Tetrahedron Letters No.35, pp. 3823-3827, 1968. Pergamon Press. Printed in Great Britain.

1,2- AND 1,4-CYCLOADDITION OF CHLOROSULFONYL ISOCYANATE TO DIENES

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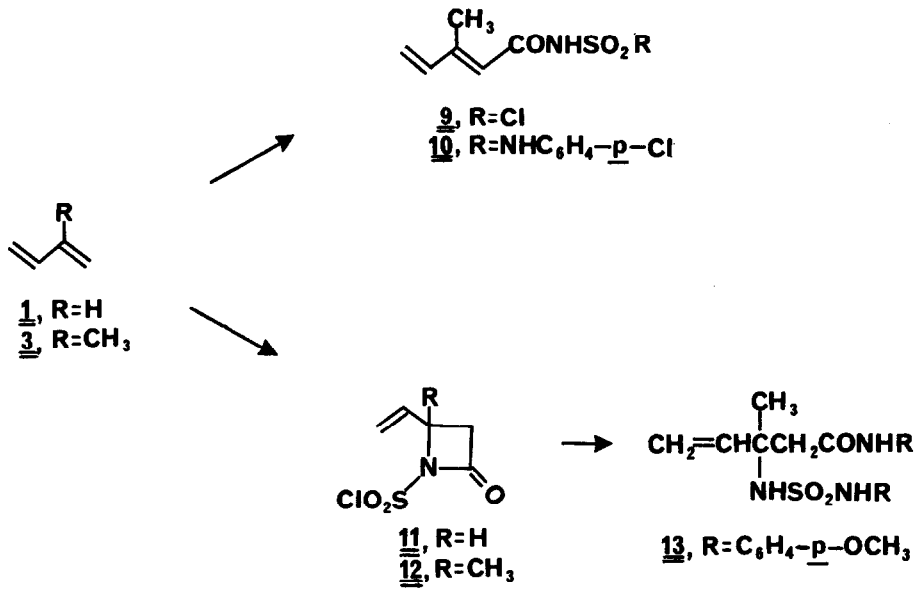
(Received in USA 2 May 1968; received in UK for publication 4 June 1968)

Hoffmann and Diehr[2] have reported on the addition of chlorosulfonyl isocyanate (CSI) to the conjugated dienes, 1,3-butadiene (1), 1-phenyl-1,3-butadiene (2), isoprene (3), 2,3-dimethyl-1,3-butadiene (4), 1,3-pentadiene (5), 2-methyl-1,3-pentadiene (6), 2,4-hexadiene (7), and cyclopentadiene (8). Typically, 3, on treatment with CSI at room temperature led to the N-chlorosulfonylcarboxamide 9, isolated as the p-chloroanilide (10), while an ethereal solution of 3 and CSI at 0° produced, after workup with p-anisidine, the dianilide 13.

