azine. Stirring was begun and a stream of dry hydrogen chloride passed into the solution. A white solid immediately precipitated and continued to form as the addition progressed. After an excess of hydrogen chloride had been added the mixture was crudely distilled, about 100 ml. of distillate being collected. The solid remaining was filtered by suction and dried at 15–60 mm. giving 12.9 g. (96%) of ammonium chloride. The distillate was fractionally distilled giving 34.0 g. of trimethylchlorosilane, b. p. 53–63°, 31.1–31.4% Cl (the pure material has b. p. 57.7°, 32.6% Cl); this represents a 63% conversion to the chlorosilane. Titration of the benzene residue indicated the presence of an additional 2.1 g. of hydrolyzable chlorine.

Reactions of Trimethyl-N-methylaminosilane

Treatment with Sodium.—No apparent reaction occurred upon refluxing trimethyl-N-methylaminosilane, b. p. 71°, with sodium.

Treatment with Trimethylchlorosilane: Preparation of Heptamethyldisilazine.—An immediate reaction occurred between 30.9 g. (0.30 mole) of trimethyl-N-methylaminosilane and 10.9 g. (0.10 mole) of trimethylchlorosilane. The reaction mixture was refluxed overnight, cooled and filtered. Distillation of the filtrate gave 21.4 g. (61%) of heptamethyldisilazine, b. p. 143–147°.

Anal. Calcd. for $C_7H_{21}Si_2N$: neut. equiv., 175.3. Found: neut. equiv., 178.1, 177.5.

Triethylsilyl Derivatives

Ammonolysis of Triethylchlorosilane.—To one liter of liquid ammonia in a 2-liter Dewar flask was added 93 g. (0.62 mole) of triethylchlorosilane[6] over a four-minute period with efficient mechanical stirring. The reaction was vigorous, volatilizing much ammonia. Stirring was stopped shortly after the addition was complete, whereupon the insoluble ammonolysis products (*ca.* 50 ml.) settled as a lower liquid phase. The ammonia was allowed to boil off through a soda lime drying tube; a latter portion of the vapor so distilled was found, upon absorption in water, to give the camphor-like odor of triethylsilanol. After the temperature of the reaction mass had risen to 0°, 500 ml. of dry heptane was added and the mixture slowly warmed.

After standing overnight the contents of the Dewar were filtered and the heptane distilled from the filtrate. Fractional distillation gave 21.4 g. (26%) of triethylaminosilane, b. p. 136.8–137.8° (753 mm.), n^{20}_D 1.4259–1.4260. Titration of this substance with 0.1 *N* hydrochloric acid in ether–water mixtures to the methyl orange endpoint gave erratic and high neutral equivalents, ranging from 141 to 148. Titration of a redistilled sample, b. p. 135.7° (748 mm.), n^{20}_D 1.4259, without ether gave consistent but still somewhat high results.

Anal. Calcd. for $C_6H_{17}SiN$: neut. equiv., 131.3. Found: neut. equiv., 134, 134, 134.

The higher boiling ammonolysis products were distilled in a modified Claisen flask at 16 mm. After the collection of a small amount (5 ml.) of material at 45° seven fractions totalling 27.6 g., b. p. 110–130°, n^{20}_D 1.433–1.450, were collected. The latter fractions probably consisted of a mixture of hexaethyldisiloxane and hexaethyldisilazine.[7]

The entire liquid ammonolysis products were taken up in ether and titrated with 5% hydrochloric acid to the methyl orange endpoint. The ether was distilled from the oily layer and the hydrolyzate then steam distilled. Distillation at atmospheric pressure of the readily volatile portion (39.6 g.) from the steam distillation gave 15.0 g. of triethylsilanol, b. p. 153.6–154.4° (758 mm.), n^{20}_D 1.4320–1.4318. The remaining portions of the steam distillate were found to contain a great deal of amino nitrogen; complete hydrolysis was however effected by refluxing for one hour with a mixture of hydrochloric and acetic acids.

Summary

1. The following new organosilicon compounds have been prepared and identified: trimethyl-N-methylaminosilane, trimethyl-N-ethylaminosilane, trimethyl-N,N-diethylaminosilane, heptamethyldisilazine and triethylaminosilane.

2. From trimethylchlorosilane the only ammonolysis product was hexamethyldisilazine. However, the stable primary amine $(C_2H_5)_3SiNH_2$ was produced from triethylchlorosilane.

