creases while that against gram-positive bacteria increases. Branching results in lowered activity, the order of activity being *n*-propyl > isopropyl > *t*-butyl ethyl derivatives.

As far as has been determined, thiolsulfinates react only with the sulfhydryl groups in amino acids and, conceivably, of protein matter as well and it has been postulated that they act by blocking essential protein —SH groups. The more or less non-specificity of action of the lower members may be related to their high diffusibility and low selective adsorption on protein surfaces. Increasing molecular size would be expected to decrease ease of diffusibility and decrease the number of opportunities for reaction with —SH groups screened by other protein structures. However, as the longer carbon chain molecules become more lipid soluble and less water soluble, an increase in the lipid content of cells (as in the acid-fast organisms) or even more probable, by having present —SH enzymes of a lipoprotein character, one should expect a selective concentration of these thiolsulfinates in the vicinity of the vulnerable —SH groups. To explain the trend in activity, this could mean that the more sensitive organisms contain more lipoprotein type of —SH enzymes than do less sensitive organisms; that the more sensitive organisms contain more total cellular lipids; that the essential —SH groups in sensitive organisms are more superficially located in the enzyme or that a combination of these factors is involved.

Acknowledgment.—We are indebted to M. E. Auerbach and staff for the analytical data, to W. F. Warner for cup-plate assays, and wish to thank Dr. C. M. Suter and Dr. J. S. Buck for encouragement and suggestions offered during the course of this investigation.

Summary

Eight synthetic alkyl thiolsulfinates have been prepared by controlled oxidation of the corresponding disulfides and isolated in the pure state. These compounds represent a new class of sulfur esters modelled after the natural antibiotic from *Allium sativum* and the structure of the latter is defined.

All thiolsulfinates prepared demonstrate antibacterial and antifungal action, with the higher members showing increasing specificity of action. This new class of antimicrobial agents appears to act by binding sulfhydryl groups essential for cell metabolism.

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[CONTRIBUTION FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY, No. 1118]

The Electron Diffraction Investigation of Isomeric Lewisites[1]

BY JERRY DONOHUE,[2] GEORGE HUMPHREY AND VERNER SCHOMAKER

This investigation of the two isomers of β-chlorovinyldichloroarsine, Lewisite I (b.p. 190° at 760 mm.) and Lewisite II (b.p. 150.2° at 760 mm.), was undertaken in order to determine which is the *cis* form and which is the *trans* form. MacDowell and Emblem[3] found the dipole moments of Lewisite I and Lewisite II to be 2.21×10^{-18} e.s.u. and 2.61×10^{-18} e.s.u., respectively,[4] and on this basis assigned the *trans* structure to Lewisite I and the *cis* structure to Lewisite II. Confirmation of this assignment seemed desirable because of the small difference between the observed moments and because of the uncertainty which we believe would necessarily arise from the presence of two polar groups ($\diagdown AsCl_2$ and $Cl\diagdown C{=}C\diagdown$ or $Cl\diagdown C{=}C\diagdown$) joined by a single bond with more or less unpredictable freedom of internal rotation in the neighborhood of an unknown preferred orientation. In addition, it was hoped that information could be obtained concerning the influence of the carbon–carbon double bond on the arsenic–carbon single bond distance and of the organic group on the arsenic–chlorine distance.

Experimental

The sample of the higher boiling isomer I was obtained from Dr. C. E. Redemann of the University of Chicago, and that of isomer II was provided by Edgewood Arsenal through the courtesy of Gen. W. C. Kabrich and Col. M. F. Peake. The constants given by Redemann for the sample of isomer I are: b.p., 72–73° at 10 mm.; d^{25} 1.8799; and $n^{25}D$ 1.6068; in fairly close agreement with the accepted values. According to Edgewood Arsenal the sample of isomer II had a refractive index corresponding to a composition of 4% of isomer I and 96% of isomer II, while chemical analysis showed 4.68% of isomer I,

(1) The work herein reported was done under Contract OEMsr-753 between the National Defense Research Committee and the California Institute of Technology.

(2) Predoctoral Fellow of the National Research Council.

