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THE CATIONIC POLYMERIZATION OF 3-*O*-ACETYL-β-L-ARABINOFURANOSE 1,2,5-ORTHOBENZOATE*

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ABSTRACT

Cationic polymerisation of 3-*O*-acetyl-β-L-arabinofuranose 1,2,5-orthobenzoate initiated by either triphenylcarbonium tetrafluoroborate or benzoylium perchlorate has been studied. The existence of living chains was demonstrated by termination of polymerisation with tritium-labelled 1-butanol. The number of growing chains reached a maximum after ~10 min and then decreased.

INTRODUCTION

The generalized mechanism of acid-catalyzed polymerisation of internal sugar orthoesters and their conversion into monomeric and dimeric anhydrides[2] suggested that the polymerisation of these compounds, when initiated by carbonium ions, would be an effective way for the formation of linear polysaccharides. It was expected for such a reaction that the formation of anhydrides would be suppressed and that chain growth would proceed at the reducing end. This possibility was demonstrated by the synthesis of D-xylan from 3-*O*-acetyl-α-D-xylopyranose 1,2,4-orthoacetate[1] and of L-arabinan from 3-*O*-acetyl-β-L-arabinofuranose 1,2,5-orthobenzoate[3] (**1**). We now describe a more-detailed study of the cationic polymerization of **1**.

RESULTS AND DISCUSSION

Preliminary experiments showed that the polymerization of **1** proceeds readily when initiated by carbonium ions and related compounds (*e.g.*, triphenylcarbonium salts, acylium salts, $MeOSO_2F$, *etc.*) in dichloromethane at 0–20° and under strictly anhydrous conditions. The polymerization initiated by triphenylcarbonium tetrafluoroborate was selected for study in more detail, as the d.p. of the resulting polysaccharides could be easily estimated from the trityl contents (each polysaccharide chain should contain a trityl group at the non-reducing end). To prove that cationic polymerisation occurs, the presence of living polysaccharide chains containing an active carbonium-ion group (acyloxonium ion) at the reducing end was demonstrated

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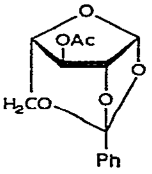
*The Synthesis of Polysaccharides: Part VI[1].

by termination of the reaction with tritium-labelled 1-butanol obtained by reduction of butyraldehyde with $NaBT_4$. The specific activity of the carbanilate of the labelled 1-butanol was unchanged after prolonged storage in acidic methanolic solution, thus demontrating the position of the tritium label for 1-butanol-*1-t* (at a C–H rather than O–H bond).

Termination of polymerization with 1-butanol-*1-t* showed that, in addition to the formation of butyl glycoside termini, two side-reactions occurred, namely significant detritylation of the products and the unexpectedly high introduction of the label into the polysaccharide. These reactions can be rationalized as follows. The coupling of each carbonium ion (initial or intermediate) with 1-butanol-*1-t* gives an equimolar amount of strong acid (HBF_4), which can catalyse both alcoholysis of trityl ethers and partial cleavage of polymer chains (both glycosidic and orthoester linkages) with the introduction of a labelled butyl residue at the point of cleavage. Immediate removal of the acid formed was therefore required, using a reagent which was unreactive towards growing chains and carbonium ions. For this purpose, the "proton sponge reagent" 1,8-bis(dimethylamino)naphthalene (DAN), which has a high basicity and extremely low nucleophilicity[4,5], was used. As far as we are aware, this is the first example of the practical use of this unique reagent in synthetic organic chemistry.



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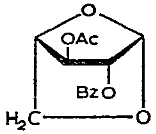

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Therefore, the polymerisation of **1** in dichloromethane initiated by triphenylcarbonium tetrafluoroborate (20:1) was carried out at 20°. After an appropriate time, the polymerization was terminated by addition of an excess of 1-butanol-*1-t* and DAN. Analysis of the mixture revealed $<1\%$ of anhydride **2**. After deacetylation and fractionation on Biogel P-4, polymeric material was obtained and analysed for arabinose[6] (*i.e.*, the yield of polysaccharide) and trityl contents[7], and for radioactivity (*i.e.*, the content of butyl residues, which is equal to the amount of growing chains). The ratio Ara:Tr gives the number average d.p.*, the ratio Bu:Tr gives the fraction of chains which are living, and the product Ara × Bu:Tr gives the yield of living chains. The results thus obtained are presented in Table I.

During polymerization, the reaction mixtures maintained the brillant yellow colour characteristic of triphenylcarbonium ions. Since the orthoester was present initially in a large excess over triphenylcarbonium ions, this observation is believed to

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*It should be taken into account that a small fraction of the inter-monomeric linkages may be of the orthoester type.