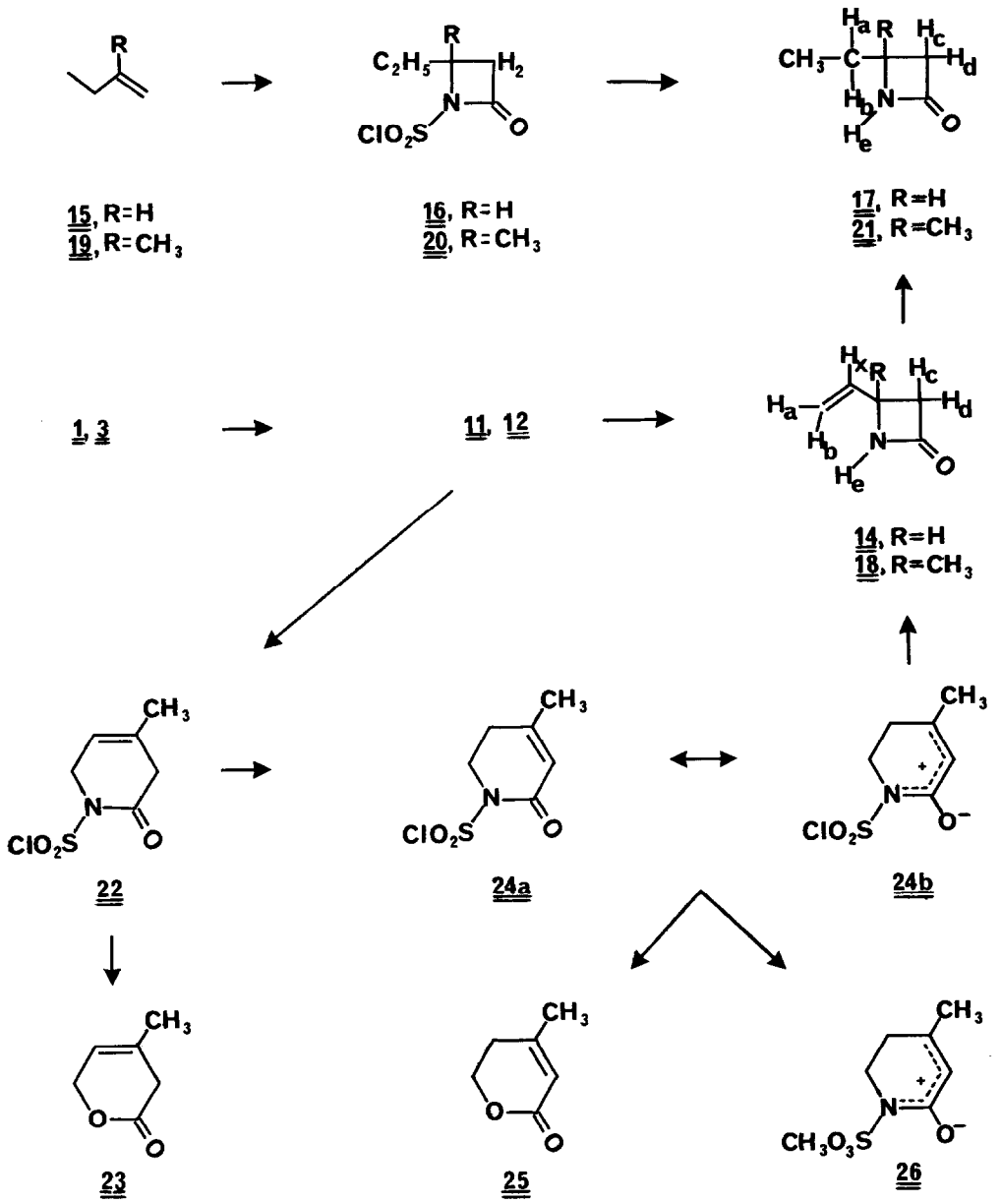


Despite the author's own cautionary statement, "Das Reaktionsvergebnis ist dabei sehr stark von den Reaktionsbedingungen abhängig," they attempted to deduce the structure of the β-lactam precursors (e.g., 11 and 12) from the anilide products, and therefrom, the mode of addition of CSI to dienes 1-8. The net result has been correct CSI cycloaddition products from 2, 3 and 5, their own uncertainty as to the β-lactam structures from 4, 6 and 7, and an incorrect mode of CSI cycloaddition to 1 and probably 8.

We have examined the reaction of CSI with 1, 3, 4 and 5 at considerably lower temperatures, isolated and identified the 1,2-cycloaddition product in each case, and have observed a series of unique 1,2-→1,4- rearrangements[3] of the initial N-chlorosulfonyl-β-lactam products which were obscured by the rigor of Hoffmann and Diehr's reaction conditions and isolation procedures.

Using isoprene (3) as an exemplary substrate (Chart I), addition of CSI in ether solution to an equimolar quantity of 3 in the same solvent at -65°, followed by a slow temperature rise to -10° and then cooling again to -65°, precipitated, in 60-80% yield, 12, mp 28-30°; $\lambda_{C=O}^{KBr}$ 1815 cm^{-1}; nmr($CDCl_3$) δ 6.49-6.04 (four peaks, 1, =CH), 5.62-5.42 (four peaks, 2, $=CH_2$), 2.23 (s, 2, CH_2) and 1.90 (s, 3, CH_3) The N-chlorosulfonyl-β-lactam 12 can be washed repeatedly with cold ether, but is unstable to recrystallization. Careful hydrolysis of 12 in ether with a saturated methanolic solution of sodium hydroxide afforded, in 50% yield, 18,[4] bp 62°/0.2 mm; $\lambda_{C=O}^{neat}$ 1750 cm^{-1}; nmr (CCl_4) δ 7.82 (broad mound, 1, H_e), 6.35-4.94 (m, 3, ABX pattern where H_x consists of four peaks between 6.35-5.83, $J_{ax} + J_{bx}$ = 27.5 Hz, and H_a and H_b are a complex multiplet between 5.45-4.94), 2.72 (d, 2, $J_{ce} = J_{de}$ = 1.50 Hz, H_c and H_d) and 1.48 (s, 3, CH_3). Hydrogenation (Pd-C) of an ethanolic solution of 18 led to the same 3-ethyl-3-methyl-2-azetidinone (21),[4,5] bp 72°/0.2 mm, obtained via CSI addition to 2-methylbutene (19), followed by benzenethiol-pyridine reduction of the N-chlorosulfonyl-β-lactam 20. Reaction of CSI with 1 in ether at reflux (16°) for one week similarly afforded 11. Since all attempts to isolate 11 led to decomposition or polymerization, it was immediately reduced with benzenethiol-pyridine to give the expected β-lactam 14[4] as a clear liquid, bp 67-68°/0.3 mm. Hydrogenation of 14 led to 17,[4] identical to that obtained via the route

CHART I


15, R=H
19, R=CH3
16, R=H
20, R=CH3
17, R=H
21, R=CH3
1, 3
11, 12
14, R=H
18, R=CH3
22
24a
24b
23
25
26

15→16→17.

