# Studies on Sulfenamides. XIV.[1] A New Method of Generating of 2,4-Dinitrobenzenesulfenylnitrene

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Received June 2, 1993

**2,4-Dinitrobenzenesulfenylnitrene (A) was produced by the oxidation of 2,4-dinitrobenzenesulfenamide (1) with *N*-bromosuccinimide, and trapped as *N*-sulfenylaziridines (3—7). In the presence of a large excess of olefins, the aziridines were produced in 6—57% yields. On the other, when a large excess of 1 was used, the aziridines were synthesized in 62—72% yields based on the olefins. *cis*-Stilbene gave a mixture of *cis*-1-(2,4-dinitrobenzenesulfenyl)-2,3-diphenylaziridine (8) and the *trans* isomer (4). On the other hand, *trans*-stilbene gave only 4. These results suggest the involvement of a biradical intermediate in these reactions.**

**Keywords** nitrene; aziridine; sulfenylaziridine; sulfenamide; *N*-bromosuccinimide; biradical

Though many reports have appeared on nitrene,[2] little is known about sulfenylnitrene. One of the reasons is that only a few methods are known for the generation of sulfenylnitrene.[3] However, sulfenylnitrene attracted our interest because of the chemical structure of the product. A 2-nitrobenzenesulfenyl or 2,4-dinitrobenzenesulfenyl group, which is frequently used for protection of amino groups, can be easily removed by hydrogen chloride or reducing reagents.[4] Therefore the reaction products of sulfenylnitrene could be important intermediate products in organic synthesis.

The usual method for generation of sulfenylnitrene is the oxidation of 2,4-dinitrobenzenesulfenamide (**1**) or $CF_3SNH_2$ with lead tetraacetate (LTA), which is a relatively strong oxidant. However, in order to avoid the oxidation of the compounds generated by the reaction of sulfenylnitrene and to extend the range of applicability of sulfenylnitrene, much milder oxidants are required.

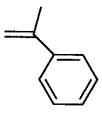
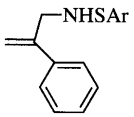
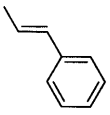
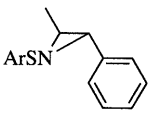
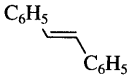
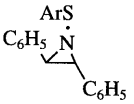
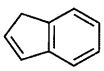
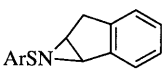
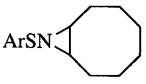
The oxidation of **1** with *N*-bromosuccinimide (NBS), which is relatively mild two-electron oxidant, was expected to give 2,4-dinitrobenzenesulfenylnitrene (**A**), as shown in Chart 1. The aim of this study was to test this assumption, *i.e.*, to examine the oxidation of **1** with NBS at room temperature, in the hope of obtaining the products in superior yields.[3]

## Results

In order to restrain **A** from attacking **1**, compound **1** was allowed to react with NBS under high dilution conditions.[4a] A solution of 1 mmol of compound **1** in dry dichloromethane (50 ml) was added dropwise to the dry dichloromethane solution (100 ml) containing an equivalent amount of NBS and an excess of olefin (method A). The results are summarized in Table I.

In the presence of a large excess of olefins, the aziridines were obtained in 6—57% yields by the reaction of **A**. Not only electron-rich olefins, but also cyclic olefins such as cyclopentene and cyclooctene reacted with **A**. Formation of aziridines by the reaction of **A** with electron-rich olefins

TABLE I. Results of the Reactions of 2,4-Dinitrobenzenesulfenamide with NBS in the Presence of Olefins

| Olefin | Product | Compd. No. | Yield (%) Method A[a] | Yield (%) Method B[b] |
|---|---|---|---|---|
|  |  | **2** | 61 | 66 |
|  |  | **3** | 37 | 62 |
|  |  | **4** | 57 | 64 |
|  |  | **5** | 54 | 62 |
|  |  | **6** | 10 | 72 |
|  |  | **7** | 6 | 69 |

*a*) The ratio of olefin *vs.* **1** was 5:1 and the yield was calculated based on **1**. *b*) The ratio of olefin *vs.* **1** was 1:5 and the yield was calculated based on the olefin.

