The Chemistry of Polycyclic Arene Imines. I. Substitution at the Nitrogen Atom of 1a,9b-Dihydro-1*H*-phenanthro[9,10-*b*]azirine

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Chlorides of carboxylic, sulfonic and phosphoric acids proved to convert phenanthrene-9,10-imine into the corresponding rearranged acet- sulfon- and phosphonamidophenanthrene. Trimethylchlorosilane and *N,O*--bis(trimethylsilyl)acetamide reacted with the imine without destruction of the aziridine ring. The silylated compound could be transferred into the respective *N*-substituted phenanthrene-9,10-imines when treated with acetyl-, methanesulfonyl-, 4-tosyl- and diethylphosphoryl chloride. A remarkably stable *N*-chlorophenanthrene-9,10-imine was obtained from the unsubstituted compound and *N*-chlorosuccinimide.

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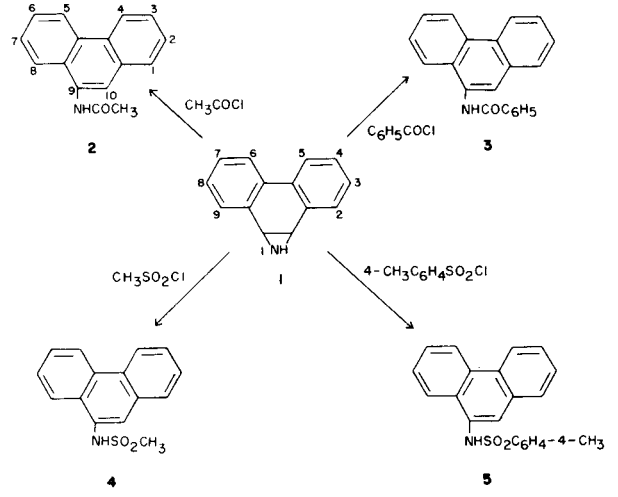
The chemistry of arene oxides has been the focus of substantial research in recent years owing to their biological relevance (1). Since the analogous arene imines are believed to be of similar importance to chemical carcinogenesis (2) (3), we find it imperative to investigate the chemical reactivity of these compounds. In previous studies (2) (4) (5) we noticed that the polycyclic imines are thermally more stable than the corresponding oxiranes, though they could be cleaved and converted into aromatic ammonium salts by heating with protic acids. Only one reaction is known, so far, in which an attack on the aziridine nitrogen does not cause ring fission (6).

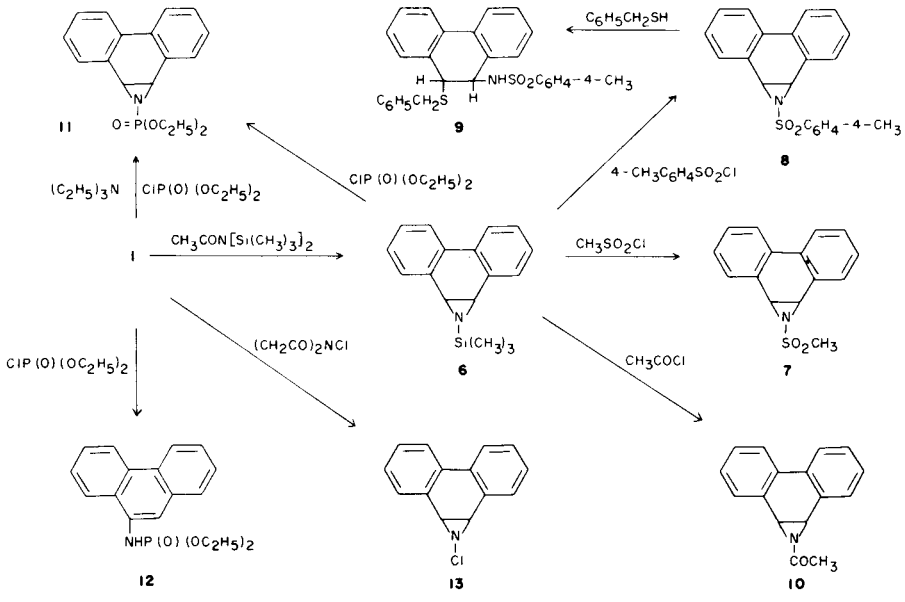
In this paper we report some reactions of 1a,9b-dihydro-1*H*-phenanthro[9,10-*b*]azirine (phenanthrene-9,10--imine, **1**) that lead to the formation of new N-C, N-Si, N-S, N-P and N-Cl bonds with either preserving or destruction of the aziridine ring.



