Asian Journal of Chemistry; Vol. 34, No. 8 (2022), 2061-2066

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2022.23768

Antibacterial Investigation and Structural Study on Few *ortho*-Mercapto-azo Compounds by Spectroscopic Techniques and DFT Calculation

MURSHIDA KARIM[1,*] and NIZAMUDDIN AHMED[2]

[1]Department of Chemistry, B.N. College, Dhubri-783324, India
[2]School of Physical Science, Sherubtse College, Kanglung, Bhutan

*Corresponding author: E-mail: karimmurshida786@gmail.com

Received: 7 February 2022; *Accepted*: 14 April 2022; *Published online*: 18 July 2022; AJC-20887

An efficient method has been applied for the synthesis of bivalent *ortho*-mercapto-azo compounds by using green reduction, condensation using ionic liquid and green debenzylation. These greener steps provide the benefits like higher yields, shorter reaction times and simple work-up. Density functional theory (DFT) calculation and XRD analysis proved the ionic nature of these compounds as 2-arylbenzo-1-thia-2,3-diazol-2-ium (BTD^+) bromide due to intramolecular cyclization between electrophilic sulfur atom and *ortho*-azo group. Some extent of LUMO orbital is present in electrophilic sulfur atom in BTD^+ bromides. These sulfenyl bromides were also found to be active against antibacterial strains.

Keywords: *ortho*-Mercapto-azo compounds, Sulfenyl bromides, DFT, Antibacterial activity, TBATB, Iron oxide-hydroxide.

INTRODUCTION

Sulfenyl halides are sulfur based electrophilic reagents that behave as a source of sulfenium cation carriers (R/Ar–S^+). These cation carriers have been considered to be unstable, unisolable and reactive as strong electrophilic reagents [1,2]. The nucleophilic substitution on the sulfenyl sulfur atom of sulfenyl halides was found to be 10^9-10^{10} times faster than that on the corresponding sp^3 carbon atom [3-5]. These halides have been used as reactive intermediate in organic synthesis in the formation of S–N, S–O, S–C and S–P bonds [6-14]. In 1954, Burawoy & Vellins [15] reported the synthesis of azobenzene-2-sulfenyl bromide, the simplest member of *ortho*-mercapto-azo compound in five steps. These sulfenyl bromides were found to be good bivalent electrophilic organosulfur compounds although the sulfenyl sulfur was stabilized by intramolecular cyclization with *ortho*-azo group (Fig. 1). Highly electronegative atoms like Cl or Br in *ortho*-mercapto-azo compounds make the S-atom sufficiently electron deficient by lowering LUMO energies and hence a strong azo-sulfur interaction is found in these sulfenyl chlorides or bromides [16].

Many chemists have reported the use of these sulfenyl halides and their derivatives for sulfenylation of electron-rich substrates [17,18], oxidation of amino acids [19], *ortho*-metallation [20], anitmicrobial agent [21], the selective modifying reagent of polypeptides and proteins [22], binding of glibenclamide to human serum albumin [23], *etc*. Due to several disadvantages in synthetic methods, including use of toxic reagents, prolonged reaction times and low yield, these *ortho*-mercapto-azo compounds lost their importance. This strong *ortho* azo-sulfur interaction provides a planar 2-arylbenzothiadiazolium (BTD^+) salt structure which imparting exceptional thermal stability, non-reactive solubility in aqueous medium and high melting crystalline solid nature. Still cyclic intramolcular sulfenium cation (BTD^+) of these sulfenyl bromides has been postulated as intermediate in reactions [24]. The gas phase quantum mechanical study shows that the singlet phenylsulfenium cation is more stable than the triplet phenylsulfenium cation [25]. To best of our knowledge, no DFT calculation has been previously reported in literature for these sulfenyl bromides for their structural investigation. In this article, the convenient, eco-friendly method for the synthesis of *ortho*-mercapto-azo compounds with high yield by avoiding hazardous chemicals and reusable catalysts is described. Moderate to high yield, simple workup, green reduction and debenzylation techniques especially cost efficiency are the key features (**Scheme-I**).

