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"Preparation and Properties of Organic
Derivatives of Tin Hydride"

Final Report

C. R. Dillard in collaboration with E. E. Holmes,
J. R. Lawson, D. E. Simmons, and J. B. Yeldell

August 31, 1952

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I. INTRODUCTION

The goals of the research project sponsored by the Office of Naval Research at Tennessee Agricultural and Industrial State University are as follows:

- (1) to prepare and study the properties of a number of organic derivatives of tin hydride, (stannane).
- (2) to deduce from the differences between the properties of these compounds and those of analogous compounds of carbon and silicon; the effects due to the more electropositive nature of tin.
- (3) to derive, wherever possible, theoretical principles which will serve as a guide to further research in this area.

The approach to this research has been dictated by the availability of apparatus and personnel, hence the choice of problems appears arbitrary. However, as the data from various experiments have been assembled, certain consistencies have become apparent. These consistencies are discussed in the final section of this report where the results of the various experiments are correlated and interpreted in the light of recent chemical theory.

II. THERMOCHEMISTRY OF SEVERAL ALKYL AND ARYL STANNANES

It is desirable to make thermochemical studies of organo-tin compounds because the data obtained can be used to calculate bond energies and the electronegativity of the metal. This information is important in that it will contribute to the theoretical interpretation of the chemical properties of organo-tin compounds.

Published values of the heats of combustion and formation of tin alkyls exist only in the case of tetraethyl tin, tetrapropyl tin, tetrabutyl tin and tetraamyl tin.¹

¹W. J. Jones, D. P. Evans, T. Gulwell and D. C. Griffiths,
J. Chem. Soc. 39-47 (1935)

In this investigation, the heats of combustion and formation of tetraethyl tin and tetrabutyl tin have been redetermined, and the heats of combustion of tetramethyl tin, tetra-n-hexyl tin and tetraphenyl tin are reported for the first time.

Experimental

Pure tetra alkyl stannanes were prepared according to the method of Kocheshkow² as modified by Jones and co-workers.¹ Ben-

²K. A. Kocheshkow, J. Gen. Chem., (USSR) 4, 1359 (1934)

zene solutions of stannic chloride were added to an excess of the appropriate grignard reagents. The excess grignard reagent was then destroyed by hydrolysis and the crude product was repeatedly distilled through an efficient fractionating column until a sample was obtained which showed no change in refractive index upon further distillation. (It was found that the index of refraction was a better criterion of purity than elementary analysis. Samples containing small amounts of impurity often gave "correct" analyses but in such cases, the observed index of refraction would change upon further distillation.)

In the preparation of tetramethyl tin, toluene rather than benzene was used as a solvent for the stannic chloride in order that the separation of the product could be more easily accomplished.

Tetraphenyl tin, a solid at room temperatures, was purified by

recrystallization from benzene.

Physical properties of the compounds studied are listed in Table I.

TABLE I
Physical Constants of Compounds Studied

Compound	B. Pt. °C	M. Pt. °C	n_D^{20}	Density at 20° C g/ml
Tetramethyl tin	78°/760mm		1.4413	1.2905
Tetraethyl tin	78°/13mm		1.4724	1.1916
Tetrapropyl tin	81°/4mm		1.4830	
Tetrabutyl tin	145°/10mm		1.4730	1.057
Tetraamyl tin	181/10mm		1.4733	1.0206
Tetra-n-hexyl tin	209°/10mm		1.4743	0.9950
Tetraphenyl tin		224°		0.432

The heats of combustion were determined in a Parr oxygen bomb calorimeter, model no. 13051. The bomb was a single valve self-sealing type constructed of Inconel. Its assembled weight was 2963.7 grams and its internal capacity was 350 cc.

The bomb was held in an oval calorimeter bucket of slightly more than 2000 cc. capacity. This in turn was contained in a plain, double walled bakelite jacket. The heat of stirring was within the limits of experimental error, moreover, this effect was eliminated by running the standardizations and determinations in exactly the same manner.

The temperature was measured by means of a precision thermometer, (certificate No. R0229), reading from 65 to 95° F.,

graduated in hundredths of a degree, and standardized by the Parr Instrument Company according to the recommendations of the National Bureau of Standards. The maximum error in differential measurements within any ten degree range was one hundredth degree Fahrenheit (0.01° F). The observed temperature rise in a combustion experiment was converted from degrees Fahrenheit to degrees Centigrade using the factor, 1° C = 1.8° F.

The charge was fired by ten centimeters of special resistance fuse wire of such dimensions that each one centimeter length burned was equivalent to 2.8 calories.

The same mass of water, within 0.1 gram, was used in each combustion. This was measured in a two liter volumetric flask at a temperature of 27° C. maintained constant by placing the flask in a thermostated water bath. The same pressure of commercial oxygen, 25 atm. absolute, was used in every run, and 1 g. of water was added to the bomb.

Nitric acid formed in the combustion* was determined by titration of the bomb washings with standard sodium carbonate, using methyl orange as indicator.

The actual temperature rise during combustion was calculated and corrected according to the method of Dickinson.³

³Dickinson, H. C., Bull. U. S. Bur. Stds. 11, 189 (1915).

