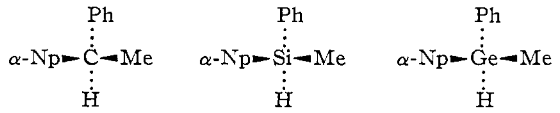
CHART I

ABSOLUTE CONFIGURATIONS AND PHYSICAL CONSTANTS OF (+)-ENANTIOMERS

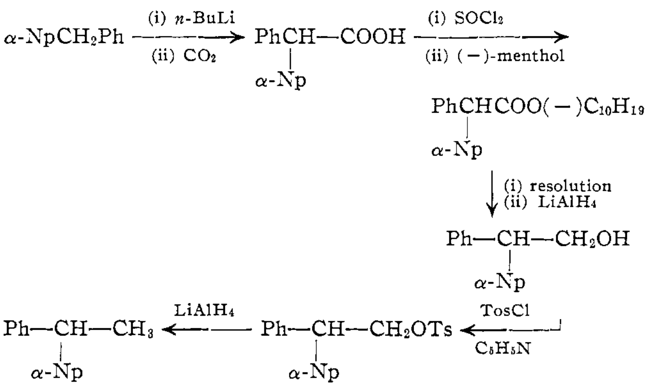


Compound	I	II	III
M.p., °C.	54–55°	63–64°	74–75°
$[\alpha]^{23}\mathrm{D}$	7.5°	34.9°	26.7°

far less to do with the specific rotation than has the electronegativity of the asymmetric atom. Indeed, a linear plot of electronegativity of the central atom (C = 2.60, Si = 1.90)[7] *vs.* specific rotation predicts a value of 2.06 for the electronegativity of germanium, in excellent agreement with the value of 2.00 determined by Allred and Rochow from n.m.r. data.

We have initiated studies comparing the physical properties of the members of this and related series, and hope to report shortly the synthesis and resolution of the related tin compound.

The synthetic sequence leading to (+)- and (−)-methyl-α-naphthylphenylmethane is shown.



α-Benzylnaphthalene[8] was metalated with *n*-butyllithium in ether–hexane and the resulting purple-red solution was carbonated to give α-naphthylphenylacetic acid, m.p. 139–141°, lit.[9] 140–141°, in 65% yield. After conversion to the acid chloride with thionyl chloride the crude acid chloride was treated directly with one equivalent of (−)-menthol in pyridine–benzene. The crude ester was crystallized from ethanol to give 79% of a diastereomeric mixture of menthyl esters, m.p. 59–68°, $[\alpha]^{23}\mathrm{D}$ −61.5° (cyclohexane, *c* 5).[10] The ester was crystallized from methanol (about 20 ml./g.) several times, finally yielding large needles. During this process the rotation increased to $[\alpha]^{23}\mathrm{D}$ −68.7° and the m.p. rose to 95–96°. The filtrates from these crystallizations were concentrated and the residue was recrystallized from methanol, two fractions of solid being removed. The filtrate was concentrated, yielding material melting at 74–80° with $[\alpha]^{23}\mathrm{D}$ −55.4°. After two recrystallizations from hexane (5 ml./g.) and one from heptane (2 ml./g.) the solid, m.p. 77–83°, $[\alpha]^{23}\mathrm{D}$ −52.0°, was crystallized from methanol (3 ml./g.) containing a trace of hexane to give the second diastereomeric ester, m.p. 84.5–85.5°, $[\alpha]^{23}\mathrm{D}$ −51.1°, as fine needle clusters.

Reduction of the more soluble (−)-menthoxy-α-naphthylphenylacetate, m.p. 84.5–85.5°, $[\alpha]^{23}\mathrm{D}$ −51.1°, with lithium aluminum hydride in ether gave as a gum after removal of the menthol by steam distillation 2-(α-naphthyl)-2-phenylethanol, $[\alpha]^{23}\mathrm{D}$ 1.95° (cyclohexane, *c* 5), not further purified but converted directly to the crystalline tosylate in pyridine at 0° in 86% yield, m.p. 132–134°, from ethyl acetate–hexane, $[\alpha]^{23}\mathrm{D}$ 35.2°. Finally, reduction with lithium aluminum hydride in tetrahydrofuran gave, after alkaline extraction, 95% of (−)-methyl-α-naphthylphenylmethane, m.p. 54–55°, from ethanol, $[\alpha]^{23}\mathrm{D}$ −7.3° (cyclohexane, *c* 10.3).

