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Electrochemical Reduction of α-Diketones and α-Diimines in the Presence of a Bielectrophilic Substrate: Synthesis of New Aza-Crown Compounds

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The electrochemical reduction of α-diketones and α-diimines with the tritosylate of diethanolamine produces the corresponding aza crown compounds. This study was conducted using cyclic voltammetry in an aprotic medium and by preparative electrolysis on a stirred mercury pool. The obtained products were fully characterized by spectroscopic IR, NMR and HRMS methods and by elementary analysis.

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Crown ethers were first introduced by Pedersen in 1967[1] and constitute an important variety of macromolecules that have been employed in a large array of applications.[2] These ethers are also used in supramolecular chemistry[3] and have drawn special interest in the environmental field for complexing heavy metals in water.[4] In addition, the compounds complexing and lipophilic properties[5] triggered their applications as drug and pharmaceutical adjuvants.[6] These compounds are also used as catalysts in organic synthesis (18-crown 6).[7]

The replacement of oxygen atoms by nitrogen atoms improves the complexing property of crown ethers and affects their selectivity for metals.[8] Consequently, aza-crown ethers constitute an important class of macrocylic complexing compounds, due to their nitrogen lone pairs and N–H moieties, rendering them able to complex both cations and anions, depending on the pH value of the aqueous solution.[9] Nitrogen-oxygen mixed donor macrocycles, such as aza-crown ethers, can form stable complexes with both alkali and transition metal cations.[10]

Alternatively, aza-crown ethers also find utility in sensor systems,[11] especially as chemosensors,[12] in the design of host-guest compounds, in a wide array of cation detection applicatoins,[13] and in ion-selective membrane electrodes.[14]

Various synthetic methods of aza-crown ethers were described,[15] starting from different reagents[16] and using different procedures.[17] The alkylation reactions of the radical anions and the electrogenerated dianions in a weakly acidic medium are widely developed in organic electrochemistry.[18]

Previously, we have shown that the electrochemically obtained dianions, stable in an aprotic medium, can react with reagents having two electrophilic centers containing two good leaving groups, such as tosylates, to generate macromolecules.[19] In this way the action of the 1,4-dianions on bis-toluene sulfonates allowed the preparation of oxa-, oxaza- and aza-crown ethers having one or multiple units of Z-CH_2-CH_2.[19]

As a continuation of this work, in this study, we describe the reaction of the dianions, obtained by the reduction of α-diketones or α-diimines, with the tritosylate of diethanolamine to give the corresponding aza-crown ethers, diesters and diamides.

Results and Discussion

Analytical study.—The electroreduction curve of the dimethylformamide as aprotic solvent, and tetrabutylammonium hypochlorite (n-Bu_4NClO_4) (0.1 M) as supporting electrolyte (blank) show a pick at −2.5 V (Figure 1). This value is low enough to allow the reduction of a great number of organic compounds.

As a preparative step for this synthesis, we have performed cyclic voltammetry measurements on the tritosylate of diethanolamine **2** in an aprotic solution. The reduction of these compounds takes place according to two irreversible cathodic peaks, located at close potentials (i.e., ca. −1.57 V and ca. −1.65 V, vs Ag/AgI/I^- reference). (Figure 2)

The first peak can be attributed to the bielectronic cleavage of the oxygen-sulfur bond, which is weaker than the nitrogen-sulfur bond. The second peak seems to correspond to a simultaneous break of the second oxygen-sulfur bond and/or the nitrogen-sulfur bond. It should be noted here that the behavior of tritosylate of diethnolamine **2** as a bielectrophile is quite similar to that of *p*-toluene sulfonamides such as the previously reported *N*,*N'*-ditosylethylene or *N*,*N'*,*N''*-tritosylate of diethylenetriamine (Scheme 1).[19,20]

However, the exploration of the cyclic voltammograms in the electrochemical study of the α-diketones, **1A**, and α-diimines, **1B**, shows that the α-diketones are reduced in two *mono*-electronic peaks, whereas the α-diimines are reduced in a single peak (Table I).

Raising the voltage sweep rate leads to an increase in the current peak. Accordingly, the gradient of a plot of the log i_p versus log v was

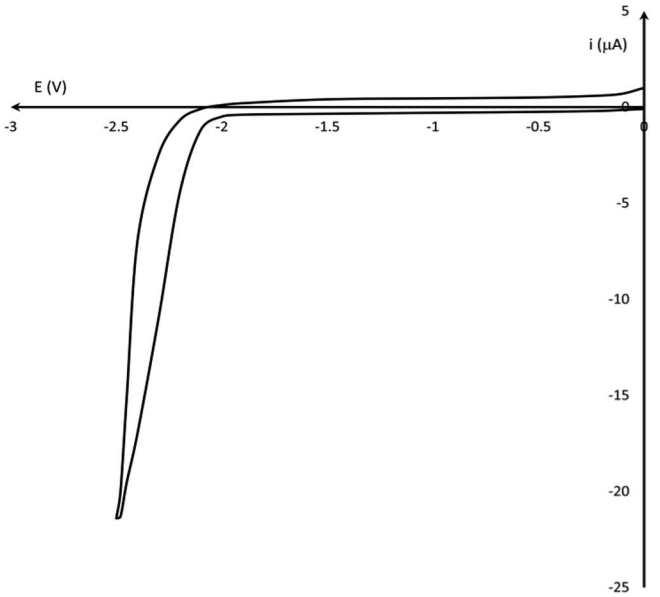

Figure 1. Blank curve of analytical solution study (DMF + n-Bu_4NClO_4) (0.1 M).

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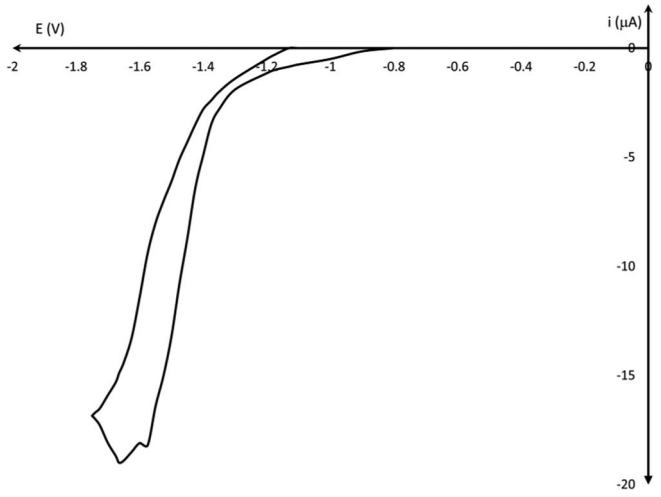


Figure 2. Voltammogram of the tritosylate of diethanolamine **2** (10^{-3} M) in DMF-Bu_4NClO_4 (0.1 M). Stationary mercury electrode. Reference electrode: Ag/AgI/I^- (0.1 M). $v = 10$ mV.s^{-1}.

determined to be ca. 0.5 for all the compounds studied, indicating a diffusion controlled process.[21]

For the α-diketones **1A**, the first reduction peak is reversible even at low-scan rates. This peak corresponds to the formation of the anion radical A^-, which, at more negative potential, undergoes a second electron transfer to form the dianion $\mathbf{1A^{2-}}$ (Figures 3a and 4a).