(3) C. A. MacDowell and H. G. Emblem, British Report (from Sutton Oaks).

(4) These values are not consistent with the value 1.77×10^{-18} e. s. u. found by C. T. Zahn and H. Mohler, *Helv. Chim. Acta*, **21**, 1292 (1938), for a preparation of β-chlorovinyldichloroarsine which, on the basis of this value, they concluded was a mixture of the *cis* and *trans* isomers.

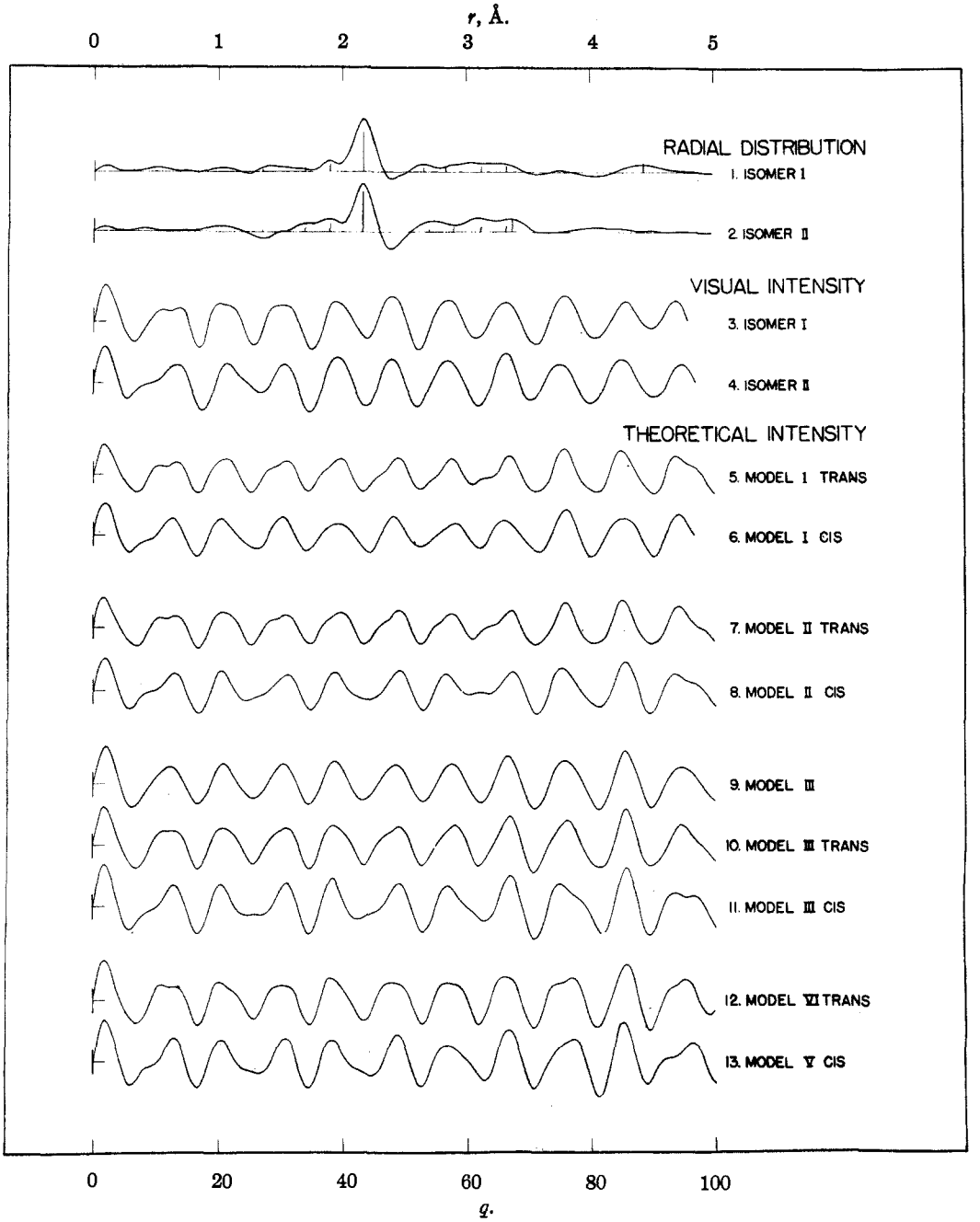


Fig. 1.—Electron diffraction curves for Lewisite. Models described in text. Curve 9 was calculated for Model III with the omission of the non-bonded As $\cdots$ Cl term; $q = (40/\lambda) \sin (\theta/2)$.