On warming to 40° for 1 hr, the 1,2-cycloadduct 12 in ether solution, ring opened and recyclized to the unstable 1,4-adduct 22 ($\lambda_{C=O}^{neat}$ 1701 cm^{-1})[6] which was hydrolyzed with sodium hydroxide in methanol to the lactone 23[4] (22% overall yield from 3); $\lambda_{C=O}^{neat}$ 1749 cm^{-1}; nmr (CCl_4) δ 5.62 (m, 1, =CH), 4.76 (m, 2, OCH_2), 2.89 (s,[7] 2, $COCH_2$) 1.78 (s,[7] 3, CH_3), ultraviolet (end absorption). The further isomerization of 22 to 24 was effected in refluxing ether (5 hr); alternatively, the dropwise addition of an equimolar amount of 3 to CSI in refluxing ether (6 hr) converted it directly to 24. In both instances, cooling to -65° precipitated light orange crystals; a cold ether wash followed by recrystallization from CH_2Cl_2—ether gave analytically pure 24,[4] mp 81-82°, in 31% yield from 3; λ_{max}^{EtOH} 256 mμ (ε 16,000); nmr ($CDCl_3$) δ 6.06 (s,[7] 1, =CH), 4.68 (t, 2, J = 6.7 Hz, CH_2NSO_2Cl), 2.63 (rough triplet, 2, J = 6.7 Hz, $=CCH_2$) and 2.17 (s, 3, CH_3). The infrared spectrum (KBr) of 24 showed no carbonyl absorption; however with decreasing polarity of solvent ($CHCl_3$, C_6H_6, CCl_4) a carbonyl band made its appearance with maximum intensity in CCl_4 at 1725 cm^{-1}.[8] In CCl_4, the spectrum must reflect the presence of the non-polarized lactam form 24a. The dipolar forms 24b are stabilized with increasing polarity of solvent with the maximum dipolar contribution to the resonance hybrid in the solid state. The fact that the ultraviolet spectrum of 24 in ethanol is unaltered on acidification strengthens these conclusions. Hydrolysis of 24 with NaOH-CH_3OH in ether led to the known δ-lactone of 5-hydroxy-3-methyl-2-propenoic acid (25);[9] $\lambda_{C=O}^{neat}$ 1735 cm^{-1}; nmr (CCl_4) δ 5.65 (s,[7] 1, =CH), 4.28 (t, 2, J = 6.2 Hz, CH_2O), 2.48 (t, 2, J = 6.2 Hz, $=CCH_2$) and 1.98 (s,[7] 3, CH_3); λ_{max}^{EtOH} 213 mμ (ε 11,000). Similar treatment of 24 with NaOH-CH_3OH in acetone led to two products, 25 and the methyl sulfonate ester 26, in 1:9 ratio. Sulfonate ester 26 was obtained as yellow platelets (from CH_2Cl_2-hexane), mp 80-82°; nmr ($CDCl_3$) δ 6.02 (s, 1, =CH), 4.50 (t, 2, J = 6.5 Hz, $CH_2NSO_3CH_3$), 3.89 (s, 3, OCH_3), 2.42 (t, 2, J = 6.5 Hz, $=CCH_2$) and 2.08 (s, 3, CH_3).

REFERENCES

1) NASA Predoctoral Research Trainee, 1966-1969.

2) H. Hoffmann and H.J. Diehr, Tetrahedron Letters, 1875 (1963).

3) Cf. the competitive formation of cyclobutane and cyclohexene adducts in the reaction of 4-methyl-1,3-pentadiene and tetracyanoethylene: C.A. Stewart, J. Am. Chem. Soc., 84, 117 (1962).

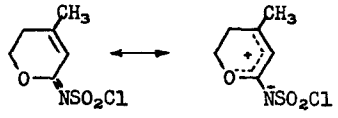
4) This compound was analyzed for C, H and N and acceptable analyses (± 0.3%) were obtained.

5) Nmr (CCl_4) δ 7.66 (broad mound, 1, H_e), 2.58 (d, 2, $J_{ce} = J_{de} = 1.0$ Hz, H_cH_d), 1.89-1.46 (m, 2, magnetically non-equivalent H_a and H_b, $\Delta\nu H_aH_b = 2.0$ Hz), 1.37 (s, 3, CH_3) and 0.95(distorted triplet, 3, CH_2CH_3).

6) This isomerization can be followed by monitoring the carbonyl shift in the infrared.

7) With fine splitting.

8) Alternate structures for 24 which have been considered include:



Mitigating against these iminoether structures is the appearance of C=O absorption in non-polar solvents, and the deshielded chemical shift of the CH_2NSO_2Cl protons in 24 (relative to the CH_2O protons in 25).

9) J.W. Cornforth, R.H. Cornforth, G. Popjak and I.Y. Gore, Biochem. J., 69, 146 (1958).

Acknowledgement. - This research was supported by Public Health Service Research Grant No. 1-RO1-A108-063-01 from the National Institute of Allergy and Infectious Diseases. The authors thank The New York State Science and Technology Foundation for Grant SSF(7)-6 to the Department of Chemistry for the purchase of the A-60-A nmr spectrometer.