The reversibility of the second reduction peak is observed only in the presence of activated alumina as a drying agent, which enables efficient limiting of the protonation reaction of the dianion $\mathbf{1A^{2-}}$ by proton impurities.

The quasi-reversible character of the second reduction peak of the α-diketones, **1A**, disappears completely upon addition of a solution of the tritosylate of diethanolamine **2**. However, the reduction current peak intensities of **1A**, remain practically unchanged (Figures 3b and 4b).

The observed changes in the voltammograms of substrates **1Aa-f** can be explained by the interaction in solution of the dianion $\mathbf{1A^{2-}}$ with the reactive tritosylate of diethanolamine **2**.

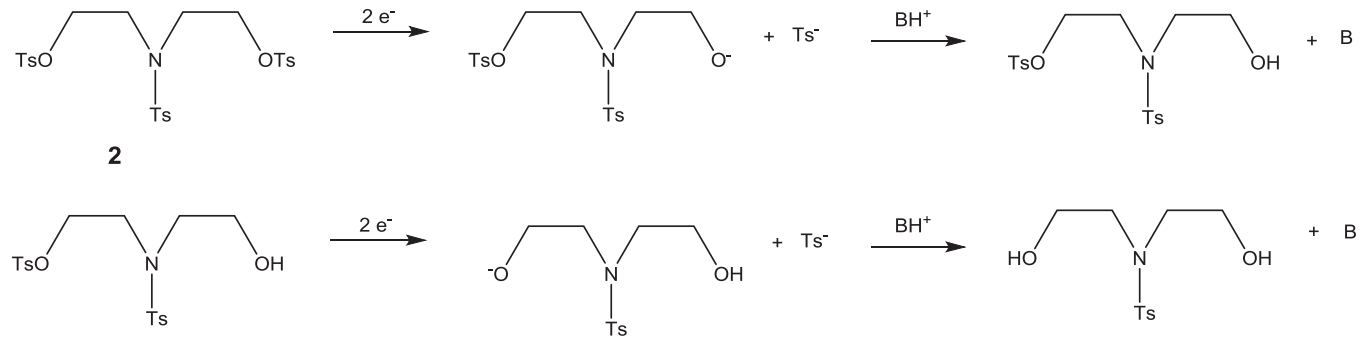
The α-diimines, **1B**, are reduced in a single bielectronic irreversible peak (Figure 5, curve a, and Table I) via an ECE mechanism and behave differently from the α-diketones **1A**. This finding can be interpreted in terms of the differences in the basicities of the corresponding radical anions. Indeed, the radical anion $\mathbf{B}^{\cdot-}$, formed by the reduction of the α-diimines, **1B,** was shown to be more basic than that obtained from the α-diketones **1A**.[22] Thereby, it can be quickly protonated from the residual impurities of the solvents,[23] giving a neutral radical, which is more electroactive than the starting substrate.

On the reverse scan, an oxidation peak appears at potentials near −0.2 V for which the current intensity is less than that of the reduction peak of the corresponding substrate. This peak disappears completely in the presence of phenol as a proton donor (Figure 5, curve c) and corresponds probably to the oxidation of the mono protonated form, $\mathbf{1BH^-}$, of the diimine **1B**.

The addition of the tritosylate of diethanolamine **2** to a solution containing $N^1,N,^2$1,2-tetraphenylethane−1,2-diimine, **1Ba**, decreases the current intensity of both the reduction and the oxidation peaks (Figure 6) as a results of the reaction between the reduced form of diimine **1Ba** and the tritosylate of diethanolamine **2**.

Therefore, the above analytical study indicates that the α-diketones **1A** and the α-diimines **1B** are reducible at lower potential than the tritosylate of diethanolamine **2**. The latter contains two good leaving groups (tosyl) and can be used as a bielectrophilic reagent, whereas compounds **1A** and **1B** constitute the binucleophilic source, toward the produced dianions, leading to the formation of the desired heterocyclic compounds.

Organic electrochemical synthesis of aza-crown compounds.— The reduction of the α-diketones **1A** and the α-diimines **1B** is realized in an aprotic solution of the substrate (**1A** or **1B**) and the tritosyle



Scheme 1. Mechanism of reduction of tritosylate of diethanolamine **2**.

Table I. Characteristics of the cyclic voltammetric curves of the used α-diketones, 1A, and α-diimines, 1B, (5×10^{-3} M) in DMF, TBAP (0.1 M). Reference Ag/AgI/I^- (0.1 M). $v = 50$ mV.s^{-1}.

Substrate		First peak		Second peak	
		Ep_1/V	Ip_1/μA	Ep_2/V	Ip_2/μA
Benzil	**1Aa**	−0.75	6.6	−1.50	5.6
Acenaphthylene-1,2-dione	**1Ab**	−0.30	5.0	−1.30	5.0
Phenanthrene-9,10-dione	**1Ac**	−0.20	4.0	−0.75	3.2
(1*S*,4*S*)-1,7,7-trimethylbicyclo[2.2.1]heptane-2,3-dione	**1Ad**	−0.35	6.5	−0.70	5.8
Naphthalene-1,2-dione	**1Ae**	−0.15	4.7	−0.45	4.5
Naphthalene-1,4-dione	**1Af**	−0.10	6.0	−1.00	5.4
N^1,N^2,1,2-tetraphenylethane-1,2-diimine	**1Ba**	−1.00	6.6	–	–
(1*S*,4*S*)-1,7,7-trimethyl-N^2,N^3-diphenylbicyclo[2.2.1]heptane-2,3-diimine	**1Bb**	−1.05	8.0	–	–
N^1,N^2-diphenylacenaphthylene-1,2-diimine	**1Bc**	−0.98	9.5	–	–

