hydrogen-ion concentrations and protein concentrations, and using visible, long-waved ultraviolet and short-waved ultraviolet light.

2. Within the limits of experimental error none of these factors influenced the values found for the molecular weight, the value of phycoerythrin being 208,000 ± 8000, and for phycocyan 106,000 ± 5000.
3. Within the limits of experimental error both of these substances consisted of a pure molecular species.
4. A sample of phycoerythrin 17 years old was found to consist of molecules of weight 208,000, together with about 30% of molecules of $^1/_6$ or $^1/_8$ of this weight; no marked separation of the two sizes of molecule was effected by recrystallization.
5. It was pointed out that the molecular weights of phycoerythrin and phycocyan, as well as that of hemoglobin, approximately were multiples of that of egg albumin.

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE COLLEGE OF LIBERAL ARTS OF NORTHWESTERN UNIVERSITY]

PURE ARSENOBENZENE AND THE MOLECULAR COMPLEXITY OF ARSENOBENZENE AND ARSENOMETHANE

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The structure of arseno compounds, which are probably the most important therapeutically and interesting chemically of all organic arsenicals, is not definitely known, although it has been quite generally accepted that they are analogous to the azo compounds, R—N═N—R. However, compounds of the two groups are quite different in solubility, ease of oxidation and reduction, action with chlorine and sulfur, etc. The published results on the molecular weights of symmetrical arseno compounds are conflicting and inadequate. The purpose of this investigation, therefore, was to determine the molecular weights of arseno compounds in associating and non-associating solvents in order to throw more light on the nature of their molecular structure.

Molecular weights for only three symmetrical compounds with the arseno linkage have been published. The first was for arsenomethane to which Auger,[2] in 1904, assigned the formula $(CH_3As)_4$ (I) from cryoscopic determinations on a solution of the yellow oil in benzene. But in 1926 Steinkopf, Schmidt and Smie[3] pointed out an error in his work and gave the

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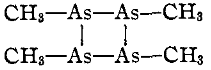
[1] Research Fellow under a grant from the Public Health Institute of Chicago. This paper is an abstract of a thesis presented by Albert B. Scott in partial fulfilment of the requirements for the degree of Master of Science at Northwestern University.

[2] Auger, *Compt. rend.*, **138**, 1705 (1904).

[3] Steinkopf, Schmidt and Smie, *Ber.*, **59**, 1463 (1926).

formula as $(CH_3As)_5$, which they represented structurally (II) as a cyclic compound with a ring of five arsenic atoms, never before known. The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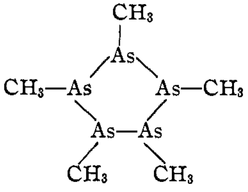
II

molecular weight of arsenobenzene in benzene solution was determined by Michaelis and Schäfer[4] and a single value of 399.8 is reported. Although the calculated molecular weight for $C_6H_5—As═As—C_6H_5$ is 304, these authors state that their value proves that the molecule has the azo-type structure and that arsenobenzene is a true analog of azobenzene. The same investigators found widely divergent values for *p*-arsenotoluene.

Arsenomethane and arsenobenzene were chosen as the first compounds to be utilized in this investigation because the two values for the molecular weight of the former do not agree and the single value for the latter does not conform satisfactorily to the azo-type structure that it is supposed to demonstrate. Because of the ease with which arseno compounds are oxidized by air, special precautions, including the use of an inert atmosphere (carbon dioxide or nitrogen), are necessary in their preparation and in molecular weight determinations. For the latter, standard ebullioscopic and cryoscopic methods were used in this investigation and, as a check on their accuracy, compounds of known molecular weight were run under conditions the same as those used for the arseno compounds.

The method of Binz, Bauer and Hallstein[5] for the reduction of phenylarsonic acid to arsenobenzene by means of hypophosphorous acid was improved by changing the time and temperature of the reaction and introducing two alkali extractions and a final recrystallization; pure arseno benzene melting at 195° was thus obtained. Because of its slight solubility, the use of very dilute solutions was necessary in the molecular weight determinations, with some corresponding sacrifice of precision. By the ebullioscopic method in carbon disulfide and benzene mean values of 334 and 402, respectively, were obtained; while cryoscopic determinations in very dilute naphthalene solution gave an average value of 642. These results indicate the existence of the normal or azo-type structure, $C_6H_5—As═As—C_6H_5$, in a non-associating solvent (carbon disulfide), but distinct association in benzene (recognized as a common associating solvent) and especially in naphthalene, possibly with complete conversion into a double molecule in the latter solvent. The average value of 402

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[4] Michaelis and Schäfer, *Ber.*, **46,** 1742 (1913).

[5] Binz, Bauer and Hallstein, *Ber.*, **53A,** 427 (1920).

in benzene solution confirms the work of Michaelis and Schäfer who found 399.8; but their interpretation that arsenobenzene is normal in such a solution is probably wrong, since a mean value of 334, much nearer the theoretical, was found in carbon disulfide. The individual values obtained in naphthalene were widely divergent, due, probably, to the necessary use of an extremely dilute solution with consequent magnification of errors in thermal control. The mean value given was obtained after rejecting extremely high and extremely low values and may be regarded only as an indication of association.

