A 300-ml round-bottomed flask, equipped with a rubber septum inlet, a thermometer well, a magnetic stirring bar, and a condenser[8] (the top of which provides an outlet attached to a mercury bubbler), was flushed with nitrogen. Into the flask was introduced 32.5 ml of 3.1 *M* borane in tetrahydrofuran (100 mmoles of BH_3). The flask was cooled to 0° and 8.7 g (103 mmoles) of 2,3-dimethyl-2-butene[9] was added to form the thexylborane. Stirring was continued for 1 hr at 0° to ensure completion of the reaction. Isobutylene (100 mmoles) dissolved in tetrahydrofuran was added and allowed to react at 0° for 30 min. Then 11.8 g (105 mmoles) of ethyl vinylacetate was added. The mixture was allowed to stand for 2 hr at 0°. Then 3.6 ml of water (200 mmoles) was added and the mixture was transferred into a 250-ml stainless steel autoclave under nitrogen. Carbonylation was achieved by filling the autoclave with carbon monoxide to 70 atm and maintaining at 50° for 3 hr. (Actually, the theoretical quantity of carbon monoxide was absorbed within 1 hr.) The material was transferred to a glass flask, 34 ml of 3 *M* sodium acetate (102 mmoles) was added, and oxidation carried out by the addition of 34 ml of 30% hydrogen peroxide. The rate of addition was controlled to maintain the temperature in the range of 30–40°. The reaction mixture was then maintained for 1 hr at 50° to ensure completion of the oxidation. After cooling, the aqueous layer was saturated with potassium carbonate and the organic phase was separated. The aqueous phase was again extracted with ether. After drying the combined extracts, distillation yielded 16.1 g (84%) of ethyl 7-methyl-5-oxooctanoate, bp 102–104° (4 mm), essentially pure by glpc and pmr examination.

[8] In our experiments the condenser was attached to a gas meter to permit a material balance on the utilization of hydride. However, this is not essential for the ordinary preparation.

[9] Originally we used material from the Phillips Petroleum Co. At the moment it is no longer available from that organization, so that we have been using material from Chemical Samples Co., Columbus, Ohio 43221.

[10] Postdoctorate Research Associate on a grant (GM-10937) supported by the National Institutes of Health.

Herbert C. Brown, Eiichi Negishi[10]
Richard B. Wetherill Laboratory
Purdue University, Lafayette, Indiana 47907

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"Allylic Bromination" by N-Bromoacetamide. A Reexamination

Sir:

The Wohl–Ziegler reaction, allylic bromination by N-bromo amides and imides,[1] is so named because the definitive experiments by Ziegler[2] which established the unique effectiveness of N-bromosuccinimide (NBS) were prompted by Wohl's earlier work with N-bromoacetamide (NBA).[3] Although Ziegler confined his own observations on the NBA reaction to the comment that[2] "die von Wohl mitgeteilten Ergebnisse auf einen nicht eben glatten Reaktionsverlauf schliessen lassen," Wohl's work has otherwise been universally accepted.[4–6]

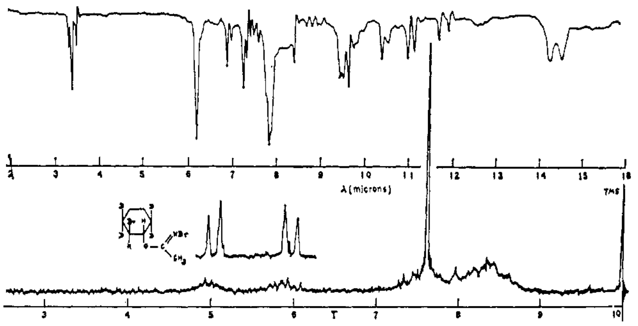

Figure 1. Infrared and nmr spectra of 2-bromocyclohexyl N-bromoacetimidate.

We now report that the principal *initial* reaction of NBA with olefins is complete within minutes in refluxing carbon tetrachloride in the presence of light,[7] that this reaction produces isolable adducts of a new type, and that there is no allylic bromination. The stoichiometry of the addition reaction has been determined using varying molar ratios of olefin to NBA and has been found to be[8]

$$\text{olefin} + 2CH_3CONHBr \longrightarrow \text{adduct} + CH_3CONH_2 \qquad (1)$$

Thus, cyclohexene (4.1 g, 0.05 mole) in CCl_4 (10 ml) was added rapidly to a refluxing suspension of NBA (6.9 g, 0.05 mole) in CCl_4 (40 ml), refluxing being maintained by the heat of a photoflood lamp mounted underneath the reaction flask. Within 5 min the solid NBA had disappeared and droplets of acetamide could be seen. The colorless mixture was cooled in ice until crystallization of the acetamide was complete and this was then collected (1.54 g; 104% based on eq 1). The mother liquor was distilled under reduced pressure to a residue of 8.1 g. The distillate was found to contain 1.6 g of cyclohexene[9] (80%, based on eq 1). The residue, diluted with 30–60° petroleum ether (10 ml) and stored overnight at −20°, afforded 0.07 g (1%) of *trans*-2-acetamidocyclohexyl bromide (**1**), mp 110–111° (lit.[10] 109–110°). The filtrate was concentrated, ethyl ether (1 ml) was added, and this solution was kept overnight at −20°. The massive crystals then obtained weighed 2.64 g (36%)[11] and melted at 28.0–28.5°. The compound (*Anal.* Calcd for $C_8H_{13}NOBr_2$: C, 32.12; H, 4.38; N, 4.72; Br, 53.46. Found: C, 32.34; H, 4.25; N, 4.69; Br, 53.57) is assigned structure **2** on the basis of this analysis and its infrared and nmr spectra, shown in Figure 1, together with the observation that thermal decomposition gives