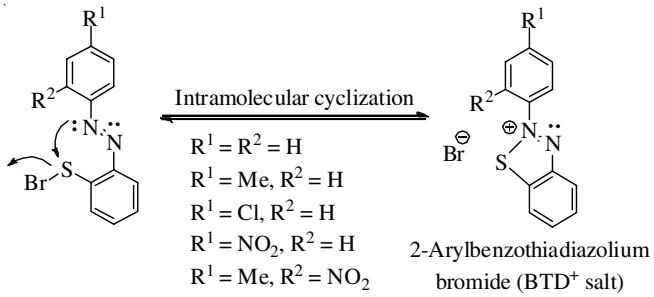


Fig. 1. Intramolecular cyclization of *ortho*-mercapto-azo compounds

EXPERIMENTAL

The reagents (nitrosoarenes, TBATB), catalyst (iron oxide-hydroxide), ionic liquid (di-*n*-butyl ammonium hydrogen sulphate) used in the synthesis of *ortho*-mercapto-azo compounds were prepared using Merck chemicals by using the procedure from literature [26-28]. Melting points were recorded on a Veego melting point apparatus and were uncorrected. IR spectra were recorded on Perkin-Elmer 73633 FTIR Spectrometer as KBr Pellet. ^{1}H and ^{13}C NMR spectra were recorded on Ultrasonic Brukar 300 MHz FT NMR spectrometer, using TMS as internal standard and $CDCl_3$ as solvent. Mass analyses were recorded by Water ZQ-400 (EI-MS) spectrometer. Compounds **I-II** were synthesized according to the procedure given by Burawoy [15]. All the compounds are characterized by ^{1}H and ^{13}C NMR .

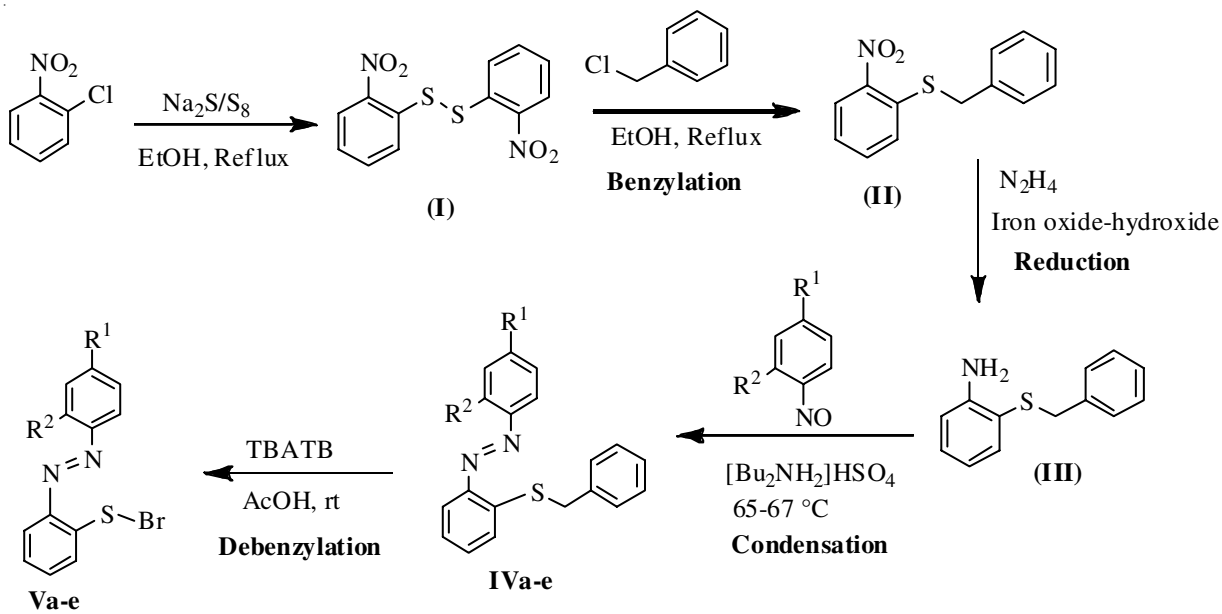
Green reduction of *ortho*-nitro group of 2-nitrophenyl benzyl sulphide: A solution of 2-nitrophenylbenzyl sulphide **(II)** (18 mmol) in isopropyl alcohol (150 mL) was added Fe-oxide-hydroxide catalyst (300 mg, 120 meshes). Then hydrazine hydrate (45 mmol) was added dropwise into the reaction mixture and stirred under reflux for 40-60 min. When the starting S-containing aromatic nitro compound has fully reacted (monitored by TLC), it was then cooled and was distilled off in rotary evaporator. The residue was recrystallized as white flakes from light petrol (40-60 ºC).

2-Aminophenyl benzyl sulphide (III): Yield: 95%, m.p.: 43-44 ºC (Lit. 44-45 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ: 3.915 (2H, s, CH_2), 4.268 (2H, s, NH_2), 6.640-6.728 (2H, m), 7.169-7.244 (7H, m), ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 39.48 (CH_2), 114.73, 117.26, 118.32, 126.87, 128.22 (2C), 128.73 (2C), 129.91, 136.38,138.14, 148.42. IR (KBr, ν_{max}, cm^{-1}): 3458, 3358 (s, NH_2 *str.*), 1310 (m, Ar. C-N *str.*) 748 (w, C-S *str.*). CHN analysis for $C_{13}H_{13}NS$: calcd. (found) %: C, 72.52 (72.60); H, 6.09 (6.10); N, 6.51 (6.30); *m/z*: 214 (M-1), 213 (M-2).

