CHAPTER 7

CYCLIC VOLTAMMETRIC INVESTIGATIONS OF 3-ARYL-4-BROMO SYDNONE AND ITS DERIVATIVES AT GLASSY CARBON ELECTRODE
Chapter 7 Cyclic voltammetric investigations of 3-aryl-4-bromo sydnones

7.1. Introduction

Mesoionic 3-aryl-4-bromo sydnone has been studied at glassy carbon electrode in non-aqueous media and its derivatives in aqueous media under different acidic conditions using cyclic voltammetric technique. Effect of cathodic peak potential ($E_{pc}$) and cathodic peak current ($i_{pc}$) has been discussed. The effect of sweep rate, concentration, pH, substituents and solvents have been evaluated. The overall electrode processes were shown to be diffusion controlled. The cationic and non-ionic surfactants were inhibited the reduction process. The effect of these surfactants on $E_{pc}$ and $i_{pc}$ has been discussed. The electrolytic products were characterized by controlled potential electrolysis.

7.2. Chemistry and Biological Relevance of Sydnones

Mesoionic compounds are dipolar five- (possibly six-) membered heterocyclic compounds in which both the negative and the positive charge are delocalized, for which a total covalent structure cannot be written, and which cannot be represented satisfactorily by any one polar structure. The formal positive charge is associated with ring atoms or an exocyclic nitrogen or chalcogen atom.

Mesoionic compounds can be considered as betaines representative are mesoionic compound sydnone as a 1,2,3-oxadiazole bearing an exocyclic oxygen atom at 5th position. These sydnone ring is represented by canonical forms only similar to betaine.

e.g. (CH$_3$)$_3$P$^+$-CH$_2$S(=O)$_2$O$, (Ph)$_3$P$^+$ CH$_2$CH$_2$O$^-$, (CH$_3$)$_3$N$^+$-CH$_2$C (=O)O$^-$
Betaine is a nutrient that plays an important role in the health of the cardiovascular system. Studies have suggested that betaine, along with other nutrients, helps to reduce potentially toxic levels of homocysteine (Hcy), a naturally occurring amino acid that can be harmful to blood vessels thereby contributing to the development of heart disease, stroke, and peripheral vascular disease (reduced blood flow to the legs and feet). Antimelanoma activity has been reported for thiadiazolium mesoionics. Sydnones undergo a variety of reactions including electrophilic aromatic substitution at the 4th position, 1,3-dipolar cycloaddition (e.g. with alkenes and alkynes) and acid induced ring cleavage to generate hydrazines. This synthetic process is valuable for some hydrazines not easily prepared by other reactions. Hydrolysis of sydnone derivatives is effectively employed to synthesise other heterocyclic compounds. Reactions of sydnone with alkenes yield pyrazoles, utilized to synthesize polymer. Double 1,3-dipolar cycloaddition between sydnones and bismalimide generates polyimides. Photolysis of sydnones gives tetrazine. Sydnones possess physiological activity of different types depending on substituents in heterocyclic ring. Sydnones find their use as anti inflammatory, antimicrobial, anticancer and analgesic agents. N-methyl sydnones, which is found to have high dielectric constant, has been used as a solvent for lithium battery electrolyte.

7.3. Review of Electrochemistry of Sydnones

The electrochemical reduction mechanism of five derivatives of 4-cyano-3-sydnones have been investigated at a hanging mercury drop electrode using cyclic, linear sweep and differential pulse voltammetric methods in B-R buffer. Studies on 4-cyano-3-substituted sydnone have also been reported using square wave voltammetry. The surface effects of GCE on the electroreduction of 4-cyano-3-(p-tolyl) sydnone have been reported. The glassy carbon is found to catalyze the electro reduction and it has been proposed to undergo one electron reductive dimerization mechanism at the mercury
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electrode\textsuperscript{23}. Reduction of 3-phenyl-4-nitrosydnone in acetonitrile has been reported using dc differential pulse polarography and CV\textsuperscript{24}. The polarographic behavior of 3-substituted 4-acetyl and 4-diazoacyl sydnones\textsuperscript{25}. The electrochemical reduction of some 3-aryl sydnones have been investigated at wax impregnated carbon paste and glassy carbon electrode using cyclic voltammetric method in Britton-Robinson buffer\textsuperscript{26}. The electrochemical reductions of some 3-aryl sydnones have been investigated at glassy carbon electrode cyclic voltammetric method in sulfuric acid media has also been reported\textsuperscript{27}. The above mentioned compounds have undergone two electron reduction and on the basis of these observations we have now extended this study to some 3-aryl-4-bromo sydnones. However, surprisingly we found that 3-aryl-4-bromo sydnones have undergone one electron reduction and not two as observed in the 3-aryl sydnones and 3-aryl-4-cyano sydnones. In the present work, we now report the experimental details and a probable mechanism for four electrons of some 3-aryl-4-bromo sydnones.