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[1] (a) C. Djerassi, *Chem. Rev.*, **43**, 271 (1948); (b) L. Horner and E. H. Winkelmann in "Newer Methods of Preparative Organic Chemistry," Vol. III, W. Forest, Ed., Academic Press Inc., New York, N. Y., 1964, p 151.

[2] K. Ziegler, A. Spath, E. Schaaf, W. Schumann, and E. Winkelmann, *Ann.*, **551**, 80 (1942).

[3] (a) A. Wohl, *Ber.*, **52**, 51 (1919); (b) A. Wohl and K. Jaschinowski, *ibid.*, **54**, 476 (1921).

[4] J. D. Park, H. J. Gerjovich, W. R. Lycan, and J. R. Lacher, *J. Am. Chem. Soc.*, **74**, 2189 (1952).

[5] R. E. Buckles, R. C. Johnson, and W. J. Probst, *J. Org. Chem.*, **22**, 55 (1957).

[6] E. Ucciani and M. Naudet, *Bull. Soc. Chim. France*, 1151 (1960).

[7] A 100-w photoflood No. 2 lamp with reflector was used.

[8] The substitution reaction envisaged by Wohl and others requires the formation of 1 mole of acetamide/mole of NBA. Buckles, *et al.*,[5] were especially interested in this point but could recover only 55–65% of the theoretical amount of acetamide calculated on this basis.

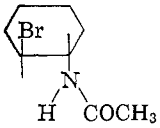
[9] Determined by titration with a standardized solution of Br_2 in CCl_4.

[10] T. L. Cairns, P. J. Graham, P. L. Barrick, and R. S. Schreiber, *J. Org. Chem.*, **17**, 751 (1952).

[11] No attempt was made to optimize the recovery of crystalline material. The residue after removal of the adduct weighed 4.91 g (64%) and its infrared spectrum was identical with that of the crystals.

principally *trans*-dibromocyclohexane and cyclohexene bromohydrin.[12,13]

The most characteristic features of the infrared spectrum are the strong bands at 6.2 and 7.85 μ, assigned, respectively, to the C=N[14] and C–O–C groupings. The nmr absorptions centered at τ 4.96, 5.87, 7.6, and 8.34 contain, respectively, one, one, three, and eight protons. That the addition to the double bond is *trans*[15] was determined by preparation of the adduct of cyclohexene-3,3,6,6-d_4.[16] The AB quartet shown for this compound has J = 9.0 Hz. Comparison of this latter spectrum with that previously[16] recorded for cyclohexene-3,3-6,6-d_4 bromohydrin indicates that H_A is at τ 4.96 and H_B at τ 5.87.



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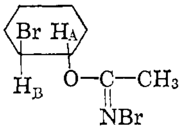

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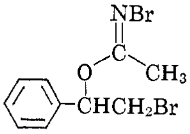

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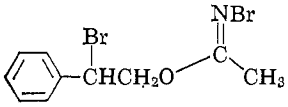

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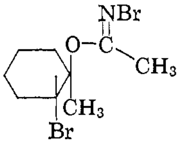

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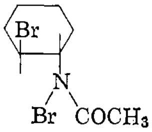

6

The adduct prepared analogously from tetramethylethylene[17,18] had mp 40–41°. The styrene adduct[17] was shown to have structure **3** rather than **4** by comparison of its nmr spectrum with that of styrene bromohydrin (styrene + HOBr) and its derived acetate. The adduct from 1-methylcyclohexene[17] was similarly assigned structure **5**.

The observations made so far indicate that the Wohl reaction must be reinterpreted in terms of a process in which bromine and N-bromoacetimidyl fragments add successively to a double bond. Although the initial stages of the reaction involving only the NBA are undoubtedly radical in nature,[19] the actual addition to the double bond need not be. Homolysis of NBA (eq 2) must be followed by rapid exchange (eq 3 or 4) which generates an N-bromoacetimidyl radical. Step 4 would be followed rapidly by steps 5[20] and then 6, the latter being necessary to account for the absence of unsaturated bromides or dibromoolefins as *primary* products.[12,13] The sequences 4, 5, 6 and 2, 3, 7 each lead to N,N-dibromoacetamide (NDBA), a compound mentioned only once[21] in the chemical literature. Interestingly, NDBA undergoes rapid addition to cyclohexene in the dark to produce **2** and the isomeric N-bromo amide **6**, mp 76°.[17] The brominating properties of NDBA, its role in NBA reactions, and the question of whether the addition to the double bond is ionic or radical are being investigated further.

