methylnaphthalene (0.095 g, 67%), which is identical in every aspect with the authentic sample.

Desulfurization of 4-Methoxybenzyl Mercaptan (3). According to the general procedure, **3** (0.308 g, 2 mmol) and $Mo(CO)_6$ (0.528 g, 2 mmol) in THF (ca. 40 mL) were converted to 4-methylanisol (0.17 g, 71%), which shows identical physical properties with those of the authentic sample.

Desulfurization of 4-Carboxybenzyl Mercaptan (4). According to a similar procedure, a mixture of **4** (0.157 g, 0.937 mmol) and $Mo(CO)_6$ (0.247 g, 0.937 mmol) in THF (ca. 40 mL) was transformed to 4-toluic acid (0.078 g, 67%), which exhibits the same physical properties as those of the authentic sample.

Desulfurization of 4-Bromobenzyl Mercaptan (5). A THF solution of **5** (0.203 g, 1 mmol) and $Mo(CO)_6$ (0.264 g, 1 mmol) was converted to 4-bromotoluene (0.108 g, 63%), which was characterized by comparing spectroscopic properties with those of the standard sample.

Desulfurization of 4-Chlorobenzyl Mercaptan (6). By a method similar to that described above, **6** (0.333 g, 2 mmol) was reduced to give 4-chlorotoluene (0.163 g, 61%), which exhibits identical spectroscopic properties with those of the authentic sample.

Desulfurization of α-(Thiomethoxy)acetophenone (7). Compound **7** (0.166 g, 1 mmol) and $Mo(CO)_6$ (0.264 g, 1 mmol) in THF (ca. 40 mL) were converted in a similar manner as described in the general procedure into the reduced product, acetophenone (0.068 g, 57%), which is identical in every aspect with the authentic compound.

Desulfurization of 2-Thionaphthol (8). The mercaptan **8** (0.322 g, 2.01 mmol) and $Mo(CO)_6$ (0.528 g, 2 mmol) in THF (ca. 40 mL) were transformed according to the procedure described above to yield naphthalene (0.112 g, 43%), which is identical with the authentic compound.

Desulfurization of 9-Fluorenone Thioketal 9. A mixture of **9** (0.256 g, 1 mmol) and $Mo(CO)_6$ (0.264 g, 1 mmol) in THF (ca. 30 mL) was refluxed for 12 h to give a brown-colored suspension. After filtration, the filter cake was washed with diethyl ether several times. The combined ether solution was evaporated, and the residue was chromatographed on silica gel and eluted with petroleum ether. From the first fraction (ca. 100 mL), **13** (0.069 g, 42%) was obtained, which exhibits the same properties as those of the authentic sample. The second fraction was identified as **14** (0.055 g, 34%): mp 190–191.5 °C (lit.[16] mp 187 °C); mass spectrom, *m/e* 328, 164; ^1H NMR ($CDCl_3$) δ 7.03 (8 H, m), 7.48, (4 H, m), 8.13 (4 H, m).

Desulfurization of 1-Adamantyl 2-Naphthylmethyl Sulfide (10). Compound **10** (0.616 g, 2 mmol) was allowed to react with $Mo(CO)_6$ (1.056 g, 4 mmol) in THF (ca. 40 mL) at refluxing temperature for 16 h. After cooling the mixture was filtered, and the filter cake was washed with ether. The organic solution was evaporated in vacuo to give the brownish residue, which was chromatographed on silica gel and eluted with petroleum ether. The first fraction afforded 2-methylnaphthalene (0.1 g, 73% based on unrecovered starting material), which exhibits the same spectroscopic data as those of the authentic sample. Further elution with petroleum ether yielded 1-adamantanethiol (0.085 g, 49% based on unrecovered starting material), which shows identical properties with those of the authentic material, and recovered the starting material (0.3 g, 49%).

Registry No. **1**, 5254-86-4; **2**, 1076-67-1; **3**, 6258-60-2; **4**, 39088-65-8; **5**, 19552-10-4; **6**, 6258-66-8; **7**, 5398-93-6; **8**, 91-60-1; **9**, 7049-31-2; **10**, 99282-02-7; **11**, 34301-54-7; **13**, 86-73-7; **14**, 746-47-4; 1-methylnaphthalene, 90-12-0; 2-methylnaphthalene, 91-57-6; 4-methylanisole, 104-93-8; 4-toluic acid, 99-94-5; 4-bromotoluene, 106-38-7; 4-chlorotoluene, 106-43-4; acetophenone, 98-86-2; naphthalene, 91-20-3.

