extractive workup with CH_2Cl_2 (3 × 50 mL) gave a mixture of a yellow oil and white solid which were separated by tituration with Et_2O (20 mL). The white solid was **15f** (40 mg), and the yellow oil was **15g** (65 mg crude, 33% yield via ^{1}H NMR internal standard of triphenyl methane, contaminated with ca. 20% of the dienone). All attempts to further purify the compound by chromatography led to hydrolysis to 4-hydroxy-4-phenyl-2,5-cyclohexadienone and other products. This ca. 80% pure compound showed: IR (neat) 3336, 1655, 1600 cm^{-1}; ^{1}H NMR δ 7.45 (m, 5 H), 6.4 (AB q, $\Delta\nu$ = 71 Hz, J = 10 Hz, 4 H), 3.44 (s, 1 H), 2.38 (s, 3 H); HRMS calcd for $C_{14}H_{13}NO_2$ m/z 227.0946, obsd 227.0946.

Reaction of 12c with Sodium Methoxide To Form 18. A solution of sodium methoxide (9 mg, 0.4 mmol) in anhydrous methanol (5 mL) was added to **12c** (110 mg, 0.4 mmol), and the reaction mixture was stirred for 0.5 h, after which time it was complete by TLC (60% EtOAc/H) analysis. Addition of H_2O (50 mL) and extractive workup with CH_2Cl_2 (3 × 30 mL) gave a yellow oil, which was chromatographed (silica gel, 2.5 × 16 cm column, 25% EtOAc/H as eluant) to give a light yellow oil identified as **18** (66 mg, 56%): IR (neat) 3316, 1651, 1534, 1319, 1272, 1076, 1055, 910 cm^{-1}; ^{1}H NMR (250 MHz) δ 7.72 (d, J = 7 Hz, 2 H), 7.6–7.2 (m, 7 H), 6.59 (d, J = 1.5 Hz, 1 H), 6.48 (d, J = 10 Hz, 1 H), 5.95 (dd, J = 10, 1.5 Hz, 1 H), 3.59 (s, 1 H), 3.49 (s, 3 H), 3.34 (AB q, $\Delta\nu$ = 69 Hz, J = 18.5 Hz, 2 H); ^{13}C NMR δ 166.0, 144.5, 140.7, 135.3, 134.5, 134.0, 132.0, 129.0, 128.8, 127.4, 126.8, 124.5, 123.7, 121.2, 111.3, 83.3, 78.3, 77.2, 52.0, 44.2; HRMS calcd for $C_{21}H_{19}O_3N$ m/z 333.1557, obsd 333.1556.

Reaction of 4-Aminobiphenyl and Phthalide To Give *N*-[2-(Hydroxymethyl)benzoyl]-4-aminobiphenyl. To a solution of 4-aminobiphenyl (1.31 g, 7.7 mmol) in anhydrous THF (25 mL) at 0 °C was added *n*-BuLi (2.0 M, 7.7 mmol, 3.9 mL) dropwise. After 15 min phthalide (1.03 g, 7.7 mmol) was added. The solution was stirred for 0.5 h, after which time TLC (60% EtOAc/H) analysis showed completion of the reaction. Addition of H_2O (50 mL), extractive workup with CH_2Cl_2 (3 × 35 mL), and 5% HCl wash of the CH_2Cl_2 layer gave a yellowish solid. The solid was triturated to give a white crystalline alcohol (1.45 g, 62%): mp 166–168 °C; IR (KBr) 3273, 1642, 1527, 1090, 840, 775 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 7.83 (d, J = 9.6 Hz, 2 H), 7.3–7.7 (m, 11 H), 4.7 (s, 2 H). Anal. Calcd for $C_{20}H_{17}O_2N$: C, 79.19; H, 5.65. Found: C, 79.38; H, 5.86.

***N*-[2-[(*tert*-Butyldimethylsiloxy)methyl]benzoyl]-4-aminobiphenyl (19).** A solution of the above alcohol (2.03 g, 6.7 mmol), imidazole (1.5 equiv, 680 mg, 10 mmol), and *tert*-butyldimethylsilyl chloride (2 equiv, 1.89 g, 13.4 mmol) in anhydrous THF (70 mL) was stirred for 1 h, after which time TLC (60% EtOAc/H) indicated complete reaction. After addition of H_2O (50 mL), extractive workup with CH_2Cl_2 (3 × 50 mL), a wash of the CH_2Cl_2 layer with cold 5% HCl (2 × 30 mL), and concentration a yellow solid was obtained. The solid was recrystallized from Et_2O/H to afford a crystalline compound identified as **19** (2 g, 72%): mp 85–86 °C; IR (KBr) 3304, 2954, 2928, 2856, 1656, 1651, 1599, 1524, 1255, 835, 762 cm^{-1}; ^{1}H NMR δ 9.58 (s, 1 H), 7.9 (dd, J = 6.5, 1.7 Hz, 1 H), 7.75 (d, J = 8.7 Hz, 2 H), 7.6 (d, J = 8.5 Hz, 4 H), 7.5–7.3 (m, 6 H), 4.9 (s, 2 H), 0.9 (s, 9 H), 0.2 (s, 6 H). Anal. Calcd for $C_{26}H_{31}O_2NSi$: C, 74.6; H, 7.5. Found: C, 74.2; H, 7.5.

