A Modified Prins Reaction Applicable to Conjugated Dienes

By **Jan J. S. Bajorek, Reto Battaglia, Graham Pratt,** and **James K. Sutherland,*** Chemistry Department, The University, Manchester M13 9PL

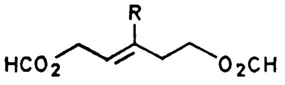
Reactions of butadiene, isoprene, and cyclopentadiene with paraformaldehyde in formic acid yield 1,5-diol diformates.

IN connection with some synthetic work we required a method for the homologation and functionalisation of conjugated dienes. The Prins reaction [1] has been widely used for the homologation of olefins but is frequently unsatisfactory because of the variety of products formed; this stems mainly from secondary reactions of the introduced hydroxymethyl group such as acetal and ether formation. If the hydroxy-group could be protected *in situ* then some of these difficulties could be overcome. It appeared to us that use of formic acid as solvent could fulfil the following conditions: (*a*) the acid would be strong enough to activate formaldehyde and produce kinetically active amounts of hydroxymethyl cation; (*b*) it would not protonate the conjugated diene system; (*c*) it would acylate the introduced hydroxymethyl group; and (*d*) it would act as a nucleophile to discharge the intermediate carbonium ion. In the event, the reaction of paraformaldehyde with butadiene in formic acid for 6 days at ambient temperature gave a 35 : 65 mixture of 1,2- (3) and 1,4- (1) adducts (73%). On warming the mixture at 65° in formic acid the ratio changed to the equilibrium value of 62 : 38.

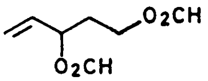
---

[1] For reviews see E. Arundale and L. A. Mikeska, *Chem. Rev.*, 1952, **51**, 505; V. I. Isagulyants, T. G. Khaimova, V. R. Meilikyan, and S. V. Pokrovskaya, *Russ. Chem. Rev.*, 1968, **37**, 17. For previous reactions with dienes, see M. C. Beets and E. A. Drubber, *Rec. Trav. chim.*, 1953, **72**, 247; E. Hanschbe, *Chem. Ber.*, 1955, **88**, 1043; M. Hellin and M. Davidson, *Bull. Soc. chim. France*, 1964, 2974; 1964, 800; B. F. Ustaushchikou and V. Sh. Fel'dblyum, *Uch. Zap. Yarosl. Tekh. Inst.*, 1960, **5**, 105.

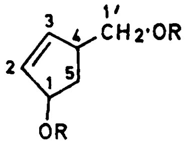
This mixture could be efficiently separated into the pure isomers by spinning-band distillation, and since the 1,2-adduct could be converted into the equilibrium mixture, the 1,4-adduct is a readily available starting material. The diformate (1) has been converted into a number of useful polyfunctional derivatives of (*E*)-pent-2-ene, *viz.* 1,5-dihydroxy-, 1,5-dibromo-, 1-acetoxy-5-bromo-, and 5-bromo-1-hydroxy-. The reaction of isoprene with paraformaldehyde in formic acid for 12 h gave only a 16% yield of a 75 : 25 mixture of the *E*- and *Z*-isomers of (2). However better results were obtained with cyclopentadiene: a 65% yield of a 50 : 50 mixture of the *cis*- and *trans*-isomers of (4) was isolated which could be hydrolysed to the mixture of diols (5). From an analysis of the n.m.r. spectrum of the mixture it was possible to show by decoupling that the spin systems shown in the Figure were present. System A was assigned to the *cis*-isomer because of the large difference in chemical shift between the α- and β-protons of the C-5 methylene group and because of the identity of $J_{1,5\beta}$ and $J_{4,5\beta}$ and of $J_{1,5\alpha}$ and $J_{4,5\alpha}$. That both A and B are 1,4- rather than 1,2-adducts follows from the chemical shifts and couplings indicated. The constitutions of the diols were confirmed by hydrogenation of the mixture to the dihydro-compounds, which on oxidation yielded 3-oxocyclopentanecarboxylic acid.