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[6] This sample, b. p. 146.5–146.8°, was provided by C. P. Haber of this Laboratory who prepared it from ethylmagnesium chloride and silicon tetrachloride.

[7] Kraus and Nelson's statement (ref. 5) that this amine "distills at 100° under a pressure of 1 mm." probably does not refer to the true boiling point of the substance.

SCHENECTADY, NEW YORK RECEIVED AUGUST 9, 1945

[CONTRIBUTION FROM THE FRICK CHEMICAL LABORATORY, PRINCETON UNIVERSITY]

Further Investigations of Polarity in Hydrocarbons Possessing Conjugated Systems

BY N. BRUCE HANNAY AND CHARLES P. SMYTH

Hyperconjugation in butadiene, and in 1-methyl-, 2-methyl-, and 2,3-dimethylbutadiene has been investigated by means of dipole moment measurements.[1] The investigations were continued more than two years ago on other related molecules, but, because of lack of time resulting from war conditions, the results have not hitherto been written up for publication.

The dielectric constants of the vapors were measured with the apparatus and technique previously described.[2] The measurements on cyclopentadiene were made by the "two-point" method, in which the dielectric constant was measured at only two pressures, and the other substances were measured by the "extrapolation" method, in which the effects of deviations from the gas laws were eliminated by several measurements over a wide range of pressure.

Materials

1,2-Dimethylbutadiene-1,3,1,3-Dimethylbutadiene-1,3,-2-Ethylbutadiene-1,3.—Materials kindly furnished by the Carbide and Carbon Chemicals Corporation were believed to be of high purity. They contained no inhibitor as they polymerize relatively slowly. Any polymer that might possibly have formed would have been removed by the double distillation carried out in the vacuum system before the vapors were admitted to the measuring cell.

Cyclopentadiene.—Dicyclopentadiene from the United States Steel Corporation was kindly furnished by the du

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[1] Hannay and Smyth, THIS JOURNAL, **65**, 1931 (1943).

[2] McAlpine and Smyth, *ibid.*, **55**, 453 (1933); de Bruyne and Smyth, *ibid.*, **57**, 1203 (1935); Wiswall and Smyth, *J. Chem. Phys.*, **9**, 352 (1941).

Pont Company. The preparation of the monomer from this was carried out as described in the literature.[3] A Claisen flask, modified to serve as a Vigreux column, was used to crack the dimer. The fraction of the product boiling in the range, 40.6–41.5°, was collected at −80° and sealed on to the vacuum system. Between runs the monomer was kept at this temperature, no appreciable polymerization taking place.

Styrene.—Dow N-100 material, believed to be of high purity, was kindly furnished by Professor A. von Hippel and Dr. S. Witcher of the Massachusetts Institute of Technology.

Experimental Results

The results of individual runs at each absolute temperature, T, are given in Table I for the polarization, P, of all the substances. As the use of the "two-point" method for cyclopentadiene increased the errors in individual P values, several runs were made at each temperature for this substance to obtain an accurate average. The dipole moment μ was calculated from the equation $\mu = 1.28 \times 10^{-20}[(P - MR_D)T]^{1/2}$, in which the molar refraction, MR_D, was obtained or calculated from the literature. The average moment value for each substance and the value of the molar refraction used in calculating it are given in Table II.

TABLE I

POLARIZATIONS AND DIPOLE MOMENTS

T, °K.	P	$\mu \times 10^{18}$
1,2-Dimethylbutadiene-1,3		
399.2	35.80	0.63
417.3	35.77	.64
441.3	35.19	.63
467.8	35.10	.64
	34.74	.62
486.8	34.85	.64
	34.85	.64
1,3-Dimethylbutadiene-1,3		
399.2	36.58	0.64
423.1	36.42	.65
447.3	36.26	.66
496.8	35.67	.66
2-Ethylbutadiene-1,3		
384.2	33.74	0.49
422.5	32.49	.43
445.1	32.34	.43
479.0	32.54	.46
Styrene		
442.4	37.78	(0.0)
	37.36	
	36.62	
462.1	38.79	(.0)
	37.50	
Cyclopentadiene		
344.4	26.89	0.54
	26.95	.54
367.0	26.50	.53
	26.91	.55
	26.23	.52
389.2	26.04	.52
	26.19	.53
	25.90	.51
	26.41	.54
416.4	26.13	.54
	25.90	.53
	26.05	.54
	25.90	.53
452.1	25.38	.51
	25.38	.51
	26.02	.56
	25.55	.53