A similar procedure employing the less soluble ester, m.p. 95–96°, $[\alpha]^{23}\mathrm{D}$ −68.7°, gave tosylate in 82% yield, m.p. 132–134°, $[\alpha]^{23}\mathrm{D}$ −35.8°, which gave (+)-methyl-α-naphthylphenylmethane in 85% yield, m.p. 54–55°, $[\alpha]^{23}\mathrm{D}$ 7.5° (cyclohexane, *c* 10.3).

The hydrocarbon was identified by comparison of the infrared spectra and mixture melting point behavior of a synthetic racemate, m.p. 64.5–66.5°, with an authentic racemic sample, m.p. 64–66°, lit.[11] 65–66°, prepared by hydroboration, followed by protonolysis, of a sample of 1-(α-naphthyl)-1-phenylethene,[12] m.p. 57–59°, lit.[11] 58–59°.

Analyses and infrared spectra of all compounds were in accord with the structures assigned.

The configuration of (+)-C*H could not be related to (+)-Si*H by mixture melting point techniques, as had been done for (+)-Si*H with (+)-Ge*H,[3] since mixtures of (+)-C*H with both (+) and (−)-Si*H formed eutectics. All three compounds gave essentially similar optical rotatory dispersion curves with positive Cotton effects, that for (+)-Si*H being in accord with the results of Sommer, *et al.*[13] From the results it is apparent that all three (+)-enantiomers have the same configuration, namely R.

Rotatory dispersion curves were determined in cyclohexane at about 25° at the concentrations (g./100 ml.) shown.

(+)-C*H (*c* 0.7) $[\alpha]_{589}$ 4.7, $[\alpha]_{500}$ 13, $[\alpha]_{400}$ 40, $[\alpha]_{350}$ 72, $[\alpha]_{325}$ 83 (peak), $[\alpha]_{310}$ 50°.
(+)-Si*H (*c* 0.25) $[\alpha]_{589}$ 32, $[\alpha]_{500}$ 53, $[\alpha]_{400}$ 102, $[\alpha]_{350}$ 168, $[\alpha]_{324}$ 251 (peak), $[\alpha]_{310}$ 232°.
(+)-Ge*H (*c* 0.32) $[\alpha]_{589}$ 21, $[\alpha]_{500}$ 41, $[\alpha]_{400}$ 75, $[\alpha]_{350}$ 122, $[\alpha]_{321}$ 171 (peak), $[\alpha]_{310}$ 160°.

Acknowledgment.—Part of this research was supported by the National Research Council of Canada. The author is indebted to Dr. R. U. Lemieux, University of Alberta, for the optical rotary dispersion spectra and to Miss Sheila Fergusson for technical assistance, as well as to Dr. G. F. Wright and other colleagues for helpful discussions.

---

[7] A. L. Allred and E. G. Rochow, *J. Inorg. Nucl. Chem.*, **5**, 269 (1958).

[8] E. Koike and M. Okawa, *J. Chem. Soc. Japan, Pure Chem. Sect.*, **74**, 971 (1953).

[9] C. J. Collins, L. S. Ciereszko, and J. G. Burr, *J. Am. Chem. Soc.*, **75**, 405 (1953).

[10] All rotations unless otherwise indicated were determined in $CHCl_3$, *c* 10.0–10.3.

[11] B. R. Brown and O. Ll. Hammick, *J. Chem. Soc.*, 1395 (1948).

[12] This experiment was performed by Mr. J. B. Pierece following the general procedures described by H. C. Brown, *et al.*

[13] L. H. Sommer, C. L. Frye, *et al.*, *J. Am. Chem. Soc.*, **83**, 2210 (1961).