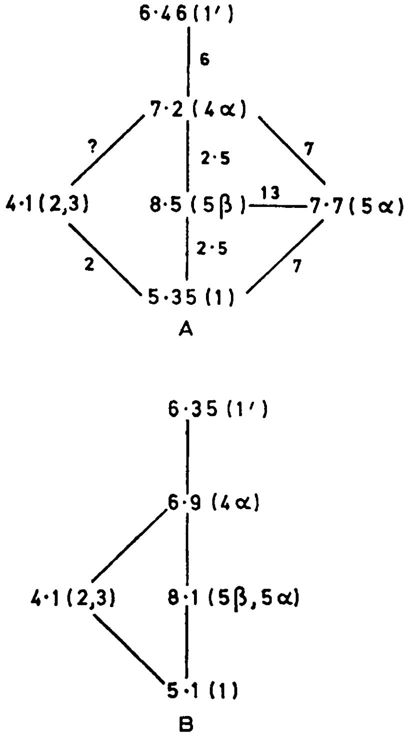
(1) R = H
(2) R = Me



(3)



(4) R = CHO
(5) R = H



Spin systems present in the diol mixture (5) (τ values; assignments in parentheses: J values in Hz indicated on the lines)

EXPERIMENTAL

N.m.r. spectra were recorded at 60 MHz for solutions in CCl_4 with Me_4Si as internal standard unless otherwise noted. ' Worked up in the usual way ' implies dilution of the reaction mixture with water, extraction with ether, and washing of the extract with sodium hydrogen carbonate solution.

Reaction of Butadiene with Formaldehyde and Formic Acid.—Butadiene (90 ml) was distilled into a mixture of paraformaldehyde (8 g) and formic acid (200 ml) maintained at −70°. The resulting mixture was shaken at ambient temperature in an autoclave for 6 days. Work-up gave a 35 : 65 mixture of 1,4- and 1,2-adducts (30·8 g). On heating at 65° in formic acid (300 ml) the ratio was changed to 62 : 38. Spinning-band distillation separated ***1-vinyltrimethylene diformate*** (3), b.p. 63·5—66·5° at 1·3 mmHg, τ 1·97 (1H, s), 2·02 (1H, s), 3·8—5·0 (4H, m), 5·83 (2H, t, J 8 Hz), and 7·96 (2H, q, J 8 Hz); and ***pent-2-enylene diformate*** (1), b.p. 81—81·5° at 1·3 mmHg, τ 1·98 (2H, s), 4·1—4·34 (2H, m), 5·39 (2H, d, J 4 Hz), 5·79 (2H, t, J 8 Hz), and 7·54 (2H, q, J 8 Hz) (Found: C, 53·0; H, 6·3. $C_7H_{10}O_2$ requires C, 53·2; H, 6·4%).

*Pent-*2-*ene-*1,5-*diol.*—A mixture of the diformate (1) (16·64 g) and sodium hydrogen carbonate (20 g) in methanol (165 ml) and water (33 ml) was refluxed for 1 h. Most of the methanol was removed *in vacuo* and, after filtration, the solution was continuously extracted with ethyl acetate overnight. Concentration of the extract gave the ***diol*** (6) (10·34 g), b.p. 86° at 0·07 mmHg, τ (after D_2O exchange) 4·30 (2H, m), 5·94 (2H, m), 6·40 (2H, t, J 7 Hz), and 7·72 (2H, m) (Found: C, 58·0; H, 9·8. $C_5H_{10}O_2$ requires C, 58·8; H, 9·9%).

*Pent-*2-*enylene Dibromide.*—The diol (6) (11 g) was stirred in acetonitrile (200 ml) and carbon tetrabromide (77 g) was added, followed by triphenylphosphine (66 g) during 20 min with cooling. After 16 h the mixture was poured into water (1 l) and extracted with petroleum (b.p. 40—60°; 3 × 300 ml). After drying ($MgSO_4$) the filtered solution was concentrated until crystals appeared. When crystallisation was completed the solid was filtered off, the filtrate concentrated, and the residue distilled to give the ***dibromide*** (7) (20·5 g), b.p. 57—60° at 0·01 mmHg (contaminated with a small quantity of bromoform), τ 4·13—4·40 (2H, m), 6·0—6·21 (2H, m), 6·68 (2H, t, J 7 Hz), and 7·2—7·65 (2H, m) [Found (purified sample): Br, 70·2. $C_5H_8Br_2$ requires Br, 70·1%].

5-*Bromopent-*2-*en-*1-*ol.*—Tetraethylammonium acetate (15 g) in acetone (130 ml) was added during 40 min to the dibromide (7) (15 g) in acetone (100 ml) cooled to 0°. After stirring overnight the mixture was worked up as usual and the product (11·8 g) refluxed with methanol (115 ml) and water (12 ml) containing sodium hydrogen carbonate (5·8 g) for 2 h. Work-up as usual followed by chromatography on grade IV alumina and elution with benzene gave the *alcohol* (4·3 g), b.p. 52—53° (bath) at 0·05 mmHg, τ (after D_2O exchange) 4·25—4·60 (2H, m), 5·97 (2H, m), 6·65 (2H, t, *J* 7 Hz), and 7·2—7·6 (2H, m) (Found: C, 36·5; H, 5·6. C_5H_9BrO requires C, 36·4; H, 5·5%). The intermediate *acetate* could also be purified; τ 4·2—4·45 (2H, m), 5·4—5·6 (2H, m), 6·66 (2H, t, *J* 7 Hz), 7·2—7·6 (2H, m), and 7·9 (3H, s).