TABLE II

MOLAR REFRACTIONS AND MOMENT VALUES

	MR_D	$\mu \times 10^{18}$
1,2-Dimethylbutadiene-1,3	29.76[b]	0.63
1,3-Dimethylbutadiene-1,3	30.37[b]	.65
2-Ethylbutadiene-1,3	29.84[a]	.45
Styrene	36.35[a]	(.0)
Cyclopentadiene	21.83[c]	.53

[a] Taken from, or calculated from, tables in Landolt-Börnstein (5th edition). [b] Egloff, "Physical Constants of Hydrocarbons," Reinhold Publishing Corp., New York, 1939. [c] Auwers and Eisenlohr, *Ber.*, **43**, 821 (1910).

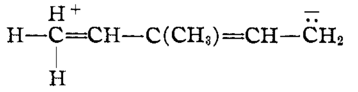
Discussion of Results

The moments of the simple butadienes previously investigated[1] gave quantitative evidence of the polarity arising from hyperconjugation. The moment of 2-methylbutadiene was found to be experimentally indistinguishable from that of propylene, for which polar structures may be written with the same charge separation as that in the polar structures contributing to the 2-methylbutadiene structure. The ratio of the moment of 1-methylbutadiene to that of 2-methylbutadiene was found to be approximately that of the charge separations in the structures responsible for their moments. Polar structures analogous to one or the other of these structures may be tentatively regarded as largely responsible for the moments of the butadienes or pentadienes under consideration in the present paper. The validity of this view of these molecules may be tested by examination of their moments from the point of view of the theory.

In addition to the non-polar structure of 1,2-dimethylbutadiene

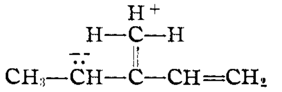
$$CH_3CH{=}C(CH_3){-}CH{=}CH_2 \quad \text{I}$$

and two compensating polar structures like those written for butadiene, one can write three polar structures such as II and three such as III below



$$H{-}\overset{H^+}{\underset{H}{C}}{=}CH{-}C(CH_3){=}CH{-}\overset{-}{\ddot{C}}H_2$$

II and



$$CH_3{-}\overset{-}{\ddot{C}}H{-}\overset{\overset{H^+}{H-C-H}}{\overset{\|}{C}}{-}CH{=}CH_2$$

III

Structure II should have a moment identical with that of the polar structures written for 1-methylbutadiene and structure III with that written for propylene or 2-methylbutadiene. If structures II and III contributed independently to the 1,2-dimethylbutadiene structure, its moment should be the resultant of the moments of 1-methylbutadiene, 0.68, and 2-methylbutadiene, 0.38, or propylene, 0.35, due account being taken of the angle between the dipoles of the two structures. The variety of forms made possible by *cis–trans* isomerism renders impossible any exact vector addition of the dipole moments resulting from II and III, but, as all the probable forms give an angle considerably greater than 90° between the two vectors, 0.68 and 0.38, a resultant close to the experimentally observed value, 0.63 should be obtained.

In 1,3-dimethylbutadiene, structures analogous

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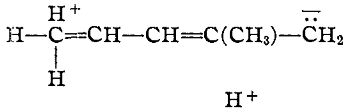
[3] Stobbe and Reuss, *Ann.*, **391**, 151 (1912); Kistiakowsky, Ruhoff, Smith and Vaughan, THIS JOURNAL, **58**, 146 (1936).

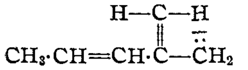
to those for 1,2-dimethylbutadiene contribute. In addition to the non-polar structure

$CH_3CH{=}CHC(CH_3){=}CH_2$ I

and the compensating polar structures like those of butadiene, there are three contributing polar structures such as II and three such as III below



$\mathrm{H{-}\overset{H^+}{\underset{H}{C}}{=}CH{-}CH{=}C(CH_3){-}\overset{..}{\bar{C}}H_2}$ II and

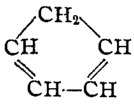


$\mathrm{CH_3{\cdot}CH{=}CH{\cdot}\overset{H^+}{\overset{H-C-H}{\overset{\Vert}{C}}}{-}\overset{..}{\bar{C}}H_2}$ III

As before, the contribution of II should give rise to a moment 0.68 and that of III to a moment 0.38. Of the three most probable forms capable of arising from *cis–trans* isomerism, space models show two to have the two dipoles pointing approximately at right angles to one another and one to have them largely opposing. The observed moment, 0.65, is a perfectly reasonable value for the resultant of these vectors. Because of the complexity of the structures of these two butadienes, their moment values can be regarded as entirely consistent with the theory of their structure, but supporting the theory only in a negative sense.