General method of condensation of nitrosoarenes with 2-(benzylthio)aniline: A mixture of 1 mmol of 2-aminophenyl benzyl sulphide (**III**) and nitrosoarenes was heated at 65-67 ºC for 45 min in presence of ionic liquid, $[Bu_2NH_2][HSO_4]$. Since this condensation reaction was exothermic in nature, the temperature quickly rose, but the temperature was not allowed to go beyond 65-67 ºC by occasional dipping of the flask in cold water bath. After being cooled, the reaction mixture was extracted with ether and the ether extract was evaporated to leave the crude product which was recrystallized from acetic acid.

2-Thiobenzylazobenzene [IVa]: Yield: 89%; m.p.: 132-133 ºC (Lit. 134-135 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 4.25 (2H, s, CH_2), 7.21-7.51 (11H, m), 7.70 (1H, d, J = 7.5 Hz), 7.90 (2H, d, J = 6.3 Hz), ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 36.92 (CH_2), 116.77, 123.13, 125.33, 126.42, 127.22, 128.48, 128.90, 128.96, 131.04, 131.18, 136.40, 139.36, 152.58; IR (KBr, ν_{max}, cm^{-1}): 1578 (N=N *str.*), 1300 (m, Ar C–N *str.*), 717 (w, C–S *str.*); UV-VIS spectra (λ_{max}, nm, ethanol): 415.2 (0.5612 due to azo group), 340 (1.8285 due to conjugated chromosphere); CHN analysis of $C_{19}H_{16}N_2S$: calcd. (found) %: C, 74.97 (75.10); H, 5.30 (5.10); N, 9.20 (9.00); *m/z*: 306 (M+2).

2-Thiobenzyl-(4′-methyl)azobenzene [IVb]: Yield: 85%; m.p.: 111-113 ºC (Lit. 115-116 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 2.43 (3H, s, CH_3), 4.25 (2H, s, CH_2), 7.20-7.45 (11H,



Scheme-I: Multi-step synthesis of *ortho*-mercapto-azo compounds

m), 7.68 (1H, d, *J* = 8.1 Hz), 7.86 (2H, d, *J* = 8.1 Hz); ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 21.53 (CH_3), 37.13 (CH_2), 116.80, 123.25 (2C), 125.50, 127.30, 128.58 (2C), 129.01 (2C), 129.73 (2C), 139.97; IR (KBr, ν_{max}, cm^{-1}): 1578 (N=N *str.*), 1300 (m, Ar C–N *str.*), 717 (w, C-S *str.*); UV-VIS spectra (λ_{max}, nm, ethanol): 430 (0.5223 due to azo group), 340 (1.9851 due to conjugated chromosphere); CHN analysis of $C_{20}H_{18}N_2S$: calcd. (found) %: C, 75.44 (75.20); H, 5.70 (6.00); N, 8.80 (9.00).

2-Thiobenzyl-(4′-chloro)azobenzene [IVc]: Yield; 87%; m.p.: 132-133 ºC (Lit. 134-135 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 4.25 (2H, s, CH_2), 7.21-7.73 (11H, m), 7.76 (3H, t, *J* = 8.4 Hz); ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 36.96 (CH_2), 117.70, 118.19, 125.44, 126.70, 127.31, 127.61, 128.61, 128.99, 130.62, 131.77,131.84, 135.53, 136.39, 140.09, 148.77, 149.32; IR (KBr, ν_{max}, cm^{-1}): 1578 (N=N *str.*), 1300 (m, Ar C–N *str.*), 717 (w, C–S *str.*). UV-VIS spectra (λ_{max}, nm, ethanol): 430 (0.5223 due to azo group), 340 (1.9851 due to conjugated chromosphere); CHN analysis of $C_{19}H_{15}N_2ClS$: calcd. (found) %: C, 67.35 (66.99); H, 4.46 (4.44); N, 8.27 (8.25).

2-Thiobenzyl-(4′-nitro)azobenzene [IVd]: Yield: 87% m.p.: 115-116 ºC (Lit. 116-117 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 4.24 (2H, s, CH_2), 7.20-7.45 (11H, m), 7.68 (1H, d, *J* = 7.8 Hz), 7.86 (2H, d, *J* = 8.1 Hz); ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 37.11 (CH_2), 116.79, 123.25 (2C), 125.49, 126.91, 127.30, 128.58 (2C), 129.01 (2C), 129.73 (2C), 130.98, 139.09; IR (KBr, ν_{max}, cm^{-1}): 1578 (N=N *str.*), 1548, 1369 (NO_2),1300 (m, Ar C–N *str.*), 717 (w, C–S *str.*); UV-VIS spectra (λ_{max}, nm, ethanol): 412 (0.5129 due to azo group), 329 (1.8241 due to conjugated chromosphere); CHN analysis of $C_{19}H_{15}N_3O_2S$: : calcd. (found) %: C, 65.31 (66.60); H, 4.33 (4.30); N, 12.03 (11.80).