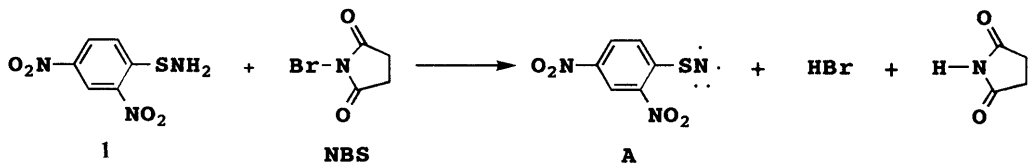



Chart 1

is known, but formation of **5**—**7** has not previously been reported.[3a,b,e,f]

α-Methylstyrene gives 1′-phenylvinyl-2,4-dinitrobenzenesulfenamide (**2**) (see Chart 3) as the main product instead of aziridines. This is the most significant difference in terms of products between 2,4-dinitrobenzenesulfenylnitrene generated with LTA and with NBS.[3a]

The results showed the reactivity of cyclic olefins with **A** to be very low, and so a large excess of **A** was necessary to give better yields of aziridines. Switching the ratio of olefin *vs.* **1** from 5:1 to 1:5 improved the yield of the aziridines to the 62—72% range (method B).

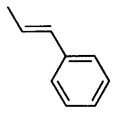
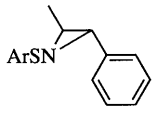
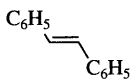
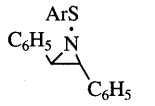
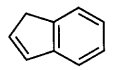
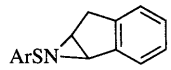
Some unreacted **1** was found in the reaction solutions of method A. Excess NBS seemed to be effective to increase the yields of **2**—**7**. However, electrophilic attack of NBS on sulfenamides was reported.[1] If **2**—**7** also consume NBS, the yields will be decreased. Protonation of the lone pair on the nitrogen of **2**—**7** may prevent the electrophilic attack of NBS upon **2**—**7**.

Two approaches are available for increasing the acidity of the reaction medium. One is to reduce the volume of the solvent of the reaction in order to increase the concentration of protons produced in the reaction. The other is to add a weak acid to the reaction solution, because strong acids will break the S–N bond of **2**—**7**.[4] The modified reaction conditions are described below, and the results with electron-rich olefins are summarized in Table II.

Compound **1** (5 mmol) was dissolved in dry dichloromethane (25 ml) and this solution was added dropwise to a dry dichloromethane solution (50 ml) containing 7.6 mmol of NBS, 5 mmol of succinimide and 25 mmol of olefin (method C). Method C was effective for preparation of **3** and **4**, but not for **2** or **5**—**7**. When method C was employed without succinimide, the yield of **3** was only 50%.

In order to elucidate the mechanism, the reaction of *cis*-stilbene (containing 5% *trans*-stilbene) was carried out and the products were examined by high-performance liquid chromatography (HPLC). The aziridines derived from *cis*-stilbene were **8** (*cis*) and **4** (*trans*) (**8**:**4**=76:24). On the other hand, *trans*-stilbene gave only **4** (see Chart 2).

TABLE II. Results of the Reaction of 2,4-Dinitrobenzenesulfenamide with NBS in the Presence of Olefins and Succinimide

| Olefin | Product | Compd. No. | Yield[a] (%) |
|---|---|---|---|
|  |  | **3** | 66 |
|  |  | **4** | 94 |
|  |  | **5** | 33 |

*a*) The ratio of olefin *vs.* **1** was 5:1 and the yield was calculated based on **1**.

## Discussion

Both singlet and triplet states are possible for nitrenes. The singlet state has two sets of lone-pair electrons on the nitrogen, and the triplet state has one lone-pair and two unpaired electrons of parallel spin. The spin state of a nitrene is commonly determined by stereospecificity of its addition to alkene according to Skell's scheme.[5] The results of the experiment using *cis*-stilbene are consistent with the reaction mechanism shown in Chart 2.

The oxidation of **1** with NBS produces singlet or triplet nitrene. When singlet nitrene is generated and reacts with *cis*-stilbene, only **8** (*cis*) will be produced. On the other hand, the triplet nitrene reacts with *cis*-stilbene to give a biradical intermediate **B**. Cyclization of **B** gives exactly the same product as in the case of singlet nitrene, *i.e.*, **8**. The rotation of the 1,2 C–C bond of **B** gives biradical intermediate **C**. Cyclization of **C** gives *trans*-aziridine. Conversion of **C** to **B** seems not to be permitted because *trans*-stilbene gave only **4**.

