tion to remove the solvent gave 3.5 g. of residue which partially solidified at room temperature. The crude product was distilled and the major fraction collected at 109–112° (2.5 mm.). The distillate solidified, m.p. 29.5–31°. Recrystallization from pentane yielded an analytical sample as fluffy, colorless needles, m.p. 30–31°.

Anal. Calcd. for $C_{12}H_{16}O_2$: C, 74.97; H, 8.39. Found: C, 75.08; H, 8.35.

The acyloin absorbs strongly at 5.94 μ in the infrared and at 246.5 mμ in the ultraviolet (ε 10,100), absorption maxima characteristic of phenyl ketones.

Isomerization of Phenylpivalylcarbinol and Benzoyl-*t*-butylcarbinol.—A mixture of the acyloin (in one case 2.0 g. of phenylpivalylcarbinol; in the other case 0.2 g. of benzoyl-*t*-butylcarbinol) and 10% of its weight of potassium cyanide in 6–10 ml. of 50% aqueous ethanol was refluxed for 3 hours. The mixture was extracted with several portions of pentane, and the dried extracts (sodium sulfate) were allowed to evaporate *in vacuo*. The infrared spectra of the two residues matched each other and the spectrum of the crossed condensation product except for very slight differences in the relative heights of the carbonyl absorption bands at 5.87 and 5.94 μ.

A second sample of phenylpivalylcarbinol (2.0 g.) and 1 ml. of 10% sodium hydroxide in 10 ml. of 50% aqueous ethanol was refluxed for 2 hours. The mixture was extracted as before to yield a residue whose infrared spectrum possessed all of the features of those referred to above.

A sample of phenylpivalylcarbinol was recovered unchanged after refluxing for 2 hours in the presence of dilute hydrochloric acid.

Spectral Analysis of the Crossed Condensation Product.— A series of synthetic mixtures of phenylpivalylcarbinol and benzoyl-*t*-butylcarbinol ranging in composition from 60 to 77% benzoyl-*t*-butylcarbinol were prepared and their infrared spectra determined. Comparison of the relative heights of the carbonyl peaks in the spectrum of the condensation product with the heights of the corresponding peaks in the reference spectra led to the assignment of the composition, 61% benzoyl-*t*-butylcarbinol and 39% phenylpivalylcarbinol to the condensation product and 60 to 70% benzoyl-*t*-butylcarbinol in the mixtures of isomers produced by the isomerization of both pure isomers. The absorption of the condensation product at 246.5 mμ indicated the presence of 77% benzoyl-*t*-butylcarbinol, and the mixtures produced by alkaline isomerization of the pure isomers were found to contain from 74 to 82% benzoyl-*t*-butylcarbinol. It was demonstrated by means of a synthetic mixture of the pure isomers that the ultraviolet absorption method provides a very reliable measure of the amount of benzoyl-*t*-butylcarbinol present if impurities other than phenylpivalylcarbinol are known to be absent. It was therefore concluded that some impurity, most likely benzoin, which is absent in the synthetic mixtures, is responsible for the discrepancy in the composition determination by the two methods.

COLUMBIA, SOUTH CAROLINA

The Stereochemistry of the Reaction of Alkyl Halides with Silver Nitrite[1,2]

BY NATHAN KORNBLUM, LEON FISHBEIN AND ROBERT A. SMILEY

When optically active 2-bromoöctane is treated with silver nitrite the 2-nitroöctane and 2-octyl nitrite produced both have the inverted configuration and both are optically pure or very nearly so. The same result is obtained with active 2-iodoöctane. In contrast, the reaction of optically active α-phenylethyl chloride with silver nitrite yields α-phenylethyl nitrite of the same configuration as the chloride and α-phenylnitroethane of the opposite configuration from the halide; furthermore, the α-phenylethyl nitrite and α-phenylnitroethane are far from optically pure. The stereochemical relationships between alcohols and nitrite esters in the α-phenylethyl and in the 2-octyl systems have been established.

The present study is part of a program designed to gain an insight into the mechanism of the reaction of silver nitrite with alkyl halides. The literature on the stereochemistry of this reaction consists of a statement alleging that when 2-bromoöctane reacts with silver nitrite the 2-nitroöctane and 2-octyl nitrite produced have the same configuration as the 2-octyl bromide.[3] The present investigation demonstrates that the reverse is actually true.

Fortunately, configurational relationships in the 2-octyl and in the α-phenylethyl systems are well established. In each system the chloride, bromide, iodide, alcohol, nitrite ester and amine possessing the same sign of rotation belong to the same configurational series (see Chart I). Furthermore, the rotations of the optically pure alcohols, nitrites and

(1) Paper VII in the series "The Chemistry of Aliphatic and Alicyclic Nitro Compounds."

(2) This research was supported by the United States Air Force under Contract No. AF 18 (600)-310 monitored by the Office of Scientific Research, Air Research and Development Command.

(3) B. Eistert, "Chemismus und Konstitution," Ferdinand Enke, Stuttgart, Germany, p. 301, 1948. This statement apparently is based on a paper by R. H. Eastman and S. D. Ross, THIS JOURNAL, 68, 2398 (1946). Actually, Eastman and Ross briefly investigated the reaction of (+)α-phenylethyl chloride with silver nitrite, but aside from the fact that the α-phenylethyl nitrite produced had undergone considerable racemization, no stereochemical conclusions can be drawn from their paper.

CHART I

	-Cl	-Br	-I	Y -OH	-ONO	-NH₂
n-C₆H₁₃CHY- CH₃	(+)[a,b,c]	(+)[b,c]	(+)[b,c]	(+)[a,b,c]	(+)[d]	(+)[c,e]
C₆H₅CHYCH₃	(+)[b,c,f]	(+)[b,c]		(+)[b,c,f]	(+)[g]	(+)[c,h]

[a] A. J. H. Houssa, J. Kenyon and H. Phillips, *J. Chem. Soc.*, 1700 (1929). [b] E. D. Hughes, C. K. Ingold and S. Masterman, *ibid.*, 1196–1270 (1937). [c] E. D. Hughes, C. K. Ingold, P. Brewster and P. Rao, *Nature*, 166, 178 (1950). [d] N. Kornblum and E. P. Oliveto, THIS JOURNAL, 71, 226 (1949); S. J. Cristol, A. Shadan and B. Franzus, Abstract of Kansas City Meeting, March 24–April 1, 1954; p. 20N. [e] P. A. Levene and A. Rothen, *J. Biol. Chem.*, 115, 423 (1936). [f] J. Kenyon and H. Phillips, *J. Chem. Soc.*, 173 (1933). [g] N. Kornblum and S. A. Herbert, Abstract 121st National Meeting, American Chemical Society, March 30–April 3, 1952, Milwaukee, Wisc., p. 61K. [h] P. A. Levene, A. Rothen and M. Kuna, *J. Biol. Chem.*, 120, 777 (1937).

amines are known. However, with the exception of α-phenylethyl chloride, the rotations of the optically pure halides have not been established. The rotations of the optically pure alcohols, nitrites and amines are given in Table I; also included are the highest recorded rotations of the halides.