The moment found for 2-ethylbutadiene, 0.45, is 0.07 higher than that of the corresponding methyl compound, a difference in the direction commonly observed between methyl and ethyl compounds and variously explained in terms of induction, contributions from hyperconjugated forms, or merely the greater strength of the ethyl group as an electron source. The difference is greater than the difference, 0.03, found between α-butylene[4] and propylene,[5] but, in view of the unavoidable uncertainties in the absolute values of these small butadiene moments, can be regarded as in qualitative agreement.

Cyclopentadiene is a 1-substituted butadiene, but the ring structure necessarily makes the molecule *cis* with respect to the central double bond produced in resonance of the compensating butadiene type.



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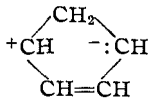
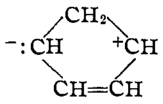
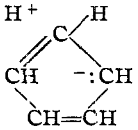


II

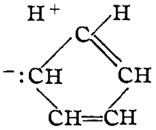


III

The polarities of II and III will, of course, cancel. In addition to resonance structures of the type II and III, resonance involving hyperconjugation can give two structures such as IV and two such as V.

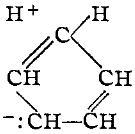


IV

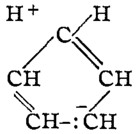


V

The moment produced by IV and V should be much smaller than the 1-methylbutadiene moment, because the *cis* form of cyclopentadiene gives a very much smaller distance for the charge separation than does similar resonance in 1-methylbutadiene. However, four more resonating forms involving hyperconjugated structures are possible for cyclopentadiene, which were not written for 1-methylbutadiene. These are two such as VI and two such as VII.



VI



VII

The corresponding forms for 1-methylbutadiene seem less likely than forms VI and VII for cyclopentadiene, where the ring structure maintains the conjugation of the double bonds in this type of resonance.

Electron diffraction[6] indicates a shortening of the C–C bond shown as double in structures II and III and consequent double bond character like the shortening of the central bond in butadiene, but no measurable shortening of the other two single bonds of the ring. This indicates that structures II and III are the most stable of the polar structures since they give double bond character to the one single bond, but not to the other two. However, contributions from the other polar structures sufficient to produce the observed moment 0.53 would produce changes in bond length well within the experimental error of the electron diffraction measurements. The dipole moment is thus consistent with the electron diffraction results, but gives evidence of contributions from other structures which are not required by the electron diffraction results.

The measurements made on styrene are insufficient to establish the absence of a very small moment in the molecule, but indicate that the moment is, probably, less than 0.2 and experimentally indistinguishable from zero. This is in agreement with the results of numerous measurements in solution, which have yielded moment values[7] between 0.0 and 0.4, really experimentally indistinguishable from 0.

One may write polar structures for styrene analogous to those written for the butadienes. In one type, the ortho or para carbon or its attached hydrogen is positive and the terminal carbon negative, while, in the other, the terminal carbon or one of its attached hydrogens is positive and the ortho or para carbon negative. Equal stabilities of the different structures would result in zero dipole moment. The absence of detectable moment shows that the two types of struc-

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[4] Smyth and Zahn, This Journal, **47**, 2501 (1925).

[5] McAlpine and Smyth, *ibid.*, **55**, 453 (1933).

[6] Schomaker and Pauling, *ibid.*, **61**, 1769 (1939).

[7] Smyth and Dornte, *ibid.*, **53**, 1296 (1931); Otto and Wenzke, *ibid.*, **57**, 294 (1935); Müller, *Physik. Z.*, **38**, 283 (1937); Gorman, Davis and Gross, *ibid.*, **39**, 181 (1938); Lee, *J. Soc. Chem. Ind. Japan*, **43**, (suppl. binding), 190 (1940).

ture differ little in stability. This absence of detectable moment when a phenyl and a vinyl group are attached to each other is consistent with the fact that the attachment of a methyl group to a vinyl to form propylene gives practically the same moment as the attachment of a methyl group to phenyl to form toluene. It should be recalled, however, that the attachment of a group producing large charge displacement, such as cyanide or chlorine, to the phenyl or the vinyl group does not give the same moment in the two cases.