95.04% of isomer II and 0.22% of arsenic trichloride. This degree of purity is sufficient for electron diffraction investigation.

Diffraction photographs were made in the usual way.[5] For both substances photographs were obtained which show the main rings extending nearly to the limit of the camera.

(5) Apparatus: L. O. Brockway, *Rev. Mod. Phys.*, **6**, 234 (1936); wave length calibration: C. S. Lu and E. W. Malmberg, *Rev. Sci Instruments*, **14**, 271 (1943); high-temperature nozzle: L. O. Brockway and K. J. Palmer, THIS JOURNAL, **59**, 2181 (1937).

Interpretation

Both the radial distribution method[6] and the correlation method[5,7] were used in interpreting the pictures. The photographs of the two isomers were found to be rather similar, but upon careful examination they showed definite, significant differences. Curves 3 and 4 of Fig. 1 were drawn in accordance with previous experience in this

(6) R. Spurr and V. Schomaker, *ibid.*, **64**, 2693 (1942).

(7) L. Pauling and L. O. Brockway, *J. Chem. Phys.*, **2**, 867 (1934).

Laboratory to represent the visual appearance of the photographs and the measurements made on them. These curves were used for the calculation of the radial distribution integrals as well as in the subsequent correlation procedure.

The radial distribution curves, 1 and 2 of Fig. 1, for the two isomers are very similar except for two significant differences. For isomer I there is a distinct, although broad, peak at 4.45 Å., while no such peak occurs on the curve for isomer II. On the other hand, the curve for isomer II lies much higher than the other at 3.3 Å. These are the non-bonded As···Cl distances which would be expected respectively for the *trans* and *cis* isomers; hence it is very probable that isomer I is the *trans* compound, and isomer II is the *cis*. The remaining significant features of both curves are interpreted as follows in terms of specific interatomic distances: 1.7 Å., C—Cl; 1.90 Å., C—As; 2.17 Å., As—Cl; 2.75 Å., C···Cl and C···As (unresolved); 3.1 Å., C···Cl; 3.3 Å., Cl···Cl (in the case of the *cis* compound, this distance is nearly coincident in the As···Cl). The various distances between 2.7 and 3.3 Å. contribute about equally with a total of about 25% to the whole scattering. It is not surprising, therefore, that the corresponding regions of the radial distribution curves are not well resolved. A reasonable interpretation may be made, however, using the bond distances indicated by the first parts of the curves, and the bond angle values found for related molecules. The vertical lines under curves 1 and 2 represent, for our best molecular models described below, the interatomic distances and scattering coefficients which are independent of the angle of internal rotation about the carbon–arsenic bond.

Since nine parameters are required to fix the configuration and dimensions of each molecule, the number of curves which would have to be calculated in a thorough correlation treatment would be prohibitive, and, furthermore, it is certain that a complete structure determination could not be achieved. Theoretical scattering curves were calculated, nevertheless, for the models listed in Table I in order to verify the conclusions from the radial distribution functions. A curve for which the As···Cl term was omitted was also calculated for model III. The *cis* and *trans* models differ only by this one term if we make the reasonable assumption that the terms which are dependent on the rotation of the $AsCl_2$ group have very large temperature factors and may therefore be neglected. General agreement is satisfactory, being best for model V *cis* and for model VI *trans*. The quantitative comparison of $q_{calcd.}/q_{obs.}$ for measurements of fifteen features, excluding those of the first and last main rings and the eighth maximum, gives 0.999 and 0.997 for the models V *cis* and VI *trans*, respectively, with average deviations of 0.010 in both cases. At large q values, particularly at the eighth and last main rings, the agreement is improved by omitting the As···Cl term. This corresponds to an appreciable temperature factor for this term; it is indicated that this temperature factor is larger for the *cis* molecule as is to be expected from the greater contribution to variation of the As···Cl distance made in this molecule by bending vibrations.

