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AN INVESTIGATION OF THE REACTION BETWEEN ANTIMONY AND SOLUTIONS OF SODIUM IN LIQUID AMMONIA.[1]

BY EDWARD B. PECK.

Received September 25, 1917.

I. Introduction.

Joannis[2] has shown that solutions of the alkali metals in liquid ammonia react with certain heavy metals which are themselves insoluble in this solvent. He found that compounds are formed with antimony, lead, bismuth and mercury, their composition corresponding to the formulas Na_3Sb, $NaPb$, $NaPb_4$, KPb_2, $NaBi$, $NaHg_{18}$, etc.

Kraus,[3] in a series of unpublished investigations, found that the compounds described by Joannis react further with an excess of the heavy metal to form compounds richer in the heavy metal. He also found that tin, tellurium, selenium and sulfur behave similarly. These compounds were found to possess electrolytic properties in dilute solution. For lead, Kraus[4] found that two-gram atoms of metal were deposited at the anode for every equivalent of electricity passing through the solution.

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[1] A thesis presented to the Faculty of Clark University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] Joannis. *Compt. rend.*, 113, 797 (1891); 114, 595 (1892).

[3] Kraus, unpublished observations.

[4] Kraus, THIS JOURNAL, 29, 1557 (1907).

At the suggestion of Dr. Kraus, Posnjak[1] and later Smyth,[2] studied these sodium-lead compounds and found that the equivalence of lead and sodium in solution does not correspond to an integral number. Smyth[3] found, on electrolyzing these solutions, that 2.26 gram atoms of lead are deposited on the anode for one equivalent of electricity. This value was found to be independent of the concentration and the current density. Smyth also attempted the analysis of these solutions, but his results were not conclusive owing to the reaction of sodium with the ammonia to form the amide according to the equation

$$Na + NH_3 = NaNH_2 + {}^1/_2H_2.$$

This reaction was facilitated by the slowness of the action of the sodium on the lead.

The present investigation was undertaken for the purpose of securing further data on the compounds formed in the interaction between the alkali metals and the heavy metals. Antimony was chosen in place of lead for the reason that it reacts rapidly enough to prevent the formation of an appreciable amount of amide.

Other compounds of sodium and antimony have been obtained as alloys. Gay-Lussac and Thenard[4] first observed that antimony and sodium react with the evolution of heat and light. Mathewson[5] has studied the alloys of antimony and sodium by the method of thermal analysis and found the compounds Na_3Sb and NaSb.

Joannis[6] allowed solutions of sodium in liquid ammonia to react with antimony until the color of the sodium solution disappeared. This gave a dark brown precipitate and a pale yellow solution. His analysis showed the compound to be Na_3Sb. This compound was very readily oxidized in air or water. Kraus[7] found that this compound reacts further with antimony to give a very soluble compound having a deep red color in concentrated solution. The present investigation was undertaken at the suggestion of Dr. Kraus with the hope that this method would throw further light on the physical chemical properties of pure metallic compounds.

II. Apparatus.

The method of carrying out this work was to introduce a weighed amount of sodium with liquid ammonia and an excess of antimony of known weight into a two-compartment bomb which was then sealed off

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[1] Posnjak, See Smyth, THIS JOURNAL, 39, 1299 (1917).

[2] Smyth, Ph.D. Dissertation, M. I. T. (1915); THIS JOURNAL, 39, 1299 (1917).

[3] Smyth, *Loc. cit.*

[4] Gay-Lussac and Thénard, "Recherches Physico-Chemique," Paris (1811).

[5] Mathewson, *Z. anorg. Chem.*, 50, 192 (1906).

[6] Joannis, *Loc. cit.*

[7] Kraus, *Ibid.*

and the reaction allowed to run to completion. The phases were separated for analysis by decanting the solution into the second compartment, leaving the excess antimony behind to be washed by distilling ammonia over from the solution. The ammonia was then distilled out of the bomb and absorbed in weighed water bottles and the weight of antimony which had reacted was obtained by difference.

The apparatus used for filling the reaction bomb is shown diagrammatically in Fig. 1.