TABLE I

POLYMERIZATION OF 3-*O*-ACETYL-β-L-ARABINOFURANOSE 1,2,5-ORTHOBENZOATE (**1**)[a]

Expt.	*Duration (min)*	*Polysaccharide yield (%)*	*Ara:Tr*[b]	*Bu:Tr*[b]	*Yield of living chains (%)*
Initiator $Tr^+BF_4^-$; terminator BuOH					
1	0.5	6	154	0.60	4
2	10	49	82	0.47	23
3	20	47	90	0.31	15
4	40	35	180	0.24	8
5	80	55	160	0.16	9
6	160	66	150	0.10	6
7	320	67	160	0.07	5
8	480	70	170	0.06	4
9	640	69	155	0.03	2
Initiator $Tr^+BF_4^-$; terminator MeOH					
10	80	63	[c]		
Initiator $Bz^+ClO_4^-$; terminator MeOH					
11	40	44			

[a] **1** (0.20 mmol) in dichloromethane (1 ml) at 20°; initiation with triphenylcarbonium tetrafluoroborate or benzoylium perchlorate (0.01 mmol). [b] See Discussion. [c] No trityl in polysaccharide.

be evidence for the reversibility of the initiation stage. Gel-chromatography of the product mixture revealed oligosaccharide fractions having extremely low contents of trityl and tritium, but a substantial content of arabinose. A possible explanation is that intramolecular glycosylation of trityl ends by an acyloxonium ion of the same chain (*cf.* ref. 8) could lead to macrocyclic oligosaccharides similar to Schardinger dextrins[9]. This possibility is being studied further.

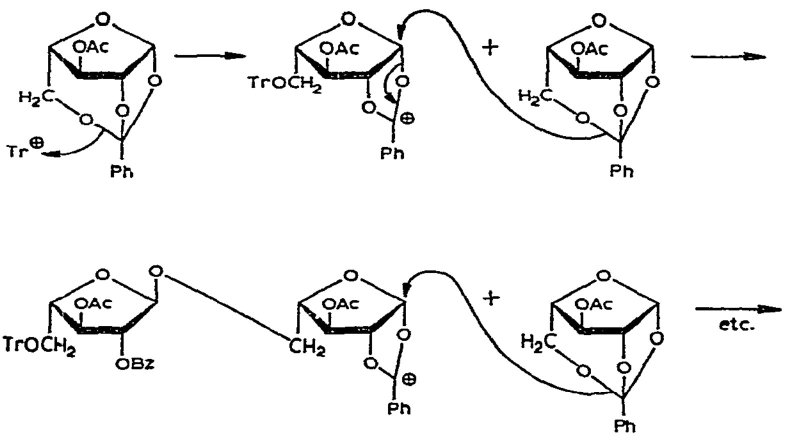
Termination of polymerization with a large excess of methanol in the absence of DAN leads, as expected, to a detritylated polysaccharide in a yield similar to that obtained when polymerization was terminated with 1-butanol-*1-t* and DAN (see Table I). Thus, this experiment proves that the combination alcohol–anhydrous HBF_4 is a specific detritylating reagent, which does not noticeably attack furanosidic linkages.

The foregoing data allow the following conclusions to be made.

(*1*) Cationic polymerization of the orthoester **1** proceeds smoothly and can be satisfactorily rationalized by the reaction mechanism shown in the annexed scheme. The main evidence for such a mechanism is the demonstration of the existence of living chains by the introduction of labelled alcohol residues.

(*2*) The absence of anhydrides from the reaction products is in complete agreement with the prediction made on the basis of the mechanism of anhydride formation[2], and therefore supports this mechanism.

(*3*) Chain growth is completed in ~1 hour, whereas the content of living chains begins to decrease after a few minutes of reaction. Probably, this is due to



reaction with solvent (*e.g.* chloride-ion abstraction from dichloromethane, *cf.* ref. 10) or to the traces of residual nucleophilic contaminants.

(*4*) The mild conditions and high rate of the reaction of the growing chains with the terminator suggest that graft polymerization leading to branched polysaccharides should be possible.

(*5*) As compared with addition polymerization[11], the cationic polymerization of the orthoester **1** proceeds very rapidly (10^5–10^6 times as fast taking into account the difference in temperature).

The initiation of polymerization with triphenylcarbonium has some undesirable features, namely the reversibility of the initiation step, the possibility of the formation of macrocyclic products, and the necessity for detritylation of the reaction products. The polymerization initiated with acylium ions should be free of these disadvantages. When polymerization was initiated with benzoylium perchlorate (generated from benzoyl chloride and silver perchlorate[12]), the results were similar to those obtained with triphenylcarbonium ion (see Table I).