The 2-Octyl System.—A total of six runs were made using optically active 2-bromoöctane; these are summarized in Table II. The rotations of Table II all were obtained using very carefully purified products.

Compound	$[\alpha]^t{}_D{}^a$	t, °C.	Reference
2-Octanol	$10.3 \pm 0.3°$	25	g,h,i,j
2-Bromoöctane	-42.1^b	20	i
2-Iodoöctane	-49.6^c	20	i
2-Octyl nitrite	$+4.55^{*d}$	27	k
2-Aminoöctane	$+5.15^*$	17	l
	$+5.14^*$	19	l
α-Phenylethanol	-44.0	16	m
	-44.35^*	16	m
α-Phenylethyl chloride	$+109^{*e}$	25	n
α-Phenylethyl nitrite	$+59.6^{*f}$	25	o
α-Phenylethyl amine	-38.73^*	19	p
	-37.95^*	25	p

^{a} All rotations taken on the pure liquid compound in a 1-dm. tube; asterisk signifies observed rotation. ^{b} Calculated from Brauns' value $[\alpha]^{20}D$ $-40.6°$ to correct for the fact that the 2-octanol employed by him had $[\alpha]^{20}D$ $+9.93°$. ^{c} Calculated from Brauns' value $[\alpha]^{20}D$ $-47.87°$ to correct for the fact that his 2-octanol had $[\alpha]^{20}D$ $+9.93°$. ^{d} Calculated from the value $\alpha^{27}D$ $+4.10°$ obtained for 2-octyl nitrite prepared from 2-octanol of $[\alpha]^{26}D$ $+9.32°$ (90% optically pure). ^{e} The rotation of optically pure α-phenylethyl chloride lies between $\alpha^{25}D$ $109°$ and $\alpha^{25}D$ $126°$ (cf. ref. n). ^{f} The conversion of α-phenylethyl alcohol to α-phenylethyl nitrite using nitrosyl chloride occurs with retention of configuration and with complete retention of optical purity (see Experimental). From this, and correcting for the fact that Herbert's α-phenylethanol was only 76% optically pure, Herbert's value of $\alpha^{25}D$ $+45.3°$ for the nitrite becomes $\alpha^{25}D$ $+59.6°$. ^{g} N. Kornblum, N. N. Lichtin, J. T. Patton and D. C. Iffland, THIS JOURNAL, 69, 309 (1947). ^{h} R. L. Shriner and J. H. Young, ibid., 52, 3332 (1930). ^{i} H. Brauns, Rec. trav. chim., 65, 803 (1946). ^{j} C. S. Marvel and C. Hsueh, THIS JOURNAL 50, 855 (1928). ^{k} This paper. ^{l} F. G. Mann and J. W. G. Porter, J. Chem. Soc., 456 (1944); F. G. Mann and J. Reid, ibid., 3384 (1950). ^{m} W. Gerrard, ibid., 106 (1945). ^{n} R. L. Burwell, A. D. Shields and H. Hart, THIS JOURNAL, 76, 908 (1954). ^{o} S. Herbert, Ph.D. Thesis, Purdue University, 1952, p. 85. ^{p} B. Holmberg, Ber., 45, 999 (1912); A. W. Ingersoll, "Organic Syntheses," Coll. Vol. II, John Wiley and Sons, Inc., New York, N. Y., 1943, p. 503.

It is clear that the reaction of 2-bromoöctane with silver nitrite gives 2-octyl nitrite having the inverted configuration.[4] In order to establish the configurational relationship of 2-nitroöctane to the bromide, the nitro compound was reduced to the amine. Dextrorotatory 2-nitroöctane gives dextrorotatory 2-aminoöctane.[5] Since a Walden inversion could not have occurred in the reduction, the amine and nitro compound have the same configuration. Clearly, 2-nitroöctane is produced with inversion. Because the rotation of optically pure 2-bromoöctane is not known the precise degree of stereospecificity in the reaction of 2-bromoöctane with silver nitrite cannot be stated. There can be no doubt, however, that this is a highly stereospecific reaction.

Consider, for example, run 6 of Table II. The

$$ROH \longrightarrow RBr \longrightarrow RONO \qquad (1)$$

sequence is accomplished with 83% retention of optical purity, while

$$ROH \longrightarrow RBr \longrightarrow RNO_2 \longrightarrow RNH_2 \qquad (2)$$

goes with 82% retention of optical purity.[6] How-

(4) See Chart I.

(5) N. Kornblum and L. Fishbein, THIS JOURNAL, 77, 6266 (1955).

(6) For a detailed discussion of run 6 see the Experimental portion of this paper.

ever these percentage retentions of optical purity are unquestionably too low. This is apparent from runs 4 and 5 (Table II) where 2-bromoöctane was treated with silver nitrite sufficient to react with but half of the bromide. The "unreacted" 2-bromoöctane was found to have undergone 21% and 19% racemization.[7] It is not possible to say what fraction of the 2-bromoöctane is racemized prior to reaction with silver nitrite in runs conducted in the ordinary way (1.5 moles of silver nitrite per mole of 2-bromoöctane) but a reasonable estimate is 5 to 10%.

There is a second reason for believing that the reaction of 2-bromoöctane with silver nitrite occurs with distinctly more than 82–83% stereospecificity. If it were only 82–83% stereospecific then conversion of 2-octanol to the bromide would have to occur without any racemization whatsoever. But this is not the case. Brauns,[8] by using an insufficiency of phosphorus tribromide and conducting the reaction at 0° for 14 days, claims to have converted 2-octanol of $[\alpha]^{20}D$ $+9.93°$ into 2-bromoöctane of $[\alpha]^{20}D$ $-40.64°$; the ratio of specific rotations of his bromide to alcohol is 4.09. In the present work this ratio ranged from 3.22 to 3.45, the average of six runs being 3.34.