$$CH_3CONHBr \longrightarrow CH_3CONH + Br \tag{2}$$

$$CH_3CONH + CH_3CONHBr \longrightarrow CH_3CONH_2 + CH_3CONBr \tag{3}$$

$$Br + CH_3CONHBr \longrightarrow HBr + CH_3CONBr \tag{4}$$

$$HBr + CH_3CONHBr \longrightarrow Br_2 + CH_3CONH_2 \tag{5}$$

$$Br_2 + CH_3CONBr \longrightarrow Br + CH_3CONBr_2 \tag{6}$$

$$CH_3CONBr + CH_3CONHBr \longrightarrow CH_3CONBr_2 + CH_3CONH \tag{7}$$

Acknowledgment. We thank the National Research Council of Canada for the support of this work.

Saul Wolfe, D. V. C. Awang
Department of Chemistry, Queen's University
Kingston, Ontario, Canada
June 30, 1967

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[12] Both of these products are the result of *intramolecular* rearrangements (S. Wolfe and D. V. C. Awang, to be published).

[13] 3-Bromocyclohexene is not a product of the thermal decomposition of **2** but *is* formed in low yield when **2** is pyrolyzed in the presence of excess cyclohexene. The fate of the imido moiety in the pyrolysis has not yet been established.

[14] L. J. Bellamy, "The Infra-red Spectra of Complex Molecules," John Wiley and Sons, Inc., New York, N. Y., 1962, pp 267–270.

[15] The geometry of the >C=NBr grouping was not established.

[16] S. Wolfe and P. G. C. Campbell, *Can. J. Chem.*, **43**, 1184 (1965).

[17] Satisfactory analytical and spectral data were obtained.

[18] The same compound was obtained using the conditions reported by Wohl.[3a]

[19] Bromine is produced when a solution of NBA in carbon tetrachloride is refluxed in the absence of an olefin. If the volatile material is slowly swept out of the system and the solvent removed when there is no further bromine evolution, the residue is found to consist of acetamide.

[20] P. Goldfinger, P. A. Gosselain, and R. H. Martin, *Nature*, **168**, 30 (1951).

[21] A. W. Hoffmann, *Ber.*, **15**, 407 (1882).

1,3-Asymmetric Induction in a Transamination Reaction[1]

Sir:

We have observed that when optically pure, deuterated imine (−)-(*S*)-I-*d* is isomerized by heating in *t*-butyl alcohol–potassium *t*-butoxide, the product is essentially optically pure (+)-(*R*)-II-*d*. The only other nonenzymatic and stereospecific 1,3-proton transfers of which we are aware involve tertiary amines as catalysts and indenes as substrates.[2]

Reduction of pivalonitrile with lithium aluminum deuteride[3] gave deuterated pivalaldehyde, which with α-phenylethylamine, α^{25}D −38.18° (neat, l = 1 dm),[4] was converted to imine (−)-(*S*)-I-*d*,[5] α^{25}D −42.48° (neat, l = 1 dm), 99.6% of one atom of deuterium/molecule (combustion and falling drop). This material (17.0 g) was heated at 75° for 78 hr in a 0.45 *M* solution of potassium *t*-butoxide to give a mixture of imines separated by preparative vpc on a 30% silicone gum column at 180° (20 ft × 3/8 in.) with helium as carrier gas. Starting material, (−)-(*S*)-I-*d*, 4.8 g (28%), α^{25}D −40.5° (neat, l = 1 dm), was recovered, retention time 25 min, and product, (+)-(*R*)-II-*d*, 8.7 g (54%), α^{25}D +5.24° (neat, l = 1 dm), retention time 41 min, was obtained. In eight runs with reaction times that varied between 10 and 126 hr (10% II, 90% I to 87% II, 13% I) α^{25}D (neat, l = 1 dm) varied from 5.62 to 5.16°.

A sample of (+)-(*R*)-II-*d* (2.9 g), α^{25}D +5.36° (neat, l = 1 dm), was hydrolyzed with concentrated hydrochloric acid in acetone to give neopentylamine-α-*d* hydrochloride (82%), mp 300–301° (evacuated tube), which was treated with 40% sodium hydroxide to give

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[1] This research was supported in part by the Directorate of Chemical Sciences, Air Force Office of Scientific Research Grant No. AF-AFOSR-124-65, and by the U. S. Army Research Office, Durham. The authors express their thanks.

[2] L. Ohlsson, I. Wallmark, and G. Bergson, *Acta Chem. Scand.*, **20**, 750 (1966).

[3] H. C. Brown and C. P. Gary, *J. Am. Chem. Soc.*, **86**, 1085 (1964).

[4] W. Theilhacker and H. G. Winkler, *Chem. Ber.*, **87**, 690 (1954).

[5] All new compounds reported here gave carbon and hydrogen analyses within 0.3% of theory.