The structural investigation of the polysaccharide synthesised by cationic polymerisation of the orthoester **1**, and the effect of initiator structure and reaction conditions will be described elsewhere.

EXPERIMENTAL

Orthoester[13,14] **1** and triphenylcarbonium tetrafluoroborate[15] were obtained as previously described; a modified method[4] was used for synthesis of DAN. Dichloromethane was purified as described earlier[3] and redistilled twice from CaH_2 in a high-vacuum system (see below) directly before use. T.l.c. was performed on silica gel, using chloroform–acetone (98:2). G.l.c. was performed on a Pye 105 chromatograph, using 3% of poly(neopentylglycol succinate) on Chromatone with nitrogen as the carrier gas and flame-ionization detection. Spectrophotometric measurements were performed using a Specol instrument, and radioactivity measurements were performed using a liquid scintillation counter Isocap-300 (Nuclear Chicago Corporation). Toluene scintillators containing PPO (5 g) and POPOP (0.2 g) in 1 litre of toluene were used for the compounds soluble in toluene, and containing PPO (660 mg), POPOP (16.5 mg), Triton X-100 (23.1 ml), and 5% aqueous trichloroacetic acid (10.8 ml) in toluene (43 ml) for water-soluble compounds (*cf.* ref. 16). Solutions were evaporated *in vacuo* at 40°.

1-Butanol-1-t. — To $NaBT_4$ (2.4 mg, 1.6 Ci/mmol, 100 mCi), freshly distilled butyraldehyde (0.20 ml, b.p. 74–75°) was added. The mixture was set aside overnight, then diluted with dry MeOH (2 ml), and distilled up to b.p. 65°. Freshly distilled 1-butanol (8 ml, b.p. 117.5–118°) was added to the residue, and the mixture was distilled, the fraction with b.p. 117.5° being collected. Labelled BuOH thus obtained (5.5 ml, 70%) had specific activity 1.93 mCi/mmol, as determined using toluene-*t* as an internal standard.

Butyl-1-t *carbanilate*. — The foregoing labelled 1-butanol (100 μl) was diluted with freshly distilled 1-butanol (53.7 vol.), and 0.50 ml of the resulting solution (5.50 mmol) was mixed with phenyl isocyanate (0.71 ml, 6.60 mmol) and dry pyridine (5 ml). After 3 h at 20°, the mixture was concentrated to dryness and the residue was twice recrystallized from light petroleum to give the carbanilate (0.78 g, 67%), m.p. 58–59° (lit.[17] m.p. 57–58°), with specific activity 0.033 mCi/mmol.

A solution of the carbanilate (0.75 g) in methanol (5 ml) containing 1% of formic acid was stored for 2 days at room temperature. Chloroform (5 ml) was then added, and the solution was concentrated to half volume. The procedure was repeated 5 times and the solution was then concentrated to dryness. The residue was recrystallised twice from light petroleum to give the carbanilate (0.65 g) with m.p. 58–59° and specific activity 0.032 mCi/mmol.

*Polymerization of 3-O-acetyl-β-*L*-arabinofuranose 1,2,5-orthobenzoate* (**1**). — (*a*) In the lower limbs of a tuning fork-shaped tube (⅄) were separately placed solutions of **1** (55.6 mg, 0.20 mmol) in benzene–dichloromethane (4:1, 1 ml), and triphenylcarbonium tetrafluoroborate (3.3 mg, 0.01 mmol) in dichloromethane (0.2 ml). A sealed capillary tube containing the terminating reagent (see below), as well as 5–6 glass beads (diameter 5–6 mm), were placed into the same tube. The contents were freeze-dried in a high vacuum, and dichloromethane (1 ml) was distilled into the tube, which was then sealed in a high vaccum. For experimental details of the high-vacuum technique, see ref. 1. The contents were carefully mixed and then stored at ~20° for an appropriate time. The capillary tube was then broken by means of the glass beads, and the contents of the tube were again mixed and kept at 20° for 5 min. The tube was opened and the reaction products were analysed as described below.

The solution of DAN (2.6 mg, 0.012 mmol) and 1-butanol-*1-t* (4.6 μl, 0.05 mmol) in dichloromethane (4–5 μl) was used as terminating reagent for experiments 1–9, and dry methanol (40 μl, 1.0 mmol) was used in experiment 10.

