

Synthesis of 4-Chloro-3-Nitrostyrene Polymerization and Copolymerization Experiments

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ABSTRACT

A method of preparation giving high yields for 4-chloro-3-nitrostyrene and some derivatives is described. First trials of free radical polymerization and copolymerization are reported and show a deactivating influence of the nitro group.

INTRODUCTION

Polymers bearing basic heterocyclic pendant units exhibit interesting properties as catalysts or complexing reagents (1). One of the best ways of obtaining them is to form the heterocycle at the ultimate step of the synthesis to allow a rapid modification of the chemical structure and to keep the fragile function (ex. thiol) intact on the heterocycle.

This method requires the initial preparation of a prepolymer with reactive sites, and the specific procedures used have already been described in the case of benzimidazolic heterocycles (2). Another, more versatile procedure could be devised to make the most of the well-known reactivity of o-chloro-nitroaryl cycles (3) and their aptitude to form various heterocycles such as benzimidazoles, benzothiazoles, etc., under very simple conditions. This reactivity could be adapted to the particular cases of monomers and polymeric precursors.

This paper first reports the synthesis of 4-chloro-3-nitrostyrene, then its conversion into various functionally modified styrenic monomers and, finally, some polymerization or copolymerization experiments.

RESULTS AND DISCUSSION

Monomer synthesis

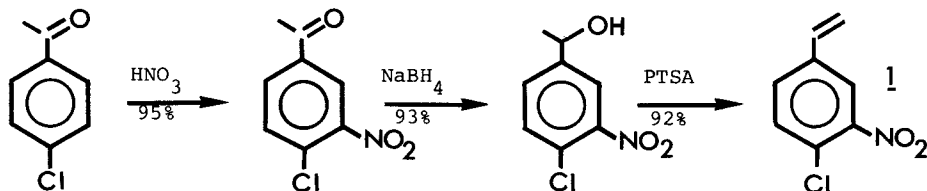
A certain number of methods for the preparation of 4-chloro-3-nitrostyrene 1 (4), 4-amino-3-nitrostyrene 2 and 3,4-diaminostyrene 3 (5,6,2) have already been reported in the literature. They do not, however, satisfy all the general requirements of rapidity, good yield and purity of the final product. Moreover, there is no common protocol between the synthesis of 1 and that of 2 and 3.

This paper reports a simple method designed to obtain 1 in large quantities and in a very pure state. This starting monomer, which can be stored indefinitely without any special precautions, may be further converted into monomers such as 2 and 3, whose synthesis is also described. This chemical transformation should be performed just before use and in exactly the required quantities, as the resulting monomers 2 and 3 present fragile amine and thiol functions whose instability over a long period is well-known.

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4-chloro-3-nitrostyrene 1

The following schema illustrates the preparation of this monomer :

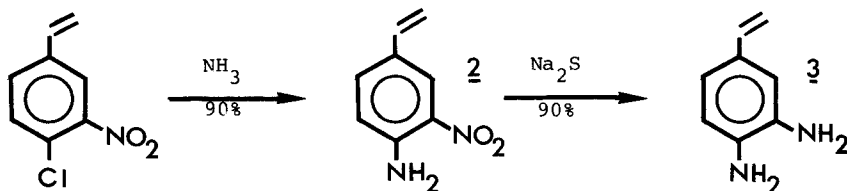


First, 4-chloroacetophenone is rapidly nitrated under smooth conditions in order to prevent the displacement of the acetyl group. Then the resulting 4-chloro-3-nitro acetophenone is transformed without purification into the corresponding secondary alcohol by reaction with NaBH_4 . Although analogous reductions have been performed in methanol, we consider it preferable to use ethanol, as this solvent reacts less rapidly with the hydride. The reduction in ethanol is very fast (< 1 hour) at 15°C , with quasi-quantitative yield. To obtain the styrenic derivative 1 by dehydration of the above-mentioned alcohol, non-classical procedures (using DMSO for example (8,9)) do not seem to be adequate, and give poor yields. Among these procedures we must emphasize the action of hot HMPT, which permits successful conversion into alkenes even with alcohols reputed to be resistant to dehydration (10,11). For example, it is the only method which allows the conversion of (4-amino-3-nitro)-1-phenylethanol (2) into 4-amino-3-nitrostyrene 2 with an acceptable yield. In our particular case, HMPT favors elimination, but it also acts as a nucleophile, which results in the formation of 4-dimethyl-amino-3-nitrostyrene as the main product of the reaction. This behavior has already been encountered in the case of 1-chloro-2-nitrobenzene and 4-chloro-3-nitrotoluene (12). Contrary to similar tests (4) we have found that the dehydration of (4-chloro-3-nitro)-1-phenylethanol is carried out most efficiently with an acidic and only slightly volatile catalyst (PTSA for example). However, it is necessary to eliminate the final product as soon as it is formed by fractionating the nitrochlorostyrene-alcohol mixture ($\Delta T_{\text{Eb}} > 40^\circ \text{C}$ at 0.5 Torr) during the entire reaction process. This is therefore a unique pot method, where both reaction and purification are carried out without the use of an inhibitor.