A ratio of 3.34 means that in going from 2-octanol to 2-bromoöctane 18% racemization occurred,[9] a value whose accuracy hinges on the accuracy of Brauns' determination of the specific rotation of 2-bromoöctane. If Brauns' value is in error by being too high, then the percentage racemization calculated for our conversions of 2-octanol to 2-bromoöctane will also be too high. Scrutiny of Brauns' paper reveals that the value he gives for the specific rotation of 2-bromoöctane probably errs by being a little on the high side.[10]

Bearing in mind that a calculation of % racemization incurred in going from 2-octanol to 2-bromoöctane which employs Brauns' values leads to a high estimate, let us consider run 6 in which the ratio of the specific rotation of 2-bromoöctane to that of the alcohol is 3.39. This corresponds to 17% racemization (83% retention of optical purity) in the step ROH → RBr. Now since the entire sequence of equation 1 occurs with 83% retention of optical purity the conclusion would appear to be that the step RBr → RONO occurs with 100% retention of optical purity. But, since some racemization of the bromide occurs prior to reaction with silver nitrite it is clear that the estimate of % racemization arrived at by using Brauns' values is too high; this, in turn, must mean that Brauns' specific rotation for 2-bromoöctane is somewhat too high.

(7) Racemization and rearrangement of alkyl bromides in the presence of silver bromide has been observed previously: W. Doering and M. Farber, THIS JOURNAL, 71, 1514 (1949); C. L. Arcus and G. V. Boyd, J. Chem. Soc., 1582 (1951).

(8) H. Brauns, Rec. trav. chim., 65, 805 (1946).

(9) To illustrate, take run 5 (Table II) which has a ratio 31.4/9.4 which equals 3.34. Now, from Brauns' ratio of 4.09 the bromide should have had a specific rotation of 9.4 × 4.09 = 38.45°. Since the bromide obtained in run 5 had $[\alpha]^{27}D$ 31.41 it would have 31.41/38.45 × 100% optical purity, which is 82% and, thus, an 18% loss in activity is incurred in going from ROH → RBr.

(10) The extent of racemization incurred in going from 2-octanol to 2-bromoöctane has been a vexed question ever since Hughes, Ingold and Masterman (J. Chem. Soc., 1137 (1937)) called attention to this problem and attempted to calculate the answer (cf. ref. 8).

TABLE II

SUMMARY OF THE REACTIONS OF OPTICALLY ACTIVE 2-BROMOÖCTANE WITH SILVER NITRITE[a]

Run	2-Octanol [α]D	t, °C	2-Bromoöctane [α]D	t, °C	2-Octyl nitrite [α]D	t, °C	% Retention of optical purity for ROH→ RONO	2-Nitroöctane [α]D	t, °C	2-Aminoöctane[b] [α]D	t, °C	% Retention of optical purity for ROH→ RNH2
1[c]	−7.32°*	29	+31.62°*	28	.....	..		−16.06°[i]	25	−2.80°*	26	63
	−8.99	29	+29.31	28								
2[d]	−7.17*	27	+32.85*	26	−3.22*	26	83	−12.77*	26	−0.17*	27	4
	−8.8	27	+30.4	26								
3[e]	+7.31*	28	−31.34*	29	+6.1[h]	30	86	+16.4[h]	30	+3.09*	25	69
	+8.96	28	−29.08	29								
4[f]	−7.60*	26	+34.09*	27	−3.05*	27	74	−14.28*	29	−3.12*	16	67
	−9.32	26	+27.03*[i]	27								
5[f]	+7.65*	27	−33.93*	27	+3.03*	27	73	+14.77*	27	+3.38*	14	72
	+9.4	27	−27.34*[i]	27								
6[g]	−7.55*	30	+33.83*	32	−3.39*	27	83	−14.19*	28	−3.81*	27	82
	−9.28	30	+31.50	32								

[a] Unless otherwise noted, all optical determinations were made on the pure liquid compound in a 1-dm. tube; asterisk represents observed rotation. [b] In runs 1, 3, 4 and 5 reduction of 2-nitroöctane to 2-aminoöctane was carried out in glacial acetic acid at 3–4 atmospheres pressure over Adams PtO2 catalyst; in run 6 reduction was accomplished with iron and glacial acetic acid. The 2-nitroöctane formed in run 2 was reduced with platinum oxide in absolute ethanol; this produces largely racemized 2-aminoöctane (cf. ref. 5). [c] Used 1.5 moles of AgNO2 for 1 mole RBr; reaction at 0° for 24 hours, then at reflux temperature for 24 hours. [d] Used 1.5 moles of AgNO2 for 1 mole RBr; reaction at 0° for 24 hours, then at room temperature for seven days. [e] Used 1.5 moles of AgNO2 for 1 mole RBr; reaction at 0° for 24 hours, then at room temperature for 60 hours. [f] Used 0.5 mole of AgNO2 for 1 mole RBr; reaction at 0° for 15 hours, then at room temperature for 60 hours. [g] Used 1.5 moles of AgNO2 for 1 mole of RBr; reaction at 0° for 96 hours. [h] C = 5.0, abs. ethanol. [i] C = 6.6, abs. ethanol. [j] "Unreacted RBr."

It follows then that the major fraction, and perhaps all, of the 17–18% racemization of the sequences of equations 1 and 2 is to be attributed to processes other than the reaction of silver nitrite with 2-bromoöctane. This reaction yields 2-nitroöctane and 2-octyl nitrite with complete retention (or something very close to complete retention) of optical purity.

When levorotatory 2-iodoöctane was treated with silver nitrite, dextrorotatory 2-octyl nitrite and dextrorotatory 2-nitroöctane were obtained. The 2-nitroöctane was reduced[5] to dextrorotatory 2-aminoöctane. Consequently, the nitro compound and the nitrite ester are both produced with inversion.

Since the rotation of optically pure 2-iodoöctane has not been established one cannot say whether its reaction with silver nitrite is free of racemization. But there can be no doubt that, here again, the reaction is highly stereospecific. The sequence

$$ROH \longrightarrow RI \longrightarrow RONO \qquad (3)$$

goes with 74% retention of optical purity (26% racemization) while the sequence

$$ROH \longrightarrow RI \longrightarrow RNO_2 \longrightarrow RNH_2 \qquad (4)$$

takes place with 79% retention of optical purity.