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(17) In this paper the periodic group notation in accord with recent actions by IUPAC and ACS nomenclature committees has been included. A and B notation is eliminated because of wide confusion. Groups IA and IIA become groups 1 and 2. The d-transition elements comprise groups 3 through 12, and the p-block elements comprise groups 13 through 18. (Note that the former Roman number designation is preserved in the last digit of the new numbering: e.g., III → 3 and 13.)

Formation of a Neutral Covalent Adduct in the Nucleophilic Aromatic Substitution Reaction Involving a Carbon Leaving Group

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Our interest in the field of nucleophilic aromatic substitution reactions[1] has prompted us to investigate the mechanism of substitution of substrates bearing the scarcely studied carbon leaving groups. We have studied the reaction of MeO^- ion in MeOH with 4-(trichloromethyl)quinazoline (**1**), a substrate somewhat related to 2-methyl-4-(tribromomethyl)quinazoline, that has been shown to be probably involved[2] in the aromatic substitution reaction of a CBr_3 group.

The reaction of **1** with methoxide ion at room temperature yields chloroform and 4-methoxyquinazoline (**2**). Undoubtedly, as observed in the 1,3,5-triazine ring,[3] the CCl_3 group is easily replaced because compound **1** is activated by two aza groups and the annelated benzene ring. Indeed, the substitution of a trihalo group seems to be strongly affected by the presence of electron-withdrawing groups. Thus poorly activated substrates, such as (trichloromethyl)pyridine[4] and -benzothiazole[5] derivatives do not undergo the aromatic substitution reaction. Interestingly, however, 2-(trifluoromethyl)quinoline is the only substrate in a large group of trifluoromethyl-substituted heterocyclic compounds to undergo the aromatic substitution reaction rather than a side-chain reaction.[6]

From a preparative point of view, the replacement of the CCl_3 group of **1** with the methoxy group is similar to the replacement of other more common leaving groups. However, the UV and ^1H NMR spectral features of this reaction of **1** are different from those of the reactions that follow the usual aromatic substitution mechanism involving the steady-state formation of an intermediate σ adduct.

Upon addition of MeO^- ion (10^{-3} M) to a 10^{-4} M methanol solution of **1** the following changes are observed. At first (Figure 1) the absorbance of **1** (λ_{max} 315 nm) decreases, and a broad absorbance increase is observed in the 260–280-nm range (λ_{max} 268 nm, isosbestic point 293 nm). After some time (nearly 1 h at room temperature) this spectrum begins to evolve toward that of 4-methoxyquinazoline (λ_{max} 262, 296, and 308 nm). This further change is nearly 100 times slower than the former and is characterized by five isosbestic points, at 275, 294, 298, 306, and 310 nm, respectively (Figure 2).

The reaction has also been monitored by ^1H NMR spectroscopy. The ^1H NMR spectrum of **1** (Figure 3a) is gradually replaced by the spectrum reported in Figure 3b, showing the partial disappearance of **1** and the appearance of new signals upfield with respect to those of **1**. If at this point the temperature is decreased, a reversible change can be observed in the relative intensities of the signals of **1** and the new ones (Figure 3c), in agreement with the fact that this situation corresponds to an equilibrium between **1** and another species (or possibly with a mixture of rapidly

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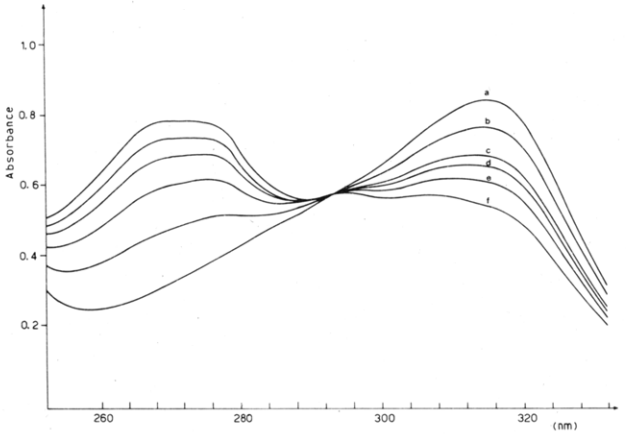


Figure 1. UV spectra for the reaction of 1 (10^{-4} M) with MeO^-Na^+ (10^{-3} M) in methanol, at 25 °C: (a) initial; (b) after 8 min; (c) after 18 min; (d) after 28 min; (e) after 48 min; (f) after 80 min.