Evidence for the correctness of the identification of the two isomers is also given by consideration of the differences between certain features of the respective curves, in particular the shoulder preceding the first maximum, the asymmetry of the second maximum, and the asymmetry of the third minimum.

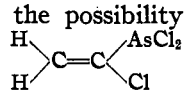
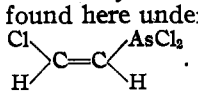
TABLE I

MODELS FOR LEWISITE

Model	As—C, Å.	∠Cl—As—Cl, deg.	∠Cl—C=C, deg.	∠Cl—As—C, deg.	∠As—C=C, deg.
I (both)	1.94	98	125	98	125
II (both)	1.94	98	120	98	125
III (both)	1.90	100	124	100	120
V (*cis*)	1.90	100	124	100	124
VI (*trans*)	1.90	100	120	100	120

In all models C=C = 1.36 Å., C—Cl = 1.69 Å., As—Cl = 2.17 Å.

Discussion

This work confirms the identification of MacDowell and Emblem[3] that isomer I, the higher boiling isomer, has the *trans* structure and that isomer II has the *cis* structure. It should be pointed out that the possibility that isomer II has the structure  is not excluded by our data, since the As···Cl and other important distances in a model for this structure could reasonably be made to be nearly the same as those found here under the assumption of the structure  . MacDowell and Emblem concluded from their consideration of the dipole moment values that neither Lewisite I nor II can have this formula. Presumably there is chemical evidence also.

The bond distances in these molecules are in accord with previous work. The arsenic–chlorine distance, 2.17 Å., is to be compared with that in arsenic–trichloride, 2.17 ± 0.02 Å.[8] The arsenic–carbon distance, 1.90 Å., is considerably less than 1.98 Å. the distance found[9] in trimethylarsine and the sum of the covalent radii, as might be expected for an arsenic–carbon bond adjacent to a double bond. A shortening of the carbon–chlorine bond from 1.76 to 1.70 Å. seems to be suggested by the radial distribution integrals, and actually this latter value is about what would

(8) S. M. Swingle, Thesis, California Institute of Technology, 1943.

(9) H. D. Springall and L. O. Brockway, THIS JOURNAL, 60, 996 (1938).

be expected from the known values[10] in the chloroethylenes.

The bond angles cannot be said to have been determined with accuracy, but it is probable that both ∠Cl—C=C and ∠As—C=C are between 120 and 125°, and that ∠Cl—As—Cl and ∠Cl—As—C are near 100°, the value found for arsenic trichloride.[8]

Summary

An electron diffraction investigation of two isomers of β-chlorovinyldichloroarsine (Lewisite) shows that isomer I (b.p. 190° at 760 mm.) has the *trans* structure, and that isomer II (b.p. 150.2° at 760 mm.) has the *cis* structure. The structural assignment depends on the chemical identification of both isomers as β-chlorovinyldichloroarsines, since the possibility that isomer II is α-chlorovinyldichloroarsine is not excluded by the electron diffraction data. The interatomic distances found are in accord with those in related substances.

(10) L. O. Brockway, J. Y. Beach and L. Pauling, THIS JOURNAL, 57, 2693(1935).

PASADENA, CALIFORNIA RECEIVED FEBRUARY 24, 1947

[CONTRIBUTION FROM THE CHEMISTRY DEPARTMENT, UNIVERSITY OF WESTERN AUSTRALIA]

Some Studies in the System $AlCl_3$–$FeCl_3$–KCl–NaCl–HCl–H_2O at 25, 30 and 35°

BY GRANT L. MILES

The results described in this report were obtained during an investigation of a hydrochloric acid process for the extraction of alumina from calcined alunite. This process involved the precipitation, through HCl, of $AlCl_3 \cdot 6H_2O$ together with other salts, especially NaCl, from solutions containing approximately 18% $AlCl_3$, 2% $FeCl_3$, 1.5% KCl and 0.5% NaCl, in addition to small amounts of other impurities, especially sulfate. The data presented refer to the compositions of solutions saturated with four solids: $AlCl_3 \cdot 6H_2O$, NaCl, KCl and $2KCl \cdot FeCl_3 \cdot H_2O$. Work on related simpler systems, such as $AlCl_3$–$FeCl_3$–KCl–HCl–H_2O and $AlCl_3$–KCl–HCl–H_2O has been reported by Malquori.[1]