4-chloro-3-nitrostyrene is insoluble in water but soluble at low temperatures in all common organic solvents.

Synthesis of various styrenic monomers deriving from 4-chloro-3-nitrostyrene

The sensitivity of the o-chloronitro site to the nucleophiles on the one hand, and the facile reduction of the nitro group on the other hand, permit the easy preparation of 3,4-disubstituted styrenic derivatives such as, for example, 4-amino-3-nitrostyrene 2, then 3,4-diaminostyrene, according to the following schema :



4-amino-3-nitrostyrene 2

We have already described a specific synthetic route for this compound and for its derivative, 3,4-diaminostyrene (2). The yields are quite good, but a delicate and time-consuming chromatographic purification is required. The new method of synthesis eliminates this drawback and permits higher yields.

Compound 2 is obtained by treatment under heat with a NH_3/MeOH solution. 4-amino-3-nitrostyrene can be recovered in its pure state from any unreacted starting product, by means of selective crystallization from alkanes.

3,4-diaminostyrene 3

This is obtained by chemical reduction of the former monomer. Acidic reductive systems are to be prohibited as they would favor the formation of oligomers. The best results are obtained with sodium dithionite or sodium sulfide. We prefer this latter reagent, which ensures a good protection of the diamino site and thus easier purification in the following stages.

All three monomers are soluble in polar organic solvents and chlorinated solvents. Only compound 1 is soluble at low temperatures in alkanes but insoluble in water. At higher temperatures, compound 2 is slightly soluble in water, while 3,4-diaminostyrene is more soluble (2.5 g per 100 ml at 25° C).

Polymerization experiments

As mentioned above, the aim of our work is to devise a general method for the preparation of polymers bearing heterocyclic pendant groups of various chemical natures. One can imagine the transformation of o-chloronitrophenyl units into o-phenylenediamine, o-aminophenol, o-aminothiophenol, etc., following the same route as the synthesis of 3, starting from 1. We have, however, preferred to concentrate our efforts on the polymerization of 4-chloro-3-nitrostyrene rather than tackling each time the complete study of a derived monomer. We report here the results of the preliminary experiments concerning radical mechanism.

Polymerization of 4-chloro-3-nitrostyrene

Various methods were tried (in bulk, emulsion and solution). Their conditions and results are summarized in Table 1. In each case the crude polymer is purified by dissolution in acetone, and precipitation occurs on addition of petroleum ether, which is a good solvent of the monomer. The purified polymer is a white powder which softens at about 290° C. The presence of residual monomer units can be characterized either by IR spectroscopy (disappearance of vinyl bands at 1630, 990 and 910 cm^{-1}) or by $^1\text{H-NMR}$ (disappearance of vinyl peaks between 5-7 ppm). In addition, the polymer is characterized by its intrinsic viscosity at 25° C in THF solution.

The polymer is insoluble in water, alcohols, aliphatic and aromatic hydrocarbons, but soluble in aprotic dipolar solvents. Rather low molecular weights (around 5000 - 10000 daltons) were obtained as a result of these first attempts. These results are not surprising (in the case of the bulk method) because of the insolubility of the polymer in the monomer, and because the solidification happens very quickly. In the emulsion state, at the emulsifier concentrations usually employed, the