The product distribution suggests the presence of **B** and **C**, which were produced by triplet nitrene. However, the experimental results can not rule out the presence of singlet nitrene. Atkinson and Judkins also reported that singlet nitrene and triplet nitrene were in equilibrium with each other.[3f]

The mechanism of formation of **2** can also be explained on the basis of a biradical intermediate as shown in Chart 3.

Triplet nitrene, generated from the oxidation of **1** with NBS, attacks the double bond of α-methylstyrene. Addition of the N-atom of the nitrene to the β-position of α-methylstyrene is desirable as it produces a biradical (**D**), of which one of the unpaired electrons is located at the tertiary carbon. The unpaired electron located at the N-atom of **D** abstracts a hydrogen atom from the methyl group. The insertion of triplet nitrene into a C–H bond of the methyl substituent may give **2**, but this mechanism does not explain the fact that β-methylstyrene does not give the corresponding sulfenamides. Presumably, sulfenamide is formed not by direct insertion into the methyl group, but *via* a biradical intermediate. However, Atkinson reported that only 1-(2,4-dinitrobenzenesulfenyl)-2-methyl-2-phenylaziridine (**9**) was produced in the reaction of α-methylstyrene and **A**, which was generated by the oxidation of **1** with LTA. The assumption that oxidations of **1** with NBS and LTA produced mainly triplet and singlet nitrene **A**, respectively, is able to explain the difference of the products. The reaction of singlet **A** with α-methylstyrene gives **9** as a product. However, singlet **A** and triplet **A** are in equilibrium with each other as described above and biradical **D** also gives **9**, so the reaction solutions from the oxidation of **1** with NBS and with LTA contained both **2** and **9** in different ratios. Both Atkinson *et al.* and we failed to isolate the minor products of the reaction.

Method A gave a comparable yield to Atkinson's method using lead tetraacetate, in which strongly oxidizing and acidic conditions cannot be avoided. Method B will be more practical than method A for synthesis, because, in most cases, olefins are more expensive than **1** which is