Reaction of Isoprene with Formaldehyde in Formic Acid.—Paraformaldehyde (16·5 g) was added to a cooled (0°) and stirred mixture of isoprene (50 ml) in formic acid (500 ml). After removal of coolant the suspension was stirred for 12 h at ambient temperature. Work-up in the usual way gave a crude product (65 g) which on distillation gave a mixture of (Z)- and (E)-3-*methylpent*-2-*enylene diformate* (13·6 g), b.p. 60—65° at 0·1 mmHg, τ 2·00 (2H, s), 4·63 (1H, m), 5·36 (2H, d, *J* 8 Hz), 5·76 (2H, t, *J* 7 Hz), 7·55 (2H, q, *J* 7 Hz), and 8·19 and 8·23 (3H) (Found: C, 56·1; H, 7·1. $C_8H_{12}O_2$ requires C, 55·8; H, 7·00%).

Reaction of Cyclopentadiene with Formaldehyde in Formic Acid.—Formic acid (100 ml) was refluxed with paraformaldehyde (14 g) until a clear solution was obtained. The stirred solution was cooled to —10° and paraformaldehyde (10 g) was added, followed slowly by freshly prepared cyclopentadiene (12·9 g). After 2 h the solution was allowed to warm to ambient temperature and stirred for a further 60 h. Work-up in the usual way gave an orange oil (26·9 g) which was rapidly distilled (b.p. 100—150° at 0·05 mmHg) and the distillate was separated by column chromatography [silica gel (500 g); elution with 9 : 1 benzene–acetone] into three fractions. The first (15·7 g), b.p. 84° at 0·1 mmHg, τ 1·92 (1H, s), 1·98 (1H, s), 3·75—4·4 (3H, m), 5·85 (2H, m), and 6·5—8·4 (3H, m) (Found: C, 56·3; H, 6·2. $C_8H_{10}O_4$ requires C, 56·4; H, 5·9%) was the mixture of 4-*formyloxycyclopent*-2-*enyl formates* (4). The second (4·73 g), b.p. 86° at 0·1 mmHg, τ 3·7—4·4 (2H, m), 5·5—6·0 (2H, m), 6·2—6·5 (1H, m), and 6·7—8·6 (3H, m), *m*/*e* 96, 78, and 66, was probably 2-oxabicyclo[2.2.1]hept-5-ene, and the third was polymeric material.

4-*Hydroxymethylcyclopent*-2-*enol* (5).—Aqueous 10% sodium hydroxide was added to a solution of the diformates (4) (3·1 g) in ethanol (50 ml) until the solution remained alkaline. The usual work-up yielded the *diols* (5) (1·85 g), b.p. 82° at 0·05 mmHg, characterised as the *bis*-p-*phenylbenzoates*, m.p. 130—131° (Found: C, 80·5; H, 5·3. $C_{32}H_{26}O_4$ requires C, 80·8; H, 5·4%).

3-*Oxocyclopentanecarboxylic Acid.*—The diols (5) (229 mg) in methanol (4 ml) were hydrogenated over 5% rhodium–charcoal at ambient temperature and pressure. Filtration and concentration gave diols (204 mg) (*m*/*e* 116) which were oxidised with Jones reagent. Work-up in the usual way yielded a sodium hydrogen carbonate-soluble fraction (158 mg), which after distillation and recrystallisation (benzene–pentane) yielded the acid, m.p. 63—64·5° (lit.,[2] 64—65°); methyl ester 2,4-dinitrophenylhydrazone, m.p. 180—181° (lit.,[3] 182°).

We thank Dr. C. M. M. Halls for experimental assistance and the S.R.C. and Schweizerischer Nationalfonds for financial assistance.

[4/150 *Received*, 25*th January*, 1974]

---

[2] R. K. Hill, P. J. Foley, and L. A. Gardella, *J. Org. Chem.*, 1967, **32**, 2330.

[3] T. Katsuyubi, *Bull. Chem. Soc. Japan*, 1959, **32**, 233.