From the following considerations it is evident that our conversion of 2-octanol to 2-iodoöctane occurred with at least 12% racemization. The highest rotation recorded for 2-iodoöctane is due to Brauns[8] who obtained $[\alpha]^{20}D$ −47.87°[11] for a sample prepared from 2-octanol of $[\alpha]^{20}D$ +9.93°. Thus the ratio of specific rotations of Brauns' iodide and alcohol is 4.82. The 2-octanol used by us had

(11) In Table I this value has been corrected to take account of the fact that the 2-octanol employed was not optically pure.

$[\alpha]^{27}D$ +9.58° and so the 2-iodoöctane, at a very minimum, should have had $[\alpha]^{27}D$ = 9.58 × 4.82 = 46.2°. Instead it possessed $[\alpha]^{27}D$ −40.75° which means at least 12% racemization in the step ROH → RI. However, this use of the ratio 4.82 assumes that −47.87° is the specific rotation of optically pure 2-iodoöctane. Since this is not necessarily so, 12% racemization is the lower limit for the step ROH → RI.

No attempt was made to learn whether 2-iodoöctane is racemized by silver iodide. It seems very likely, however, that some racemization of 2-iodoöctane occurs prior to its conversion to 2-octyl nitrite and 2-nitroöctane.[12]

In summary, little, or none, of the racemization of sequences 3 and 4 can be attributed to the reaction of silver nitrite with 2-iodoöctane; this reaction gives 2-nitroöctane and 2-octyl nitrite of the inverted configuration and with little or no loss of optical purity.

The α-Phenylethyl System.—Table III summarizes the results of three runs in which α-phenylethyl chloride was treated with silver nitrite. These data, in conjunction with the configurational relationships of Chart I reveal that the α-phenyl nitroethane is produced with inversion whereas the α-phenylethyl nitrite has the same configuration as the chloride from which it is made.[13]

A second notable departure from the pattern of the 2-octyl series is the large amount of racemization which occurs when α-phenylethyl chloride is

(12) In this connection note the report that optically active 2-iodoöctane on treatment with silver iodide at 73° suffers as much as 40% loss of optical activity. H. Schechter and T. Moritsugu, Abstracts of Papers, 121st Meeting of American Chemical Society, March 30, 1952, p. 69k.

(13) This striking observation is discussed in the summary paper of this series. N. Kornblum, et al., THIS JOURNAL, 77, 6269 (1955).

TABLE III

SUMMARY OF THE REACTIONS OF OPTICALLY ACTIVE α-PHENYLETHYL CHLORIDE WITH SILVER NITRITE[a]

Run	α-Phenylethanol[b] α_D	t, °C.	Opt. purity, %	α-Phenylethyl chloride α_D^i	t, °C.	Opt. purity, %	α-Phenylethyl nitrite[b,d] α_D^i	t, °C.	Opt. purity, %	α-Phenyl nitroethane α_D^i	t, °C.	α-Phenylethyl amine[b,e] α_D^i	t, °C.	Opt. purity, %
1[f]	−17.24°	33	39	−20.68°	29	19	−4.25°	32	7.2	+1.28°	32	+3.20°	32	8.4
2[f]	−35.99	28	81	−43.65	28	40	−8.45	26	14	+2.80	27	+6.50	27	17
3[g]	+4.94	28	28	+10.86[h]	27	....	....					....		
				+0.90[i]	27									

[a] All rotations given in this Table are observed rotations which, unless otherwise noted, were taken on the pure liquid compound in a 1-dm. tube. [b] The rotations for optically pure α-phenylethyl alcohol, nitrite and amine are given in Table I, along with the maximum rotation observed for the chloride. [c] % retention of optical purity for ROH → RCl in runs 1–3 are 49, 49%, —, respectively. [d] % Retention of optical purity for RCl → RONO in runs 1–3 are 38, 36%, —, respectively. [e] % Retention of optical purity for RCl → RNH₂ in runs 1–3 are 44, 43, —, respectively. [f] Used 1.5 moles of AgNO₂ for 1 mole of RCl; reaction at 0° for 24 hours. [g] Used 0.5 mole of AgNO₂ for 1 mole of RCl; reaction at 0° for 22 hours. [h] l 2 dm. [i] "Unreacted RCl," l 2 dm. (92% racemization).

treated with silver nitrite (Table III).[14] Thus, in the single step RCl → RONO the α-phenylethyl nitrite retains only 36–38% of the optical purity of the α-phenylethyl chloride. Moreover, after exposure to silver chloride at 0° for 22 hours the "unreacted" α-phenylethyl chloride has only 8% of its original activity (run 3). Under such circumstances any attempt to arrive at an estimate of the stereospecificity of the reaction of α-phenylethyl chloride with silver nitrite is but an exercise in arithmetic.

Experimental[15]

Reaction of Active 2-Bromoöctane with Silver Nitrite.— The details for run 6 (Table II) illustrate the general procedure. (−)-2-Octanol, b.p. 65° (4 mm.), n^{20}D 1.4264, α^{30}D −7.55°, d^{30}_4 0.813,[16] [α]^{30}D −9.28°, was converted to the bromo compound with phosphorus tribromide.[17] Rectification[18] gave a 76% yield of (+)-2-bromoöctane, b.p. 60–61° (5 mm.), n^{20}D 1.4500, α^{32}D +33.83°, d^{32}_4 1.074,[18] [α]^{32}D +31.5°.

In a one-liter three-necked flask fitted with a mercury sealed tantalum stirrer, an addition funnel, and a condenser connected to two Dry Ice traps, was placed 104 g. (0.675 mole) of silver nitrite (Mallinckrodt, dried over potassium hydroxide) and 300 ml. of anhydrous ether. The reaction flask was cooled to 0° and then, with continuous stirring (in the absence of light), 87 g. (0.45 mole) of the (+)-2-bromoöctane, n^{20}D 1.4500, α^{32}D +33.83°, d^{32}_4 1.074,[18] [α]^{32}D +31.5°, was added, dropwise, over a three-hour period. After addition was complete, the mixture was stirred at 0° for 96 hours; only at the end of this time was a negative Beilstein test obtained. The silver salts were removed by filtration and washed thoroughly with anhydrous ether. The filtrate and washings were combined and dried over anhydrous sodium sulfate, after which the solution was concentrated by distilling off the ether *in vacuo* at room temperature. The residue then was rectified[18] under reduced pressure. Eleven fractions were obtained; all gave a negative Beilstein test.