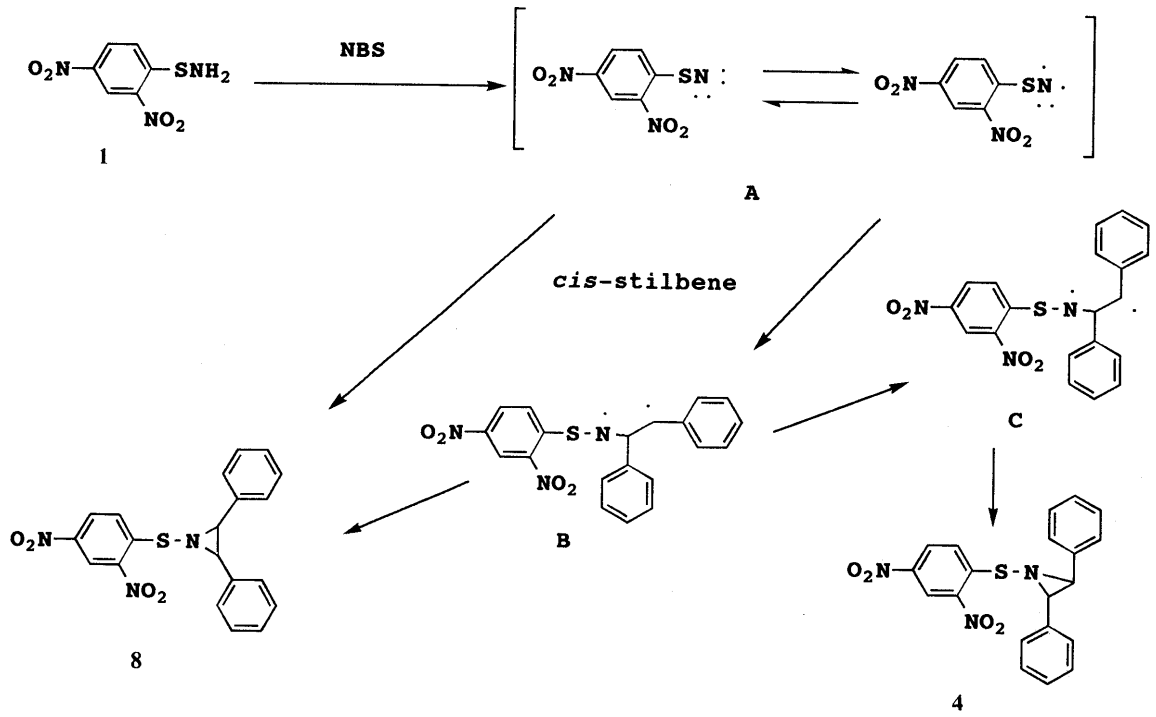



Chart 2

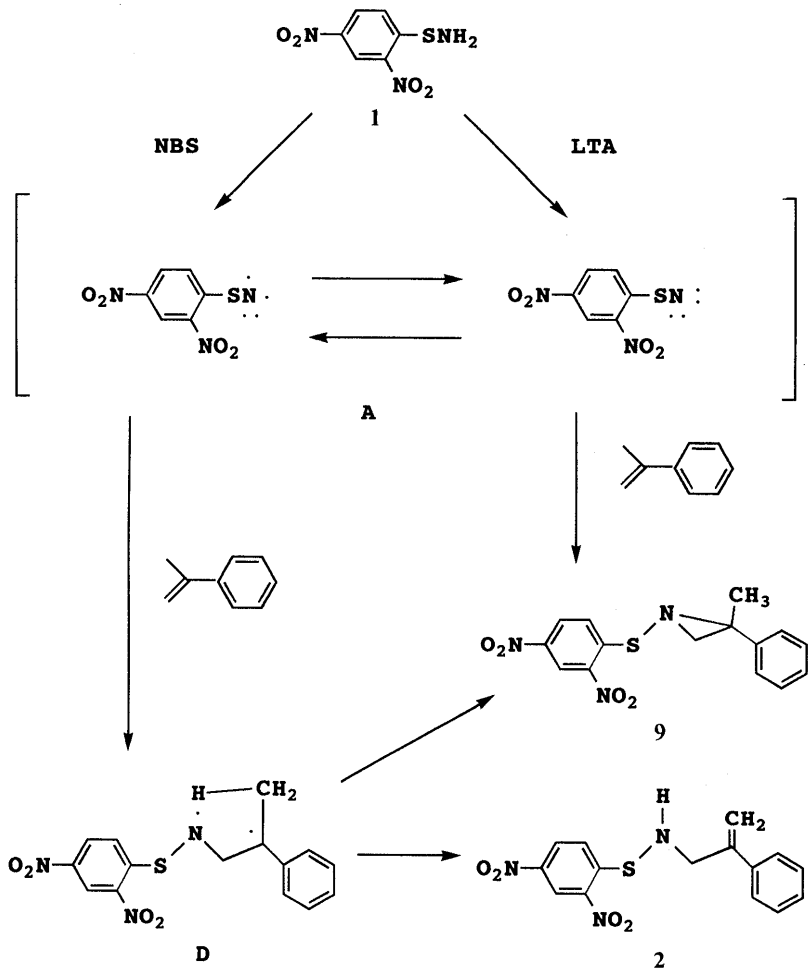



Chart 3

obtained from commercially available 2,4-dinitrophenylsulfenyl chloride and aqueous ammonia solution. Arenesulfenylnitrenes generated by thermal extrusion of bridging nitrogen from 1,4-dihydro-1,4-iminonaphthalenes gave better yields of aziridines, but the substrates are more difficult to produce than **1**.[3d] Though application of method C to *β*-methylstyrene or *trans*-stilbene gave good results, its application to indene did not. One reason is that epiminoindanes are more active compounds than **3**—**7**.[6]

## Experimental

**Materials** 2,4-Dinitrobenzenesulfenamide (**1**) was prepared from 2,4-dinitrobenzenesulfenyl chloride (Tokyo Kasei) and aqueous ammonia in acetonitrile.[3a] *cis*-Stilbene was prepared by the known method and purified on a silica gel column using benzene–hexane (1 : 1) as an eluant.[7] Other olefins were distilled before use, except *trans*-stilbene. Dichloromethane was distilled over calcium chloride and stored over molecular sieves.

**Apparatus** Infrared (IR) and nuclear magnetic resonance spectra (NMR) were obtained as described previously.[1] Mass spectra (MS) were obtained with a Hitachi M-2000. HPLC was carried out as described previously.[8] Melting points are not corrected.