miscellar system is not sufficiently stable at the beginning of the reaction, nor during it, to keep the required dispersion. An increase in the concentration of the surfactant generally results in a decrease of the average molecular weight. Nevertheless, solution polymerizations highlight the slowness of the reactions, which cannot be improved by increasing the temperature (up to 120° C for example). These observations should be compared with those concerning 4-nitrostyrene (13,14), whose polymerization always gives rise to very low molecular weights (≤ 3500 daltons). As invoked in this latter case, two hypotheses taking into account the presence of the NO_2 group in the meta position vs the vinyl group can be upheld. In the first hypothesis, the difficulties are attributed to a decrease in reactivity in comparison with styrene (5 to 6 times lower). However, experimental observations show that the presence of a Cl atom in the 4-position greatly improves the results, and that the experiment at 30° C causes the average molecular weight to double. The second hypothesis supposes an anormal addition of the macroradical on the monomer (in the para position of the nitro group) resulting in a strong stabilization and a deactivating transfer. In this case, the validity of the second hypothesis could be checked by addition of a highly reactive co-monomer capable of decreasing the frequency of the transfer, followed by the complete analysis of the resulting copolymers.

<u>Polymerization methods</u>	Initiator molar percent/monomer	C_m (a)	Time (h)	Temperature (°C)	Polymer yield	$[\eta]^{(b)}$ (ml.g ⁻¹)
<u>Bulk</u>	A.I.B.N. 0.6%		48	100	60%	6
<u>Emulsion</u> With sodium laurylsulfate (30%/monomer)	$\text{Na}_2\text{S}_2\text{O}_8$ 0.7%	10%	24	70	40%	5
	$\text{Na}_2\text{S}_2\text{O}_5$ 0.7%					
<u>Solution</u> in DMF	A.B.I.N. 2%	26%	24	70	35%	5.5
	D.C.P.O.D.C. 1%	25%	24	30	20%	9

Table I. Polymerization of 4-chloro-3-nitrostyrene

(a) Monomer concentration in weight per 100 ml of solvent
 A.I.B.N. azobisisobutyronitrile
 D.C.P.O.D.C. dicyclohexylperoxydicarbonate

(b) Intrinsic viscosity in THF at 25° C.

4-chloro-3-nitrostyrene copolymerization

Experiments were carried out on solutions using DMF as solvent, and acrylamide then methylmetacrylate as co-monomers. The former co-monomer was chosen for recovering hydrophilic polymers which can be further used as catalysts in aqueous medium. The latter is very reactive and known for its aptitude to copolymerize with many other monomers.

Moreover, it possesses a very easily hydrolysable chemical function (ester). Table II groups the results of two typical experiments.

Acrylamide

Copolymerization is effective when the initial molecular ratio acrylamide / styrene is greater than 2. The copolymer thus obtained is soluble both in water and acetone. Polyacrylamide is soluble in water, but not in acetone, while poly(4-chloro-3-nitrostyrene) is insoluble in water. The analytical determination of chlorine shows that there are 5 acrylamide units for 1 styrene unit when the starting molecular ratio is equal to 3 ; this indicates a high percentage of copolymerization.

Keeping in mind the low weight of the acrylamide unit, the measured viscosity argues for an increased degree of polymerization, but the yield remains poor.

Methylmethacrylate

Copolymerization is already observed for an initial molecular ratio acrylate / styrene as low as ≥ 1 . The resulting copolymer is soluble in benzene (which is not a solvent for polychloronitrostyrene) and is characterized by the presence of aromatic rings (IR spectroscopy). The analytical determination of chlorine indicates the presence of 3 acrylic units for 1 styrene unit, which is identical to the initial molecular ratio and represents an "ideal" copolymerization. Moreover, one observes a great increase in the average molecular weight and in the yield.

M_1	M_2	(a) C_m	(b) M_1/M_2	(c) A.I.B.N.	Tempe- rature (°C)	Time (h)	Polymer yield	$[\eta]^{(d)}$ ml.g^{-1}
Chloronitro styrene	Acrylamide	30	1/3	3%	80	60	40%	10
Chloronitro styrene	Methyl metacrylate	30	1/3	2%	50	48	65%	10

Table II. Copolymerization of 4-chloro-3-nitrostyrene in NN-dimethylformamide

- (a) Monomer concentration ($M_1 + M_2$) in weight per 100 ml of solvent
- (b) Initial molar ratio of the monomers
- (c) Initiator azobisisobutyronitrile molar percentage/ $M_1 + M_2$
- (d) Intrinsic viscosity in THF at 25° C

EXPERIMENTAL

4-chloro-3-nitroacetophenone

50 g of 4-chloroacetophenone were added to a stirring solution of 500 ml of nitric acid ($d = 1.52$) cooled to 0° C at a rate limiting the temperature to 3° C. 15 mn after addition, the content of the reactor

was poured into iced water (2 l). The precipitated solid was removed by filtration and washed with water until neutrality was obtained. The resulting yield was 97 % of chromatographically pure product, usable without any further purification after drying.