7.4. Experimental

Reagents and chemicals

All the compounds used in the preparations of 3-aryl-4-bromo sydnones and substituted sydnones are of very high purity. 3-aryl-4-bromo sydnones used in our study were prepared in the laboratory and purified by previously published results\textsuperscript{28}. The solvents used are acetonitrile, DMSO and DMF were of A.R grade. Britton Robinson buffer was used as a supporting electrolyte for variation of pH, which was prepared by mixing 0.04 M each of acetic acid, phosphoric acid and boric acid, sodium hydroxide and hydrochloric acid was used to get the required pH. Cetyl trimethyl ammonium Bromide (CTAB), and Triton X-100 were used as cationic, and nonionic surfactants respectively. All solutions were prepared by double distilled deionized water.
Effective electrode area

The effective electrode area was determined by chronoamperometry with a 1mM Potassium hexacyano ferrate solution (1e exchange) in 1M Potassium chloride at 25° C (D0=7.63). The area obtained for the glassy carbon electrode was 0.069cm².

Cyclic voltammetry

Blank Cyclic voltammograms were recorded in solutions of 50mM sulphuric acid and also in 40mM Britton-Robinson buffer. Separately, in different partially aqueous media prepared by mixing acetonitrile, DMF and DMSO with water.

All samples were purged well nitrogen for 10 minutes to remove any dissolved oxygen before voltammetric measurements were recorded. The solutions were blanketed with a stream of nitrogen and the mixture was thermostated.

7.5. Results and Discussion

Aqueous media

The cyclic voltammograms of 3-aryl-4-bromo sydnone and its derivatives at a concentration of 2mM in aqueous DMF medium using 50 mM H₂SO₄ as the supporting electrolyte, with a sweep rate of 50 mVs⁻¹ at glassy carbon electrode Fig. 7.1. It is found to undergo a one electron reductive dimerization.

From the differential pulse voltammogram recorded for the reduction of 3-aryl-4-bromo sydnones, the half peak with (ΔW₁/₂) is obtained (data is not shown) using the equation²⁹.

\[ ΔW_{1/2} = 90.4/n \quad (1) \]
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The number of electrons (n) involved in the reduction process is found to be one on the basis of the above results the following mechanism is proposed for the electrochemical reduction of 3-aryl-4-bromo sydnones.

From the theoretical method also we calculated the number of electrons by using Randles-Sevcek's equation

\[ i_p = 2.99 \times 10^5 n(\alpha n)^{1/2} A D_0^{1/2} v^{1/2} C_0^* \ldots \] (2)

Where, \( i_p \) is the peak current \( \mu A \), \( \alpha \) is the charge transfer coefficient. \( D_0 \) is the diffusion coefficient \( cm^2/s \), \( A \) is the surface area of the electrode \( cm^2 \), \( v \) is the scan rate \( mVs^{-1} \), \( C_0^* \) is the concentration in mM.

Here the value of \( n \) is equals to one. Further evidence was given by the spectral data in the next section.

Identification of product analysis

Controlled potential electrolysis was carried out using H-type cell by applying a potential of -630 mV vs. SCE. Products of the electrolysed species were isolated by bulk electrolysis at the glassy carbon electrode and the reduced product was characterized by NMR and mass spectral studies.

The formation of a stable protonated species is further evidenced by the spectral data.