2-Thiobenzyl-(2′-nitro-4′-methyl)azobenzene [IVe]: Yield: 85% m.p.: 126-133 ºC (Lit. 126-127 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 2.43 (3H, s, CH_3), 4.24 (2H, s, CH_2), 7.20-7.45 (10H, m), 7.68 (1H, d, *J* = 7.8 Hz), 7.86 (2H, d, *J* = 8.1 Hz); ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 21.54 (CH_3), 37.11 (CH_2), 116.79, 123.25 (2C), 125.49, 126.91,127.30, 128.58 (2C), 129.01 (2C), 129.73 (2C), 130.98, 139.09; IR (KBr, ν_{max}, cm^{-1}): 1578 (N=N *str.*), 1548, 1369 (NO_2),1300 (m, Ar C–N *str.*), 717 (w, C–S *str.*); UV-VIS spectra (λ_{max}, nm, ethanol): 412 (0.5129 due to azo group), 329 (1.8241 due to conjugated chromosphere); CHN analysis of $C_{20}H_{17}N_3O_2S$: calcd. (found) %: C, 66.10 (66.40); H, 4.71 (4.70); N, 11.56 (10.80).

General method of green debenzylation of 1-{2-(benzylthio) phenyl}-2-aryldiazene: Equimolar mixture of azo-compound (**IV**) and TBATB both in acetic acid were refluxed for 5 min at 60 ºC. It was then allowed to cool at room temperature and then was kept in the refrigerator for about 30 min to get yellow crystals of the sulfenyl bromide. It was filtered off, washed and was recrystallized from acetic acid.

Azobenzene-2-sulfenyl bromide [Va]: Yield: 94%; yellow crystals; m.p.: 220-222 ºC (Lit. 224-226 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 7.70 (3H, d, *J* =6.9 Hz), 7.91-8.03 (2H, m), 8.17 (2H, d, *J* = 6 Hz), 8.57 (2H, d *J* = 8.1 Hz), 9.604 (2H, d, *J* = 7.8 Hz); ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 122.54 (2C), 125.71, 128.80, 130.62 (2C), 130.87,133.15, 134.19, 140.23, 151.14; IR (KBr, ν_{max}, cm^{-1}): 2923 (C-H *str.*), 1624 (Ar. C=C *str.*), 1301 (Ar. C–N *str.*), 764 (C–S *str.*); UV-VIS spectra (λ_{max}, nm, ethanol): 336 (0.4514 due to azo group), 342 (0.5758 due to conjugated chromosphere); CHN analysis of $C_{12}H_9N_2BrS$: calcd. (found) %: C, 49.16 (49.00); H, 3.09 (3.10); N, 9.55 (9.40); *m/z*: 213 (M), 214 (M+1), 215 (M+2).

4′-Methyl-azobenzene-2-sulfenyl bromide [Vb]: Yield: 93%; yellow crystals; m.p.: 228-229 ºC (Lit. 231-232 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 2.50 (3H, s), 7.45 (2H, d, *J* = 8.1 Hz), 7.88-8.06 (4H, m), 8.52 (1H, d, *J* = 8.1 Hz), 9.56 (1H, d, *J* = 8.4 Hz); ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 21.55 (CH_3), 122.29 (2C), 125.55, 128.63, 130.81, 131.21 (2C), 134.00, 138.17, 144.62, 144.84, 151.11; IR (KBr, ν_{max}, cm^{-1}): 3009.1, 2930.6 (CH_3 *str.*), 1624 (Ar. C=C *str.*), 1301 (Ar. C–N *str.*), 764 (C–S *str.*); UV-VIS spectra (λ_{max}, nm, ethanol): 365 (0.5943 due to azo group); CHN analysis of $C_{13}H_{11}N_2BrS$: calcd. (found) %: C, 50.83 (50.50); H, 3.61 (3.10); N, 9.12 (9.00).

4′-Chloroazobenzene-2-sulfenyl bromide [Vc]: Yield: 90%; yellow crystals; m.p.: 224-225 ºC (Lit. 231-232 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 7.59-7.71 (4H, m), 7.96-8.15 (2H, m), 8.62 (1H, d, *J* = 8.1 Hz), 9.619 (1H, d, *J* = 8.4 Hz); ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 1226.16, 128.30 (2C), 129.04, 129.74, 131.07, 131.60, 133.60, 134.67, 137.28, 147.83, 150.98; IR (KBr, ν_{max}, cm^{-1}): 3009.1, 2930.6 (CH_3 *str.*), 1624 (Ar. C=C *str.*)1301 (Ar. C–N *str.*), 764 (C–S *str.*); UV-VIS spectra (λ_{max}, nm, ethanol): 365 (0.5943 due to azo group); CHN analysis of $C_{12}H_8N_2BrClS$: calcd. (found) %: C, 44.99 (50.02); H, 2.46 (2.40); N, 8.55 (8.50).