DEPARTMENT OF CHEMISTRY
UNIVERSITY OF TORONTO
TORONTO 5, CANADA
A. G. BROOK

RECEIVED JULY 8, 1963

The Synthesis and Stability of N,N′-Bisuccinimidyl

Sir:

The nature of the chain-carrying species in free radical brominations by N-bromosuccinimide (NBS) has been the focus of continuing controversy.[1] It has recently been shown that the relative reactivities of NBS and bromine toward alkylbenzenes are experimentally indistinguishable over a wide range of substrate structure and reaction conditions,[1] indicating

---

[1] (a) R. E. Pearson and J. C. Martin, *J. Am. Chem. Soc.*, **85**, 354 (1963); (b) G. A. Russell, C. DeBoer, and K. M. Desmond, *ibid.*, **85**, 365 (1963); (c) C. Walling, A. L. Rieger, and D. Tanner, *ibid.*, in press.

either that the succinimidyl radical and bromine atom have identical reactivity, or more likely that the bromine atom is the chain-propagating species in both cases. An unequivocal source of succinimidyl radical is clearly necessary for final resolution of this problem. From the facile dissociation of the O–O bond in acyl peroxides it can be inferred that N,N′-bisuccinimidyl (I) would be a convenient radical source. However, a number of unsuccessful attempts have been made to prepare compound I and it has even been proposed that it is incapable of existence on the grounds that the predicted resonance energy of the succinimidyl radical would reduce the N–N bond dissociation energy to zero.[2]

Encouraged by older reports of the normal stability of tetraacetylhydrazine[3] and of N,N′-biphthalimidyl[4] (structures which we have confirmed by modern spectral methods), we have reinvestigated the problem and report here the synthesis and proof of structure of N,N′-bisuccinimidyl and the results of some preliminary attempts to effect its dissociation to succinimidyl radicals.

The reaction of N-aminosuccinimide[5] (characterized by its benzylidine derivative, m.p. 175°, lit.[5] m.p. 173–175°; *Anal.* Calcd. for $C_{11}H_{10}N_2O_2$: C, 65.33; H, 4.98; N, 13.85. Found: C, 65.17; H, 5.01; N, 13.69) with succinic anhydride in acetic acid gave N,N′-bisuccinimidyl (I) in good yield as white needles, m.p. 309–310°. *Anal.* Calcd. for $C_4H_4O_2N$: C, 48.98; H, 4.11; N, 14.28. Found: C, 49.25; H, 4.36; N, 14.45. Chemical evidence for the assigned structure was obtained by reduction with lithium aluminum hydride in refluxing tetrahydrofuran, which gave N,N′-bipyrrolidinyl (III) in about 10% yield, m.p. (picrate) 165–167°, lit.[6] m.p. 165–167°. *Anal.* Calcd. for $C_8H_{16}N_2 \cdot C_6H_3N_3O_7$: C, 45.53; H, 5.18; N, 18.96. Found: C, 45.45; H, 5.15; N, 18.96. Furthermore, cleavage of III with Raney nickel[6] gave pyrrolidine, whose sulfonamide derivative was identical with authentic material on the basis of the mixture melting point and infrared spectra. Both the infrared and n.m.r. spectra of III, which was isolated by preparative v.p.c., were completely consistent with the assigned structure, which had been proved previously[6] by independent synthesis and cleavage as before. The bulk of the products was composed of higher boiling materials, probably arising from C–N cleavage of the tetraacylhydrazine,[7] and the absence of the isomeric pyridazine IV was further established by v.p.c.