Recrystallization from ethanol gave white needles which melted at 98° C.

IR (KBr pellet) ν cm^{-1} : 1685 - 1695 (2 bands $\overset{\overset{1}{\text{C}}}{\text{C}} = \text{O}$) ; 1530 and 1560 (NO_2). $^1\text{H-NMR}$ (CDCl_3) δ ppm : 2.68 (s, methyl) ; 8.38 (d, H_1) ; 8.08 (q, H_6) ; 7.65 (d, H_5) ; $J_{56} = 8.1$ hz ; $J_{16} = 2$ hz.

Anal. calcd for $\text{C}_8\text{H}_6\text{NO}_3\text{Cl}$: C, 48.12 ; H, 3.00 ; N, 7.02 ; O, 24.1 ; Cl, 17.79 ; found : C, 48.24 ; H, 2.86 ; N, 6.99 ; O, 24.2 ; Cl, 17.70.

(4-chloro-3-nitro)-1-phenylethanol

8 g of sodium borohydride were added portionwise under stirring to a suspension of 40 g of 4-chloro-3-nitroacetophenone in 1 l of absolute ethanol by maintaining the temperature at about 15° C. The resulting mixture became clear, turning light brown and then colorless after half an hour. The solution was maintained at 15° C for another hour and then 200 ml of methanol were added to decompose the remaining hydride. After the mixture had been allowed to stand at room temperature for two hours, the solvents were removed by rotary evaporation and the viscous residue was worked up again into the smallest amount of ethylacetate. This solution was poured under strong stirring (turbine) into 500 ml of iced water to precipitate the desired material, which was filtered immediately. A second fraction (8 to 10 %) was extracted from water (in which the product is slightly soluble) with ethyl acetate, and after concentration of the solution the workup was as described above. After drying under a vacuum dessicator, a 95 % yield of chromatographically pure light yellow product was obtained. m.p. 54° C (lit. 48° C) B.p. = 130° C (0.6 Torr). Small amounts could be recrystallized from petroleum ether.

IR (KBr pellet) ν cm^{-1} : 3320 (OH) disappearance of the bands at 1690. $^1\text{H-NMR}$ (CCl_4) δ ppm : 1.40 (d, methyl) ; 2.9-3 (s, OH) ; 4.75 (q, H_α) ; 7.30 (s, H_5 , H_6) ; 7.63 (s, H_2).

Anal. calcd for $\text{C}_8\text{H}_9\text{NO}_3\text{Cl}$: C, 47.64 ; H, 3.97 ; N, 6.95 ; O, 23.80 ; Cl, 17.62 ; found : C, 47.54 ; H, 4.04 ; N, 6.98 ; O, 23.86 ; Cl, 17.50.

4-chloro-3-nitrostyrene

The preceding alcohol (100 g) was poured into a Claisen flask equipped with a small Vigreux column (5-6 cm) and an ice-cooled receiving apparatus without intermediate water refrigeration. 2.5 g of 4-toluenesulfonic acid were added to the melted mixture under magnetic stirring and vacuum (< 0,5 Torr) by heating to 90° C and by maintaining this temperature for an hour. Then, slow distillation of the styrene between 60° C and 100° C (according to the variations in pression) was provoked by increasing the temperature progressively. It should be noted that at the end of the reaction it is necessary to heat the flask to 160° C in order to complete the transformation. 93 % of a chromatographically pure compound melting at 30° C was obtained. This styrene cannot be recrystallized because of its high solubility in all organic solvents and its low melting point. Purification could be carried out by chromatography on a small silica column with CCl_4 as eluant.

IR (liq.) ν cm^{-1} : 1630 (vinyl) ; 1535, 1365 (NO_2), 3090 ($\text{C} = \text{CH}_2$) 990, 910 (vinyl) disappearance of the band OH at 3320.