4′-Nitroazobenzene-2-sulfenyl bromide [Vd]: Yield: 87%; yellow crystals; m.p.: 223-224 ºC (Lit. 224-225 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 7.76-7.79 (2H, m), 7.96-7.99 (1H, m), 8.07-8.09 (2H, m), 8.53 (1H, d, *J* = 8.1 Hz), 9.60 (1H, d, *J* =8.7 Hz); ^{13}C NMR ($CDCl_3$, 300 MHz) δ ppm: 126.28, 127.15, 128.40, 1129.26, 131.09, 134.79, 134.90, 145.44; IR (KBr, ν_{max}, cm^{-1}): 3074.53 (C-H *str.*), 1597.06 (N=N *str.*), 1539.20, 1357.89 (NO_2 *str.*), 763.81 (C-S *str.*); UV-VIS spectra (λ_{max}, nm, ethanol): 329 (A 0.1570), 441 (A 0.0328); CHN analysis of $C_{12}H_8N_3O_2BrS$: calcd. (found) %: C, 44.33 (44.10); H, 2.86 (2.60); N, 11.93 (11.70).

4′-Methyl-2′-nitro-azobenzene-2-sulfenyl bromide [Ve]: Yield: 86%; yellow crystals; m.p.: 226-227 ºC (Lit. 228-229 ºC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ ppm: 2.66 (3H, s, CH_3), 7.76-7.79 (2H, m), 7.96-7.99 (1H, m), 8.07-8.09 (2H, m), 8.53 (1H, d, *J* = 8.1 Hz), 9.60 (1H, d, *J* =8.7 Hz); ^{13}C NMR ($CDCl_3$, 300 MHz,) δ ppm: 21.58 (C of CH_3), 126.28, 127.15, 128.40, 1129.26, 131.09, 134.79, 134.90, 145.44; IR (KBr), ν_{max}, cm^{-1}: 3074.53 (C-H *str.*), 1597.06 (N=N *str.*), 1539.20, 1357.89 (NO_2 *str.*), 763.81 (C-S *str.*); UV-VIS spectra (λ_{max}, nm, ethanol): 331 (0.1570), 448 (0.0328); CHN analysis of $C_{13}H_{10}N_3O_2BrS$: calcd. (found) %: C, 44.30 (44.10); H, 2.8 (2.60); N, 11.90 (11.70); *m/z*: 215 (M).

Antibacterial activity study: For determining the antibacterial activity, five bacterial strains; three pathogenic strains namely *Escherichia coli*, *Klebsiella, Staphylococcus aureus* and two non-pathogenic strains namely *Lactobacillus casei*, *Bacillus cereus* were selected randomly. *E. coli*, Gram-

positive bacteria cause diarrhea, *S. aureus*, Gram-negative bacteria cause food poisoning by producing toxins and *Klebsiella*, Gram-negative bacteria cause pneumonia. The synthesized compounds were tested for their antibacterial activity by using disk diffusion method by measuring the zone of inhibition (ZOI) on agar plates. The synthesized compounds were dissolved in distilled water (30 mg/mL) and further diluted at the required quantities of 30 µg/mL concentrations. Ceftriaxone as reference at concentration of 30 µg was tested for comparison of the antimicrobial activity.

Computational details: The geometrical minima of both benzothiadiazolium (BTD^+) salt and pure covalent structures (without intramolecular cyclization) of the *ortho*-mercapto-azo compounds were optimized with 6-311++G(d,p) basis set with Becke three parameter exchange and Lee, Yang and Parr correlation functional (B3LYP) [29,30] and was confirmed by frequency calculations. Thereafter, on the optimized geometry, single point (SP) energy calculations were performed at the same level of theory in ethanol and aqueous phases using PCM. To observe consistency in results we have repeated our calculations at MP2/6-311++G(d,p) level of theory. All calculations were performed in Gaussian 09. The difference in total electronic energy (ΔE) of BTD^+ salt and pure covalent structures (without cyclization) in gas, ethanol and aqueous phases at both levels of theory are presented in Table-1. The shapes of LUMO of compounds **Va** and **Vb** in BTD^+ salt and pure covalent are shown in Fig. 2.

Crystal structure of azobenzene-2-sulfenyl bromide: ORTEP diagram of azobenzene-2-sulfenyl bromide [**Va**] is shown in Fig. 3. The selected experimental and optimized structure parameters of thiadiazolium ring of azobenzene-2-sulfenyl bromide are listed in Table-2.