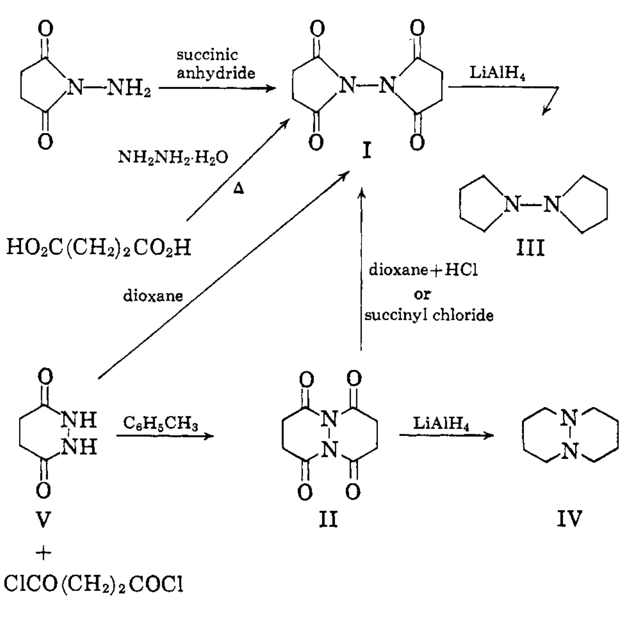
Surprisingly, the product of the thermal dehydration of succinic acid and hydrazine hydrate, which has been identified[8] as the 6-ring isomer (II) of N,N′-bisuccinimidyl, was identical in all respects with compound I. The principal basis for the earlier structural assignment was the reaction of the cyclic succinhydrazide (V) with succinyl chloride, which, after 24 hr. in refluxing dioxane, gave the same product as that from the thermal dehydration.[8] Independent work[6] showed subsequently, however, that hydride reduction of the product alleged to be II actually yielded N,N′-bipyrrolidinyl (III).

We have prepared authentic II by refluxing for 1 hr. a solution of cyclic succinhydrazide (V) and succinyl chloride in toluene (instead of dioxane). Perhydro-1,4,6,9-tetraketopyridazo(1,2-*a*)pyridazine (II) was obtained in 60% yield as white crystals, m.p. 250° dec. (*Anal.* Calcd. for $C_4H_4O_2N$: C, 48.98; H, 4.11; N, 14.28. Found: C, 49.17; H, 4.30; N, 14.54) and was reduced by lithium aluminum hydride in refluxing tetrahydrofuran to perhydropyridazo(1,2-*a*)pyridazine (IV) in 10% yield. The dipicrate of IV melted at 155°, lit.[6] m.p. 155–158°. *Anal.* Calcd. for $C_4H_8N \cdot C_6H_3N_3O_7$: C, 40.13; H, 3.70; N, 18.72. Found: C, 40.38; H, 4.00; N, 18.77. The infrared and n.m.r. spectra of IV were consistent with its structure, established previously by an independent synthesis,[6] which we have repeated and confirmed, and the absence of III was established by v.p.c. as before. When this product (II) was refluxed for 1 hr. in dioxane containing either hydrochloric acid or succinyl chloride, it rearranged completely to N,N′-bisuccinimidyl (I). Clearly compound II would not survive Feuer's reaction conditions, and would rearrange as it was formed. A thermal rearrangement of II to I was also observed, in a sealed tube at about 240° without solvent.

Additional support for the assigned structures was obtained from the infrared and ultraviolet spectra. The infrared spectrum of N,N′-bisuccinimidyl (I) corresponded strikingly to that of N-bromosuccinimide in both the carbonyl and fingerprint region, the only major difference being the relative positions of two bands in the 9–11 μ region. The ultraviolet spectrum of N,N′-bisuccinimidyl (I) in dioxane had $\lambda_{\max}$ 213, 227, and 241 mμ (ε 480, 350, and 340, respectively) as compared to succinimide in the same solvent with $\lambda_{\max}$ 222, 230, and 246 mμ (ε 144, 96, 88). The ultraviolet spectrum of II in dioxane was much more intense with $\lambda_{\max}$ 229, 273 mμ (ε 6.6×10^3, 5.3×10^2) as compared to succinhydrazide (V) with $\lambda_{\max}$ 242 mμ (ε 6.1×10^3).

These results establish that the long-sought-after N,N′-bisuccinimidyl (I) actually can be obtained easily from the thermal dehydration of succinic acid with hydrazine hydrate. Moreover, they indicate that the 5-membered ring is more stable than the 6-membered ring in this series. Thus, thermal rearrangement of II to I can be effected, but in no case has the reverse transformation been observed.

Although it had been anticipated that I would be a stable substance, the degree of stability actually ob-



---

[2] H. J. Dauben and L. L. McCoy, *J. Am. Chem. Soc.*, **81**, 4863 (1959).