The calorimeter constant was determined by the combustion of

*Nitric acid was formed by the combustion of residual nitrogen in the bomb. It was found that the combustion reactions proceeded more smoothly when the bomb was not flushed with oxygen prior to the final filling.

benzoic acid (standard sample 39 g.) supplied by the National Bureau of Standards. The isothermal heat of combustion of this sample is certified to be 26.4388 abs. kj. per gram true mass when burned in pure oxygen at 25-30 atm. pressure in a bomb of approximately 1/3 liter volume. For convenience in these measurements, the calorimeter constant was expressed in calories per degree, derived from the international kilojoule by using the conversion factor; 1 calorie = 0.0041840 abs. kj.

The value of the calorimeter constant was found to be 2421 $\pm$ 2 cal. per degree. Detailed calibration data is given in Table II.

TABLE II

Standardization of the Bomb Calorimeter

Run No.	Calorimeter Const. (cal/degree)
1	2427
2	2415
3	2428
4	2417
5	<u>2420</u>
Mean	2421 $\pm$ 2.1

Samples of the tetra-alkyl stannanes were weighed directly in the sample cup of the bomb and the procedure used in the determination of their heats of combustion was identical with that used in the standardization of the calorimeter.

A slight modification was adopted in the case of the highly volatile tetramethyl tin. Samples of this compound were weighed

and sealed in soft glass ampoules. A 0.5 gram pellet of benzoic acid was placed in the bomb with each sample to insure breakage of the ampoule and to initiate the combustion of the tetramethyl tin. In the calculations of the heat of combustion, corrections were made for the heat due to the benzoic acid.

The solid tetraphenyl tin was compressed into pellets weighing approximately one gram.

In most of the experiments, the combustion reaction went to completion as was evidenced by the consistent results and by the fact that stannic oxide was left as a white residue. In cases where the residue was dark or discolored, it was obvious that the combustion had been incomplete.

Calculation of Heats of Combustion

Combustion data on the compounds investigated are given in Table III. In order to express the experimental results in calories per mole under the conventional conditions of temperature and pressure, the following corrections were applied:

- (i) All weighings were reduced to weight in vacuo.
- (ii) The bomb process was corrected for the combustion of the fuse wire and formation of nitric acid.
- (iii) The bomb process was corrected to constant temperature.
- (iv) The pressure was reduced to one atmosphere.
- (v) The combustion was converted from a constant volume process to one of constant pressure.

Correction (i) was applied at the outset. This required the knowledge of the densities at room temperature of all the substances weighed. Reliable figures were available for all of these except tetraphenyl tin, in which case the density was measured and found to be 0.432 g/ml.

TABLE III
Heats of Combustion and Formation
of
Tetra-organo-tin Compounds

Compound	Observed - ΔH (comb.) Kcal/mole	Heat of formation Kcal/mole
Tetramethyltin	945 927 929 934 Mean $\frac{934}{934} \pm 2.8$	- 9
Tetraethyltin	1541 1548 1552 1547 Mean $\frac{1547}{1547} \pm 1.5$ (1521) ^a	± 27 (± 39) ^a
Tetra-n-butyltin	2624 2806 2819 Mean $\frac{2819}{2816} \pm 3.9$ (2773) ^a	± 57 (± 111) ^a
Tetra-n-hexyltin	4063 4065 4050 Mean $\frac{4050}{4060} \pm 3.2$	± 119
Tetraphenyltin	3178 3175 3189 3184 3182 Mean $\frac{3182}{3182} \pm 1.8$	± 581

^aData of Jones and co-workers, ref. 1.

Correction (ii) was determined by measuring the unburned wire and by titrating the nitric acid formed in the reaction with standard sodium carbonate.

The initial temperature of most of these experiments was approximately 27° C., which was about two degrees below average room temperature. The heat of the actual bomb process was corrected to this temperature rather than 25° using the equation suggested by Washburn.⁴

⁴Washburn, J. Res. Nat. Bur. Stds. 10, 525 (1933).

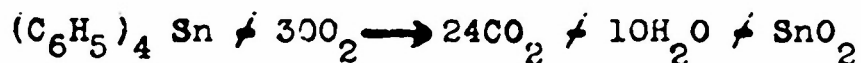
The observed heat of the bomb process was corrected to the heat of combustion at one atmosphere pressure with all of the substances in their standard states, according to the method of Washburn⁴ (loc. cit.). In the case of the compounds studied in this investigation, this correction was well within the limits of experimental error.

Correction (v) was computed according to the equation,

$$\Delta H = \Delta U_r + \Delta nRT$$

where ΔH is the heat of combustion at constant pressure, ΔU_r is the corrected heat of combustion at constant volume, Δn is the change in the number of moles of gaseous substances involved in the combustion reaction, R is the gas constant and T is the absolute temperature. The general equation for the combustion of the compounds studied in the investigation* is $(C_n H_{2n+1})_4 Sn + (6n+2) O_2 \rightarrow SnO_2 + 4n CO_2 + (4n+2) H_2O$ and at room tempera-

*With the exception of tetraphenyl tin; the equation for the combustion of this substance is



ture; $\Delta n = (6n / 2) - 4n = 2n / 2$.

The values of $-\Delta H$ listed in Table III represents the heat liberated when one mole of the given substance in its standard state burns in oxygen at one atmosphere pressure, the process occurring at approximately 27° C. These values have uncertainties of 0.1 to 0.3% which is the maximum precision obtainable with apparatus of the type used in this investigation. However, much of the thermochemical data used to calculate heats of formation and bond energies are known with no greater accuracy.

Calculation of the Heats of Formation

The heats of formation were calculated from the heats of combustion and the results are given in Table III. In these calculations the heats of formation of liquid water, gaseous carbon dioxide and solid stannic oxide were taken to be 68.317^5 , 94.052^6 , and 138.8^7 kcal. per mole, respectively.