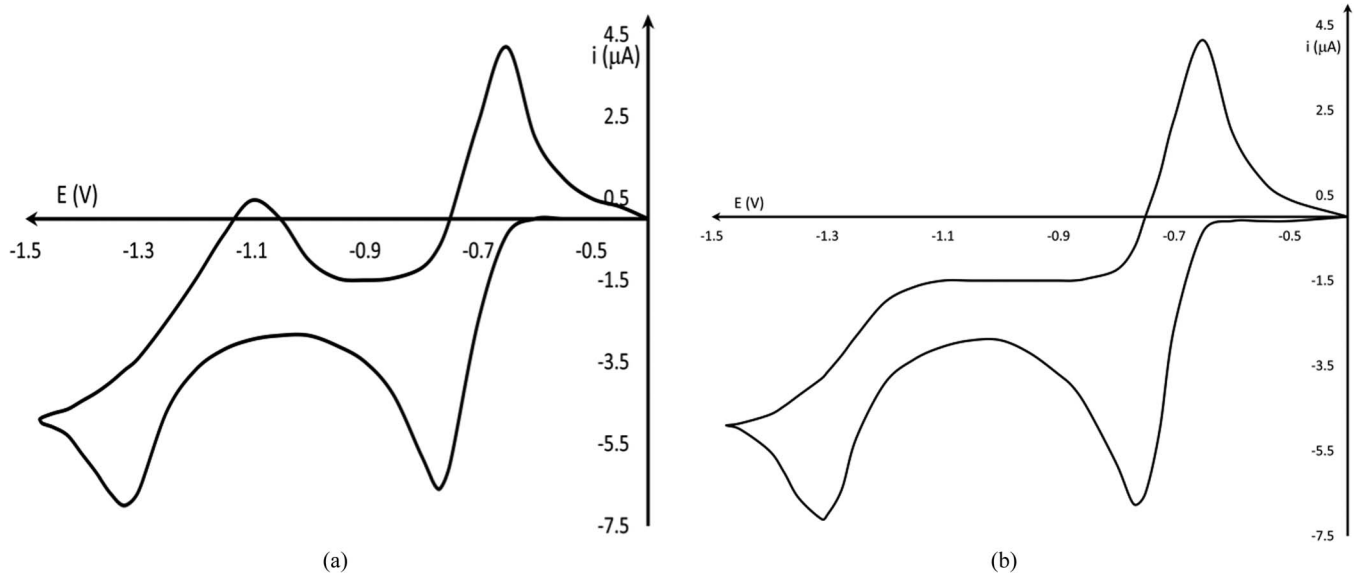


Figure 3. Cyclic voltammetric curves of: (a) Benzil **1Aa** (10^{-3} M). (b) Benzil **1Aa** after addition of the tritosylate of diethanolamine **2** (10^{-3} M) in 0.1 M DMF-Bu_4NClO_4. Stationary mercury electrode. Reference electrode: Ag/AgI/I^- (0.1 M). $\nu = 10$ mV.s^{-1}.

of diethanolamine **2**. The reaction is undertaken on a stirred mercury pool in an electrolysis cell, at potentials corresponding to the first reduction peak of the α-diketone **1A** or the α-diimine **1B** (Table I), to produce the corresponding binucleophilic species and to avoid their second reduction, (leading to non nucleophilic species), as well as the reduction of the tritosylate of diethanolamine **2** (-111.57 V). The choice of the working potential is very interesting in a such synthetic method, because it allows to select the desired species and to control their formation, which is not possible with ordinary organic synthetic reactions. This reduction reverses the reaction side by generation of binucleophilic groups (C-O^- and C-N^-) from the corresponding electrophiles (C=O and C=N).

The products shown in Tables II and III have different and variable structures, confirming the reaction of the tritosylate of diethanolamine **2** as a bielectrophile with the dianion as a binuclephile, to yield the corresponding heterocyclic aza-crown compounds **3** (except for compounds **1Aa** and **1Ba**) with a variable amount of the imposed charge, exceeding 2 F.mol^{-1}.

For substrates **1Ab-d** and **1Bb-c**, the reaction yields the corresponding diesters **3Ab-d** or diamides **3Bb-c** as aza-crown products. The formation of such compounds can be explained by the presence of the oxygen, as impurities in the solution introduced by the continuous nitrogen bubbling (less than 0.3%) disturb the reaction results. The bubbling of nitrogen is necessary to avoid the protonation of the anion radicals issue from the simultaneous reduction of the substrate.

In fact, the imposed potential of the working electrode allows the simultaneous formation of the radical anions $\mathbf{A}^{\cdot -}$ (or $\mathbf{B}^{\cdot -}$) and the superoxide ion O_2^-. Under these conditions, a radical duplication reaction of the two electrogenerated radical anions can give rise to an unstable cyclic peroxydic intermediate (Scheme 2), which evolves by cleavage of the central C-C bond allowing the bidentate dicarboxylate (Scheme 2) or diamidate (Scheme 3) diions. The reaction with the tritosylate of diethanolamine **2**, affords the corresponding aza-crown diesters or diamides, respectively.

Note that the formation of this type of peroxide intermediate through the reaction of substituted olefins with electron withdrawing

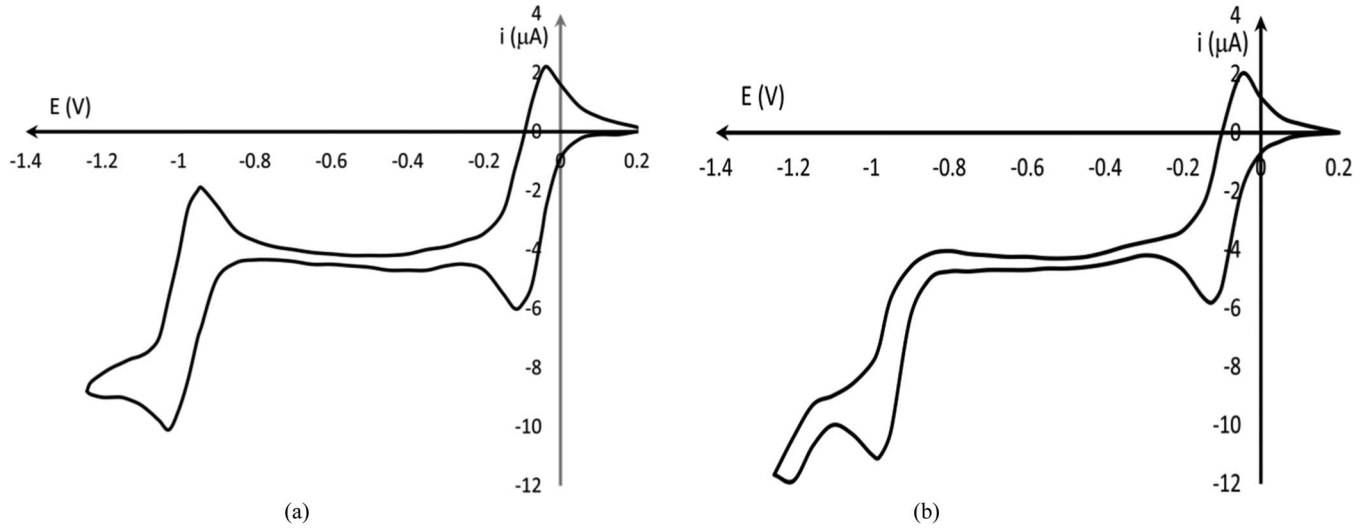


Figure 4. Cyclic voltammetric curves of: (a) Naphthalene-1,4-dione **1Af** (10^{-3} M). (b) Naphthalene-1,4-dione after addition of the tritosylate of diethanolamine **2** (10^{-3} M) in 0.1 M DMF-Bu_4NClO_4. Stationary mercury electrode. Reference electrode: Ag/AgI/I^- (0.1 M). $\nu = 10$ mV.s^{-1}.