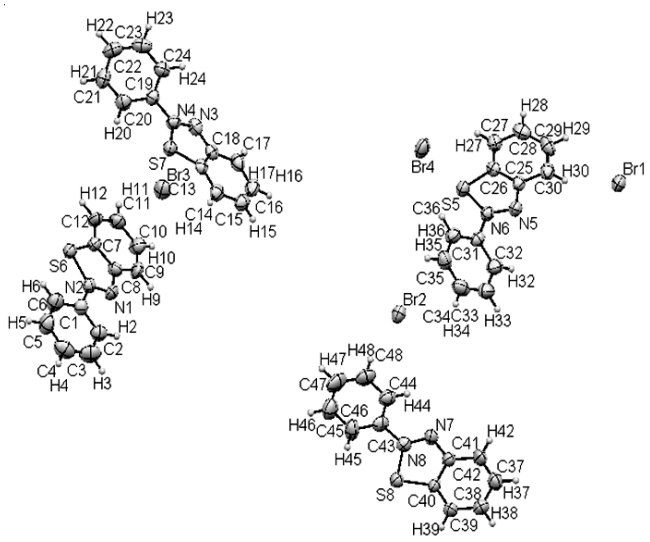


Fig. 3. ORTEP diagram of azobenzene-2-sulfenyl bromide

RESULTS AND DISCUSSION

Eco-friendly reduction of nitro group, condensation of nitrosoarenes with amine using ionic liquid and TBATB mediated green debenzylation are used as key chemical reactions towards their multi-step synthesis. The main drawback of Burawoy method was the low yield in the condensation between aromatic amines (**III**) and nitrosoarenes due to the formation of black resins. This condensation was studied by using ionic

TABLE-1
ΔE (kcal/mol) AT B3LYP/6-311++G (d,p) AND MP2/6-311++G(d,p) LEVELS OF THEORY IN GAS, ETHANOL AND AQUEOUS PHASES

Compd. No.	B3LYP/6-311++G(d,p)				MP2/6-311++G(d,p)			
	ΔE_{gas}	$\Delta E_{ethanol}$	$\Delta E_{aqueous}$	S–Br (Å)	ΔE_{gas}	$\Delta E_{ethanol}$	$\Delta E_{aqueous}$	S–Br (Å)
Va	–8.96	–12.47	–12.61	2.49 (2.26)*	–10.47	–14.02	–17.63	2.49 (2.26)*
Vb	–9.21	–12.63	–12.78	2.50 (2.26)*	–10.99	–14.76	–14.92	2.50 (2.26)*
Vc	–8.37	–11.74	–11.70	2.47 (2.26)*	–9.80	–13.09	–13.15	2.47 (2.26)*
Vd	–7.98	–10.74	–10.87	2.45 (2.26)*	–8.74	–11.43	–11.56	2.45 (2.26)*
Ve	–9.11	–11.49	–11.56	2.47 (2.26)*	–9.10	–11.51	–11.59	2.47 (2.26)*

()* implies S–Br bond distance in pure covalent structures

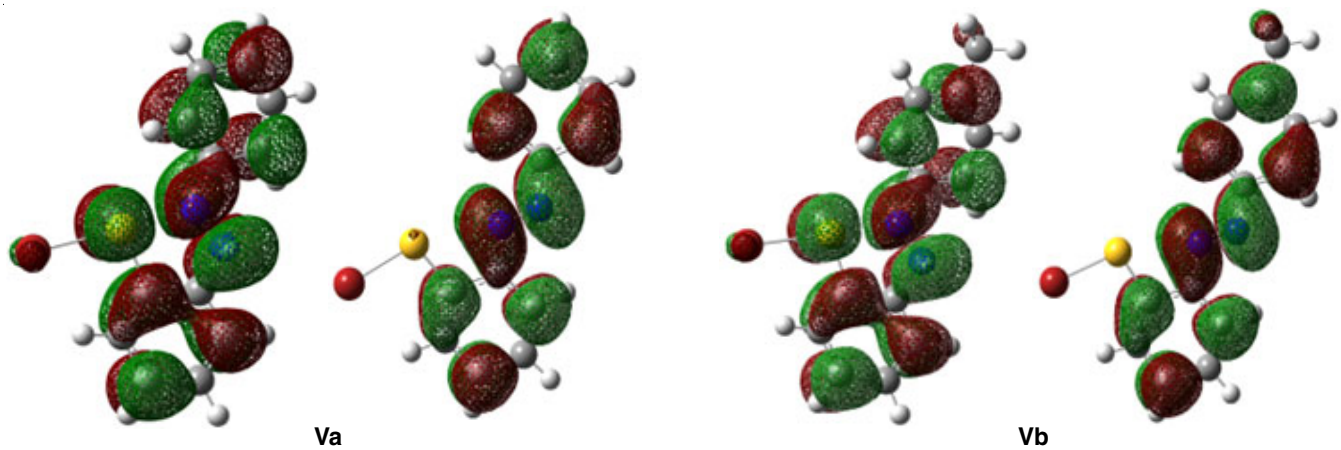


Fig. 2. Shapes of LUMO of azobenzene-2-sulfenyl compounds **Va** and **Vb** in BTD^+ salt and pure covalent structures

TABLE-3
ZOI PRODUCED BY TESTED SULFENYL COMPOUNDS AGAINST BACTERIAL STRAINS

Compd. No.	Antibacterial activity (ZOI, mm)				
	Escherichia coli	*Klebsiella*	*Staphylococcus aureus*	*Lactobacillus casei*	*Bacillus cereus*
Va	12	14	14	13	No activity
Vb	10	10	11	10	No activity
Vc	11	12	12	12	No activity
Vd	12	13	14	14	No activity
Ve	No activity	No activity	No activity	No activity	No activity
Ceftriaxone	21	22	18	16	No activity