⁵D. D. Wagman, J. E. Kilpatrick, W. U. Taylor, K. S. Pitzer and F. D. Rossini, J. Res. Nat. Bur. Stds. 34, 143, 1945.

⁶E. J. Prossen, R. S. Jessup and F. D. Rossini, J. Res. Nat. Bur. Stds. 33, 447 (1944)

⁷J. Moose and S. W. Parr, J. Am. Chem. Soc. 46, 2656 (1924)

Discussion of Results

Comparison of the heats of combustion of tetraethyl tin and tetrabutyl tin reported by Jones and co-workers¹ (loc. cit.), with the values obtained in this investigation reveals that the results are consistently higher in the latter case. This difference is greater than that expected for a small difference in reference temperature. However, since the previous report does not include any experimental details, other than a brief description of the calorimeter, it is not possible to ascertain reasons for the apparent discrepancies.

The principal source of error in experiments of this type, where one of the combustion products is a solid, is failure to obtain complete combustion. This would lead to low values of the observed heat of combustion.

Inspection of Table III reveals that there is about 158 kcal per mole increase in the heat of combustion per CH_2 group added in lengthening the alkyl radical chains from methyl to hexyl. This is in agreement with the increase of 157.5 kcal per CH_2 group observed in the heats of combustion of homologous paraffin hydrocarbons.

III. CALCULATION OF BOND ENERGIES

In the case of diatomic molecules, the term "bond energy" is defined as the energy required to dissociate the molecule into its atoms. Such energies can be determined directly by spectroscopic or by thermochemical means. In the case of polyatomic molecules, it is not possible to unambiguously define the "bond energy" because of the undetermined influence of the several bonds upon one another. Moreover it has been pointed out that the electronic energy levels of the atoms in a compound may be different from the ground states of the isolated atoms.⁸ Unfortunately, data con-

⁸L. H. Long and R. G. W. Norrish. Phil. Trans. Roy. Soc., London A 241, 587 (1949).

cerning these excited electronic states are not always available.

In the case of polyatomic molecules in which all the bonds are alike, one can determine the energy required to break all of the bonds and by dividing by the total number of bonds broken, obtain an "average bond energy" which represents a lower limit to the true

bond energy.⁹ Rough values of the bond energies of polyatomic

⁹L. Pauling, "Nature of the Chemical Bond". Cornell Univ. Press, Ithaca, 1940 pp. 52-58.

molecules containing unlike bonds may be determined by subtracting known bond energies from the energy required to totally dissociate the molecules into atoms.

Using Pauling's empirical values of single bond energies and heats of atomization⁹, together with the thermochemical data obtained in this investigation, we have calculated the tin-carbon bond energies in tetramethyl tin and tetraethyl tin. The required data is summarized in Table IV.

TABLE IV

Data Used In The Calculation of Bond Energies

Process	ΔH_{298} (Kcal)/mole
ΔH formation $(CH_3)_4Sn$	-9.
ΔH formation $(C_2H_5)_4Sn$	27.
ΔH vaporization $(CH_3)_4Sn^{(a)}$	- 7.5
ΔH vaporization $(C_2H_5)_4Sn^{(b)}$	- 9.5
$Sn(solid) \longrightarrow Sn(gas)^{(c)}$	78.0
$C(graphite) \longrightarrow C(gas)^{(c)}$	124.3
$H_2(gas) \longrightarrow 2 H(gas)^{(c)}$	51.7
Empirical bond energy, $D(C - H)^{(c)}$	87.3
Empirical bond energy, $D(C - C)^{(c)}$	58.6

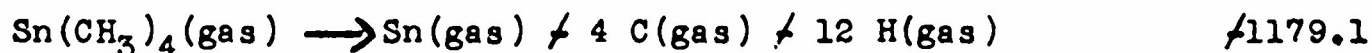
(a) estimated from vapor pressure data

(b) estimated using Trouton's rule

(c) L. Pauling, reference 9

Calculations of the bond energies were made as follows:

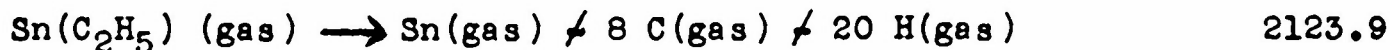
	ΔH
$\text{Sn}(\text{CH}_3)_4(\text{liquid}) \longrightarrow \text{Sn}(\text{solid}) + 4 \text{ C}(\text{graphite}) + 6 \text{ H}_2(\text{gas})$	- 9.0
$\text{Sn}(\text{CH}_3)_4(\text{gas}) \longrightarrow \text{Sn}(\text{CH}_3)_4(\text{liquid})$	- 7.5
$\text{Sn}(\text{solid}) \longrightarrow \text{Sn}(\text{gas})$	+ 78.0
$4 \text{ C}(\text{graphite}) \longrightarrow 4 \text{ C}(\text{gas})$	+ 497.2
$6 \text{ H}_2(\text{gas}) \longrightarrow 12 \text{ H}(\text{gas})$	+ 620.4



Subtracting the energy of twelve C-H bonds, (1047.6 kcal), and dividing the remainder by four, yields 32.9 kcal/mole as the energy of the Sn-C bond in tetramethyl tin.