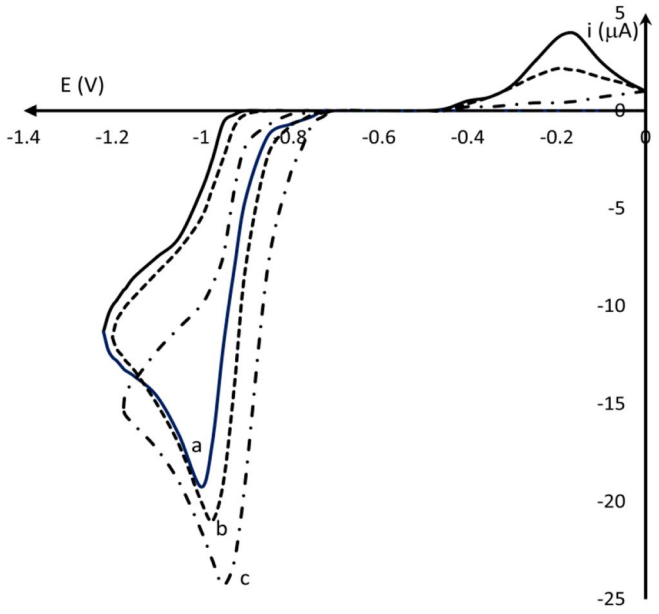


Figure 5. Cyclic voltammetric curves of: (a) N^1,N,^{2}1,2-tetraphenylethane-1,2-diimine **1Ba** (10^{-3} M). (b) N^1,N,^{2}1,2-tetraphenylethane-1,2-diimine **1Ba** (10^{-3} M) + 5 μL of phenol (5×10^{-2} M). (c): N^1,N,^{2}1,2-tetraphenylethane-1,2-diimine **1Ba** (10^{-3} M) + 15 μL of phenol (5×10^{-2} M) in 0.1 M DMF-Bu_4NClO_4. Stationary mercury electrode. Reference electrode: Ag/AgI/I^- (0.1 M). $\nu = 10$ mV.s^{-1}.

groups in the presence of the potassium superoxide was previously reported by Hoz.[24] In addition, we have previously show that the cyclic diesters are not formed upon addition of an oxygen trap to the medium.[25]

In order to explain how the concentration of O_2 is sufficient to transform 0.5 g of the starting material into the products, **3Aa-d** and **3Ba-c**, it was previously established that a redox catalytic process

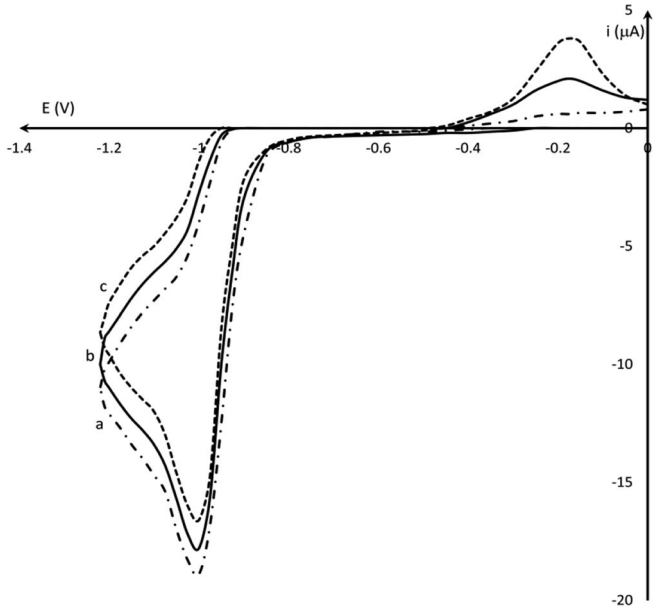


Figure 6. Cyclic voltammetric curves of: (a) N^1,N,^{2}1,2-tetraphenylethane-1,2-diimine **1Ba** (10^{-3} M). (b) N^1,N,^{2}1,2-tetraphenylethane-1,2-diimine **1Ba** (10^{-3} M) + tritosylate of diethanolamine **2** (10^{-3} M). (c) N^1,N,^{2}1,2-tetraphenylethane-1,2-diimine **1Ba** (10^{-3} M) + the tritosylate of diethanolamine **2** (2×10^{-3} M) in 0.1 M DMF-Bu_4NClO_4. Stationary mercury electrode. Reference electrode: Ag/AgI/I^- (0.1 M). $\nu = 10$ mV.s^{-1}.

occurred between the superoxide ion $O_2^{-\cdot}$ and the α-dikotones **1A**,[19] regenerating the molecular oxygen.

The continuous bubbling of nitrogen gas allows us to compensate for the oxygen consumed by the reaction, showing that the traces of oxygen result in products **3** in good yields.

For the reactant **1Aa**, the cleavage of the central C-C bond leads to two carboxylate species that react by nucleophilic attacks on both *O*-tosylate groups of the tritosylate of diethanolamine **2**, yielding the symmetric acyclic diester **3Aa** (Scheme 4). However, the obtained product from the split of the acyclic dimine **1Ba** is not a sufficiently strong nucleophile to react with substrate **2**, instead easily capturing a proton, to afford the corresponding amide **3Ba**. (Scheme 4)

The experimental results shown in Tables II and III indicate that only the naphthalene-1,2-dinone **1Ae** and the naphthalene-1,4-dinone **1Af** yield aza-crown ethers, **3Ae** and **3Af**, respectively (Scheme 5). Indeed, compounds **1Ae** and **1Af** having quinoidal structures are more easily reducible than molecular oxygen.[26] Therefore, at the potential of electrolysis, the superoxide ion is not electrogenerated and the reaction does not take place.

In an attempt to improve the yields of the cyclic products, we thought to use alkaline salts as an electrolytic support instead of tetrabutylammonium perchlorate in order to promote the formation of macroheterocycles by complexation of the alkaline ion as reported in the literature.[27]

Therefore, the obtained voltammogram represented in Figure 7b shows, for example, that Benzil **1Aa** is reduced into the corresponding bielectronic product in the presence of lithium perchlorate as a supporting electrolyte. However, the preparative electrolysis in solutions containing the α-diketones, **1A**, and the tritosylate of diethanolamine **2** does not afford the expected product but instead gives the corresponding α-hydroxyketone (Scheme 6). This finding is probably observed due to the formation of the ion pair O^-, Li^+ with a significant covalent character,[28] inhibiting the nucleophilic properties of the oxyanion.