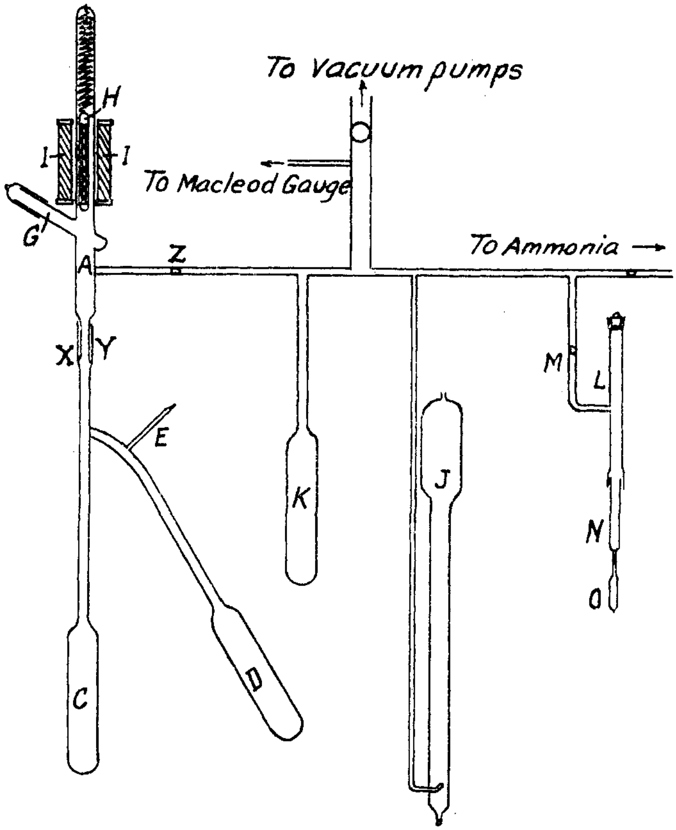

Fig. 1.

The filling device A was connected to the vacuum pumps and the ammonia cylinder by the horizontal glass tube provided with a stopcock Z. The bomb C was connected to the bottom of the filling device by a glass sleeve sealed with de Khotinsky cement. The lower part of the filling tube Y was made of the same diameter as the arms of the bomb and the end of the vertical arm of the bomb was provided with a sleeve, X, just wide enough to slip over the lower end of the filling tube.

The bombs consisted of two cells, C and D, of from 30 to 50 cc. capacity, connected by arms of about 6 mm. internal diameter and 20 cm. long. On the bent arm was connected a narrow tube, E, through which the ammonia was distilled off after the reaction and washing was completed. The tube from the branch to the enlarged sleeve was about 10 cm. long to allow sufficient room for sealing off the bomb after filling. A weighed amount of antimony was placed in the bottom of the reaction chamber C of the bomb before it was connected to the filling device. The sodium which was introduced in a manner similar to that used by Smyth[1] was sealed up in a small glass capsule, and this capsule placed across the filling tube through the side tube G. A notch opposite the side tube held the sodium capsule in place where it could be dropped into the bomb by breaking it in two. The side arm had a cap which was sealed on with de Khotinsky cement. The earlier bombs were made of ordinary soda glass, but this was later changed to a very strong glass of low temperature coefficient as earlier bombs had exploded.

When the apparatus had been evacuated and the desired amount of ammonia distilled into the bomb, the sodium capsule was broken and allowed to drop into the bomb. The capsule was broken by the electromagnetic hammer H which consisted of a piece of soft iron sealed up in a glass tube and suspended by a steel spring from the top of the filling tube. This hammer was actuated by means of the solenoid I placed outside the tube.

The manometer tube J showed the pressure on the solution and also acted as a safety valve to adjust the pressure at which the ammonia was run into the apparatus. This was so designed as to allow the excess ammonia to escape under any desired head of mercury. The chamber K was an ammonia reservoir to be used for drawing off ammonia from the bomb or as a reservoir of ammonia gas in filling the sodium capsule.

The weighed charges of sodium were put up by means of the device on the right of the figure. The straight tube L was connected to the vacuum system and ammonia supply by a side tube, M, provided with a stopcock. The top of the tube L was provided with a carefully ground stopper and at the bottom with a flange to allow a tube of the same diameter to be sealed on after the manner described above in connection with the bomb and filling tube. The tube N, about 8 cm. long and 0.4 cm. internal diameter, was drawn down to a fine capillary, on the end of which was the capsule O for receiving the sodium. This capsule was about 4 cm. long and 0.2 cm. internal diameter and file scratched across the middle to facilitate breaking with the hammer H. When a larger capsule was required a bulb was blown on the end. The lower end of the capsule was left open through a capillary opening so that the whole tube NO could be thoroughly cleaned and dried. Then the lower end of the cap-

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[1] Smyth, *Loc. cit.*

sule was sealed and the whole tube weighed and attached to D. A piece of freshly cut sodium was dropped through the top of L into N and a small glass weight placed on it. The apparatus was then evacuated. When all the air had been removed, the sodium was softened by heating with an oil bath. As soon as the sodium began to collapse, a slight pressure of ammonia from K was applied through M, which drove the sodium through the capillary to the bottom of the capsule, leaving the oxide behind. It was necessary to avoid overheating the sodium, as otherwise it attacks the glass. It was also necessary to have the capillary clear and the sodium quite free from the center of the capsule where it was later to be broken open.