Isolation of (−)-2-Octyl Nitrite.—Fraction I from the above rectification weighed 20 g., b.p. 47° (5 mm.), n^{20}D

1.4096. This was, in turn, rectified[18] at 6 mm. a total of 8 fractions being taken. Fractions 1–6 distilled in the range 48–49°, were yellow-green and had n^{20}D ranging from 1.4090 (fraction 1) to 1.4094 (fraction 6). Fractions 2–5 (n^{20}D 1.4092) were combined and the rotation measured; α^{29}D −3.36°. Fractions 1–6 were combined (13.2 g., 18% yield) and given a final rectification.[18] Eight fractions were obtained, b.p. 40–41° (3 mm.), n^{20}D 1.4088–1.4094. 2-Octyl nitrite is reported[19] to have n^{20}D 1.4082. Fractions 4 and 5 were combined: n^{20}D 1.4090; α^{27}D −3.39°. *Anal.* Calcd, for C₈H₁₇NO₂: C, 60.38; H, 10.70. Found: C, 60.51; H. 10.50.

Isolation of (−)-2-Nitroöctane.—Fractions V–VIII from the rectification of the reaction mixture, b.p. 82–83° (5 mm.), were all colorless, and had n^{20}D ranging from 1.4278 to 1.4292. They were combined (22 g.), washed with three 10-ml. portions of methanesulfonic acid, then with water. The crude product was dried over magnesium sulfate, then rectified[18] yielding 7.9 g. (11% yield) of (−)-2-nitroöctane, b.p. 69–70° (1 mm.), n^{20}D 1.4280, α^{28}D −14.19°. This represents fractions 6, 7 and 8. *Anal.* Calcd. for C₈H₁₇-NO₂: C, 60.38; H, 10.70. Found: C, 60.58, 60.50; H, 10.45, 10.55; lit. values[17]: b.p. 102–104° (20 mm.), n^{20}D 1.4280. Additional (6.7 g., 9% yield) (−)-2-nitroöctane was obtained by combining fractions 1–5 and 9 and rerectifying[18]; α^{28}D −13.44°, n^{20}D 1.4279.

Determination of Optical Purity of the 2-Octyl Nitrite and 2-Nitroöctane of Run 6.—2-Octanol (n^{20}D 1.4264, α^{27}D +7.60°) was converted to 2-octyl nitrite, b.p. 52° (6 mm.), n^{20}D 1.4092, α^{27}D +4.10° (neat), in 47% yield by the nitrosyl chloride procedure.[19] It has been shown previously that nitrite ester formation *via* the agency of nitrosyl chloride occurs with retention of configuration and no racemization.[19] This was corroborated by the following experiment: 8.3 g. of the (+)-2-octyl nitrite of α^{27}D +4.10° was added to 50 ml. of redistilled methanol and the solution was kept at room temperature overnight (protected from light). The methyl nitrite formed and the excess methanol were removed *in vacuo* at room temperature. The residue was again treated with 50 ml. of methanol and the procedure repeated, after which the product was rectified.[18] All six fractions were colorless, had b.p. 78–79° (10 mm.), n^{20}D 1.4264, and when combined (4.1 g., 62% yield) had α^{27}D +7.52°. Thus there was complete absence of racemization.

Since (+)-2-octanol of α^{27}D +7.60° gives (+)-2-octyl nitrite of α^{27}D +4.10° it follows that (−)-2-octanol of α^{30}D −7.55° should produce (−)-2-octyl nitrite of α^{27}D −4.07° in the absence of racemization. However, for the sequence ROH → RBr → RONO of run 6 (Table II) (−)-2-octanol of α^{30}D −7.55° gave (−)-2-octyl nitrite of α^{27}D −3.39°. This corresponds to 17% racemization.

When the (−)-2-nitroöctane obtained in run 6, α^{28}D −14.19°, is reduced a 68% yield of analytically pure 2-aminoöctane, n^{20}D 1.4240, b.p. 60–61° (11 mm.), α^{27}D −3.81°, is obtained.[5] Since optically pure 2-aminoöctane has α^{19}D 5.14° (Table I) the 2-aminoöctane of α^{27}D −3.81° is 74% optically pure. However, the (−)-2-aminoöctane of α^{27}D −3.81° is obtained from (−)-2-octanol of [α]^{30}D −9.28° which is only 90% optically pure and consequently the 2-aminoöctane would have had α^{27}D −4.63° if there had been no racemization. Since the 2-amino-

(14) Apropos of Table III it should be emphasized that the "% Retention of Optical Purity" given for α-Phenylethyl Nitrite and α-Phenylethyl Amine are for the sequences RCl → RONO and RCl → RNO₂ → RNH₂, respectively. This is to he contrasted with Table II in which the "% Retention of Optical Purity" are for the sequences ROH → RBr → RONO and ROH → RBr → RNO₂ → RNH₂. In other words in the α-phenylethyl series the % Retention of Optical Purity is even smaller (relative to the 2-octyl series) than might appear at first glance.

(15) Unless otherwise noted, all optical determinations were made on the pure liquid in a one decimeter tube.

(16) From the data of R. H. Pickard and J. Kenyon (*J. Chem. Soc.*, 99, 45 (1911)) on density *vs.* temperature.

(17) N. Kornblum, N. N. Lichtin, J. T. Patton and D. C. Iffland, THIS JOURNAL, 69, 309 (1947).

(18) Rectifications were carried out with a 20-inch modified Widmer column (M. Smith and H. Adkins, *ibid.*, 60, 657 (1937)) fitted with a variable take-off head.

(19) N. Kornblum and E. P. Oliveto, *ibid.*, 69, 465 (1947).

octane has α^{27}D 3.81° it follows that the sequence ROH → RBr → RNO₂ → RNH₂ occurred with an over-all retention of optical purity of 82%.