Conclusions

The electrochemical reduction of certain bifunctional α-diketones, **1A**, and α-diimines, **1B**, in the absence of a proton donor produces the corresponding dianions $\mathbf{1AO_2^{2-}}$ (or $\mathbf{1BO_2^{2-}}$) after the dimerization of the two anion radicals $\mathbf{1A^{-\cdot}}$ (or $\mathbf{1B^{-\cdot}}$) and $O_2^{-\cdot}$. The nucleophilicity of the dianions was explored during the synthesis of macrocyclic aza-crown compounds by performing electrolyses in the presence of a bielectrophile, the tritosylate of diethanolamine **2**. The choice of the tritosylate of diethanolamine **2** as the bielectrophilic reagent is based on its unreactivity at the reduction potential of the α-diketones, and the α-diimines, enabling the nucleophilic substitution. Certain α-diketones, such as **1Ab**, **1Ac** and the **1Ad**, yield the corresponding cyclic diesters through a mechanism of formation involving the reduced form of the dissolved oxygen. The same phenomenon was observed with the α-diimine analogs, giving the corresponding macrocyclic aza-crown diamide. However, the electrochemical reduction of substrates **1Ae** and **1Af** is easier than the reduction of oxygen and yields the corresponding aza-crown ethers.

Experimental.—Melting points were determined with an Electrothermal 9100 apparatus. ^{1}H and ^{13}C NMR spectra were recorded using a Bruker Advance 300 MHz spectrometer in $CDCl_3$ with tetramethylsilane as the internal standard. IR spectra were performed in chloroform using a Bruker Alpha ATR spectrometer. HRMS spectra were collected on an AH MS-50 spectrometer in electronic mode at an ionization potential of 70 eV. Anhydrous DMF (10 ppm, anhydroscan) was purchased from Labscan and dried over activated alumina. All chemicals were purchased from Sigma-Aldrich and were used without further purification.

Electrochemical.—Cyclic voltammetry measurements were performed using a PAR scanning potentiostat model 362. The cell was a three-electrode type with a mercury pool as working electrode (12 cm^3 surface), the counter electrode was a polished platinum wire,

Table II. Electrolysis of α-diketones, 1A, in the presence of the tritosylate of diethanolamine 2 in a solution of DMF-Bu_4NClO_4, (0.1 M). Working electrode: mercury pool (A = 12 cm^2). Reference electrode Ag/AgI/I^- (0.1 M).

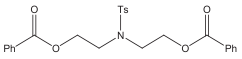
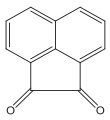
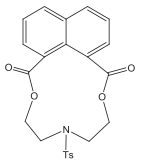
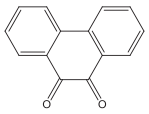
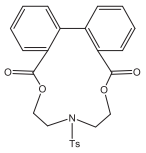
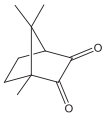
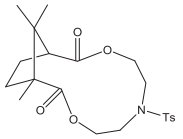
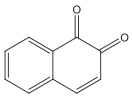
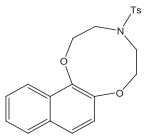
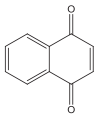
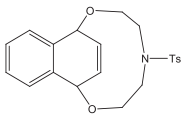
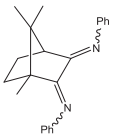
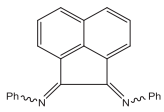
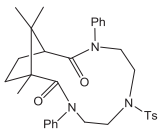
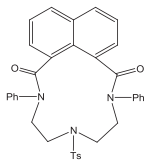
Substrate		Electrolysis potential (V)	Charge consumed (F.mol^{-1})	Product **3**		Yield (%)
	**1Aa**	−0.75	3.20		**3Aa**	60
	**1Ab**	−0.75	2.20		**3Ab**	95
	**1Ac**	−0.50	2.10		**3Ac**	48
	**1Ad**	−0.60	2.40		**3Ad**	77
	**1Ae**	−0.40	2.00		**3Ae**	30
	**1Af**	−0.35	1.97		**3Af**	25

Table III. Electrolysis of α-diimines, 1B, in the presence of the tritosylate of diethanolamine 2 in a solution of DMF-Bu_4NClO_4, (0.1 M). Working electrode: mercury pool (A = 12 cm^2). Reference electrode Ag/AgI/I^- (0.1 M).

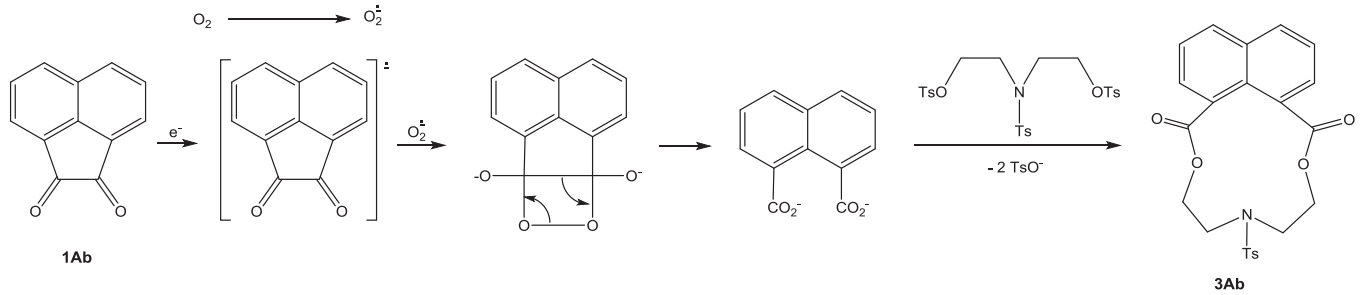
Substrate		Electrolysis potential (V)	Charge consumed (F.mol^{-1})	Product **3**		Y (%)
	**1Ba**	−0.95	3.50	Ph-NHCO-Ph	**3Ba**	100
	**1Bb**	−1.05	3.10		**3Bb**	35
	**1Bc**	−0.95	2.40		**3Bc**	20

1 mm diameter. The solvent-supporting was a solution of tetrabutylammonium perchlorate 0.1 mol.L^{-1} in DMF. The reference electrode, consisting of the system Ag/AgI/I^- (0.1 M), was maintained near the mercury surface.

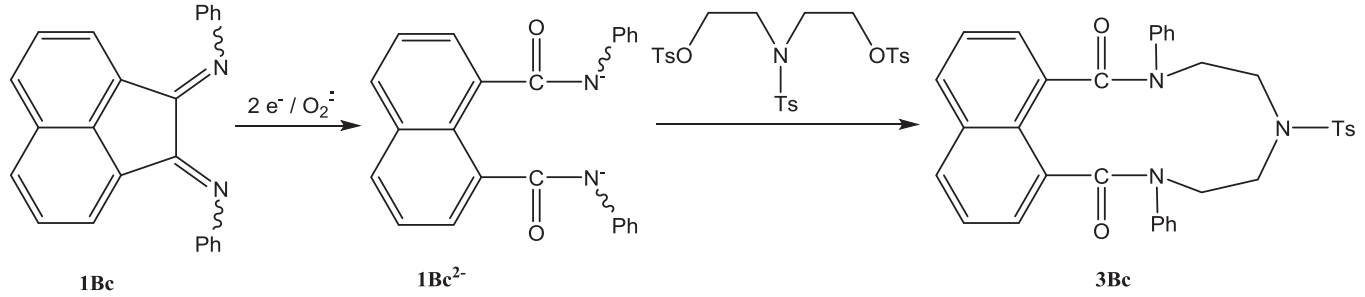
Preparative electrolyses were carried out at room temperature (25°C) in a conventional three compartment U-cell with a central compartment, between the analyte and the catholyte. Mercury was used as a cathode and platinum as an anode. The solvent-supporting was a solution of tetrabutylammonium perchlorate 0.1 mol.L^{-1} in DMF. The current generator (Tacussel model PJT 35-2) was coupled with an integrator (Tacussel model IG5) for coulometric measurements.