In the case of tetraethyl tin the thermochemical equations are as follows:

	ΔH
$\text{Sn}(\text{C}_2\text{H}_5)_4(\text{liquid}) \longrightarrow \text{Sn}(\text{solid}) + 8 \text{ C}(\text{graphite}) + 10 \text{ H}_2(\text{gas})$	+ 27.0
$\text{Sn}(\text{C}_2\text{H}_5)_4(\text{gas}) \longrightarrow \text{Sn}(\text{C}_2\text{H}_5)_4(\text{liquid})$	- 9.5
$\text{Sn}(\text{solid}) \longrightarrow \text{Sn}(\text{gas})$	+ 78.0
$8 \text{ C}(\text{graphite}) \longrightarrow 8 \text{ C}(\text{gas})$	+ 994.4
$10 \text{ H}_2(\text{gas}) \longrightarrow 20 \text{ H}(\text{gas})$	+ 1034.0



Subtracting the energies of four C-C bonds (234.4 kcal), plus twenty C-H bonds (1746 kcal) and dividing the remainder by four, yields 35.9 kcal/mole as the Sn-C bond energy in tetraethyl tin.

Similar calculations yielded 37 kcal/mole and 39 kcal/mole as the Sn-C bond energies in tetrabutyl tin and tetrahexyl tin, respectively. However, these latter figures represent small differences between relatively large numbers and for that reason are merely approximations.

It can be concluded that (1) the bond energies in these organotin molecules are additive and (2) in the compounds studied the Sn-C bond energy has a reasonably constant value.

IV. INFRARED STUDIES

It has been the intention of the Physics Department at this University to initiate a program of research in infrared spectroscopy. In anticipation of this program, an investigation of the infrared spectra of organotin compounds was undertaken on this project. Since no instrument was available on this campus, samples of the desired compounds were sent to a commercial laboratory where spectrograms were made.

The data reported here are of a preliminary nature and the conclusions reached are tentative. Our own instrument has been recently purchased and as soon as it is installed this work will be extended.

Experimental

The compounds studied were prepared in a state of high purity as described in an earlier section of this report. Spectrograms of the compounds studied are shown in figures I and II. They include tetramethyl tin, I-A; tetraethyl tin, I-C; tetrapropyl tin II-F; tetraphenyl tin I-E; tetra-n-amyl tin, II-H; tetra-n-hexyl tin, I-D; tetraphenyl tin, I-B; diethyl tin dichloride, II-G; and tripropyl tin chloride, II-J. In these figures the percent transmission is plotted against wavelength and against wave number. In the case of tetramethyl tin, the measurements made on samples of 0.2 mm. thickness and 0.01 mm. thickness are shown on the same spectrogram.