Electron impact mass spectrum has two molecular ion peaks at m/z 271 and 273 (ratio 1:1) agrees with the molecular weight of the protonated species.
The possible mass fragmentation pattern is given below

\[
\begin{align*}
M^+, m/z : 271, M^{+2} m/z : 273 \\
\xrightarrow{-\text{HBr}} \quad m/z : 191 \\
\xrightarrow{-\text{N}^+} \quad m/z : 107
\end{align*}
\]

In mass spectrum we got peaks at m/z 541, 543 and 545 in the intensity ratio 1:2:1. It is as shown below. It indicates that the compound has undergone one electron reductive dimerization containing two bromine atoms.
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Reaction and Mechanism

The sydnone ring is represented by resonance hybrid of dipolar and tetrapolar structures.

\[
\begin{align*}
R-N- & \quad C-Br \\
\text{Mesoionic structure} & \\
R-N- & \quad C-Br
\end{align*}
\]

This protonated species must be stable due to delocalization and phototropic shifts.

Effect of pH

The pH was varied in the range of 1.0 to 5.0 using Britton-Robinson Buffer as the supporting electrolyte at 2mM concentration of 3-aryl-4-bromo sydnone at a scan rate of 50 mVs\(^{-1}\). The cathodic peak potential \(E_{pc}\) shift towards more negative potential from
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-547 mV at pH 1.0 to -943 mV at pH 5.0 Fig. 7.2. There was no reduction peak observed in the basic media.

Effect of concentration

The cyclic voltammetry showed successive enhancement of peak current on increasing acetyl sydnone concentration. The plot of current (obtained by measuring the peak height) versus the respective concentration of acetyl sydnone was found to be linear in the range 1mM to 5mM. The variation of peak current ($i_p$) with acetyl sydnone concentration in the linear concentration range Fig. 7.3. The concentration of 3-aryl-4-bromo sydnone was increased from 1mM to 5mM in 50 mM H$_2$SO$_4$ as a supporting electrolyte at a sweep rate of 50 mVs$^{-1}$. The cathodic peak current increases linearly with the concentration of sydnone and hence obeys Randles-Sevic equation, which implies that the process is diffusion controlled.

It was also observed that the peak potential shift towards more negative values from $-612$mV vs. SCE to $-661$mV vs. SCE (Table 7.1). This kind of shift in $E_{pc}$ in the cathodic direction with increasing concentration of the sydnone indicates that the products of sydnone molecules are adsorbed over the electrode surface. This kind of shift has been predicted theoretically and observed experimentally for other reactions.

Effect of scan rate

The effect of scan rate on the electro reduction of 3-aryl-4-bromo substituted sydnones 2mM was examined in different aqueous solvent DMF, DMSO and acetonitrile in 50mM H$_2$SO$_4$ was used as a supporting electrode. The scan rate was varied from 10 to 200 mVs$^{-1}$. In all the cases, the cathodic peak current was proportional to the square root of the scan rate. Under these conditions the current process was diffusion controlled. Fig. 7.4 shows the linear relationship between the square root of scan rate and cathodic peak currents of 3-aryl-4-bromo sydnone derivatives at glassy carbon.
electrode. The cathodic peak shifts towards more negative potential with increase in scan rate.

**Effect of solvents**

The reduction of 3-aryl-4-bromo sydnone 2mM was studied in three different aqueous organic solvents in 50mM H₂SO₄ as the supporting electrolyte with a sweep rate of 50 mVs⁻¹. The reduction potentials were found to be -697, -544 and -622 mV in DMF, acetonitrile and DMSO respectively (Table 7.2). The easier reduction was observed in the case of acetonitrile. It is reasonable to explain that many properties in solution are affected by interactions between the analyte and solvent molecules. These interactions may be non specific (polarity and polarizability effects) and specific (e.g. resulting from the hydrogen bonding between analyte and the solvent). The solvation process takes place in two steps. In the first, the complex through the hydrogen bonding is formed. These complexes are solvated by non-specific interactions in the second step. In all other cases the general trend is due to an increase in the dielectric constant, which has the highest value in DMSO.²⁶

**Effect of substituents**

Electron-withdrawing groups accelerate reduction whereas electron donating groups lowers reduction.³⁷ Accordingly, methyl and methoxy sydnone undergo reduction at -707 and -566 mV respectively (Table 7.3) represents the substituent effect on the peak parameters of sydnone derivative studied. Both methyl and methoxy groups stabilize the positive charge. The methyl group has positive inductive and hyper conjugative effect whereas the methoxy donates electrons by resonance, i.e., positive mesomeric effect and the dipole associated with it operates in the opposite direction, i.e., negative inductive effect. The hyper conjugation effect of the methyl group operates through the framework of the benzene ring.
The negative inductive effect of methoxy group substantially decreases with distance but its positive mesomeric effect is greatly felt by the aromatic ring as well as the heterocyclic ring in conjugation with it. Therefore, the methoxy group increases the electron density in the aromatic part even more than what the methyl does, which is observed in the peak potential. Therefore, it will be more difficult to reduce the methoxy-substituted sydnone as compared to the methyl-substituted one, as it is evident from the reduction potentials.