With the capsule filled with pure sodium, it was sealed off at the capillary. The tube N was opened at the capillary by blowing a hole through the tip. It was then removed from the upper tube and cleaned, after which it was weighed together with the filled capsule. This, together with the original weight, gave the weight of sodium in the capsule by difference. This weight of sodium was checked by weighing the filled sodium capsule and weighing again after the sodium had been removed.

The antimony used was Kahlbaum's, and came in bars. This was sawed into pieces weighing about 0.6 g. and polished so that there were no loose pieces or fine dust. If fine antimony was used, it was found that very small pieces were carried with the solutions in decanting, thus giving inaccurate results in the analysis.

The ammonia was put up in a steel cylinder over sodium in the manner described by Kraus.[1] The hydrogen was blown off and a pure ammonia obtained by this method.

III. Manipulation.

The apparatus will probably be better understood by describing a typical run. The sodium capsule was placed across the filling tube and the side arm closed with its cap. Then a weighed piece of antimony was placed in the vertical chamber of the bomb and the bomb sealed to the filling tube. This made a closed system which was evacuated by means of a pair of rotary oil pumps. The pressure was reduced to about 0.0001 mm. of mercury and the system carefully tested with a MacLeod gage for leaks. In exhausting, the bomb was heated to drive the gas out of the antimony.

When the apparatus was found to be tight, ammonia was condensed in the vertical chamber of the bomb by surrounding it with a bath of liquid ammonia and then opening the valve to the cylinder containing the pure ammonia. When a sufficient quantity of ammonia had been condensed, the sodium was introduced by breaking the capsule in two with the electro-magnetic hammer. The intensity of the hammer blow

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[1] Kraus, This Journal, 30, 1205 (1908).

could be adjusted by raising or lowering the solenoid outside the tube. Generally, a very light blow sufficed, and the capsule broke clean without shattering. This later was important in getting the check on the weight of sodium.

The first stage of the reaction, which was very rapid, was allowed to go on at the temperature of the ammonia bath. The reaction could be hastened by stirring which was accomplished by removing the bath from the bomb chamber and placing it around the auxiliary chamber K. After a small amount of the ammonia had been boiled off, the bath was returned around the bomb. As soon as the blue color of the sodium solution had disappeared, the bomb was sealed off at F.

The bomb was then hung up with the solution chamber of the bomb in a bath of running water. This was found necessary in order to prevent the ammonia from distilling off from the solution into the second chamber, thus changing the concentration of the solution. The bomb was left undisturbed for from two months to a year in order that the reaction might proceed to completion, after which the contents were separated and analyzed.

The separation was carried out as follows: The solution was poured from the chamber C into the chamber D, leaving the excess antimony and the empty sodium capsule behind. These were washed several times by distilling the pure solvent from the solution back to the original chamber. The distillation was accomplished by immersing the chamber C in ice-water and leaving the solution at room temperature. The washing process was continued until the condensed ammonia was colorless.

When the washing was complete, the various components were separable for analysis. The chamber with the solution was immersed in a bath of boiling ammonia to reduce the pressure in the bomb. Then the narrow side tube E was broken off near the end, the bomb removed from the bath, and connected to a train of two weighed water bottles. These bottles contained gas-free water and absorbed the ammonia, the weight of which was obtained by difference. The bomb had to be removed from the bath before connecting to the water train or the water would suck back into the bomb and spoil the analysis. Care had to be taken to boil the solution from the top by heating with the hand or the solution would superheat and boil over. When the ammonia was all driven off, the bomb was broken open, the excess antimony and the excess sodium capsule were weighed, which gave all the data necessary for an analysis.

IV. Behavior of the Compound.

Before turning to the analytical results it will be of interest to discuss the behavior of the solutions and the properties of the compounds. When sodium dissolves in liquid ammonia, it forms a deep blue solution. As the solution reacts with antimony, which is itself insoluble, the color diminishes and a dark brown precipitate collects in the bottom of the cell. Finally, the solution becomes light yellow in color. This part of the reaction is very rapid, being completed in an hour or two, and is attended by the evolution of considerable heat. The compound formed at this stage is evidently the one studied by Joannis,[1] Na_3Sb. The next change observed is the appearance of a deep red-colored solution, and the general disappearance of the precipitate. The color deepens until all of the precipitate has disappeared. This last reaction is much slower than the first, because of the slight solubility of the reacting compound. If these solutions could be thoroughly stirred the final equilibrium would be attained much more rapidly. In this work the bombs were only occasionally shaken. Care should be exercised in handling the bombs, as they are liable to explode.