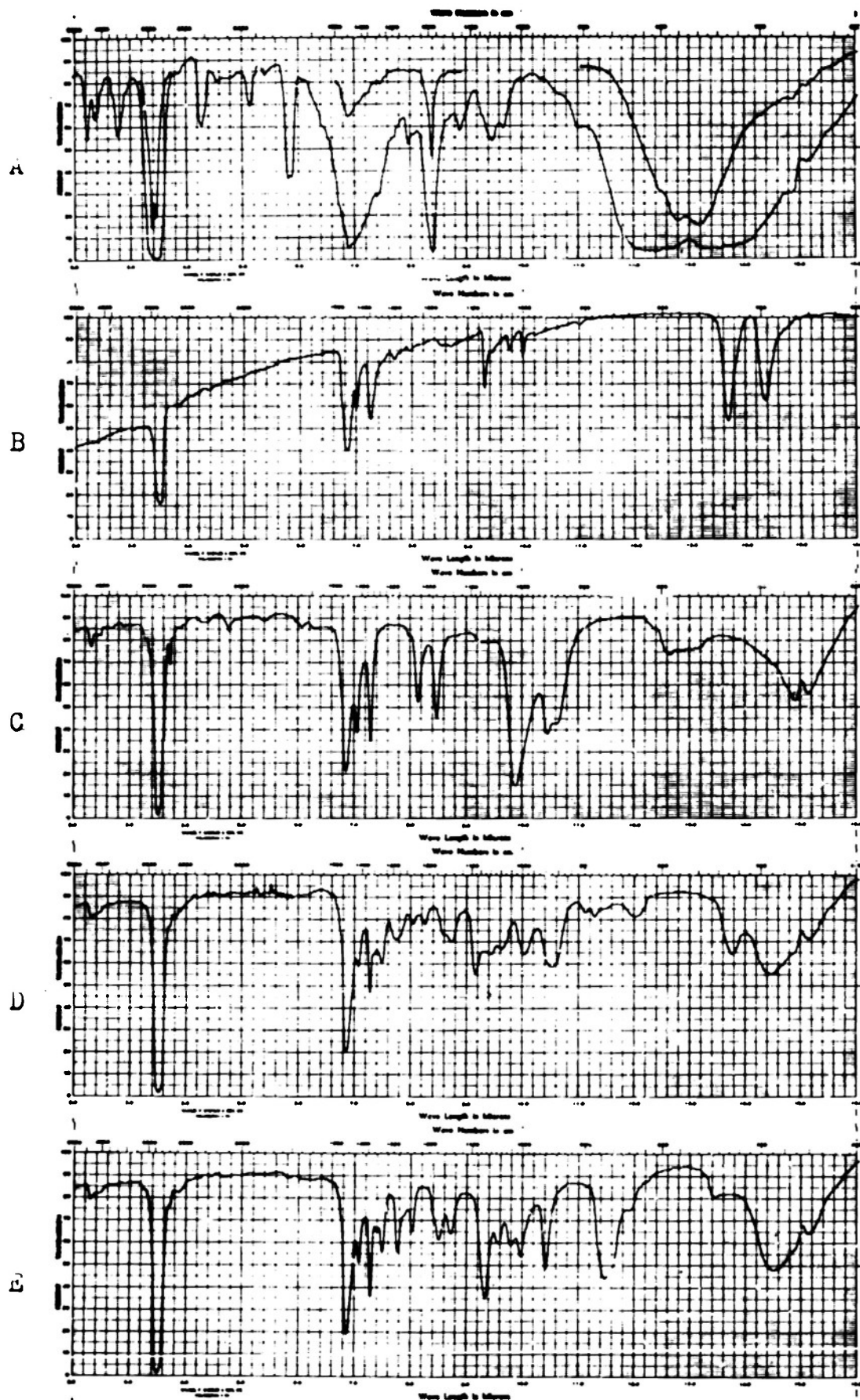


FIGURE I.

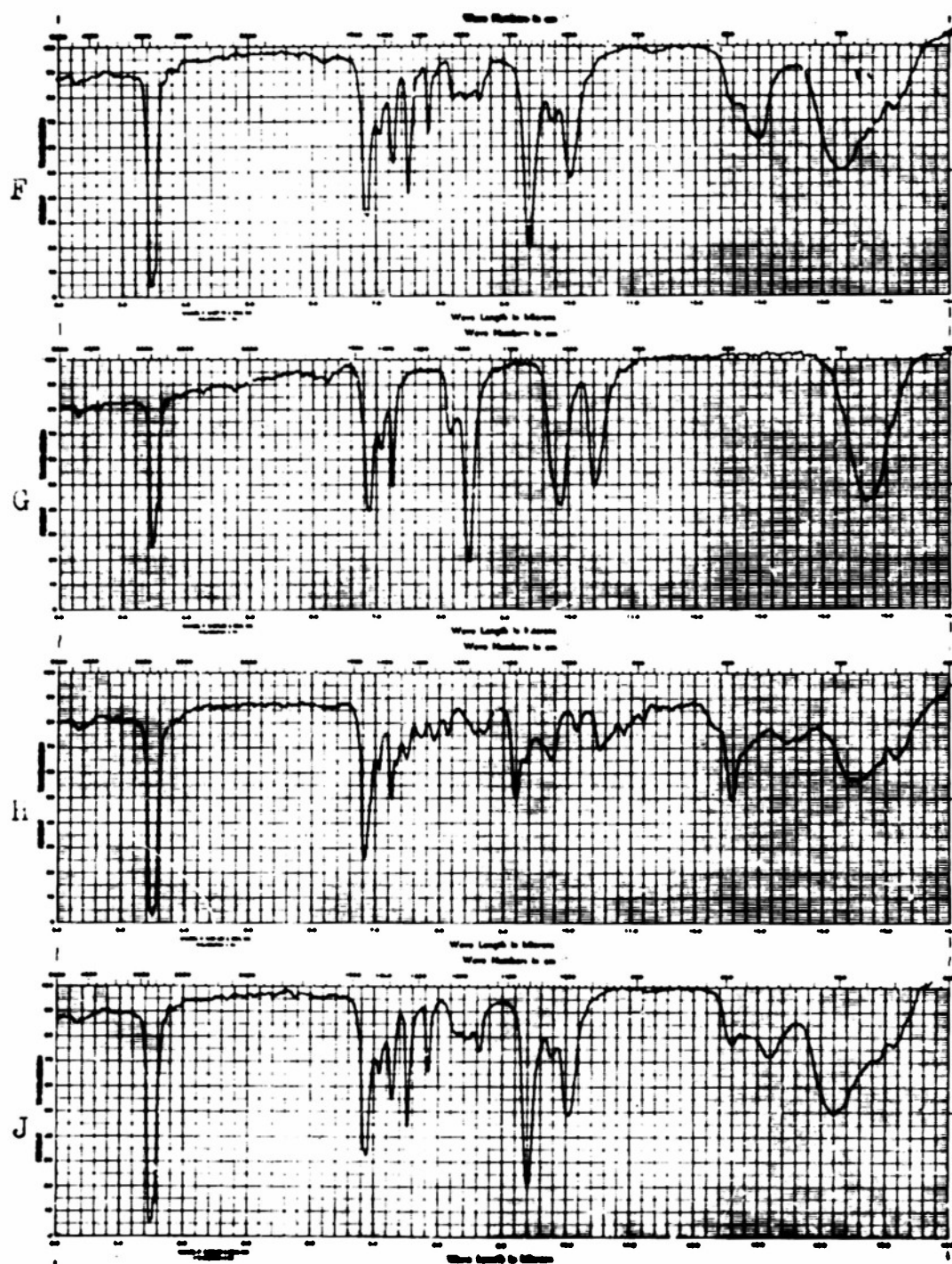


FIGURE 11.

The spectrograms were recorded at Samuel Sadtler and Son, Inc., employing a Baird Associates double beam spectrophotometer equipped with rock salt optics. The spectral region covered was from two to sixteen microns. The spectral slit widths extended from 0.003 inch to 0.17 inch. The position of the sharp absorption bands are determined to $\pm$ 0.025 micron.

The spectra, with the exception of two samples, were obtained in the liquid state using Baird liquid cells with thickness of 0.01 and 0.20 mm. The spectrum of tetraphenyl tin was obtained in a Nujol mull. The spectrum of diethyl tin dichloride was run in a saturated carbon tetrachloride solution.