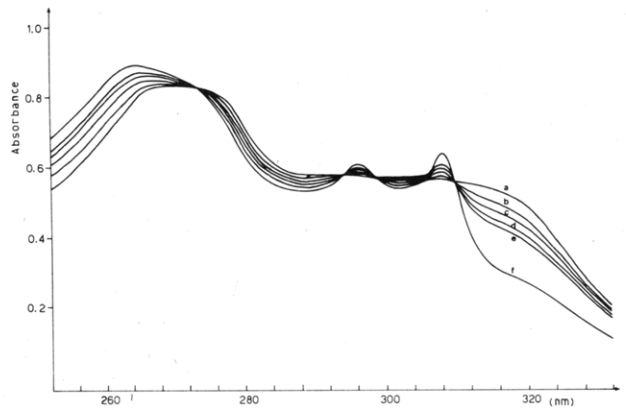


Figure 2. As figure 1: (a) after 80 min; (b) after 140 min; (c) after 200 min; (d) after 260 min; (e) after 320 min; (f) after 24 h.

exchanging compounds). With time, though, the intensities of all the above signals decrease, and correspondingly the intensity of the signals of 4-methoxyquinazoline (**2**) increases. Compound **2** (Figure 3d) is the only final product, and is not further affected by MeO^- ion under these conditions. Of course in CD_3OD $CDCl_3$ cannot be detected by ^1H NMR as a reaction product, but it was verified that $CHCl_3$ is formed (δ in CH_3OH 7.7) when the reaction was carried out in CH_3OH and followed by CW ^1H NMR (Varian EM 360 instrument). The UV and ^1H NMR spectral features detected after the addition of MeO^- ion are not consistent with the presence of the anionic σ adduct **3** which is expected to exhibit a bathochromic shift and larger NMR upfield shift,[7] but rather with the presence of a neutral adduct between **1** and MeOH, such as **4** or, less probably,[8] its 1-*H* isomer (see Scheme I), formed upon rapid protonation of the undetected adduct **3**.

Experiments carried out with **1** in MeOH in the presence of acids support the above reported explanation. Addition of CF_3COOH to a MeOH solution of **1** in MeOH gives the neutral covalent adduct of MeOH with **1**.

The mass spectrum of the covalent adduct of MeOH and **1** contains all the peaks observed in that of **1**. However, there are several new peaks including the base peak (m/e 161, $(M - CCl_3)^+$) which must be formed from the covalent adduct. The latter loses easily a molecule of methanol, so that the molecular ion cluster in the mass spectrum is very

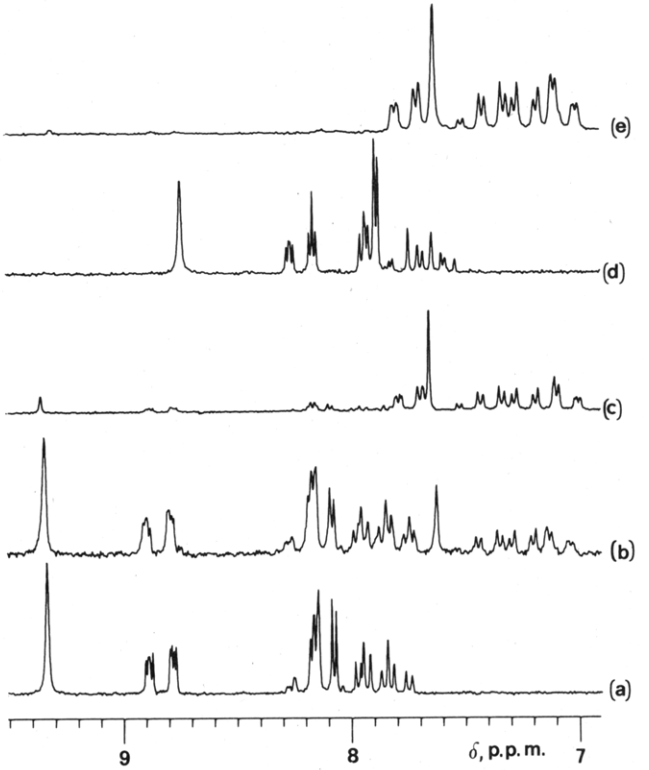
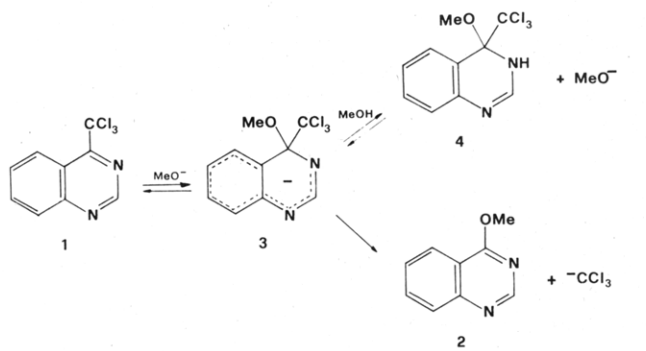