TABLE-2
BOND LENGTHS, BOND ANGLES OF AZOBENZENE-2-SULFENYL BROMIDE FROM CRYSTALLOGRAPHIC DATA AND ITS COMPARISON WITH OPTIMIZED STRUCTURE IN DFT CALCULATION IN GROUND STATE

Parameters	Experimental data	Theoretical (DFT) data	
Bond length (Å)/ Bond angle (°)	Single crystal XRD	B3LYP/6-311++G(d,p)	MP2/6-311++G(d,p)
S(5)-N(6)	1.730 (4)	2.072	2.072
N(5)-N(6)	1.304 (5)	1.264	1.264
N(5)-C(25)	1.345 (7)	1.371	1.371
C(25)-C(26)	1.397 (7)	1.423	1.423
S(5)-C(26)	1.725 (5)	1.759	1.759
C(26)-S(5)-N(6)	87.2 (2)	80.9	80.9
N(5)-N(6)-S(5)	118.4 (4)	114.6	114.6
C(25)-C(26)-S(5)	109.3 (4)	115.0	115.0
N(6)-N(5)-C(25)	107.9 (5)	111.0	111.0
N(5)-C(25)-C(26)	117.1 (5)	118.2	118.2

liquid; di-*n*-butyl ammonium hydrogen sulphate $[Bu_2NH_2]$-$[HSO_4]$ instead of acetic acid at 65-67 ºC and found high yields. To test the efficiency of ionic liquid, the reaction conditions were examined but the yields are found high only at 65-67 ºC. Importantly no benzene ring bromination was observed during debenzylation of thioethers **Va-e** with excess equivalent of TBATB. From XRD data, it reveals that sulfenyl bromide exists as BTD^+ salt structure and the S–Br bond distance (1.740 Å) is not beyond their covalent bond distance. The C-S-N bond angle (87.2º) implies that the sulfur atom has used two pure *p* atomic orbitals instead of any hybrid orbitals in BTD^+ salt structure. The bond angles at the N-atoms of azo group (118.3º and 109º) revealed that both of these are sp^2 hybridized state. Mass spectral analysis shows *m/z* = 214 (M-Br) *i.e.* absence of Br-atom. This implies that in this sulfenyl bromide compound the *ortho*-azo-group is involved in a benzothiadiazolium bromide (BTD^+) salt structure.

The stability of BTD^+ salt and pure covalent structures of *ortho*-mercapto-azo compounds are observed in terms of total electronic energy. The negative energy difference value implies that the BTD^+ salt structure of all sulfenyl compounds more stable than the pure covalent structures. Table-1 showed that the S-Br bond distance is found to be longer in BTD^+ salt structure in comparison to pure covalent structure. It is concluded that some extent of LUMO orbital in BTD^+ salt structure and no LUMO orbital present in pure structure. Out of five sulfenyl bromides, four sulfenyl bromides (**Va-d**) were found to be active against four bacterial strains. Only *Bacillus cereus* was found to be inactive against any tested synthesized compounds. All the tested compounds were found to be much less effective than standard drug (ceftriaxone). The ZOI produced by all active sulfenyl compounds against five bacterial strains are presented in Table-3.

Conclusion

Efficient multi-step synthesis of azobenzene-2-sulfenyl bromides were described. Simple work-up, green reduction, green debenzylation reactions, high yields made this synthesis quite simple and convenient over the existing methods. The sulfur atom uses two pure atomic orbitals instead of hybrid orbitals in intramolecular cyclization for the formation of C–S and S–N bonds and can act as "sulfenium cation carriers.

ACKNOWLEDGEMENTS

The authors thank Dr. Pradip Kr. Bhattacharyya, Associate Prof., Arya Vidyapeeth College for allowing to do DFT calculation and Dr. Rita Mahanta, Formerly Professor, Cotton College & Dr. Naba Kumar Hazarika, Formerly Prof., Gauhati Medical College, Guwahati, India for helping to study bacterial activities.

ACKNOWLEDGEMENTS

The authors also thank Dr. S.K. Bhattacharjee, Formerly Prof., Gauhati University, Guwahati for valuable suggestions, Principal, B.N. College and HoD, Guahati University for providing laboratory facilities and spectroscopic data.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1. K. Kobayashi, S. Sato, E. Horn and N. Furukawa, *Tetrahedron Lett.*, **39**, 2593 (1998); https://doi.org/10.1016/S0040-4039(98)00277-9
2. A.J. Parker and N. Kharasch, *Chem. Rev.*, **59**, 583 (1959); https://doi.org/10.1021/cr50028a003
3. S. Oae, Organic Sulfur Chemistry: Structure and Mechanism, CRC Press (1991).
4. J.L. Kice and N.A. Favstritsky, *J. Am. Chem. Soc.*, **91**, 1751 (1969); https://doi.org/10.1021/ja01035a025
5. S.H. Smallcombe and M.C. Caserio, *J. Am. Chem. Soc.*, **93**, 5826 (1971); https://doi.org/10.1021/ja00751a041
6. L. Craine and M. Raban, *Chem. Rev.*, **89**, 689 (1989); https://doi.org/10.1021/cr00094a001