Analysis of the Spectrograms

A preliminary study has been made of the spectrograms of the six symmetrically substituted alkyl stannanes, SnR_4 , where R indicates methyl, ethyl, propyl, butyl, amyl and n-hexyl groups successively.

This study was undertaken with the view of realizing the following objectives:

- (1) to secure a unique physical characterization of these compounds by means of their infrared absorption spectra.
- (2) to provide additional experimental evidence for the assumption that, even in complex molecules, certain molecular groupings of atoms retain their characteristic group vibrations.
- (3) to observe the effect of the complexity of the substituent alkyl group in the compounds of the type SnR_4 upon the so called skeletal vibrations of molecules possessing this symmetry (T_d).
- (4) to supply vibrational frequencies that may be used to calculate certain thermodynamical data for compounds of this type.¹⁰

¹⁰E. B. Wilson, Chem. Rev. 17, 27, (1940)

Of the compounds reported here, only tetramethyl tin has been previously studied spectroscopically.¹¹ A complete assignment of the fundamental frequencies of this compound has been made in the spectral region 1 to 15 μ .¹²

¹¹C. F. Kettering and W. W. Sleator, *Physics* 4, 39 (1933)

¹²C. W. Young, J. S. Koehler and D. S. McKinney, *J. Am. Chem. Soc.* 69, 1410 (1947)

The spectrogram of tetramethyl tin shown in Fig. I-A, is in exact agreement with that obtained by earlier workers,¹¹ therefore we have used the assignment of frequencies given by Young¹² and co-workers as a basis for assignments in the case of the higher members of this series. Also taken into account were the results of the analysis of the Raman spectra of tetraethyl silane¹³ and the infrared analysis of tetraethyl lead¹⁴ for which analogous vibrational frequencies should be expected.

¹³H. Murato, R. Okawara and T. Watase, *J. Chem. Phys.* 18, 1308, (1950)

¹⁴A. B. F. Duncan and J. W. Murray, *J. Chem. Phys.* 2, 636 (1934)

Preliminary assignments are listed in Table V, where ν (C-H) denotes stretching vibrations of the C-H bonds and δ (C-H) denotes deformation vibrations.

Consideration of the results from the point of view of the stated objectives of this investigation reveals the following:

- (1) It is possible to uniquely characterize each of the compounds of the type SnR_4 , by means of its infrared spectrum. A scrutiny of Figs. I and II reveals that the more significant spectral differences appear in the range 9 to 16 microns, the so-called "finger print region".

TABLE V
Preliminary Assignment of Group Vibrations

Compound	Observed Frequencies (cm ⁻¹)	
	ν (C-H)	δ (C-H)
Tetramethyltin	2906, 2958	1449, 1193, 781
Tetraethyltin	2849	1460, 1416, 1370, 1229, 1180, 790
Tetrapropyltin	2890	1456, 1416, 1377, 1333, 1279, 1218, 1190, 1160, 794 769, 701
Tetrabutyltin	2857	1458, 1412, 1373, 1333, 1289, 1247, 1176, 1147, 745, 690
Tetraamyltin	2857	1464, 1416, 1379, 1366, 1337, 1297, 1263, 1232, 1170, 1152, 743 691
Tetrahexyltin	2857	1460, 1412, 1374, 1333, 1287, 1244, 1211, 1163, 1145, 727, 691

- (2) Table V reveals the degree to which CH_3 and CH_2 group vibrational frequencies are associated with stretching, $\nu(\text{C-H})$, and deformation, $\delta(\text{C-H})$, modes of vibrations remain invariant throughout the series of increasingly complex molecules, going from tetramethyl tin to tetra-n-hexyl tin.
- (3) No skeletal vibrations appear in the spectral range embraced by the present survey.

These results indicate the necessity of extending the measurements over a wider spectral range (50 cm.^{-1} to 5000 cm.^{-1}), and of re-examining the high frequency region under higher dispersion.

If this is done it should be possible to (1) make positive assignments of all observed frequencies on the assumption of a molecular model having symmetry T_d ; (2) make an approximate calculation of the effective "R-masses", assuming that the radical behaves as a point mass^{15,16}; (3) calculate force constants of Sn-C bonds in molecules of the type SnR_4 .

¹⁵R. K. Sheline, J. Chem. Phys. 18, 602 (1950)

¹⁶R. K. Sheline and K. Pitzer, J. Chem. Phys. 18, 595 (1950)

V. ATTEMPTED PREPARATION OF CHLOROETHYL STANNANES

Several attempts were made to prepare chloroethyl tin chlorides of the general formula, $(\text{Cl C}_2\text{H}_4)_y\text{SnCl}_{(4-y)}$, where y is an integer, 1 to 4. Two methods of attack were employed: (1) photochemical chlorination with elementary chlorine in the presence of phosphorous pentachloride; (2) reaction with sulfonyl chloride in the presence of benzoyl peroxide.

Both procedures have been used successfully to prepare ana-

logous silicon compounds,^{17,18,19} however in the case of the tin

- ¹⁷Ushakov and Itenberg, J. Gen. Chem. USSR 7, 2495 (1937)
¹⁸Krieble and Elliott, J. Amer. Chem. Soc. 67, 1810 (1945)
¹⁹Sommer and Whitmore, J. Amer. Chem. Soc. 68, 485 (1946)
-

compounds, replacement of the alkyl radical by chlorine rather than chlorination was the principal reaction.