In contrast to phenanthrene-9,10-oxide (7) (8), **1** reacted neither by alkyl mercaptane nor by aqueous sodium azide below 100°. It proved also refractory to methyl iodide, phenacyl bromide, benzyl chloride, carbamoyl chloride and dimethyl sulfate that are known to react with *aliphatic* aziridines (9). Imine **1** was, however, attacked by chlorides of both carboxylic and sulfonic acids. Acetyl and benzoyl chloride gave exclusively *N*-9-phenanthrenylacetamide (**2**) and -benzamide (**3**). Methane- and 4-toluenesulfonyl chloride afforded the corresponding sulfonamides **4** and **5** as the major products.

A ring preserving reaction was shown to take place between **1** and some reactive silicon compounds. When **1** was treated at room temperature with trimethylchlorosilane in the presence of triethylamine or pyridine, the nitrogen proton was replaced by the trimethylsilyl group to form 1a,9b-dihydro-1-trimethylsilyl-1*H*-phenanthro[9,10-*b*]-azirine (**6**). In the absence of the external acid-trapping amine only one half of the aziridine underwent silylation, while the other half was converted into 9-aminophenanthrene hydrochloride. Application of *N,O*-bis-(trimethylsilyl)acetamide as silylation agent (10) was of advantage as it did not require the addition of a tertiary amine. Compound **6** proved extremely sensitive to moisture that hydrolyzes the silyl group to give the starting aziridine **1**. This group could be replaced also by some other nucleophiles. Thus, methane- and 4-toluenesulfonyl chloride yielded sulfonyl aziridines **7** and **8**, respectively. The latter compounds proved to be considerably more reactive towards nucleophiles than the unsubstituted imine. While no reaction occurred between **1** and benzyl mercaptan in boiling benzene or THF, the reagent and **8** formed 9,10--dihydro-9-(4-methyl)benzenesulfonamido-10-(phenylmethyl)thiophenanthrene (**9**) in 46% yield.

In analogy to the reaction of **6** and the sulfonyl chlorides, the silyl compound could be converted by acetyl chloride into 1-acetyl-1a,9b-dihydro-1*H*-phenanthro-[9,10-*b*]azirine (**10**), which, however, rearranged at room temperature to **2** by the mechanism outlined previously

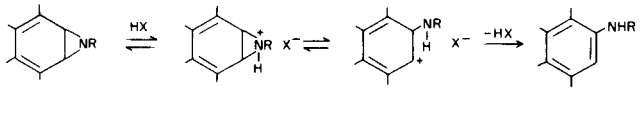


(2).

Diethyl chlorophosphate reacted slowly with **6** to give diethyl 1a,9b-dihydro-1-phosphonato-1*H*-phenanthro-[9,10-*b*]azirine (**11**), albeit in a very poor yield. Much better results (73% yield) were obtained when a mixture of imine **1** and excess triethylamine (or pyridine) was treated with the chlorophosphate. When, however, the phenanthrene imine was subjected to the reagent in the absence of triethylamine or when the chlorophosphate and the tertiary amine were added to **1** simultaneously, the sole product was *N*-9-phosphonamidophenanthrene (**12**).

Substitution of the N-H proton of **1** by a chlorine atom was affected by *N*-chlorosuccinimide in either boiling carbon tetrachloride or ether. The *N*-chlorophenanthrene--9,10-imine (**13**), so formed, proved to be unusually thermally stable. It could be heated up to 131° without decomposition. In contrast to aliphatic *N*-chloroaziridines (**11**) the stability of **13** cannot be attributed to a highly polarized structure. The existence of a chlorine-nitrogen double bond would readily promote the rearrangement into the fully aromatized compound.

The marked difference in the stability of the unsubstituted- and *N*-alkylphenanthrene-9,10-imine (**2**) (**4**) *vs.* that of the *N*-acetyl, -sulfonyl and -phosphoryl compounds (**7**, **8**, **10**, **11**) towards cold (dilute) protic acids also deserve some attention. We explain these differences by the electronic effect of the various R groups on the following possible transformations.