**Typical Example of Isolation of Products from the Reaction Mixture** *trans*-1-(2,4-Dinitrobenzenesulfenyl)-2,3-diphenylaziridine (**4**): Compound **1** (0.22 g) in dry $CH_2Cl_2$ (50 ml) was added to dry $CH_2Cl_2$ (100 ml) containing *trans*-stilbene (0.90 g) and NBS (0.18 g) over a period of 4 h with a syringe pump. The reaction solution was stirred overnight, washed with 5% aqueous $NaHCO_3$ solution (30 ml) and twice with water (30 ml), and dried over $Na_2SO_4$. The solution was concentrated and the residue was purified on a silica gel column using benzene as an eluant to give **4** (0.226 g), mp 138—141 °C. IR (KBr) $cm^{-1}$: 1582 ($NO_2$), 1340 ($NO_2$). $^1$H-NMR ($CDCl_3$) $\delta$: 9.06 (1H, d, $J$=2.35 Hz, aromatic proton), 8.54 (1H, d, $J$=9.22 Hz, aromatic proton), 8.38 (1H, dd, $J$=2.41, 9.18 Hz, aromatic proton), 7.46—7.35 (10H, m, aromatic proton), 3.88 (2H, s, CH). MS $m/z$: 393 ($M^+$), 194 ($M^+ - (O_2N)_2C_6H_3S$), 180 ($(C_6H_5CH)^{2+}$). *Anal.* Calcd for $C_{20}H_{15}N_3O_4S$: C, 61.06; H, 3.84; N, 10.68. Found: C, 60.90; H, 3.78; N, 10.48.

The following compounds were obtained by essentially the same procedure as above.

1′-Phenylvinyl-2,4-dinitrobenzenesulfenamide (**2**): mp 107—108 °C. IR (KBr) $cm^{-1}$: 3370 (NH), 3100 (C=CH), 1590 ($NO_2$), 1510 ($NO_2$), 1340 ($NO_2$). $^1$H-NMR ($CDCl_3$) $\delta$: 9.08 (1H, d, $J$=2.40 Hz, aromatic proton), 8.22 (1H, dd, $J$=2.37, 9.12 Hz, aromatic proton), 8.04 (1H, d, $J$=9.06 Hz, aromatic proton), 7.43—7.36 (5H, m, aromatic protons), 5.48 (1H, s, vinyl proton), 5.32 (1H, dd, $J$=0.90, 2.02 Hz, vinyl proton), 4.07 (2H, dd, $J$=0.90, 5.68 Hz, $-CH_2-$), 2.94 (1H, t, $J$=5.64 Hz, NH). MS $m/z$: 331 ($M^+$). *Anal.* Calcd for $C_{15}H_{13}N_3O_4S$: C, 54.53; H, 3.68; N, 12.48. Found: C, 54.53; H, 3.68; N, 12.48.

1-(2,4-Dinitrobenzenesulfenyl)-2-methyl-3-phenylaziridine (**3**): mp 120—121 °C. IR (KBr) $cm^{-1}$: 1595 ($NO_2$), 1517 ($NO_2$), 1340 ($NO_2$). $^1$H-NMR ($CDCl_3$) $\delta$: 9.12 (1H, d, $J$=2.32 Hz, aromatic proton), 8.52 (1H, d, $J$=9.00 Hz, aromatic proton), 8.38 (1H, dd, $J$=2.40, 9.10 Hz, aromatic proton), 7.40—7.28 (5H, m, aromatic protons), 3.15 (1H, br, CH), 2.86 (1H, m, CH), 1.60 (3H, d, $J$=5.74 Hz, $CH_3$). MS $m/z$: 331 ($M^+$), 199 ($(O_2N)_2C_6H_3S^+$), 132 ($M^+ - (O_2N)_2C_6H_3S^+$). *Anal.* Calcd for $C_{15}H_{13}N_3O_4S$: C, 54.37; H, 3.95; N, 12.68. Found: C, 54.30; H, 3.80; N, 12.64.

*N*-(2,4-Dinitrobenzenesulfenyl)-1,2-epiminoindane (**5**): mp 167—168 °C. IR (KBr) $cm^{-1}$: 1590 ($NO_2$), 1510 ($NO_2$), 1340 ($NO_2$). $^1$H-NMR ($CDCl_3$) $\delta$: 9.12 (1H, d, $J$=2.07 Hz, aromatic proton), 8.37 (1H, dd, $J$=2.37, 9.10 Hz, aromatic proton), 7.47 (1H, d, $J$=7.26 Hz, aromatic proton), 7.35—7.23 (4H, m, aromatic proton), 3.67 (1H, br, CH), 3.53 (1H, br, CH), 3.35 (1H, d, $J$=17.85 Hz, $CH_2$), 3.25 (1H, dd, $J$=4.34, 17.84 Hz, $CH_2$). MS $m/z$: 329 ($M^+$), 130 ($M^+ - (O_2N)_2C_6H_3S$), 116 ($M^+ - (O_2N)_2C_6H_3SN$). *Anal.* Calcd for $C_{15}H_{11}N_3O_4S$: C, 54.70; H, 3.36; N, 12.75; S, 9.73. Found: C, 54.65; H, 3.44; N, 12.47; S, 9.59.