Reaction of (−)2-Bromoöctane with One-half of the Stoichiometrical Amount of Silver Nitrite.—Run 5 (Table II) was carried out in anhydrous diethyl ether at 0° for 15 hours then at room temperature for 60 hours using 89 g. (0.46 mole) of (−)2-bromoöctane (b.p. 59–60° (5 mm.), n^{20}D 1.4500, α^{27}D −33.93°, d^{26}_4 1.0805,[16] [α]^{27}D −31.41°) and 35.4 g. (0.23 mole) of silver nitrite. The silver salts were removed, washed with ether and the washings combined with the ethereal filtrate. The solvent was removed *in vacuo* at room temperature and the residue was distilled *in vacuo*. Six fractions were obtained, all of which gave a positive Beilstein test for halogen and a positive Griess–Ilosvay test for nitrite ester.[20]

(a) **Isolation of (+)2-Octyl Nitrite.**—Fractions 1 and 2 were combined and rectified through a concentric tube column. This gave (+)2-octyl nitrite (3.3 g., 9% yield), n^{20}D 1.4094, b.p. 50° (9 mm.), α^{27}D +3.03°.

(b) **Isolation of "Unreacted" (−)2-Bromoöctane.**—Fraction 3 (18.7 g.), b.p. 60–80° (2 mm.), n^{20}D 1.4406, was combined with "high boiling" material (26.3 g., n^{20}D 1.4300–1.4500) obtained in the rectification of (+)2-octyl nitrite and repeatedly washed with methanesulfonic acid and then with water. The product was dried over anhydrous sodium sulfate then rectified[18] yielding a 70% recovery of colorless "unreacted" (−)2-bromoöctane, b.p. 46° (1 mm.), n^{20}D 1.4502, α^{27}D −27.34°, a 19% loss in optical purity.

(c) **Isolation of (+)2-Nitroöctane.**—Fractions 4–6 (14.2 g.), b.p. 80–95° (2 mm.), n^{20}D 1.4364–1.4515, were combined with high boiling material (6.0 g., n^{20}D 1.4298) obtained in the purification of the recovered (−)2-bromoöctane. The mixture was washed repeatedly with methanesulfonic acid, with water, and then dried over anhydrous sodium sulfate. Rectification[18] gave 8.0 g. (23% yield) of 2-nitroöctane, b.p. 73–74° (2 mm.), n^{20}D 1.4280, α^{27}D +14.77°. Reduction[5] of this 2-nitroöctane gave an 81% yield of (+)2-aminoöctane, b.p. 55–56° (9 mm.), n^{20}D 1.4240, α^{14}D +3.38°.

Reaction of Active 2-Iodoöctane with Silver Nitrite.—(+)2-Octanol (67.3 g., n^{20}D 1.4264, α^{27}D +7.80°, d^{27}_4 0.8137, [α]^{27}D +9.58°) was saturated with anydrous hydrogen iodide at 0° and then kept at refrigerator temperature for 40 hours. On working up the mixture there was obtained 76.96 g. (62% yield) of (−)2-iodoöctane, b.p. 83° (8 mm.), n^{20}D 1.4882, α^{27}D −53.31°, d^{27}_4 1.3080, [α]^{27}D −40.75°; lit. values: n^{20}D 1.4890,[21] [α]^{20}D −49.6[8] (see footnote 11).

A slurry of 85 g. (0.555 mole) of dry silver nitrite in 250 ml. of anhydrous ethyl ether was made in a 500-ml. three-necked flask fitted with a tantalum stirrer, dropping funnel and a reflux condenser fitted with a calcium chloride drying tube. The flask was cooled to 0° and 100 g. (0.416 mole) of (−)2-iodoöctane, (n^{20}D 1.4882, [α]^{27}D −40.75°) was added dropwise to the stirred mixture over a period of three hours. The mixture was allowed to stir at ice temperature for 16 hours and then at room temperature for 24 hours more. A negative Beilstein test was obtained at this time.

The silver salts were removed and washed with ether. The washings were added to the filtrate, the ether was removed by flash distillation *in vacuo* and the residue then was rectified, a total of 23 fractions being collected.

Fractions 2–8 were combined to give 10.84 g. (16% yield) of (+)2-octyl nitrite; all the fractions were yellow and had b.p. 42° (5 mm.), n^{20}D 1.4087–1.4089, α^{28}D +3.12°, d^{28}_4 0.8586, [α]^{28}D +3.64°. The optical purity retained in the sequence ROH → RI → RONO is thus 74%. *Anal.* Calcd. for $C_8H_{17}ONO$: C, 60.38; H, 10.69; N, 8.80. Found: C, 60.32; H, 10.56; N, 8.62.

The crude (+)2-nitroöctane (fractions 16–22, 15 g.) was shaken with *ca.* 4 g. of phosphorus pentoxide for 15 minutes, washed twice with 20-ml. portions of sirupy phosphoric acid, with water until neutral to litmus and finally, after drying over Drierite, it was rectified. There was obtained 6.5 g. of pure (+)2-nitroöctane, b.p. 75° (5 mm.), n^{20}D 1.4280, d^{28}_4 0.9222, α^{28}D +12.29°, [α]^{28}D +13.33°. *Anal.* Calcd. for $C_8H_{17}NO_2$: C, 60.38; H, 10.69; N, 8.80. Found: C, 60.19; H, 10.56; N, 8.80. When 4.75 g. of this (+)2-nitroöctane was reduced[5] with iron and glacial acetic acid (+)2-aminoöctane was obtained in 52% yield, b.p. 77° (10 mm.), n^{20}D 1.4245, α^{28}D +3.82°, d^{28}_4 0.7690, [α]^{28}D

+4.96°. This (+)2-aminoöctane gave a benzamide which, after recrystallization from 95% ethanol, melted 101–102°. Mann and Porter[22] report m.p. 101–102°. From Table I, and the fact that the 2-octanol employed was 94% optically pure, it follows that the over-all sequence ROH → RI → RNO₂ → RNH₂ occurs with 79% retention of optical purity.