**Effect of surfactants**

Surfactants even in trace quantities can exert a strong effect on the electrode process. Adsorption of such substances at the electrode may inhibit the electrolytic process, bring about the irregularity in the voltammogram and cause shift in the wave to more negative potential. Surface active substances have the common tendency of accumulation at interfaces. The lack of affinity between the hydrophilic portion of the surfactant and water leads to a repulsion of these substances from the water phase as a consequence of reduction of the microscopic 3-aryl-4-bromo sydnone water interfaces. These particles thus accumulate at the surface of the electrode and thus decrease the current. Addition of surfactant results in the shift of \( E_{pc} \) towards more negative potential. This may be attributed to the direct adsorption of the surfactants at the glassy carbon electrode surface are replaced by the surfactant molecules. At higher concentration of surfactant there was no reduction observed (Table 7.4). Similar effect was observed for non-ionic surfactant.

**Non-aqueous media**

The cyclic voltammetry of 2mM 3-aryl-4-bromo sydnones were recorded in the potential range -350 to -1000 mVs\(^{-1}\) at glassy carbon electrode in 0.1 M tetra butyl ammonium iodide (TBAI) with DMF. It exhibits in the forward scan one reduction wave and in the backward scan one oxidation wave at 50mVs\(^{-1}\) as shown in Fig. 7.5. The reduction wave was increased with the sweep rate and oxidation wave in the backward
scan. The difference between the reduction and oxidation potentials is around 100 mVs⁻¹, which indicates that one electron change occurred during the reduction of 3-aryl-4-bromo sydnones in non-aqueous media. The current was linear when the concentration increases from 2mM to 12mM.

The aspect of the voltammogram is the same for all the scan rates 50, 100, 150, 200, 300, 400 and 500 mVs⁻¹ and concentrations. The voltammograms were recorded in a restricted potential range with a ten times better resolution for potential value readings at different scan rates. Analysis of the wave located ~-0.9 V according to the usual electrochemical tests, shows that it corresponds to a quasi-reversible mono electronic charge transfer.

The standard rate concentration $k_s$ of the charge transfer process was calculated using the Nicholson \(^41\) between the anodic and cathodic peak potentials separation $\Delta E_p$ and the function $\Psi$

$$\Psi = 28.8 k_s \sqrt{v} \ldots \quad (3)$$

One obtains $k_s \approx 2 \times 10^{-3}$ M indicating an intermediate charge transfer process \(^42\).

The peak current for all compounds increases with square root of the sweep rate $\sqrt{v}$. A plot of $i_p$ as a function of $v$ is $\sqrt{v}$ linear, characteristic for a diffusion controlled process Fig. 7.6.

7.6. Conclusion

3-aryl-4-bromo sydnones undergo one electron reductive dimerization. Cathodic peak current increases linearly with the square root of scan rate and also with the concentration of the electro-active species. This suggests that the overall electrode process is a diffusion controlled. The electro-donating group lowers reduction and electron-withdrawing group accelerate reduction. Inductive and mesomeric effects play a dominant role in the reduction process.
Table 7.1: Effect of variation of concentration of 3-aryl-4-bromo sydnone at glassy carbon electrode in 50mM sulphuric acid, scan rate 50 mVs⁻¹.

<table>
<thead>
<tr>
<th>Concentration/mM</th>
<th>E(pc),mV</th>
<th>icpc,µA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>-612</td>
<td>4.14</td>
</tr>
<tr>
<td>2.0</td>
<td>-627</td>
<td>7.6</td>
</tr>
<tr>
<td>3.0</td>
<td>-638</td>
<td>8.25</td>
</tr>
<tr>
<td>4.0</td>
<td>-647</td>
<td>9.66</td>
</tr>
<tr>
<td>5.0</td>
<td>-661</td>
<td>10.03</td>
</tr>
</tbody>
</table>

Table 7.2: Effect of different aqueous organic solvents and the scan rate scan rate on voltammetric parameters for reduction of 3-aryl-4-bromo sydnone (2mM) at glassy carbon electrode in 50mM sulphuric acid, scan rate 50 mVs⁻¹.