*N*-(2,4-Dinitrobenzenesulfenyl)-1,2-epiminocyclopentane (**6**): mp 141—143 °C. IR (KBr) $cm^{-1}$: 1582 ($NO_2$), 1510 ($NO_2$), 1340 ($NO_2$). $^1$H-NMR ($CDCl_3$) $\delta$: 9.14 (1H, d, $J$=2.11 Hz, aromatic proton), 8.46 (1H, dd, $J$=2.38, 9.13 Hz, aromatic proton), 8.39 (1H, d, $J$=8.94 Hz, aromatic proton), 2.19—2.11 (2H, m, aliphatic protons), 1.82—1.62 (6H, m, aliphatic proton). MS $m/z$: 281 ($M^+$). *Anal.* Calcd for $C_{11}H_{11}N_3O_4S$: C, 46.97; H, 3.94; N, 14.93. Found: C, 46.70; H, 3.70; N, 14.83.

*N*-(2,4-Dinitrobenzenesulfenyl)-1,2-epiminocyclooctane (**7**): mp 161—162 °C. IR (KBr) $cm^{-1}$: 1590 ($NO_2$), 1502 ($NO_2$), 1340 ($NO_2$). $^1$H-NMR ($CDCl_3$) $\delta$: 9.13 (1H, d, $J$=2.22 Hz, aromatic proton), 8.47 (1H, d, $J$=9.36 Hz, aromatic proton), 8.42 (1H, dd, $J$=2.26, 9.1 Hz, aromatic proton), 2.32—2.17 (4H, m, aliphatic protons), 1.71—1.35 (10H, m, aliphatic proton). MS $m/z$: 323 ($M^+$), 124 ($C_8H_{14}N^+$). *Anal.* Calcd for $C_{14}H_{17}N_3O_4S$: C, 52.00; H, 5.29; N, 12.99; S, 9.91. Found: C, 51.74; H, 5.24; N, 12.91; S, 9.95.

**HPLC** A typical example is described. An aliquot (20 $\mu$l) of reaction solution was injected into a Nova-pak cartridge (Millipore Ltd.), and 80% aqueous MeOH was used as the mobile phase. The detector was operated at 254 nm.

## References and Notes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6) *a*) D. C. Horwell, C. W. Rees, *J. Chem. Soc., Chem. Comm.*, **1969**, 1428; *b*) When compound **5** (100 mg) as refluxed in EtOH (10 ml) for 2 h, 1-ethoxy-2-(2,4-dinitrophenylthio) aminoindane (70 mg, 61%) was precipitated after cooling of the reaction mixture. mp 175—176 °C. IR (KBr) $cm^{-1}$: 3285 (NH), 1590 ($NO_2$), 1510 ($NO_2$), 1340 ($NO_2$). HRMS Calcd for $C_{17}H_{17}N_3O_5S$: 375.0887. Found: 375.0880. $^1$H-NMR ($CDCl_3$) $\delta$: 9.11 (1H, d, $J$=2.32 Hz, aromatic proton), 8.34 (1H, dd, $J$=2.33, 9.08 Hz, aromatic proton), 8.21 (1H, d, $J$=9.08 Hz, aromatic proton), 7.38 (1H, d, $J$=7.26 Hz, aromatic proton), 7.32—7.20 (3H, m, aromatic proton), 4.79 (1H, d, $J$=3.77 Hz, NH), 3.85 (1H, m, CH–N), 3.73 (2H, q, $J$=6.96 Hz, $CH_3C\underline{H}_2O$), 3.41 (1H, dd, $J$=6.66, 16.09 Hz, $CH_2$), 3.08 (1H, d, $J$=5.35 Hz, CHO), 2.81 (1H, dd, $J$=4.62, 16.18 Hz, $CH_2$), 1.26 (3H, t, $J$=6.97 Hz, $C\underline{H}_3CH_2O$).
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