4-Methoxy-4-phenyl-2,5-cycloexadienone *N*-[2-[(*tert*-Butyldimethylsiloxy)methyl]benzoyl]imine (20). A solution of **19** (2 g, 5 mmol) in 5% H_2O/CH_3OH (200 mL) with $LiClO_4$ (2 g) was cooled to 0 °C. After addition of crushed $NaHCO_3$ (2 g), the mixture was anodically oxidized at 0.2 A for 1.5 h, after which time TLC (60% EtOAc/H) indicated complete reaction. After addition of H_2O (100 mL), extractive workup with CH_2Cl_2 (3 × 75 mL) gave a yellow oil identified as **20** (0.9 g, 45% yield): IR (neat) 3441 (m), 2954, 2929, 2856, 1668, 1650, 1251, 1088, 1073, 835 cm^{-1}; ^{1}H NMR δ 7.92 (d, J = 7.8 Hz, 1 H), 7.8 (dd, J = 7.7, 1.3 Hz, 1 H), 7.6 (t, J = 7.7, 1.3 Hz, 1 H), 7.25–7.45 (m, 6 H), 6.55

(AB q, $\Delta\nu$ = 14 Hz, J = 11.3 Hz, 4 H), 5.25 (s, 2 H), 3.39 (s, 3 H), 0.98 (s, 9 H), 0.15 (s, 6 H); ^{13}C NMR δ 181.6, 155.3, 145.9, 144.6, 139.6, 132.9, 131, 129.7, 128.8, 128.7, 128.1, 126.7, 126.4, 126.3, 125.7, 63.5, 52.6, 26.0, 18.4, -5.3; HRMS calcd for $C_{27}H_{33}O_3NSi$ m/z 447.2231, obsd 447.2235.

4-Methoxy-4-phenyl-2,5-cyclohexadienone *N*-Acetylimine (8g). To a solution of **20** (170 mg, 0.4 mmol) in THF (20 mL) was added Bu_4NF (1.0 M) at 0 °C. After 0.5 h reaction, K_2CO_3 (300 mg) was added. A new slower-moving fluorescent spot was visible by TLC (60% EtOAc/H, R_f = 0.15 versus R_f = 0.77 for **20**). Triethylamine (100 mg, 1 mmol) was then added, followed by dropwise addition of acetyl chloride (35 mg, 0.45 mmol). After 5 min H_2O (35 mL) was added, and extractive workup with CH_2Cl_2 (3 × 50 mL) gave **8g** as a yellow oil (31 mg, 35%) which had spectroscopic properties identical with an authentic sample.

4-Hydroxy-4-phenyl-2,5-cyclohexadienone *N*-[2-[(*tert*-Butyldimethylsiloxy)methyl]benzoyl]imine (21). A solution of **19** (250 mg, 0.6 mmol) in 10% H_2O/THF (150 mL) and DMF (8 mL) with $LiClO_4$ (2 g) was cooled to 0 °C. After addition of crushed $NaHCO_3$ (2 g), the mixture was anodically oxidized at 0.2 A for 1.5 h, after which time the reaction was complete by TLC (60% EtOAc/H). Addition of H_2O (100 mL) and extractive workup with CH_2Cl_2 (3 × 35 mL) gave a dark yellow oil which was chromatographed (Florisil, 2.5- × 15-cm column, 25% EtOAc/H as eluant) to give an almost translucent oil identified as **21** (102 mg, 42%): IR (neat) 3328, 2954, 2928, 1662, 1598, 1251, 1038, 836 cm^{-1}; ^{1}H NMR δ 8.15 (d, J = 7.9 Hz, 1 H), 7.97 (d, J = 7.9 Hz, 1 H), 7.37-7.31 (m, 2 H), 7.14-6.98 (m, 5 H), 6.1 (AB q, $\Delta\nu$ = 29 Hz, J = 10 Hz, 4 H), 5.63 (s, 2 H), 1.03 (s, 9 H), 0.13 (s, 6 H); ^{13}C NMR δ 180.8, 155.4, 148.7, 143.2, 141.4, 132.9, 130.6, 129.9, 128.5, 127.6, 126.8, 126.5, 125.3, 121.7, 69.9, 62.8, 25.9, 18.1, -5.4; HRMS calcd for $C_{26}H_{31}NO_3Si$ m/z 433.2074, obsd 433.2062.

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Supplementary Material Available: Procedures not described in the Experimental Section and ^{1}H NMR spectra of all new compounds (50 pages). This material is contained in libraries on microfiche, immediately follows the article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.