Great care was necessary in the preparation of arsenomethane as the yellow oil because it is readily oxidized and also passes rapidly to red or brown-black, solid modifications of hitherto unknown molecular complexity. The preparation and molecular weight determinations were carried out in an inert atmosphere and the ebullioscopic solvents were saturated with nitrogen. The theoretical value of 450 suggested by Steinkopf, Schmidt and Smie for the molecular weight of the yellow oil was checked to within 5.3% by a mean value of 474 in carbon disulfide solution. A value of 476 (mean of two determinations giving 491 and 461) was found in benzene solution for the molecular weight of a mixture of about equal amounts of the red solid and yellow oil obtained by allowing the yellow oil to stand for four days in an inert atmosphere in a sealed ampule. The close agreement between the values obtained for the mixture and for the yellow oil alone makes it appear that the red solid has the same molecular weight, at least in solution, as the oil.

Experimental Part

Preparation of Arsenobenzene $(C_6H_5—As=As—C_6H_5)_x$.—Analyses showed that the method of Binz, Bauer and Hallstein[5] for the reduction of phenylarsonic acid by hypophosphorous acid resulted in impure arsenobenzene. A satisfactory method of preparation was worked out as follows. A mixture of 1 liter of 50% hypophosphorous acid with a solution of 100 g. of recrystallized phenylarsonic acid[6] in 700 cc. of water was vigorously stirred in a flask fitted with a mercury-sealed stirrer in a water-bath at 55–60°. If a hard cake formed during the reaction it was pulverized in a mortar and returned to the flask. After four and one-half hours the reaction mixture was forced by carbon dioxide pressure into an anaerobic filter and the precipitate washed on the filter with 500 cc. of 10% sodium hydroxide solution followed by 500 cc. of warm 5% sodium hydroxide. During this filtration and during the entire subsequent purification process, all contact of the arseno compound with air was avoided by the maintenance of the compound or of the solution containing it in an atmosphere of carbon dioxide. The crude arsenobenzene was removed from the filter and vigorously stirred with two successive 200-cc. portions of 10% sodium hydroxide solution, the yellow powder being filtered off after each extraction and finally washed on the filter with 500 cc. of warm 5% sodium hydroxide followed by 1 liter of distilled water and dried for two days over phosphorus pentoxide in an evacuated carbon dioxide atmosphere. For recrystallization, the dry, crude product was dissolved in the minimum quantity of boiling chlorobenzene and the hot, filtered solution allowed to cool.

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[6] Palmer with Adams, This Journal, **44**, 1361 (1922).

The first crop of crystals only was utilized. These were filtered off, washed with absolute ether, recrystallized as before and again washed with ether. The final product (weight about 12 g.) consisted of perfectly white needles melting at 195° when heated in the usual capillary tube at the rate of 1° per minute near the melting point. Other preparations described in the literature have melted at 196°,[7] 208°,[5] 212°.[4] Crystallographic examination of the arsenobenzene prepared in this investigation showed it to consist of strongly birefringent needles, all of one type.

Anal. Subs., 0.0995, 0.1051: 26.79 cc. iodine (a), 28.17 (b) [1 cc. (a) = 0.001839 g. As, (b) = 0.001850]. Calcd. for $C_{12}H_{10}As_2$: As, 49.31. Found: 49.51, 49.59.

Preparation of Arsenomethane $(CH_3As)_5$.—Following the general method of Auger,[2] arsenomethane was prepared as a bright yellow oil by stirring 100 g. of sodium methylarsonate with 350 cc. of 50% hypophosphorous acid for three hours in a water-bath at 70°. Traces of impurities in the sodium methylarsonate were found to cause immediate formation of brown and red solid modifications of arsenomethane, but the intermediate can be prepared in adequate purity by Quick and Adams'[8] modification of "Meyer's reaction," the product from the second recrystallization from alcohol being thoroughly washed with a mixture of equal volumes of alcohol and water to remove any trace of the original materials as well as all of the sodium iodide. The immiscible oil was transferred to a small separatory funnel, washed 5 times with 25-cc. portions of 5% sodium hydroxide solution followed by similar portions of water, and then sealed in ampules, all in an atmosphere of carbon dioxide; yield, good. The clear, yellow oil boiled at 178° under 15mm. pressure, but all attempts to purify it further by fractional distillation under reduced pressure resulted in the immediate formation of some of the red, solid modification, so the material was finally used without further purification.

Anal. Subs., 0.0553, 0.0563: 21.44, 21.48 cc. iodine (1 cc. = 0.002126 g. As). Calcd. for $(CH_3As)_5$: As, 83.30. (Auger found 82.50.) Found: 82.42, 81.11.