Reaction of Active α-Phenylethyl Chloride with Silver Nitrite.—Run 2 (Table III) was carried out as follows: (−)α-phenylethanol, b.p. 69–70° (2 mm.), n^{20}D 1.5278, α^{28}D −35.99°, d^{28}_4 1.0072,[18] [α]^{28}D −35.73°, was converted to (−)α-phenylethyl chloride according to Eliel[23] in 88% yield, b.p. 54° (3 mm.), n^{20}D 1.5270, α^{28}D −43.65°; lit. values: α^{18}D −106°, n^{20}D 1.5262,[24] α^{25}D +109°,[25] n^{25}D 1.5250.[28]

To a stirred slurry of 77 g. (0.50 mole) of silver nitrite in 300 ml. of anhydrous diethyl ether maintained at 0°, was added 47.4 g. (0.336 mole) of the (−)α-phenylethyl chloride α^{28}D −43.65°). This took three hours after which the mixture was stirred for 21 hours at 0°. Only then was a negative Beilstein test obtained (the reaction was conducted in a dark room). The silver salts were filtered off, washed thoroughly with ether and the combined filtrate and extracts dried over anhydrous sodium sulfate. The ether was removed *in vacuo* at room temperature and the residue distilled at 10 mm. Fraction 1 was yellow-green, b.p. 66°, n^{20}D 1.4928, α^{28}D −8.44°, and weighed 21.7 g. Fraction 2, yellow-green, b.p. 66–67°, n^{20}D 1.4930, weight 10.0 g. Fraction 3, yellow-green, b.p. 66–67°, n^{20}D 1.4935, weight 1.3 g. Distillation was discontinued at this point leaving 14.0 g. of an orange residual liquid. Fractions 1 and 2 were combined and rectified[18] at 4 mm. After a forerun of 0.2 g. there was obtained 23.0 g. (45% yield) of (−)α-phenylethyl nitrite collected as six, roughly equal, fractions. All six boiled in the range 49–50° (4 mm.) and had n^{20}D 1.4926–1.4928; the third fraction had α^{26}D −8.45[27]; lit. value: n^{25}D 1.4912.[26,28]

For the isolation of (+)α-phenylnitroethane the 14.0 g. of orange residual liquid from the initial distillation was combined with 2.9 g. of high boiling material from the purification of (−)α-phenylethyl nitrite and this was rectified[18] twice. There was obtained 5.5 g. (10% yield) of (+)α-phenylnitroethane, b.p. 92° (2 mm.), n^{20}D 1.5215, α^{27}D +2.80°; lit. value: n^{25}D 1.5212.[29] *Anal.* Calcd. for $C_8H_9NO_2$: C, 63.57; H, 5.96; N, 9.27. Found: C, 63.39; H, 6.21; N, 9.02.

When the (+)α-phenylnitroethane of α^{27}D +2.80° was reduced over platinum in glacial acetic acid[5] (+)α-phenylethylamine, b.p. 71° (10 mm.), n^{20}D 1.5269, α^{27}D +6.50°, was obtained in 58% yield; lit. value: n^{20}D 1.5264.[30] The (+)α-phenylethylamine was characterized by its benzamide derivative, m.p. 124–125° (recrystallized from absolute ethanol); lit. values: m.p. 124.5–125.5° for the (−)-benzamide derivative,[31] m.p. 120° for the racemic benzamide derivative.[32] *Anal.* Calcd. for $C_{15}H_{15}NO$: C, 80.0; H, 6.67; N, 6.22. Found: C, 79.81, 79.82; H, 6.89, 6.81; N, 6.57, 6.48.

Determination of the Optical Purity of the α-Phenylethyl Nitrite and the α-Phenylethylamine of Run 2.—Burwell, Shields and Hart[25] recently have shown that the rotation of optically pure α-phenylethyl chloride lies in the range α^{25}D 109–126°. Using the lower of these two values the

(20) N. Bose, *Analyst*, **56**, 504 (1931).

(21) A. Audsley and F. Goss, *J. Chem. Soc.*, 363 (1942).

(22) F. G. Mann and J. W. G. Porter, *ibid.*, 456 (1944).

(23) E. L. Eliel, THIS JOURNAL, **71**, 3970 (1949).

(24) W. Gerrard, *J. Chem. Soc.*, 106 (1945).

(25) R. L. Burwell, A. D. Shields and H. Hart, THIS JOURNAL, **76**, 908 (1954).

(26) R. H. Eastman and S. D. Ross, *ibid.*, **68**, 2398 (1946).

(27) In run 1 (Table III) the 58.6 g. of (−) α-phenylethyl nitrite obtained by simple distillation of the reaction product had b.p. 62–63° (9 mm.) and n^{20}D range of 1.4927–1.4935. This, on rectification[18] at 3 mm., gave 42.6 g. (44% yield) of (−)α-phenylethyl nitrite which was collected in ten fractions; b.p. range 52–53°, n^{20}D 1.4926–1.4927. Fraction 7 had α^{12}D −4.25°.

(28) A sample of racemic α-phenylethyl nitrite prepared *via* the nitrosyl chloride procedure[19] had b.p. 49.5–50° (5 mm.), n^{20}D 1.4928. *Anal.* Calcd. for $C_8H_9O_2$: N, 9.27. Found: N, 9.35, 9.23.

(29) M. Konowalow, *J. Russ. Phys. Chem. Soc.*, **26**, 514 (1894).

(30) H. R. Snyder and J. H. Brewster, THIS JOURNAL, **71**, 292 (1949).

(31) W. Marckwald and R. Meth, *Ber.*, **38**, 808 (1905).

(32) M. Kann and J. Tafel, *ibid.*, **27**, 2308 (1894).

optical purity of the α-phenylethyl chloride having $\alpha^{28}D$ −43.65° is 40%.

Dextrorotatory α-phenylethyl alcohol yields dextrorotatory α-phenylethyl nitrite (nitrosyl chloride in pyridine). Furthermore, thermal decomposition of dextrorotatory α-phenylethyl nitrite yields dextrorotatory α-phenylethyl alcohol. This is the basis for the configurational relationship for these two compounds given in Chart I.[33] Conversion of α-phenylethyl alcohol to the nitrite by nitrosyl chloride not only retains configuration but occurs with complete retention of optical purity. This was demonstrated as follows:

(−)α-Phenylethyl alcohol (86 g., 0.7 mole), $n^{20}D$ 1.5265, $\alpha^{28}D$ −32.2°, was treated with nitrosyl chloride.[19] The (−)α-phenylethyl nitrite obtained (46 g., 44% yield) had $n^{20}D$ 1.4926, $\alpha^{26}D$ −42.5°, b.p., 52° (2 mm.). Anal. Calcd. for $C_8H_9NO_2$: C, 63.57; H, 5.96; N, 9.26. Found: C, 63.22; H, 5.99; N, 8.91. When a sample of this nitrite ($\alpha^{28}D$ −42.5°) was methanolyzed at room temperature according to the procedure employed with (+)2-octyl nitrite (vide supra), (−)α-phenylethyl alcohol, $n^{20}D$ 1.5261, $\alpha^{26}D$ −32.2°, was obtained.[11]

In run 2 of Table III, (−)α-phenylethyl chloride of 40% optical purity yield (−)α-phenylethyl nitrite of $\alpha^{28}D$ −8.45°. Thus this nitrite is $8.45/59.6 \times 100 = 14\%$ optically pure and the step RCl → RONO took place with $14/40 \times 100 = 36\%$ retention of optical purity.