Experimental

Solutions of approximately the correct composition were shaken with excess of the expected solid phases in sealed tubes made from 7 × 1 inch test-tubes. These were rotated in a thermostat maintained at the indicated temperatures (±0.05°) for periods of not less than three days. Duplicate tests showed that this period was ample to ensure complete equilibrium.

Solutions were separated from the solid phases by supporting the tubes vertically in the bath overnight, after which the tubes were quickly unsealed and about 20 ml. of clear supernatant liquor was transferred rapidly to a small weighed conical flask. The transfer was made with a warm predried pipet, the tip of which had been slightly shortened. Losses of hydrogen chloride by fuming were practically eliminated by the addition of about 30 ml. of water to the conical flask, prior to weighing.

Solids were separated by decantation and were dried with blotting paper. Examination of the solid residues was carried out using a petrological microscope. The crystals were ground and mounted in chlorobenzene. The various crystal species were identified by the following properties

$AlCl_3 \cdot 6H_2O$	Colorless and anisotropic
$2KCl \cdot FeCl_3 \cdot H_2O$	Bright orange color and anisotropic
KCl	Isotropic, and refractive index (1.49) below that of chlorobenzene (1.523)
NaCl	Isotropic, and refractive index (1.54) above that of chlorobenzene

(1) G. Malquori, *Gazz. chim. ital.*, 59, 556 (1929).

Reagents.—Analytical Reagent grade potassium chloride, sodium chloride and ferric chloride were used. Aluminum chloride hexahydrate was obtained in a very pure form by passing hydrogen chloride into a solution of aluminum chloride prepared from aluminum metal. The double salt $2KCl \cdot FeCl_3 \cdot H_2O$ was prepared as follows: 320 g. of anhydrous ferric chloride and 148 g. of potassium chloride were dissolved in just sufficient quantities of 6 *M* hydrochloric acid and water, respectively, at 90°. The two solutions were mixed and allowed to cool slowly. The crystals of the double salt which separated were washed with concentrated hydrochloric acid. A further yield of the double salt could be obtained by adding the appropriate amount of potassium chloride to the heated mother liquor.

Analytical Methods.—Aluminum was estimated by precipitation with oxine, following the separation of the iron by double precipitation with caustic soda. Iron was estimated volumetrically, using potassium dichromate and diphenylamine indicator. Reduction was by stannous chloride. Potassium was estimated by the modified chloroplatinate method in which the potassium chloroplatinate is reduced and weighed as platinum. Sodium was estimated directly by the magnesium uranyl acetate method. Total chloride was estimated by the Volhard method, which was found to give very consistent results.

The free acid content was estimated directly by titration with caustic soda, using methyl orange indicator. The end-point of this titration was made more apparent by carrying out the titration in a blue light. However, the free acid values finally adopted were those calculated from the total chloride content of the solution, and consequently subject to cumulative error. Duplicate estimations for the other analyses agreed within the following limits: Cl, 0.1% (0.04%); K, 1% (0.01%); Na, 2% (0.005%); Fe, 0.5% (0.01%); Al, 1% (0.02%). The parenthesized figures give the calculated deviation in the free acid content, as a percentage of the total sample. The cumulative error involved for the five analyses should therefore be less than 0.1% of the total sample, in terms of free acid content. The calculated values were considered more reliable than those obtained by the direct method, because in iron-containing solutions the value of the free acid as found directly was up to 2% higher than the calculated value, and this discrepancy was found to increase steadily with the iron content. For iron-free solutions the estimated and calculated free acid contents agreed to within 0.1% of the total sample. In those cases where no analyses are recorded in Table I the required chloride equivalents were found by interpolation in the appropriate solubility curve. In all but two instances only the sodium content was involved, and as this sub-