A test for the side reaction of sodium with ammonia to form the amide was carried out as soon as the first compound was completely formed. This was done by attaching a eudiometer tube to the apparatus. The lead tube from the apparatus was connected to the supply tube A and blew off under a layer of mercury into the eudiometer tube, filled with gas-free water. Ammonia was rapidly boiled off from the solution for about ten minutes, and in that time about 0.3 cc. of insoluble gas appeared over the water. This shows that there was no appreciable amount of amide formed.

The residue from these solutions was dark brown in color when covered with a thin film of ammonia, but when all the ammonia was driven off there remained a bluish gray metallic residue. This residue could be readily crumbled and had no crystalline structure, the latter probably due to the conditions of precipitation. This product oxidized only slowly in air and in water.

The compound redissolved in ammonia, but with some difficulty if all the ammonia had been driven off. From some of the solutions, which apparently were not saturated, a metallic mirror was deposited on the walls of the bomb. This layer was redissolved only with the greatest difficulty. The nature of this deposit has not been determined.

V. Experimental Results.

The results of the analyses are shown in Table I.

The concentrations of the solutions are expressed in gram atoms per liter of ammonia. The volume was calculated by using the value of Keyes and Brownlee[2] for the specific volume of ammonia at 20° (1.6387), and assuming the volume of the solution to be the same as that of the pure ammonia. The latter assumption, of course, is an approximation.

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[1] Joannis, *Loc. cit.*

[2] Keyes and Brownlee, "Thermodynamic Properties of Ammonia," p. 14. John Wiley and Sons, Inc., 1916.

TABLE I.

Series A.			Series B.				
Wt. of Na.	Wt. of Sb.	Sb/Na.	Wt. of Na.	Wt. of Sb.	Sb/Na.	G. NH_3.	G. atoms Na. Liter NH_3.
0.2021	2.445	2.315	0.00237	0.0152	1.198	12.926	0.0049
0.1986	2.3345	2.249	0.00610	0.0594	1.853	4.352	0.0372
0.1328	1.5310	2.206	0.00993	0.0837	1.613	6.713	0.0393
0.0745	0.9067	2.329	0.01100	0.1147	1.978	7.852	0.0375
0.0592	0.6681	2.1595	0.02580	0.2924	2.169	6.974	0.0982
0.0288	0.3379	2.246	0.02880	0.3379	2.246	6.291	0.1229
0.0284	0.2441	1.650	0.03071	0.3583	2.333	1.874	0.4347
..	..	..	0.09115	1.0799	2.267	..	..
..	..	..	0.4080	4.8049	2.254	8.673	1.2482

In Series A the amount of ammonia was not determined as it was expected that the values would be independent of the concentration, as was found to be the case with lead. The results showed, however, that there was a concentration effect. In Series B, the concentration was determined. The results are treated graphically in Curves A and B, Fig. 2.

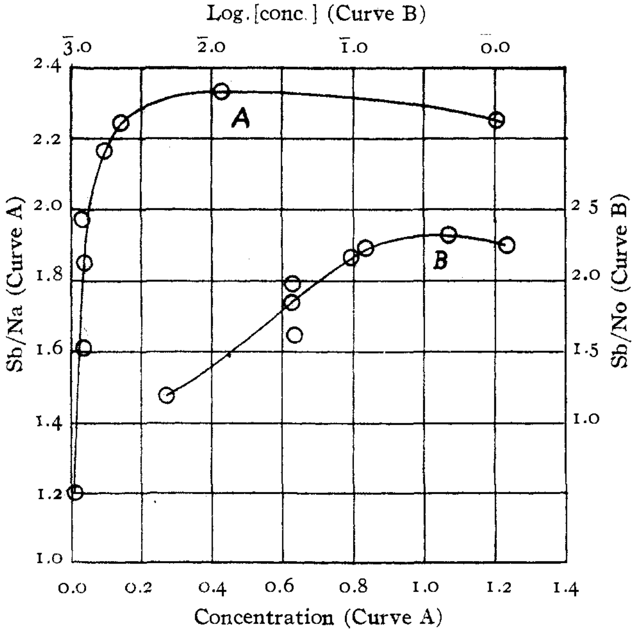

Fig. 2.