Molecular Weight Determinations.—In the ebullioscopic molecular weight determinations the apparatus and procedure of McCoy[9] were used. In the case of arsenomethane the solvents were previously saturated with nitrogen. In order to avoid undue dilution it was found desirable to dissolve the samples of arsenobenzene in the minimum amount of the desired solvent before the inner tube of the apparatus was placed in its final position. The usual apparatus and technique, with slow but continuous mechanical stirring, were employed for the cryoscopic determinations. As the temperature differences to be measured in the case of arsenobenzene are small, because of its slight solubility, particular care must be taken in thermal control. All temperatures were measured by an accurate Beckmann thermometer. Of the solvents used in the molecular weight determinations, the naphthalene was purified by two recrystallizations from alcohol followed by a fractional sublimation at about 70°; the benzene was the C. P., thiophene-free grade of the Eastman Kodak Company; and the carbon disulfide was obtained in exceptional purity by treating the technical product with ceresin wax according

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[7] Michaelis and Schulte, *Ber.*, **14**, 912 (1881).

[8] Quick and Adams, THIS JOURNAL, **44**, 809 (1922).

[9] McCoy, *Am. Chem. J.*, **23**, 353 (1900).

to the method of McKelvy and Simpson.[10] The data obtained for arsenobenzene and arsenomethane, together with those for standards run under the same conditions, are given in Tables I and II, respectively.

TABLE I

THE MOLECULAR WEIGHT OF ARSENOBENZENE IN VARIOUS SOLVENTS

A. Determinations in Naphthalene

Sample No.	Wt. of sample, g.	Wt. of solvent, g.	F. p. lowering, °C.	Mol. wt., found	Mol. wt., calcd.
		p-Dibromobenzene Standards			
1	0.5327	9.996	1.584	232	
2	.1167	9.996	.351	229	$C_6H_4Br_2$
3	.3342	20.982	.482	228	236
			Mean =	230	
		Arsenobenzene			
1	0.1813	10.113	0.181	684	
2	.0643	30.033	.025	591	
3	.1343	25.000	.060	618	$C_6H_5—As{=}As—C_6H_5$
4	.0709	25.000	.029	675	304
			Mean =	642	

B. Determinations in Benzene

Sample No.	Wt. of sample, g.	Vol. of solvent, cc.	B. p. elevation, °C.	Mol. wt., found	Mol. wt., calcd.
		Camphor Standards			
1	0.1310	31.70	0.100	136	$C_{10}H_{16}O$
2	.0822	20.00	.090	150	152
			Mean =	143	
		Arsenobenzene			
1	0.1184	18.00	0.051	423	
2	.1183	21.30	.050	364	$C_6H_5—As{=}As—C_6H_5$
3	.1661	26.00	.050	419	304
			Mean =	402	

C. Determinations in Carbon Disulfide

Sample No.	Wt. of sample, g.	Vol. of solvent, cc.	B. p. elevation, °C.	Mol. wt., found	Mol. wt., calcd.
		p-Dibromobenzene Standards			
1	0.1220	17.00	0.057	244	
2	.1365	21.00	.050	252	$C_6H_4Br_2$
3	.2468	23.70	.088	230	236
			Mean =	242	
		Arsenobenzene			
1	0.1487	17.00	0.050	339	
2	.1992	20.30	.058	328	$C_6H_5—As{=}As—C_6H_5$
3	.2025	18.00	.065	336	304
			Mean =	334	

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[10] McKelvy and Simpson, THIS JOURNAL, **44**, 108 (1922).

Table II

The Molecular Weight of the Red and Yellow Forms of Arsenomethane

Sample No.	Wt. of sample, g.	Vol. of solvent, cc.	B. p. elevation, °C.	Mol. wt., found	Mol. wt., calcd.
		p-Dibromobenzene Standards[a]			
1	0.7880	16.30	0.373	251	$C_6H_4Br_2$
2	.3643	28.50	.170	247	236
	A. Determinations on the yellow oil in carbon disulfide				
1	3.4825	16.00	0.875	483	
2	1.3533	16.00	.350	469	$(CH_3As)_5$
3	1.2029	15.00	.332	469	450
			Mean =	474	
B. Determinations on a mixture of approximately equal amounts of the red and yellow forms of arsenomethane in benzene					
1	0.5988	32.00	0.125	491	$(CH_3As)_5$
2	.1756	25.00	.050	461	450
			Mean =	476	

[a] See Table I B and C for standards for Parts A and B of Table II. Additional *p*-dibromobenzene samples were run (1) in carbon disulfide saturated with nitrogen and (2) in benzene saturated with nitrogen.

Summary

1. A method for preparing pure arsenobenzene from phenylarsonic acid is given in detail.

2. Arsenobenzene has been found to have a molecular weight corresponding to the monomolecular, azo-type structure, $C_6H_5—As{=}As—C_6H_5$, in a non-associating solvent, but to be distinctly associated in benzene and naphthalene solutions.

3. $(CH_3As)_5$ and not $(CH_3As)_4$, the first formula suggested, has been confirmed as the molecular formula of arsenomethane in the form of the yellow oil, and the red, solid form may have the same molecular weight.

4. The custom of representing all arseno compounds by the general formula R—As=As—R is unjustified.

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