Figure 3. ^1H NMR spectra for the reaction of **1** with MeONa in CD_3OD: (a) compound **1**; (b) **1** + MeONa, at 28 °C, immediately after mixing; (c) solution b at −15 °C; (d) solution (b) after 10 min; (e) neutral adduct **4**. (The spectra were recorded at different recorder amplitude and reflect the relative intensities only.)

Scheme I



weak. These mass spectrum features, the very low molecule ion peak, and the easy loss of the trihalomethyl group to yield the base peak are also observed in the mass spectrum of the covalent hydration adduct of 4-(trifluoromethyl)pteridine.[9]

The ^1H NMR spectrum of the neutral adduct in CD_3OD (Figure 3e) matches that observed at low temperature (Figure 3c) after the addition of MeO^- to **1**, except for the H-2 signal, whose chemical shift value could be affected by the presence of a small amount of the anionic σ adduct in rapid equilibrium with adduct **3**. Indeed addition of MeONa modifies the chemical shift of this signal. This rapid change is followed by the appearance of **1** and also by the slow formation of 4-methoxyquinazoline. The final product is **2** only, as observed in the direct reaction of **1** with MeO^- ion. The spectrophotometric study of the behavior of the adduct in the presence of methoxide ion matches that one deduced by ^1H NMR spectroscopy.

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When the MeOH solution of the neutral covalent adduct (λ_{max} 268 nm) reacts with methoxide ion, two subsequent UV spectrophotometric changes are detected. At first an absorbance decrease for the adduct is observed together with an increase in the 310–320-nm range where 1 absorbs. At the end of this primary process the UV spectrum is very similar to that observed at the end of the primary interaction between 1 and methoxide ion (Figure 1). The following spectrophotometric change is identical with that reported in Figure 2, and corresponds to the eventual formation of the substitution product 2.

The reversible covalent "solvation" of C=N bonds of nitrogen heteroaromatic compounds,[10] and notably of quinazoline compounds,[8] has been well described in water and has also been reported in other protic solvents, such as alcohols. No reference has been given so far to the possible role of covalent "solvation" adducts in the course of nucleophilic aromatic substitution, if exception is made for the reaction of 6,7-dihalogenopteridines with H_2O.[11] However, in the latter reaction the site of attachment of the OH group in the neutral covalent adduct (C-4) is different from the site involved in the hydroxy dehalogenation reaction (C-7). The formation and the isolation of a neutral covalent adduct under nonacidic conditions is not common. A well-known example is given by the reaction of 4-(trimethylammonium)quinazoline in water.[12] The latter substrate is similar to 1 because of the presence of a substituent with strong electron-withdrawing power and relatively poor leaving group ability.

Experimental Section

Melting points are uncorrected. UV spectra were recorded on a Cary Model 219 instrument. ^{1}H NMR spectra were obtained with a Bruker WP 80 SY instrument, unless otherwise stated. Mass spectra were obtained with a Kratos MS 80 spectrometer.

4-(Trichloromethyl)quinazoline (1) was prepared according to a method similar to that reported for the preparation of 2-(tribromomethyl)quinoline.[13] A 2.16 N solution of Cl_2 in AcOH (22 mL, 24 mmol) was added in 10 min to 70 mL of an AcOH solution of 4-methylquinazoline (1 g, 7 mmol) and anhydrous sodium acetate (3.6 g, 44 mmol) kept at 70 °C. The reaction mixture was further heated at 90–95 °C for a few minutes, and again at 70 °C for 30 min. The cold reaction mixture was poured into ice water, and the resulting solid was collected by filtration and purified by chromatography (silica gel, benzene) to give 1.4 g of a yellowish product: mp (petroleum ether 40–70 °C) 91–91.5 °C; ^{1}H NMR (CD_3OD) δ 7.7–8.3 (m, 3 H, H6–H8), 8.83 (two multiplets, 1 H, H-5), 9.33 (s, 1 H, H-2); UV (MeOH) λ_{max} 315 (ϵ 3950), 233 nm (ϵ 29 160); mass spectrum, calcd for $C_9H_5N_2Cl_3$ (M^+, $^{35}Cl_3$) m/e 245.952 05, found 245.9517; yield 82%.