[3] R. Stollé, *J. prakt. Chem.*, **69**, 145 (1904).

[4] H. D. K. Drew and H. H. Hatt, *J. Chem. Soc.*, 16 (1937).

[5] T. Curtius, K. Hochschwender, and H. Thiemann, *J. prakt. Chem.*, **92**, 102 (1915).

[6] H. Stetter and H. Spangenberger, *Chem. Ber.*, **91**, 1982 (1958).

[7] The crude product had a strong OH band in the infrared and part of the material had the same retention time in the v.p.c. as 1,4-butanediol. Cleavage of the C–N bond in cases where the nitrogen bears more than one acyl group is well known (R. L. Hinman, *J. Am. Chem. Soc.*, **78**, 2463 (1956); K. C. Schreiber and V. P. Fernandez, *J. Org. Chem.*, **26**, 1744 (1960)).

[8] (a) H. Feuer and J. E. Wyman, *Chem. Ind.* (London), 577 (1956); (b) H. Feuer, G. B. Bachman, and E. H. White, *J. Am. Chem. Soc.*, **73**, 4716 (1951).

served was unexpected. N,N′-Bisuccinimidyl was recovered quantitatively from a solution in chlorobenzene (b.p. 130°) containing a two molar excess of bromine and from a mixture of diphenyl ether and tetralin (3:1) (b.p. *ca.* 230°) in each case after refluxing for 24 hr. under irradiation with a 275-w. sun-lamp through a Pyrex flask. Also, N,N′-bisuccinimidyl was recovered in 95% yield after heating for 24 hr. in a sealed tube at 400–500°.[9]

The N–N bond energy in N,N′-bisuccinimidyl and closely related cyclic N,N′-diimides may be qualitatively represented as that of hydrazine less the difference between the resonance energies of the radical and the ground state dimer. While one might anticipate a cancellation of the resonance energy term for the radical by that due to the unshared pair on nitrogen in the dimer, the striking stability of the dimer suggests some extra stabilization in the ground state leading to a net *increase* in N–N bond energy. Experiments bearing on this question and that of the stability of the succinimidyl radical are currently in progress.

[9] It has been noted previously that N,N′-biphthalimidyl is an inefficient initiator for vinyl polymerization (C. Walling and A. N. Naglieri, J. Am. Chem. Soc., **82**, 1820 (1960).

UNION CARBIDE RESEARCH INSTITUTE E. HEDAYA
UNION CARBIDE CORP. R. L. HINMAN
TARRYTOWN, NEW YORK S. THEODOROPULOS

RECEIVED JULY 26, 1963

The Acidities of Weak Acids in Dimethyl Sulfoxide

Sir:

Price and Whiting[1] recently reported the use of a dimethyl sulfoxide solution of the sodium salt of dimethyl sulfoxide ("dimsylsodium")[2] as a reagent for titrating weak acids, such as alcohols, using triphenylmethane as an indicator. They obtained stoichiometric end points for all of the titratable acids tried except for glycerine (see Table I). We have likewise been using dimsyl reagents, as well as triphenylmethide reagents, to prepare alcohol-free alkoxide solutions. The method is advantageous in that the conversion of alcohol to alkoxide is practically instantaneous, strong reducing conditions do not prevail, and the equivalence point is readily observed because of the presence of the indicator. However, the method is limited as to the type of cation which may be used. Table I shows a comparison of titration data reported by Price and Whiting using dimsylsodium with data we obtained using dimsylpotassium. It may be seen that most acids having pK_a values lower than triphenylmethane's, with the exception of alcohols and amines, give stoichiometric end points with both ions. With alcohols, the triphenylmethyl anion becomes visible when only about one-half the calculated amount of dimsylpotassium has been added. Tetrahydrofuran solutions of triphenylmethides may be used to prepare both sodium and potassium alkoxides. In the latter case, however, end points occur when about 85% of the calculated amount of triphenylmethide solution has been added. With triphenylmethylcesium the method is not practical because the end point occurs when only about 50% of the calculated amount of base has been added.