Electroorganic synthesis of aza-crown esters 3A and diamides 3B.—In a typical preparative electrolysis, the three compartments of the electrochemical cell were filled with a solution of tetrabutylammonium perchlorate (0.1 M) in DMF. In the cathodic compartment 0.4 to 0.5 g of the substrate were added and the electrolysis started by fixing the working corresponding potential for each substrate after degassing the solution. The solution was purged continuously with nitrogen gas and magnetically stirred.

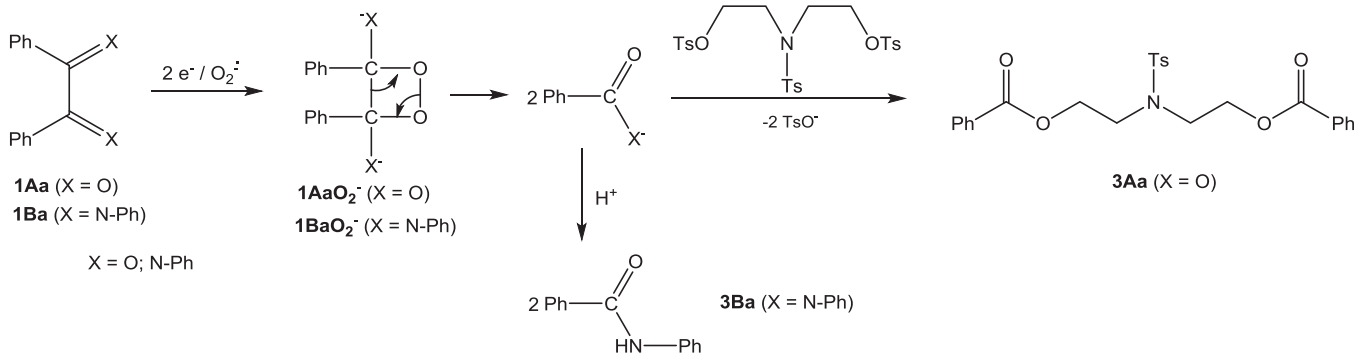
When the value of the current reached 0.1% of its initial value, the electrolysis was stopped. The catholyte was filled with an aqueous solution of sodium hydrogenocarbonate $NaHCO_3$ to a low basic pH



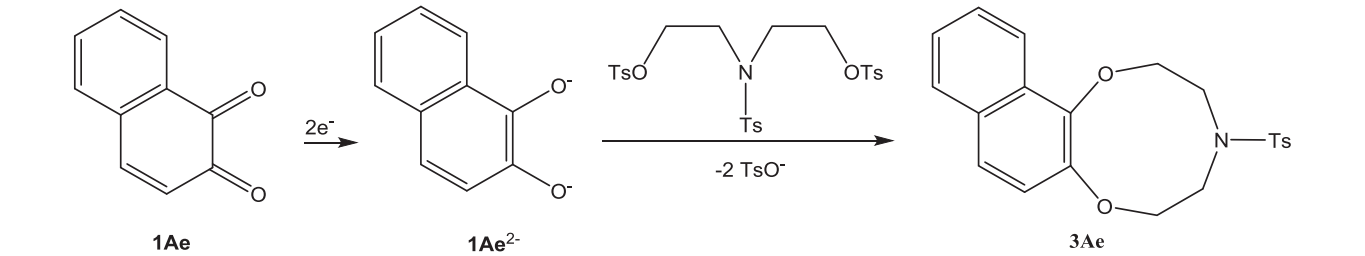
Scheme 2. Mechanism of formation of aza-crown diesters **3Ab**.



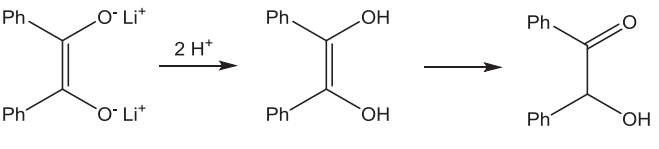
Scheme 3. Mechanism of formation of the diamide aza-crown diamide **3Bc**.



Scheme 4. Mechanism of cleavage of the C-C bond of the α-diketone **1Aa,** and the α-diimine **1Ba,** followed by the formation of the amide **3Aa** and the amide **3Ba**.



Scheme 5. Electrochemical reduction of substrate **1Ae** and the formation of aza-crown ether **3Ae**.



Scheme 6. The ion pair O^-, Li^+ evolution.

medium. The solution was extracted three times with diethyl ether, washed with distilled water, and dried on $MgSO_4$. The crude product obtained after evaporation of the solvent was purified by chromatography on a silica gel 60 column, using petroleum ether/ethyl acetate (70/30) as eluent. All products were characterized by ^1H and ^{13}C NMR spectroscopy, IR spectroscopy, EI mass spectrometry and elemental analysis.

2,2'-(tosylazanediyl)bis(ethane-2,1-diyl) dibenzoate ***3Aa***.—Mp (°C) = 71°C; IR $\nu_{C=O}$ = 1719 cm^{-1}; ^1H NMR ($CDCl_3$), δ (ppm): 2.34 (s., 3H, CH_3), 3.66 (t., 4H, $2CH_2$-N), 4.51 (t., 4H, $2CH_2$-O), 7.10-7.90 (m., 14H, CH_{ar}); ^{13}C ($CDCl_3$), δ (ppm): 21.4 (1C, CH_3-), 47.5 (2C, $2CH_2$-N), 62.8 (2C, $2CH_2$-O), 127.0, 128.0, 129.4, 129.5, 129.7, 133.1, 136.2, & 143.6 (18C, C_{ar}), 166.1 (2C, CO); m/z:

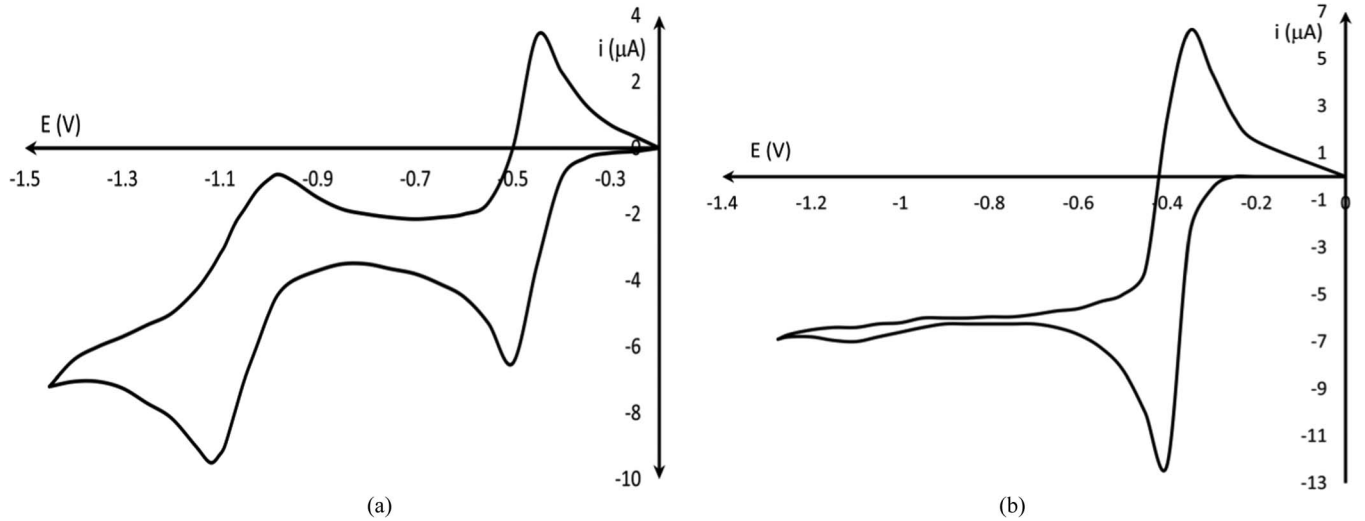


Figure 7. Cyclic voltammetry on a stationary mercury electrode; Reference electrode: Ag/AgI/I^- (0.1 M); $\nu = 10$ mV.s^{-1} of: (a) Benzil **1Aa** (10^{-3} M) in 0.1 M DMF-Bu_4NClO_4; (b) Benzil **1Aa** (10^{-3} M) in 0.1 M DMF-$LiClO_4$.

$[M+H]^+ = 468.2$ (55%), $[M+Na]^+ = 490.2$, $[M+K]^+ = 506.0$, 364.3 (100%), 149.0 (52.5%), 105 (15%); HRMS: Calcd. 467.14026, Found: 467.14011; Anal. Calcd. for $C_{25}H_{25}NO_6S$: C 64.22%, H 5.39%, N 3.00%, Found: C 64.08%, H 5.33%, N 2.93%.

5-tosyl-4,5,6,7-tetrahydro-1H-naphtho[1,8-ij][1,7,4]dioxaazacyclododecine-1,9(3H)-dione ***3Ab***.—Mp (°C) = 191°C; IR $\nu_{C=O} = 1724$ cm^{-1}; ^1H NMR ($CDCl_3$), δ (ppm): 2.41 (s., 3H), 3.66 (t., 4H, $2CH_2$-N), 4.57 (t., 4H, $2CH_2$-O), 7.28-8.03 (m., 10H, CH_{ar}); ^{13}C ($CDCl_3$), δ (ppm): 21.5 (1C, CH_3-), 49.6 (2C, $2CH_2$-N), 65.3 (2C, CH_2-O), 125.2, 127.4, 127.5, 129.6, 129.8, 132.6, 134.2, 135.1, & 143.9 (16C, $16C_{ar}$), 170.0 (1C, C = O); m/z: $[M+H]^+ = 440.0$ (100%), $[M+K]^+ = 478.0$ (55%), 346.0 (20%), 239.7 (15%), 141.0 (15%), 105.0 (5%), 441.0 (20%), 442.0 (10%); HRMS: Calcd. 439.10896, Found: 439.10881; Anal. Calcd. for $C_{23}H_{21}NO_6S$: C 62.86%, H 4.81%, N 3.19%, Found: C 62.77%, H 4.74%, N 3.14%.

9-tosyl-8,9,10,11-tetrahydro-5H-dibenzo[i,k][1,7,4]dioxaazacyclotridecine-5,13(7H)-dione ***3Ac***.—IR $\nu_{C=O} = 1722$ cm^{-1}; ^1H NMR ($CDCl_3$), δ (ppm): 2.40 (s., 3H, CH_3-), 3.55 (t., 4H, $2CH_2$-N), 4.40 (t., 4H, $2CH_2$-O), 7.15-7.81 (m., $12H_{ar}$); ^{13}C ($CDCl_3$), δ (ppm): 21.5 (1C, $1CH_3$-), 48.6 (2C, $2CH_2$-N), 65.6 (2C, $2CH_2$-O), 127.2, 127.4, 128.8, 129.9, 130.5, 131.0, 135.8, 141.3 & 143.8 (18C, $18CH_{ar}$), 167.5 (2C, 2CO); m/z: $[M+H]^+ = 466.2$ (100%), $[M+K]^+ = 504.0$, $[M+H]^+ = 488.3$ (30%), $[M+H]^+ = 483.3$ (100%), HRMS: Calcd. 465.12461, Found: 465.12447; Anal. Calcd. for $C_{25}H_{23}NO_6S$: C 64.50%, H 4.98%, N 3.01%, Found: C 64.42%, H 4.89%, N 2.93%.

(1S,11S)-1,14,14-trimethyl-6-tosyl-3,9-dioxa-6-azabicyclo[9.2.1]tetradecane-2,10-dione ***3Ad***.—IR $\nu_{C=O} = 1728$ cm^{-1}; ^1H NMR ($CDCl_3$), δ (ppm): 0.96 (s., 6H, $2CH_3$), 1.21 (s., 3H, $1CH_3$), 2.42 (s., 3H, $1CH_3$), 1.70-1.95 & 2.88 (m., 4H, $2CH_2$), 2.14 (m., 1H, 1CH), 3.53 (t., 4H, $2CH_2$-N), 4.22 (t., 4H, $2CH_2$-O), 7.23-7.75 (m., 4H, $4CH_{ar}$); ^{13}C ($CDCl_3$), δ (ppm): 21.3 (1C, $1CH_3$), 22.15 (1C, $1CH_3$), 23.5 (2C, $2CH_3$), 25.4 (1C, $1CH_2$), 32.6 (1C, $1CH_2$), 45.7 (2C, $2CH_2$-N), 45.9 (1C, 1C), 51.3 (1C, C), 57.6 (1C, C), 60.3 & 60.9 (2C, $2CH_2$-O), 128.8, 130.0, 138.7 & 141.0 (6C, $6C_{ar}$), 173.8 & 174.8 (2C, 2CO); HRMS: Calcd. 423.17156, Found: 423.17161; Anal. Calcd. for $C_{21}H_{29}NO_6S$: C 59.55%, H 6.90%, N 3.31%, Found: C 59.51%, H 6.84%, N 3.28%.