(*b*) Solutions of **1** (0.2 mmol) and silver perchlorate (2.5 mg, 0.012 mmol) in dry $MeNO_2$ (0.1 ml) were placed into the limbs of the ⅄-tube, as described above. A capillary containing freshly distilled benzoyl chloride (1.4 mg, 0.01 mmol) in dichloromethane (10 μl) and glass beads were also placed in the tube. After drying the tube contents and distillation of dichloromethane (1 ml) thereinto, the tube was sealed, and cooled to $-78°$, and reaction was initiated by breaking the capillary tube. The contents of the tube were mixed, heated during 15 min to room temperature, and maintained thereat for 40 min. The tube was opened, dry methanol (0.1 ml) was added, and the mixture was kept at room temperature for 30 min and then analysed as described below.

Treatment and fractionation of the products of polymerization. — A few drops of pyridine were added to the mixtures, which were then concentrated. The residues were treated with 0.1M methanolic MeONa (1 ml, 20°, 16 h), then neutralized with CO_2, and concentrated. The products were partitioned between water and ether (0.2 ml of each), and the aqueous layers were subjected to gel-permeation chromatography on a column (60 cm $\times$ 2.5 cm^2) of Biogel P-4 by elution with water (blue dextran and arabinose were eluted from the column with 38 and 118 ml, respectively). Fractions between 35 and 65 ml were collected and concentrated, and the residues were analyzed as follows.

Aliquots (50 μl) of the reaction mixtures (before deacetylation) were mixed with a 1% solution of 2,3,4-tri-*O*-acetyl-1,6-anhydro-β-D-glucopyranose (internal standard) in toluene (40 μl), and the solutions were analysed by g.l.c. (190°); the yields of anhydride **2** thus found were always $<1\%$.

Polymeric fractions (see above) were dissolved in water (5 ml). Aliquots (20 μl) were used for analysis of arabinose contents by the phenol–sulphuric acid method[6]. Aliquots (80 μl) were mixed with toluene scintillator (5 ml), and the resulting homogenous solutions were used for radioactive measurements (the radioactivity of butyl-*1-t* carbanilate as a standard was measured in the same scintillator solution in parallel experiments). The data obtained for the polymeric fractions were within the range of 10^3–2×10^4 c.p.m. Aliquots (80 μl) were mixed with 0.60 ml of water and 1.80 ml of conc. H_2SO_4, and the solutions were used for trityl determination[7].

REFERENCES

1 Part V: A. F. Bochkov, I. V. Obruchnikov, and N. K. Kochetkov, *Zh. Obshch. Khim.*, 44 (1974) 1197.

2 A. F. Bochkov, I. V. Obruchnikov, V. N. Chernetsky, and N. K. Kochetkov, *Carbohyd. Res.*, 36 (1974) 191.

3 A. F. Bochkov, V. N. Chernetsky, and N. K. Kochetkov, *Izv. Akad. Nauk SSSR, Ser. Khim.*, (1975) 465.

4 R. W. Alder, P. S. Bowman, W. R. S. Stelle, and D. R. Winsterman, *Chem. Commun.*, (1968) 723.

5 R. W. Alder and J. E. Andersson, *J. Chem. Soc. Perkin II*, (1973) 2086.

6 H. M. Dubois, K. A. Gilles, J. K. Hamilton, P. A. Rebers, and F. Smith, *Anal. Chem.*, 28 (1956) 350.

7 H. C. Srivastava, K. V. Kamalingam, and S. Chakrabarti, *Indian J. Chem.*, 7 (1969) 98.

8 A. F. Bochkov and N. K. Kochetkov, *Carbohyd. Res.*, 39 (1975) 355.

9 D. French, *Advan. Carbohyd. Chem.*, 12 (1957) 189.

10 W. S. Johnson, M. B. Gravestock, R. J. Parry and D. A. Okerie, *J. Amer. Chem. Soc.*, 94 (1972) 604.

11 N. K. Kochetkov, A. F. Bochkov, and I. G. Yazlevetsky, *Carbohyd. Res.*, 9 (1969) 49.

12 G. A. OLAH, S. J. KHUN, W. S. TOLGYESI, AND E. B. BAKER, *J. Amer. Chem. Soc.*, 84 (1962) 2733
13 N. K. KOCHETKOV, A. YA. KHORLIN, A. F. BOCHKOV, AND I. G. YAZLOVETSKY, *Izv. Akad. Nauk SSSR, Ser. Khim.*, (1966) 2030.
14 A. F. BOCHKOV, YA. V. VOZNY, V. N. CHERNETSKY, A. V. RODIONOV, AND V. M. DASHUNIN, *Izv. Akad. Nauk SSSR, Ser. Khim.*, (1975) 420.
15 H. J. DAUBEN AND L. R. HONNEN, *J. Org. Chem.*, 25 (1960) 1442.
16 B. W. FOX, *J. Appl. Rad. Isotopes*, 19 (1968) 717.
17 L. BOUVEAULT AND G. BLANC, *Bull. Soc. Chim. Fr.*, (3) 31 (1904) 673.