<table>
<thead>
<tr>
<th>Scan rate mVs⁻¹</th>
<th>Acetonitrile</th>
<th>DMF</th>
<th>DMSO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E(pc),mV</td>
<td>icpc,µA</td>
<td>E(pc),mV</td>
</tr>
<tr>
<td>10</td>
<td>-414</td>
<td>1.14</td>
<td>-561</td>
</tr>
<tr>
<td>20</td>
<td>-477</td>
<td>2.19</td>
<td>-579</td>
</tr>
<tr>
<td>100</td>
<td>-602</td>
<td>5.26</td>
<td>-760</td>
</tr>
<tr>
<td>200</td>
<td>-773</td>
<td>8.55</td>
<td>-852</td>
</tr>
</tbody>
</table>
Table 7.3: Influence of substituents on voltammetric parameters for reduction of 3-aryl-4-bromo sydnone and its derivatives (2mM) at glassy carbon electrode in 50mM sulphuric acid, scan rate 50 mVs⁻¹.

<table>
<thead>
<tr>
<th>Compound</th>
<th>E_{pc},mV</th>
<th>i_{pc},μA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x10⁻³M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>la</td>
<td>-627</td>
<td>7.6</td>
</tr>
<tr>
<td>lb</td>
<td>-623</td>
<td>9.13</td>
</tr>
<tr>
<td>lc</td>
<td>-644</td>
<td>5.04</td>
</tr>
</tbody>
</table>

Table 7.4: Effect of variation of surfactant concentration on voltammetric parameters for reduction of 3-aryl-4-bromo sydnone (2mM) at glassy carbon electrode in 50mM sulphuric acid, scan rate 50 mVs⁻¹.

<table>
<thead>
<tr>
<th>[Surfactant] 10⁻⁵M</th>
<th>CTAB</th>
<th>Triton X-100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E_{pc},mV</td>
<td>i_{pc},μA</td>
</tr>
<tr>
<td>1.0</td>
<td>-580</td>
<td>3.6</td>
</tr>
<tr>
<td>2.0</td>
<td>-630</td>
<td>3.77</td>
</tr>
<tr>
<td>3.0</td>
<td>-728</td>
<td>3.95</td>
</tr>
<tr>
<td>4.0</td>
<td>-732</td>
<td>4.03</td>
</tr>
<tr>
<td>5.0</td>
<td>-743</td>
<td>5.17</td>
</tr>
</tbody>
</table>
Fig. 7.1. Cyclic voltammogram of 2mM (a) Solid curve: 3 methoxy-4-bromo sydnone. Dashed curve: 3-aryl-4-bromo sydnone, Dotted curve: 3 methyl-4-bromo sydnone, in 50mM sulphuric acid, scan rate = 50 mV s\(^{-1}\) at glassy carbon electrode (aqueous media).
Fig. 7.2. Effect of pH on peak currents of 2mM of 3-aryl-4-bromo sydnone scan rate 50 mVs\(^{-1}\) at glassy carbon electrode, in 50mM sulphuric acid (aqueous media).

Fig. 7.3. Effect of concentration on peak currents of 3-aryl-4-bromo sydnone scan rate 50 mVs\(^{-1}\) at glassy carbon electrode in 50mM sulphuric acid (aqueous media).
Fig. 7.4. Effect of scan rate on peak currents of 2mM 3-aryl-4-bromo sydnone at glassy carbon electrode in 50mM sulphuric acid (aqueous media).
Fig. 7.5. Cyclic voltammogram of (2mM) of 3-aryl-4-bromo sydnone, scan rate 50mVs⁻¹ at glassy carbon electrode in 0.1 M TBAI (non-aqueous media).

Fig. 7.6. Effect of scan rate on peak currents of 2mM of 3-aryl-4-bromo sydnone at glassy carbon electrode in 0.1 M TBAI (non-aqueous media).
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