4-tosyl-3,4,5,6-tetrahydro-2H-naphtho[2,1-b][1,4,7]dioxazonine ***3Ae***.—Mp (°C) = 148°C; IR $\nu_{C=C} = 1666$ cm^{-1}; ^1H NMR ($CDCl_3$), δ (ppm): 2.39 (s., 3H, CH_3-), 3.55 (t., 4H, $2CH_2$-N), 4.42 (t., 4H, $2CH_2$-O), 7.16-7.89 (m., 10H, 10 CH_{ar}); ^{13}C ($CDCl_3$), δ (ppm): 21.1 (1C, CH_3), 45.1 (2C, $2CH_2$-N), 69.5 (2C, $2CH_2$-O), 117.8, 122.2, 124.8, 126.2, 126.9, 128.3, 128.7, 128.8, 130.0, 132.1, 138.7, 141.0, 143.3 & 146.4 (16C, $10C_{ar}$); HRMS: Calcd. 383.11913, Found: 383.11881; Anal. Calcd. for $C_{21}H_{21}NO_4S$: C 65.78%, H 5.52%, N 3.65%, Found: C 65.69%, H 5.45%, N 3.47%.

5-tosyl-1,4,5,6,7,9-hexahydro-3H-1,9-ethenobenzo[i][1,7]dioxa[4]azacycloundecine ***3Af***.—Mp (°C) = 136°C; IR $\nu_{C=C} = 1498$ cm^{-1}; ^1H NMR ($CDCl_3$), δ (ppm): 2.35 (m., 3H, CH_3-), 3.48 (t., 4H, $2CH_2$-N), 3.58 (t., 4H, $2CH_2$-O), 5.35 & 6.12 (d.m., 2H, 2CH =), 7.29-7.89 (m., 8H, $8CH_{ar}$); ^{13}C ($CDCl_3$), δ (ppm): 21.1 (1C, CH_3), 47.7 (2C, $2CH_2$-N), 67.2 (2C, $2CH_2$-O), 75.3 (2C, 2CH-O), 126.6, 128.8, 130.0, 136.2, 138.7 & 141.0 (12C, $12C_{ar}$), 129.8 (2C, 2CH =); HRMS: Calcd. 383.11913, Found: 383.11902; Anal. Calcd. for $C_{21}H_{21}NO_4S$: C 65.78%, H 5.52%, N 3.65%, Found: C 65.68%, H 5.47%, N 3.58%.

N-phenylbenzamide ***3Ba***.—Mp (°C) = 163°C; IR $\nu_{C=C} = 1530$ cm^{-1}, $\nu_{C=O} = 1600$ cm^{-1}, $\nu_{N-H} = 3340$ cm^{-1}; ^1H NMR ($CDCl_3$), δ (ppm): 7.12-7.87 (m., 10H, $10CH_{ar}$), ^{13}C ($CDCl_3$), δ (ppm): 122.5, 124.9, 128.2, 128.6, 129.0, 131.7, 135.0 & 136.7 (12C, $12C_{ar}$), 167.6 (1C, 1CON); HRMS: Calcd. 197.08406, Found: 197.08384; Anal. Calcd. for $C_{13}H_{11}NO$: C 65.78%, H 5.52%, N 3.65%, Found: C 65.69%, H 5.47%, N 3.59%.

(1S,11S)-1,14,14-trimethyl-3,9-diphenyl-6-tosyl-3,6,9-triazabicyclo[9.2.1]tetradecane-2,10-dione ***3Bb***.—Mp (°C) = 42°C; IR $\nu_{C=O} = 1743$ cm^{-1}; ^1H NMR ($CDCl_3$), δ (ppm): 0.99 (s., 6H, $2CH_3$), 1.15 (s., 3H, CH_3-), 1.71 & 1.96 (d.m., 2H, $1CH_2$), 1.74 & 3.12 (d.m., 2H, $1CH_2$), 2.36 (s., 3H, CH_3-), 2.41 (t., 1H, CH), 3.54 (m., 4H, $2CH_2$-N), 3.65 & 3.73 (d.m., 4H, $2CH_2$-NCO), 7.18-7.90 (m., 14H, CH_{ar}); ^{13}C ($CDCl_3$), δ (ppm): 18.1 (1C, CH_3-), 21.6 (1C, CH_3-C_{ar}), 22.7 (2C, $2CH_3$), 23.0 (1C, $1CH_2$-), 33.1 (1C, $1CH_2$), 45.3 (2C, $2CH_2$-N), 46.6 and 47.9 (2C, $1CH_2$-NCO), 47.8 (1C, 1C), 51.9 (1C, 1C), 59.7 (1C, C), 126.9, 127.2, 128.2, 129.6, 129.7, 129.8, 129.9, 130.9, 134.4 (14C, $15HC_{ar}$), 135.7 (1C, $1C_{ar}$-S), 143.8 (1C, $1C_{ar}$-CH_3), 144.2 & 144.8 (2C, $2C_{ar}$-N), 177.5 & 181.3 (2C, 2CON); HRMS: Calcd. 573.26613, Found: 573.26605; Anal. Calcd. for $C_{33}H_{39}N_3O_4S$: C 69.08%, H 6.85%, N 7.32%, Found: C 68.99%, H 6.80%, N 7.27%.

2,8-diphenyl-5-tosyl-3,4,5,6,7,8-hexahydro-1H-naphtho[1,8-ij][1,4,7]triazacyclododecine-1,9(2H)-dione ***3Bc***.—Mp (°C) = 115°C; IR $\nu_{C=O}$ = 1709 cm^{-1}; ^{1}H NMR ($CDCl_3$), δ (ppm): 2.40 (s., 3H, $1CH_3$), 3.1 (t., 4H, $2CH_2$-N), 3.8 (t., 4H, $2CH_2$-O), 7.18-8.50 (m., 14H, $14H_{ar}$); ^{13}C ($CDCl_3$), δ (ppm): 21.5 (1C, $1CH_3$-), 42.0 (2C, $2CH_2$-N), 46.0 (2C, $2CH_2$-NTs), 122.6 (2C, $2HC_{ar}$), 126.3 (2C, $2HC_{ar}$), 127.9 (2C, $2HC_{ar}$), 128.5 (2C, $2HC_{ar}$), 128.6 (2C, $2HC_{ar}$), 130.0 (2C, $2HC_{ar}$), 131.5 (2C, $2C_{ar}$), 132.3 (2C, $2HC_{ar}$), 134.3 (1C, $1C_{ar}$), 135.5 (1C, $1C_{ar}$), 136.7 (1C, $1C_{ar}$-S), 143.6 (2C, 2N-C_{ar}), 143.9, (1C, $2C_{ar}$-CH_3), 164.3 (2C, 2CON); HRMS: Calcd. 589.20353, Found: 589.20348; Anal. Calcd. for $C_{35}H_{31}N_3O_4S$: C 71.29%, H 5.30%, N 7.13%, Found: C 71.18%, H 5.19%, N 7.08%.

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