Summary

The dielectric constants of the vapors of 1,2-dimethyl-, 1,3-dimethyl-, and 2-ethylbutadiene, and of cyclopentadiene and styrene have been measured and used to calculate the dipole moments of the molecules. The moment values are consistent with the molecular structures required by the previously discussed theory of hyperconjugation and resonance, thus lending support to the theory.

PRINCETON, N. J. RECEIVED NOVEMBER 14, 1945

[CONTRIBUTION FROM THE DEPARTMENT OF BIOLOGY, MASSACHUSETTS INSTITUTE OE TECHNOLOGY]

A Fibrous Modification of Insulin. I. The Heat Precipitate of Insulin

BY DAVID F. WAUGH

When insulin is heated in the presence of dilute acid a series of changes take place, the end result of which may be the formation of a visible flocculent precipitate. This flocculation, termed the "heat precipitate" by du Vigneaud, forms most rapidly in the presence of sulfuric acid and salt.[1,2,3,4]

Slightly different conditions lead to the formation of a clear gel which shows either flow or static double refraction depending on the protein concentration. The insulin has been modified to give anisodiametric micelles.[5] These have been shown to be fibrils.[6]

The author will discuss aspects of fibril formation (such as reversibility, reactions involved, reaction kinetics and chemical modification of fibril formation) in other publications of this series. To interpret the results of such studies an understanding of the relationships between fibril and floccule formation is necessary. Fibril formation seems to be a prerequisite for floccule formation. However, floccule formation does not always follow fibril formation, for preparations may be obtained which contain only fibrils or varying proportions of fibrils and floccules.

This publication considers the structure of the floccule and correlations between rates of fibril and floccule formation. As will be shown the floccule has a spherocrystalline structure. A number of intra- and extra-cellular structures have a similar arrangement of their component parts. Insulin spherites are therefore of considerable interest.

I. Experimental Techniques

The insulin[7] solutions to be heated were sealed into annealed Pyrex ampules made from 8-mm. tubing. Each ampule, 20 cm. long, had a total volume of about 3 ml. One ml. of solution was generally enclosed.

Double refraction measurements to be reported here were usually made in the presence of varying quantities of floccules. Quantitative measurements were therefore not attempted. Rocking the tube between crossed polaroids produced sufficient flow so that the appearance of faint or strong flow or weak, strong, or intense static double refraction could be timed conveniently. Only the longer fibrils, estimated to be 5–10 thousand ångström units long (assuming an axial ratio of 50–100), are oriented by this means if flow double refraction is obtained. Static double refraction, which depends on hindrance of free rotation, may also involve much shorter fibrils.

Microscopic examinations were made with a standard petrographic microscope. Information concerning analysis by polarized light, double refraction, and particularly the properties of objects having radial symmetry may be found in recent reviews.[8]

Crystalline insulin was used except where noted.

II. Insulin Fibrils

A few results are presented as a preparation for discussing floccule formation. When heated at 100° a sample of 2% amorphous or crystalline insulin in hydrochloric or phosphoric acids at *p*H 2.3–2.5 generally shows little or no floccula-

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(1) Blatherwick, Bischoff, Maxwell, Berger and Sahyun, *J. Biol. Chem.*, **72**, 57 (1927).

(2) du Vigneaud, Geiling and Eddy, *J. Pharmacol.*, **33**, 497 (1928).

(3) Gerlough and Bates, *ibid.*, **45**, 19 (1932).

(4) du Vigneaud, Sifferd and Sealock, *J. Biol. Chem.*, **102**, 521 (1933).

(5) Langmuir and Waugh, THIS JOURNAL, **62**, 2771 (1940).

(6) Waugh, *Am. J. Physiol.*, **133**, 484 (1941).

(7) The author is indebted to Dr. G. H. A. Clowes of Eli Lilly & Co. for his generous gifts of amorphous insulin and to Dr. H. Sydney Newcomer for making available crystalline insulin prepared by Squibb and Sons.

(8) Schmitt in "Medical Physics," edited by Glaser, New York Book Publishers, New York, N. Y., 1944.