7. N. Kharasch, S.J. Potempa and H.L. Wehrmeister, *Chem. Rev.*, **39**, 269 (1946); https://doi.org/10.1021/cr60123a004
8. Q.T. Do, D. Elothmani and G. Le Guillanton, *Tetrahedron Lett.*, **39**, 4657 (1998); https://doi.org/10.1016/S0040-4039(98)00871-5
9. M. Iwasaki, T. Fujii, K. Nakajima and Y. Nishihara, *Angew. Chem. Int. Ed.*, **53**, 13880 (2014); https://doi.org/10.1002/anie.201408121
10. G.H. Schmid, A. Modro, F. Lenz, D.G. Garratt and K. Yates, *J. Org. Chem.*, **41**, 2331 (1976); https://doi.org/10.1021/jo00875a025
11. W.H. Mueller and P.E. Butler, *J. Am. Chem. Soc.*, **90**, 2075 (1968); https://doi.org/10.1021/ja01010a029
12. N. Kharasch, *J. Chem. Educ.*, **33**, 585 (1956); https://doi.org/10.1021/ed033p585
13. I.V.E. Koval, *Russ. Chem. Rev.*, **64**, 731 (1995); https://doi.org/10.1070/RC1995v064n08ABEH000172
14. J. Tan, F.S. Liang, Y.M. Wang, X. Cheng, Q. Liu and J. Yuan, *Org. Lett.*, **10**, 2485 (2008); https://doi.org/10.1021/ol800765s
15. A. Burawoy and C.E. Vellins, *J. Chem. Soc.*, 90 (1954); https://doi.org/10.1039/jr9540000090
16. K. Sanjib, P. Kabita, P. Barman, D. Hazarika and S.K. Bhattacharjee, *Acta Crystallogr. Sect. E Struct. Rep. Online*, **60**, 179 (2004); https://doi.org/10.1107/S1600536803029702
17. N. Ahmed, T. Bhattacharjee, P. Barman and S.K. Bhattacharjee, *Synth. Commun.*, **43**, 2663 (2013); https://doi.org/10.1080/00397911.2012.733476
18. A. Burawoy and A. Chaudhuri, *J. Chem. Soc.*, 653 (1956); https://doi.org/10.1039/jr9560000653
19. P. Barman, S.K. Bhattacharjee and T. Bhattacharjee, *Synth. Commun.*, **41**, 2870 (2011); https://doi.org/10.1080/00397911.2010.515361
20. T. Bhattacharjee, M. Kalita, D. Chakravarty, P. Barman and V.G. Puranik, *J. Coord. Chem.*, **67**, 1702 (2014); https://doi.org/10.1080/00958972.2014.922683
21. T. Bhattacharjee, P. Barman, T. Thakuria, R. Sarma, R.D. Dutta Kalita and B. Sarma, *Heteroatom Chem.*, **24**, 502 (2013); https://doi.org/10.1002/hc.21124
22. A. Fontana and E. Scoffone, *Methods Enzymol.*, **25**, 482 (1972); https://doi.org/10.1016/S0076-6879(72)25044-3
23. B. Hellman, J. Lernmark, J. Sehlin, M. Söderberg and I.-B. Täljedal, *Endocrinology*, **99**, 1398 (1976); https://doi.org/10.1210/endo-99-5-1398
24. G.K. Helmkamp, D.C. Owsley, W.M. Barnes and H.N. Cassey, *J. Am. Chem. Soc.*, **90**, 1635 (1968); https://doi.org/10.1021/ja01008a039
25. O. Bortolini, A. Guerrini, V. Lucchini, G. Modena and L. Pasquato, *Tetrahedron Lett.*, **40**, 6073 (1999); https://doi.org/10.1016/S0040-4039(99)01261-7
26. M.K. Chaudhuri, A.T. Khan, B.K. Patel, D. Dey, W. Kharmawophlang, T.R. Lakshmiprabha and G.C. Mandal, *Tetrahedron Lett.*, **39**, 8163 (1998); https://doi.org/10.1016/S0040-4039(98)01818-8
27. M. Benz, A.M. van der Kraan and R. Prins, *Appl. Catal. A.*, **172**, 149 (1998); https://doi.org/10.1016/S0926-860X(98)00111-2
28. P.J. Das and J. Das, *RSC Adv.*, **5**, 11745 (2015); https://doi.org/10.1039/C4RA12298D
29. A.D. Becke, *J. Chem. Phys.*, **98**, 5648 (1993); https://doi.org/10.1063/1.464913
30. C. Lee, W. Yang and R.G. Parr, *Phys. Rev.*, **37**, 785 (1988); https://doi.org/10.1103/PhysRevB.37.785