When tetraethyl tin was used as the starting material a mixture of the ethyltin chlorides, stannic chloride and ethyl chloride were the only products. When ethyltin trichloride was used as the starting material, the products were stannic chloride and ethyl chloride.

In the case of the peroxide catalyzed reaction with sulfuryl chloride, a free radical mechanism was indicated. Ethane, ethylene, and butane were found among the gaseous reaction products. These were identified by measurement of their characteristic vapor pressures at several temperatures, and by determination of their molecular weights. Since the experiments were not designed to collect these substances quantitatively, it is not possible to report exact yields. In as much as in no case were the desired chloroethyl tin chlorides obtained, this phase of the investigation was discontinued.

VI. SOME PROPERTIES OF ETHYLTIN CHLORIDES

In order to separate and identify possible products in the chlorination experiments, it was necessary to collect data on the physical properties of the ethyl tin halides. Little such information is found in the current chemical literature. Therefore, very pure samples of these compounds were prepared and a careful study of their physical properties was made.

The results of these studies are summarized in Table VI.

Those properties not previously reported in the literature are denoted by asterisks.

Experimental

The ethyl tin chlorides were prepared by refluxing, according to the method of Kocheshkow²⁰, calculated amounts of anhydrous

²⁰Kocheshkow, Ber. 66, 1661, 1933.

stannic chloride and tetraethyl tin for 10-12 hours. Purification of the crude materials was achieved by repeated fractionation through a small Vigreux column until products were obtained which showed no change in refractive index upon further distillation and which, upon analysis for tin and chlorine, agreed within 1% of the theoretical.

Anal. Calc. for $C_2H_5SnCl_3$; Sn, 46.9; Cl, 41.8. Found Sn, 46.1
Cl, 41.2. Calc. for $C_4H_{10}SnCl_2$; Sn, 48; Cl, 28.6
Found: Sn 47.8; Cl 29.0. Calc. for $C_6H_{15}SnCl$; Sn, 49.2;
Cl, 14.7. Found: Sn, 48; Cl, 14.7.

The densities of the liquid compounds were measured with a precision of .001 g/ml. at 20₂ 0.1° C. The melting points of the liquid samples were determined from cooling curves and the melting point of the solid diethyl tin dichloride was determined in a capillary tube in the conventional manner. The vapor pressures were determined by the boiling point method, the external pressure being maintained constant within $\pm$ 0.5 mm. Plots of $\log_{10} P$ versus $(1/T)$ were linear from 10 mm. to atmospheric pressure.

Molecular refractions were calculated using the atomic refractions

TABLE VI

Physical Properties of Ethyl Tin Chlorides

Formula	Density		Ref. Index	Mole Refraction		Melting Point	Vapor Pressure ^a		Calcd. Bo. Pt.	Calcd. Heat of Vaporization	Trouton's Const.
	g/ml at 20°	20°		Calcd	Found		Equation Constant	B		Cal/mole	cal/mole degree
$C_2H_5SnCl_3$	1.965	n_D^{20}	1.5408*	41.80°	40.61*	10°*	2554*	8.377*	192	11672*	25.1*
					(40.22) ^d				(196) ^b		
$(C_2H_5)_2SnCl_2$						84°	2753*	8.385*	227	12581*	25.2*
									(220) ^b		
$(C_2H_5)_3SnCl$	1.429	1.5055	50.54 ^c	50.15		15°	2652*	8.416*	206	12119*	25.3*
			(50.20) ^d						(205) ^b		

^aConstants for the equation $\log_{10} P = -\frac{A}{T} + B$;^bpreviously reported values (Ref 20);^ccalculated from atomic refractions;^dcalculated from bond refractions;

tions of carbon, hydrogen and chlorine given by Eisenlohr,²¹ and

²¹F. Eisenlohr, Z Physik Chem. 75, 585 (1910).

that of tin given by Jones and co-workers¹ (loc. cit.) as determined in tetraethyl tin.

Since the value of the atomic refraction of tin varies with the nature of the groups to which it is attached, the agreement of the observed values of the molar refraction with the calculated values is as good as can be expected.

Recently, West and Rochow²² have devised a system of bond re-

²²R. West and E. G. Rochow, J. Am. Chem. Soc., 74, 2490 (1952)

fractions for tin compounds. Using appropriate values from their list and the C-C and C-H bond refractions of Denbigh,²³ calculated

²³K. G. Denbigh, Trans. Faraday Society, 36, 936, (1940)

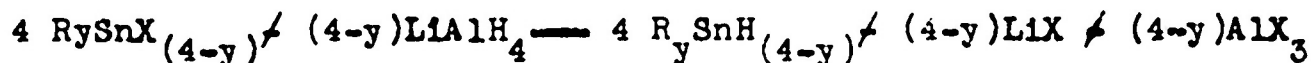
molecular refractions are obtained which are in excellent agreement with the experimental values.

VII. PREPARATION OF ETHYL STANNANES

Finholt and co-workers²⁴ have described the preparation of

²⁴A. E. Finholt, A. C. Bond, Jr., K. W. Wilzbach and H. I. Schlesinger, J. Am. Chem. Soc. 69, 2692, (1947).

methylstannanes by the reaction of lithium aluminum hydride with the appropriate methyltin halide according to the general equation



where R represents the methyl radical, X represents a halogen and y is an integer, 1, 2, or 3. It is implied that this procedure can be applied to the preparation of analogous compounds where the

radical, R, may represent any alkyl or aryl group.