While electron donating alkyl groups stabilize the positive charge on the aziridinium ion **b**, electron attracting substituents cause destabilization of this species and lead to the rearrangement into carbocation **c**. The latter forms readily the aromatized aminophenanthrene **d**. This Scheme can also explain our failure to preserve the three membered ring in the reaction of **1** with acetyl, sulfonyl and phosphoryl chlorides as well as the successful application of trimethylsilyl derivative **6** (having electron releasing groups) in the synthesis of imines **7**, **8** and **11**.

EXPERIMENTAL

1a,9b-Dihydro-1*H*-phenanthro[9,10-*b*]azirine (**1**).

The unsubstituted aziridine was prepared as described previously (12). Application of 36 mg of the shift reagent tris-(dipivalomethanato)-europium for 30 mg (3 equivalents) of **1** in 0.5 ml of deuteriochloroform gave (after 2 hours) the following extended 100 MHz pmr spectrum: δ 8.09 (t, 2H, J = 8 Hz, H3, H8 or H4, H7), 8.49 (t, 2H, J = 8 Hz, H3, H8 or H4, H7), 9.68 (d, 2H, J = 8 Hz, H2, H9), 9.90 (d, 2H, J = 8 Hz, H5, H6), 12.86 (s, 2H, H1a, H9b).

Reaction of **1** with Acid Chlorides.

A.

Typically, 0.3 g (3.8 mmoles) of acetyl chloride was added to a solution of 300 mg (1.55 mmoles) of **1** and 5 ml of triethylamine in 50 ml of methylene chloride. The mixture was stirred for 30 minutes at room temperature, treated with 30 ml of 5% aqueous sodium bicarbonate and washed with water. The organic layer was dried (magnesium sulfate) and the solvent evaporated. The residue was recrystallized from a mixture of benzene and petroleum ether to give 323 mg (88%) of *N*-9-phenanthrenylacetamide (**2**), mp 213-215° [literature (13) 213-215°].

B.

In the same manner **1** (in THF) was treated with benzoyl chloride to yield *N*-9-phenanthrenylbenzamide (**3**) of mp 199-201° (from benzene-petroleum ether) [literature (14) 199-201°].

C.

The reaction of **1** and methanesulfonyl chloride gave colorless *N*-9-phenanthrenylmethanesulfonamide (**4**) of mp 187-188°; ir (Nujol): 3230 (NH), 1148, 1153 cm^{-1} (>SO_2N); uv (chloroform): λ max (log ε) 238 (sh) (4.00), 245 (sh) (4.54), 253 (sh) (4.66), 257 (4.72), 277 (4.11), 291 (3.92), 310 (3.96), 338 (2.45), 356 nm (2.34); 60 MHz pmr (deuteriochloroform): δ 3.04 (s, 3H, C*H*$_3$), 7.15-7.90 (m, 7H, Ar*H*), 8.60 (d, 2H, J = 8 Hz, H4, H5); ms: (70 eV, 100°) m/e (relative intensity) 271 ($M^{+\cdot}$, 25), 192 ($C_{14}H_{10}N^+$, 50), 178 ($C_{14}H_{10}^{+\cdot}$, 1), 165 ($C_{13}H_9^+$, 100).

Anal. Calcd. for $C_{15}H_{13}NO_2S$: C, 66.40; H, 4.82; S, 11.82. Found: C, 66.29; H, 4.75; S, 11.60.

The compound was identical with a sample of **4** obtained from *trans*-9,10-dihydro-10-aminophenanthr-9-ol (15) by the following procedure. A mixture of 150 mg (0.71 mmole) of the amino-alcohol in 5 ml of dry pyridine and 700 mg (6.1 mmoles) of methanesulfonyl chloride was stirred at room temperature for 5 hours. Dilute (10%) hydrochloric acid was added and the organic material was taken into chloroform. The organic layer was washed firstly with 5% aqueous sodium bicarbonate and then with water, dried (magnesium chloride) and concentated. The red residual oil was titurated with toluene and recrystallized twice from toluene and twice from methanol to yield 50 mg (30%) of pure **4**.

D.

The reaction of **1** and 4-toluenesulfonyl chloride yielded **N**-9-phenanthrenyl(4-methyl)benzenesulfonamide (**5**) of mp 189-190° that was identical with an authentic sample prepared according to Shudo and Okamoto (15).

E.