$^1\text{H-NMR}$ (CDCl_3) δ ppm $\begin{array}{c} \text{H}_X \\ \diagdown \\ \text{C} \\ \diagup \\ \text{A}_Y \end{array} = \text{C} \begin{array}{c} \text{H}_A \\ \diagup \\ \text{C} \\ \diagdown \\ \text{H}_B \end{array}$: 5.43 (d, H_A) ; 5.82 (d, H_B).
 6.70 (q, H_X) ; 7.50 (H_5, H_6) ; 7.85 (H_2) ; $\text{J}_{\text{BX}} = 17$ Hz, $\text{J}_{\text{AX}} = 10$ Hz ;
 $\text{J}_{\text{AB}} = 0$ Hz.

Anal. calcd. for $\text{C}_8\text{H}_6\text{NO}_2\text{Cl}$: C, 52.32 ; H, 3.29 ; N, 7.63 ; O, 17.44 ; Cl, 19.34 ; found : C, 51.62 ; H, 3.13 ; N, 7.58 ; O, 17.62 ; Cl, 20.2.

4-amino-3-nitrostyrene

20 g of the preceding compound were poured into a 500 ml stainless steel autoclave containing a cooled solution of 12 g of anhydrous ammoniac in 150 ml of methanol.

The reactor was maintained at 150°C for 24 hours. After cooling, the mixture was allowed to come slowly to the atmospheric pressure and then the solvent was removed. The residue was washed with water and extracted with ether. After drying and elimination of the solvent, the crude product was recrystallized from hexane. 90 % of pure red needles, m.p. 83°C were obtained. Their characteristics are identical to those of (2).

3,4-diaminostyrene

The preceding nitro compound (20 g) was added to a hot hydroethanolic solution (120 ml ethanol + 120 ml water) of 120 g sodium sulfide ($\text{Na}_2\text{S}, 9\text{H}_2\text{O}$). After heating at reflux for 4 hours, the ethanol was removed and the remaining aqueous mixture extracted with ethylacetate. After drying (Na_2SO_4), the solvent was removed and the recrystallization was carried out by dissolving the crude product in boiling petroleum ether, giving white plates in 90 % yield, m.p. 52°C . Characteristics are identical to those of (2).

Polymerization of 4-amino-3-nitrostyrene

bulk

The polymerization was carried out by placing the monomer and the catalyst (Table I) in a sealed ampoule. The mixture was heated at 100°C for 2 days. The resulting vitreous solid was dissolved into the smallest possible amount of acetone and precipitated in an excess of petroleum ether. After filtration and drying, a white powder, melting at $230 - 250^\circ\text{C}$ was obtained.

emulsion

The monomer was added portionwise at reaction temperature to a deoxygenated aqueous emulsifier solution (Table I), under vigorous stirring and nitrogen sweeping. After 10 minutes the initiator was added, dissolved in a little water. After 24 hours the mixture was cooled and complete precipitation of the polymer was accomplished by dissolving aluminium sulfate. The solid was worked up and characterized as described above.

solution

The catalyst was added to a solution of 5 g of monomer in 20 ml of deoxygenated dimethylformamide (Table I) under nitrogen and stirring, and the mixture was maintained for 24 hours at the reaction temperature. After removing the solvent by rotary evaporation, the crude residue was worked up as previously described.

Copolymerization of 4-amino-3-nitrostyrene

The procedure was identical to that of polymerization starting from 5 g of monomer and comonomer in 15 ml of dimethylformamide (Table II). The copolymer was precipitated by pouring the mixture into methanol, then filtered and dried under vacuum. IR spectroscopy showed the characteristic superposition of the absorption bands of the two homopolymers.

CONCLUSION

The comparison between the copolymerization of 4-chloro-3-nitrobenzene and its (homo)polymerization underlines the difficulty of recovering high average molecular weight polymers, principally due to a deactivating transfer to the monomer. This drawback can be circumvented by the use of either active comonomers or initiators which operate at lower temperatures. The polymers obtained are suitable for attempting chemical transformations on the aromatic sites with the aim of introducing pendant heterocyclic groups. Further work is under way concerning the reaction of 4-chloro-3-nitrostyrene with other, more active, initiators, either in solution or in improved emulsion conditions. Its reaction with other monomers is also being studied, with the aim of elucidating the influence of the nitrophenyl group.

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