However, in this investigation, it has been observed that there are two factors which limit the application of this procedure in the case of the organo stannanes. These factors are as follows:

- (1) There is a large difference between the volatilities of the methyl stannanes and stannanes containing heavier radicals. This difference is comparable to that observed between tetramethyl tin, (normal B. Pt. 78° C), and tetraethyl tin, (normal B. Pt. 177° C). Consequently, higher distillation temperatures are required for purification of the higher alkyl stannanes even when the pressure is reduced. This results in considerable decomposition of these inherently unstable compounds.
- (2) It has been observed that lithium aluminum hydride attacks the alkyl radicals as well as the halogens of the alkyl tin halide. The products of this side reaction are, hydrogen, hydrocarbons, polymeric solids and metallic tin. The amount of side reaction is quite appreciable at and above room temperature. It has also been demonstrated that tetraethyl tin reacts with lithium aluminum hydride to give similar products.

Because of the above mentioned difficulties, only the ethyl stannanes have been prepared in quantities sufficient for a study of their properties.

Experimental

The procedure followed was essentially that described by Finholt²⁴ (loc. cit.). In the preparation of triethyl stannane and diethyl stannane, diethyl ether was used as a solvent and the products were purified by distillation through a small Vigreux column.

under reduced pressure. In the preparation of ethyl stannane, dibutyl ether was used as the solvent and the product was purified by fractional condensation on a vacuum line.

The identities of the compounds were established by molecular weight determination and by analysis for tin and hydrolyzable hydrogen. Physical properties studied included vapor pressure, refractive index, and density. The individual compounds and their properties are described below.

Triethyl Stannane: Calcd. for $(C_2H_5)_3SnH$: Sn 57.48; hydrolyzable H, 0.487%. Found: Sn, 56.2; hydrolyzable H, 0.49%. Density, 1.258 g/ml at 20° C. $n_D^{20} = 1.4700$. Vapor pressures were determined by the boiling point method. The plot of $\log P$ versus $(1/T)$ was linear in the pressure range between 10 and 200 mm. and is represented by the equation, $\log_{10} P = -2273/T + 8.36$. By extrapolation, the normal boiling point was found to be 142° C.

Diethyl Stannane: Calcd. for $(C_2H_5)_2SnH_2$: M. Wt., 178.7; hydrolyzable H, 1.1%. Found: M. Wt., 176; hydrolyzable H, 1%. Vapor pressures were measured on the vacuum line. The best straight line through fourteen points is represented by the equation, $\log_{10} P = -2041/T + 8.67$. By extrapolation the normal boiling point was found to be 81° C.

Ethyl Stannane: Calcd. for $(C_2H_5)SnH_3$: M. Wt., 150.7; hydrolyzable H, 1.9%; C_2H_5 -, 19.3%. Found: M. Wt., 150.5; hydrolyzable H, 1.7%; C_2H_5 - 19%. Vapor pressures were measured on the vacuum line. The best straight line through thirteen points is represented by the equation, $\log_{10} P = -1470/T + 7.65$. The normal boiling point was calculated to be 34° C.

VIII. SUMMARY

As a result of this investigation, several significant differences between the organic derivatives of stannane and those of analogous compounds of carbon and silicon have become apparent. In every case these differences may be attributed to the more electropositive nature of tin.

(1) Carbon-carbon, (C-C), and silicon-carbon, (Si-C), "bond energies" estimated by Pauling,⁹ (loc. cit.) are 58.6 kcal/mole and 57.6 kcal/mole, respectively. The closeness of these values indicates a similarity in bond type in these cases. The tin-carbon, (Sn-C), "bond energies" computed in this investigation by analogous procedures is about 35 kcal/mole. Thus a profound difference in bond type between this and the former cases is indicated.

(2) No important skeletal vibrations were observed in the spectral region covered by the infrared studies reported here. It might be expected that, in the case of tetraethyl tin and higher alkyl stannanes, an absorption band would occur at 900 cm^{-1} since this is a characteristic C-C stretching frequency.²⁵ Failure to observe

²⁵G. Herzberg, "Molecular Spectra and Molecular Structure, II. Infrared and Raman Spectra of Polyatomic Molecules", D. Van Nostrand, New York, 1945, page 195.

such a band in the spectra of these compounds may be due to the change in moment produced by the presence of tin as the central atom.

(3) The unsuccessful attempts to prepare chloroethyl stannanes, by methods used to prepare analogous compounds of silicon, is further evidence of a difference in bond type. Owing to the large difference in electronegativity between tin and carbon, cleavage of the alkyl group with the formation of tin halides was the predominant reaction.

(4) The relative electronegativity of the elements is a particularly important factor in the preparation of hydrides. For example, it has been observed that if the electronegativity of a metal is less than 1.5 on Pauling's scale,²⁶ the hydride of the metal may

²⁶L. Pauling (loc. cit.) page 64.

be prepared by the reaction of lithium aluminum hydride with an alkyl derivative; whereas the metal chloride either does not react with lithium aluminum hydride or is reduced to free metal by this reagent. On the other hand, elements having an electronegativity greater than 1.5 on Pauling's scale yield hydrides when the chloride is reacted with lithium aluminum hydride while the alkyl derivatives are unaffected. It appears that the element, tin, is unique in that both alkyl groups and chlorine in alkyltin chlorides are attacked by lithium aluminum hydride. Only by careful control of the temperature can the halogen be replaced by hydrogen exclusive of side reactions. This suggests that the electronegativity of tin is considerably less than the value of 1.7 given in Pauling's table.

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