Treatment of **1** with diethyl chlorophosphate afforded diethyl *N*-9-phosphonamidophenanthrene (**12**) that was identical with a sample obtained from **11** and trifluoro acetic acid (*vide infra*), pale yellow oil; ir (neat): 3200 (NH), 1245 cm^{-1} (PO); 60 MHz pmr (deuteriochloroform): δ 1.34 (dist, t, 6H, C*H*$_3$), 2.25 (s, 1H, N*H*), 4.46 (m, 4H, C*H*$_2$), 7.17-8.06 (m, 7H, Ar*H*), 8.48 (d, 2H, J = 8 Hz, H4, H5); ms: (70 eV, 100°) 329 ($M^{+\cdot}$).

Anal. Calcd. for $C_{16}H_{20}NO_3P$: C, 65.65; H, 6.12; N, 4.25. Found: C, 65.31; H, 6.08; N, 4.55.

1a,9b-Dihydro-1-methylsulfonyl-1*H*-phenanthro[9,10-*b*]azirine (**7**).

To a stirred solution of 190 mg (0.98 mmole) of **1** in 60 ml of dry THF was added, under exclusion of air and moisture, 0.105 ml of *N,O*-bis(trimethylsilyl)acetamide (10) (or 2.5 ml of triethylamine followed by 1.25 ml of trimethylchlorosilane). The mixture was stirred for 15 minutes and to the solution of the silylated aziridine **6** [60 MHz pmr (carbon tetrachloride) δ 0.48 (s, 9H, C*H*$_3$), 0.62 (s, 2H, H1a, H9b), 7.15-7.50 (m, 6H, Ar*H*), 7.89 (d, 2H, J = 7 Hz, H5, H6)] 148 mg (1.3 mmoles) of methanesulfonyl chloride was added and the stirring continued for 30 minutes. The mixture was digested with excess of 5% aqueous sodium bicarbonate and the resulting oil extracted with ether. The solvent was evaporated and the residue taken into methylene chloride. The dried solution (magnesium sulfate) was concentrated and treated with petroleum ether and the precipitate recrystallized from ether (or methanol) to give 140 mg (52%) of fine colorless needles of **7**. Further 102 mg (38%) of **7** was obtained by concentration of the mother liquor, mp 159-161°; ir (Nujol): 1140 cm^{-1} (>SO_2N); uv (methanol: λ max (log ε) 222 (4.29), 228 (sh) (4.15), 267 (4.20), 273 (4.21), 277 (4.26), 287 (sh) (4.07), 303 nm (sh) (3.11); 300 MHz pmr (deuteriochloroform): δ 3.027 (s, 3H, C*H*$_3$), 4.398 (s, 2H, H1a, H9b), 7.361 (ddd, 2H, $J_{2,3} = J_{3,4} = 7.5$ Hz, $J_{3,5} = 1.1$ Hz, H3, H8), 7.459 (ddd, 2H, $J_{4,3} = 7.5$ Hz, $J_{4,5} = 8$ Hz, $J_{4,2} = 1.5$ Hz, H4, H7), 7.589 (dd, 2H, $J_{2,3} = 7.5$ Hz, $J_{2,4} = 1.5$ Hz, H2, H9), 8.042 (d, 2H, $J_{5,4} = 8$ Hz, H5, H6); ms: (70 eV, 100°) m/e (relative intensity) 271 ($M^{+\cdot}$, 0.3), 192 ($C_{14}H_{10}N^+$, 100), 178 ($C_{14}H_{10}^{+\cdot}$, 7), 165 ($C_{13}H_9^+$, 73).

Anal. Calcd. for $C_{15}H_{13}NO_2S$: C, 66.40; H, 4.82; N, 5.16; S, 11.82. Found: C, 66.32; H, 4.79; N, 5.04; S, 11.52.

1a,9b-Dihydro-1-[(4-methylphenyl)sulfonyl-1*H*-phenanthro[9,10-*b*]azirine (**8**).