Reaction of 4-(Trichloromethyl)quinazoline (1) with Methoxide Ion. Compound 1 (0.2 g, 0.81 mmol) was dissolved in 10 mL of MeOH, and 1.18 mmol of sodium methoxide was added at 25 °C. The TLC analysis (silica gel, benzene–ethyl acetate 1:1) showed that after 10 min the concentration of 1 had decreased and two compounds had formed with R_f values 0.32 and 0.06, respectively. However, after 5 h only the compound with R_f 0.32 was present, whereas the substrate and the compound with R_f 0.06, corresponding (TLC) to the covalent adduct 4 were absent.

The reaction mixture was neutralized with HCl and poured into water. The resulting solution was continuously extracted with ether for 16 h. The ether solution was dried. Removal of the solvent left a yellow oily residue (125 mg) that was identified as 4-methoxyquinazoline[14] (yield 97%).

Covalent Adduct between 1 and MeOH. CF_3COOH (0.50 mL, 6.5 mmol) was added at room temperature to a methanol solution of 1 (0.30 g, 1.2 mmol in 15 mL). The reaction was followed by TLC (silica gel, benzene–ethyl acetate 1:1). After 2 h, when compound 1 was absent and one product only was detected, the reaction mixture was poured into 100 mL of water containing 6.5 mmol of NaOH to yield a white solid. The ether solution of the latter was mixed with the ether extract (a TLC analysis showed the presence of 1 in both the ether solutions), and the resulting solution was washed with water and dried. The residue, after evaporation, was subjected to column chromatography (silica gel, benzene–ethyl acetate 1:1). After the elution of compound 1 (0.2 g), the covalent adduct was collected (95 mg): mp (washed with petroleum ether 40–70 °C) 110–111 °C; ^{1}H NMR (CD_3OD) (see Figure 3e); UV (CH_3OH) λ_{max} 268 nm; mass spectrum, calcd for $C_{10}H_9N_2OCl_3$ (M^+, $^{35}Cl_3$) m/e 277.978 27, found 277.9781; yield 28% (the small yield contrasts with the complete conversion of 1 into 4; this fact is related to the partial return of 4 into 1 during the workup).

Registry No. 1, 99356-81-7; 4-methoxyquinazoline, 16347-95-8; 4-methylquinazoline, 700-46-9.

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Dimethyl Benzoquinone-2,5-dicarboxylate

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Of the three possible isomeric dimethyl benzoquinonedicarboxylates, only the 2,3-isomer has been described in the literature.[1] We now report the synthesis and characterization of the 2,5-isomer.

Results and Discussion

Dimethyl 1,4-dioxocyclohexane-2,5-dicarboxylate (2), which is commercially available (Aldrich), exists exclusively in the enol form. The strong hydrogen bonding between the enol and the ester carbonyl function, shown by the lack of a hydroxyl absorption in the infrared spectrum, results in a planar structure, as proven by X-ray crystal structure determination.[2] Hydrogen bonding is the reason for the extreme reaction conditions necessary to transesterify this diester.[3]

This hydrogen bonding also results in remarkable resistance to oxidation. Although many oxidation methods were investigated on this compound, only activated manganese dioxide[4] in toluene cleanly oxidized this material. However, curiously only the hydroquinone derivative, dimethyl hydroquinone-2,5-dicarboxylate (3), was the product. This compound also shows a weak absorption for the hydroxyl group in the infrared spectrum. The lowered frequency, 3250 cm^{-1}, is indicative of intramolecular chelation with the carbonyl group, whose absorption frequency is also remarkably low (1680 cm^{-1}).

Again numerous oxidation procedures were attempted in order to further oxidize this hydroquinone derivative to the desired dimethyl benzoquinone-2,5-dicarboxylate (1). Among these methods were the following: nitrogen oxides, lead tetraacetate, persulfate, ceric ammonium nitrate, etc., which all resulted in decomposition or no re-

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