The (+)α-phenylnitroethane produced in run 2 has $\alpha^{27}D$ +2.80° and, by catalytic reduction with Adams catalyst in glacial acetic acid,[5] there was obtained (+)α-phenylethylamine having $\alpha^{27}D$ +6.50°; this amine is $6.50/37.95 \times 100 = 17\%$ optically pure. Thus the sequence RCl →

(33) We are indebted to Dr. S. A. Herbert for these experiments (ref. o, Table I).

RNO2 → RNH2 occurred with $17/40 \times 100 = 43\%$ retention of optical purity.

Reaction of (+)α-Phenylethyl Chloride with One-half of the Stoichiometrical Amount of Silver Nitrite (Run 3), Table III.—This was carried out using 51 g. (0.36 mole) of (+)α-phenylethyl chloride (b.p. 48–49° (1–2 mm.), $n^{20}D$ 1.5271, $\alpha^{27}D$ +10.86°, l 2 dm.) and 27.7 g. (0.18 mole) of silver nitrite in 300 ml. of anhydrous ether. The addition of the chloride was made over a three-hour period with continuous stirring (absence of light). The mixture then was stirred for 19 hours at 0°. The silver salts were filtered off, washed thoroughly with ether and the filtrate and washings were combined. After removal of the solvent in vacuo at room temperature, the residue was distilled and 16 fractions were obtained.

(a) **Attempted Isolation of α-Phenylethyl Nitrite.**—Fractions 1–9 having $n^{20}D$ 1.5110–1.5225 were combined (36.7 g.) and rectified repeatedly but it proved impossible to isolate α-phenylethyl nitrite free of the chloride.

(b) **Isolation of "Unreacted" (+)α-Phenylethyl Chloride.**—Fractions 10–12, $n^{20}D$ 1.5245–1.5228 (3.0 g.), were combined with 19.0 g. of high boiling material ($n^{20}D$ 1.5195–1.5278) from the attempted isolation of the nitrite ester, and the mixture was rectified.[18] There was obtained 7.5 g. (30% recovery) of "unreacted" (+)α-phenylethyl chloride, b.p. 46–47° (1–2 mm.), $n^{20}D$ 1.5271, $\alpha^{28}D$ +0.90° (l 2 dm.). Anal. Calcd. for C_8H_9Cl: C, 68.33; H, 6.41. Found: C, 68.70, 68.66; H, 6.61, 6.60.

The "unreacted" α-phenylethyl chloride thus retained $0.90/10.86 \times 100 = 8\%$ of its optical activity.

(c) **Attempted Isolation of α-Phenyl Nitroethane.**—Fractions 13–15 having $n^{20}D$ 1.5215–1.5248 were combined (7.7 g.) and twice rectified[18] in vacuo. The nitro compound free of halogen could not be isolated.

LAFAYETTE, INDIANA

The Reduction of Optically Active 2-Nitroöctane and α-Phenylnitroethane[1,2]

BY NATHAN KORNBLUM AND LEON FISHBEIN

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Conditions are described for reducing optically active nitro compounds to active amines. In this way the configurational relationship of 2-nitroöctane and of α-phenylnitroethane to other compounds of the 2-octyl- and α-phenylethyl series is established. Not all reducing agents give optically active amines; the implications of this fact are discussed briefly.

In order to determine the stereochemistry of the reaction of silver nitrite with 2-octyl and α-phenylethyl halides, a method of establishing the configurations of 2-nitroöctane and α-phenylnitroethane was needed.[3] Reduction to the amines seemed an attractive way of relating these nitro compounds to the halides. It transpired that the nitro compounds could be reduced to optically active amines with little, if any, loss in optical purity—but not by all reducing agents.

Thus, reduction of optically active 2-nitroöctane by lithium aluminum hydride gives 2-aminoöctane in 73% yield, but the amine is completely racemic. In contrast, reduction by iron powder and acetic acid produces optically active 2-aminoöctane (expt. 1 and 2, Table I). The amount of racemization for the entire sequence ROH → RBr → RNO2 → RNH2 is 18%. Hence, even if all of the racemization for this sequence occurs in the step RNO2 →

(1) Paper VIII in the series "The Chemistry of Aliphatic and Alicyclic Nitro Compounds."

(2) This research was supported by the United States Air Force under Contract No. AF18(600)-310 monitored by the Office of Scientific Research, Air Research and Development Command.

(3) N. Kornblum, L. Fishbein and R. Smiley, THIS JOURNAL, 77, 6261 (1955).

RNH2, the iron and acetic acid reduction is 82% stereospecific. However, there are cogent reasons for believing that a good part (and perhaps all) of the 18% racemization takes place prior to the step RNO2 → RNH2[3] so that the iron and acetic acid reduction must occur with considerably better than 82% retention of optical purity.

The 2-aminoöctane produced on hydrogenating (-)2-nitroöctane, $\alpha^{27}D$ −12.77°, over Adams catalyst is 96% racemized when absolute ethanol is the solvent (expt. 7). Repetition, except that reduction was interrupted after 55% of the theoretical amount of hydrogen had been absorbed, gave (−)2-aminoöctane of $\alpha^{27}D$ −0.48°, i.e., 89% racemized. Of especial interest was the observation that the recovered (−)2-nitroöctane had $\alpha^{27}D$ −0.15°; the "unreacted" 2-nitroöctane had suffered a 99% loss of optical activity (expt. 8).

Since optically active 2-nitroöctane is racemized on forming salts,[4] this loss of activity is readily intelligible. Not only does the solution become basic because of the 2-aminoöctane produced but, in addition, a small amount of alkali is liberated on

(4) N. Kornblum, N. N. Lichtin, J. T. Patton and D. C. Iffland, ibid., 69, 309 (1947).