A solution of 220 mg (1.14 mmoles) of **1** in 50 ml of dry THF was treated, as above, with either 0.250 ml of *N,O*-bis(trimethylsilyl)-acetamide, or with 1.5 ml of trichlorosilane and 5 ml of triethylamine. The silyl compound was then reacted with 450 mg (2.36 mmoles) of 4-toluenesulfonyl chloride and the mixture allowed to stand for 60 minutes at room temperature. The reaction mixture was digested with cold water and the organic material extracted with a 1:1 ratio of ether and ethyl acetate. The solution was washed with water (3×) and then stirred for 3 hours with 60 ml of 10% aqueous sodium hydroxide. The organic layer was washed with water, dried (magnesium sulfate) concentrated and the yellow residue dissolved in methylene chloride. Addition of petroleum ether afforded slow crystallization of **8** as colorless prisms, yield 310 mg (78%); mp 168-171° (from ether) [literature (15) 168-171°]; ir and uv were identical with the reported spectra (15); 300 MHz pmr (deuteriochloroform): δ 2.374 (s, 3H, CH_3), 4.456 (s, 2H, H1a, H9b), 7.320 and 7.372 (ABq, 4H, $J_{AB} = 9.3$ Hz, C_6H_4), 7.280 (two superimposed dd, 4H, $J_{3,2} = 8.4$ Hz, $J_{3,4} = 7.7$ Hz, $J_{4,5} = 8.1$ Hz, H3, H4, H7, H8), 7.797 (d, 2H, $J_{2,3} = 8.4$ Hz, H2, H9), 7.978 (d, 2H, $J_{5,4} = 8.1$ Hz, H5, H6); ms: (70 eV, 120°) m/e (relative intensity) 347 ($M^{+\cdot}$-SO_2, 10), 192 ($C_{14}H_{10}N^+$, 100), 178 ($C_{14}H_{10}^{+\cdot}$, 6), 165 ($C_{13}H_9^+$, 73).

trans-9,10-Dihydro-9-(4-methyl)benzenesulfonamido-10-(phenylmethyl)-thiophenanthrene (**9**).

To a solution of 300 mg (0.865 mmole) of **8** and 0.22 ml (1.87 mmoles) of benzylmercaptan in 100 ml of 1,4-dioxane was added a solution of 0.4 g of sodium carbonate in 60 ml of water. After 24 hours at reflux the solution was cencentrated and the organic material extracted with chloroform, washed with 5% aqueous sodium bicarbonate, water and dried on magnesium sulfate. The solvent was evaporated and the residue chromatographed on silica gel (hexane-methylene chloride served as eluent) to give 163 mg (40%) of **9** as colorless prisms; mp 104-105°; ir (Nujol): 3220 (NH), 1155 cm^{-1} (>SO_2N); uv (chloroform): λ max (log ε) 244 (4.27); 268 nm (4.27); 300 MHz pmr (deuteriochloroform): δ 2.445 (s, 3H, C*H*$_3$), 4.322 (d, 1H, J = 7.2 Hz, H10), 4.618 (d, 1H, J = 7.2 Hz, H9), 4.692 (s, 1H, NH), 6.484 (s, 1H, C*H*$_2$), 6.509 (s, 1H, C*H*$_2$), 6.992-7.662 (m, 13H, Ar*H*), 7.745 (d, 2H, J = 7 Hz, H7, H8), 7.778 (d, J = 7 Hz, H4, H5); ms: (35 eV, 180°), 456 [(M-CH_3)$^+$, 5], 348 [(M-$C_7H_7S^{+\cdot}$), 100], 286 ($C_{14}H_8NO_2S_2^+$, 25), 192 ($C_{14}H_{10}^{+\cdot}$, 22), 165 ($C_{13}H_9^+$, 8); under chemical ionization - thermal fragmentation m/e 347 ($C_{14}H_9NHSO_2C_7H_7$), 300 ($C_{14}H_9SCH_2C_6H_5$).

Anal. Calcd. for $C_{28}H_{25}NO_2S_2$: C, 71.31; H, 5.34; N, 2.97; S, 13.60. Found: 71.10; H, 5.13; N, 2.70; S, 13.38.

Diethyl 1a,9b-Dihydro-1-phosphonato-1*H*-phenanthro[9,10-*b*]azirine (**11**).