The limitations in the titration method for preparing alkoxides are unexpected. The reported[3] pK_a values of alcohols are 16–19 and of triphenylmethane, 33. This large difference between them means that the alcohols should be converted almost completely to alkoxides before a significant proportion of triphenylmethane will remain as its conjugate base. In contrast, our results show that significant quantities of triphenylmethide can exist in solutions having an alcohol–alkoxide ratio of one or more. The implication is that the two types of acids have approximately the same acidity. Furthermore, the very low acidities of alcohols under the conditions used here are not caused by some unique function of dimethyl sulfoxide, since comparable results are obtained in tetrahydrofuran solutions. The vast changes in the apparent acidity of alcohols as the medium and cation are varied have led us to undertake a detailed, quantitative study of these acid–base equilibria.

TABLE I

Acid	Lit. pK_a[a]	Moles of dimsyl ion per mole of acid to give visible concn. of Ph_3C^- Na^{+b}	K$^+$
Benzoic acid	4.2		1.01
Acetic acid	4.8	1.03	
2,4,6-Trichlorophenol	6.2		1.01
Phenol	9.9	1.02	0.99
Formanilide			[1.00][c]
Glycerol		1.56	1.00
1-Methoxy-2-propanol			0.54
Dipropylene glycol methyl ether			.54
Tripropylene glycol methyl ether			.53
Water	15.7	1.00	.64
Ethanol	18		.31
n-Butyl alcohol		0.98	.45
t-Butyl alcohol	19	1.06	.33
Cyclopentadiene	17	0.99	.97
Indene	21	.98	.98
Diphenylamine	23	.99	1.00
Aniline	27	<.01	<0.01
Triphenylmethane	33		

[a] See ref. 3. [b] See ref. 1. [c] Used to standardize the reagent.

The general method of Stearns and Wheland[3c] is being used with dimethyl sulfoxide as the solvent and di- and triphenylmethane as the indicators. McEwen[3b] estimated the pK_a values of the indicators to be 35 and 33, respectively, but since the data are not precise we have chosen to use dimethyl sulfoxide as the reference acid. We find that the respective acidities of the indicators are approximately 0.6×10^3 and 13×10^3 times that of the solvent. The latter value does not agree with the estimated value of 21 as reported by Corey and Chayakowski,[2] which was obtained by treatment of an equilibrium mixture of dimsylsodium and triphenylmethane with D_2O and analysis of the resultant triphenylmethane for deuterium content. The reason for the large difference between the two values is not known, but we believe the present value is more reliable because it was obtained by direct measurement on the equilibrium mixture. The relative acidities of the indicators agree well with the estimates of McEwen.[3b]

We have measured the acidities of *t*-butyl and *n*-butyl alcohols over a range of values for $[RO^-]/[ROH]$. At low $[RO^-]/[ROH]$, the acidity is relatively high. As $[RO^-]/[ROH]$ increases the acidity decreases rapidly and becomes constant at $[RO^-]/[ROH]$ greater than 2. The limiting value for the acidity is about 7×10^3 times that of dimethyl sulfoxide and is, within experimental error, the same for both alcohols. The alcohols are different in that the apparent acidity of *n*-butyl alcohol increases more rapidly as $[RO^-]/[ROH]$ decreases.

It is interesting to compare these data with a study by Stewart, O'Donnell, Cram, and Rickborn[4] of the

---

[1] G. G. Price and M. C. Whiting, *Chem. Ind.* (London), 775 (1963).

[2] E. J. Corey and M. Chayakowski, *J. Am. Chem. Soc.*, **84**, 866 (1962).

[3] (a) P. S. Danner, *ibid.*, **44**, 2832 (1922); (b) W. K. McEwen, *ibid.*, **58**, 1124 (1936); (c) R. S. Stearns and G. W. Wheland, *ibid.*, **69**, 2025 (1947); (d) J. Hine and M. Hine, *ibid.*, **74**, 5266 (1952). (e) A. Streitwieser, Jr., *Tetrahedron Letters*, No. **6**, 23 (1960).

[4] R. Stewart, J. P. O'Donnell, D. J. Cram, and B. Rickborn, *Tetrahedron*, **18**, 917 (1962).