To a cooled solution (5°) of 0.36 g (1.86 mmoles) of **1** and 0.6 ml of triethylamine (or pyridine) in 20 ml of carbon tetrachloride, there was injected, under argon 0.35 ml (2.42 mmoles) of freshly distilled diethyl chlorophosphate. The reaction mixture was allowed to warm up to 10° within 60 minutes and then quenched with cold water. The organic layer was dried (magnesium sulfate) and filtered through activated charcoal. The solvent was evaporated and the yellow oily residue extracted into hot cyclohexane. Upon cooling there crystallized 0.45 g (73%) of colorless **11**, mp 124-126°; uv (methanol): λ max (log ε) 222 (4.28), 228 (sh) (4.16), 267 (4.23), 273 (4.25), 278 (4.44), 284 (sh) (4.14), 289 (sh) 4.07), 301 (sh) (3.06), 309 nm (sh) (2.60); 300 MHz pmr (deuteriochloroform): δ 1.283 (t, 6H, $J_{CH_3.CH_2} = 7$ Hz, C*H*$_3$), 4.113 (dq, 4H, $J_{CH_2.CH_3} = 7$ Hz, $J_{P.CH_2} = 7.5$ Hz, C*H*$_2$), 4.193 (d, 2H, $J_{PH} = 16$ Hz, H1a, H9b), 7.350 (dd, 2H, $J_{3,2} = J_{3,4} = 7.5$ Hz, H3, H8), 7.440 (ddd, 2H, $J_{4,3} = 7..5$ Hz, $J_{4,5} = 8.2$ Hz, $J_{4,2} = 1.2$ Hz, H4, H7), 7.572 (dd, 2H, $J_{2,3} = 7.5$ Hz, $J_{2,4} = 1.2$ Hz, H2, H9), 8.067 (d, 2H, $J_{5,4} = 8.2$ Hz, H5, H6); ms (40 eV, 50°) m/e (relative intensity) 329 ($M^{+\cdot}$, 100), 300 ($C_{16}H_{15}NPO_3^+$, 18), 192 ($C_{14}H_{10}N^+$, 44), 178 ($C_{14}H_{10}H^{+\cdot}$, 18), 165 ($C_{13}H_9^+$, 22).

Anal. Calcd. for $C_{16}H_{20}NO_3P$: C, 65.65; H, 6.12; N, 4.25; P. 9.40. Found:

C, 65.70; H, 6.05; N, 4.25; P. 9.25.

When **11** was refluxed for 5 minutes with excess of trifluoroacetic acid followed by neutralization with potassium carbonate and extraction into methylene chloride, **12** was formed in quantitative yield. The compound was identical with the sample obtained from **1** and diethyl chlorophosphate.

1-Chloro-1a,9b-dihydro-1*H*-phenanthro[9,10-*b*]azirine (**13**).

A solution of 500 mg (2.59 mmoles) of **1** and 347 mg (2.60 mmoles) of *N*-chlorosuccinimide in 80 ml of carbon tetrachloride was refluxed for 30 minutes. One third of the solvent was evaporated. The mixture was cooled and the succinimide filtered off. Further concentration of the filtrate afforded yellow crystals that were taken into ether, washed (2×) with water, dried (magnesium sulfate) and treated with activated charcoal. Partial evaporation of the ether followed by slow cooling gave 470 mg (80%) of colorless crystals, mp 123-134° (explodes at 131°); uv (methanol): λ max (log ε) 225 (4.36); 254 (4.22), 283 (4.92); 304 nm (sh) (3.52); 300 MHz pmr (deuteriochloroform): δ 4.040 (s, 2H, H1a, H9b), 7.321 (ddd, 2H $J_{3,2} = J_{3,4} = 6.8$ Hz, $J_{3,5}$ 1.1 Hz, H3, H8), 7.396 (ddd, 2H, $J_{4,3} = 6.8$ Hz, $J_{4,5} = 7.7$ Hz, $J_{4,2}$ 1.1 Hz, H4, H7), 7.592 (dd, 2H, $J_{2,3} = 6.8$ Hz, $J_{2,4} = 1.1$ Hz, H2, H9), 7.947 (d, 2H, $J_{5,4} = 7.7$ Hz, H5, H6); ms: (35 eV, 70°) m/e (relative intensity) 229 [$M^{+\cdot}$ (^{37}Cl), 21], 227 [$M^{+\cdot}$ (^{35}Cl), 63], 192 ($C_{14}H_{10}N^+$, 100), 178 ($C_{14}H_{10}^{+\cdot}$, 87), 165 ($C_{13}H_9^+$, 45).

Anal. Calcd. for $C_{14}H_{10}ClN$: C, 73.85; H, 4.42; Cl, 15.57; N, 6.15. Found: C, 73.65; H, 4.33; Cl, 15.76; N,6.48.

Acknowledgement.

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