In Curve A, the ratio Sb/Na is plotted against the concentration of sodium and in Curve B the ratio Sb/Na is plotted against the logarithm of the concentration for the purpose of redistributing the points for dilute solutions. In plotting Curve A, the curve in the concentrated region is in a measure governed by the results of Series A. These values justify drawing the curve through the points of higher concentration, for there are several values that certainly would be on that curve if their exact concentration had been determined.

The ratio Sb/Na increases very rapidly with concentration in dilute solution to a maximum of 2.3 at a concentration of about 0.4 *N*. There is a slight decrease in the ratio Sb/Na beyond this concentration which might become constant if the concentrations were corrected for change in density. Mr. Allison,[1] working in this laboratory, has obtained similar results for tellurium and sodium. He obtained a maximum for the ratio Te/Na = 1.98 at a concentration of about 0.1 *N* with respect to sodium. The fall in the curve beyond the maximum in concentrated solutions is more pronounced than for antimony and sodium. It is apparent from these data that, if this investigation had been confined to a range of concentration above 0.4 *N*, it would have appeared that the ratio Sb/Na were substantially independent of concentration, as Smyth[2] found for lead. It appears from this work that a concentration effect might have been found in the lead-sodium equilibria had they been studied at higher dilutions.

The precision of this work was limited entirely by the manipulation of the solutions in the bombs. The smallest weight involved, namely, that of the sodium, was about ten times smaller than that of the antimony. This weight could be determined very accurately, in most cases to 0.02 mg., as was shown by the checks. These solutions may not have reached equilibrium and this apparently is the chief source of error in this work. Indeed, the slight decrease from the maximum may be due to this phenomena, for these solutions were very viscous and some showed a precipitate which would suggest this explanation. One result, at a sodium concentration of 0.0219 *N*, gave a value Sb/Na = 3.142. This result agrees with no other analytical results, but a single similar result was obtained in the electrolysis of very dilute solutions at the temperature of liquid ammonia.

VI. Electrolysis of the Solutions.

The electrolysis of these solutions was undertaken for the purpose of determining the electrolytic properties of the metallic compounds in solution. This part of the work was carried out in a manner similar to that of Smyth.[2] The apparatus used for the electrolysis is shown diagrammatically in Fig. 3.

The cell A had a capacity of 150 cc. and was calibrated at 10 cc. intervals. This cell had two long arms, B and C, through which the electrodes were introduced. The arm B had a side tube, P, through which the sodium capsule was introduced. Instead of an electro-magnetic

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[1] Allison, Master's Thesis, Clark University, June, 1916.

[2] Smyth, *Loc. cit.*

hammer, the capsule was broken open by a glass rod, D, which was fitted into the top of the side tube by a piece of heavy rubber tubing. A blow from outside was transmitted to the capsule by this glass rod. Connection with the ammonia cylinder was made by the tube E at the bottom of the cell and through the tube F to each of the arms of the cell. The cell was set in a Dewar flask, Z, which contained liquid ammonia at its boiling point. The electrodes were suspended from their leads, G and H, which consisted of tubes filled with mercury and supplied with platinum hooks. These tubes slid in glass caps that fitted to the limbs of the cell which were contracted to make well-fitting sleeves for the lead tubes. These fittings were made tight with rubber tubing. These caps through which the leads slid were necessary, as the electrodes had to be both raised and lowered in the cell and removed from the cell for weighing. Tight connections, such as were used in the analytical work, were not necessary, as the cell was opened to the air when the electrodes were removed. A long bar of antimony, which could be lowered to any depth in the solution, served as cathode, while a piece of platinum foil with a surface of 8 cm². was used as anode.

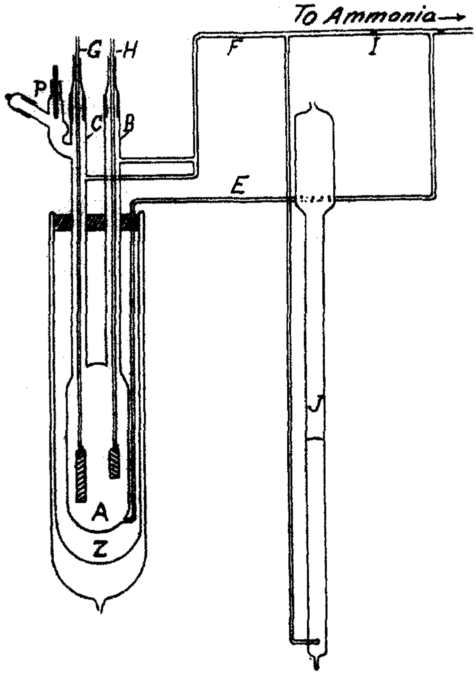

Fig. 3.

Fine pieces of antimony were placed in the cell and the solution made up by introducing the sodium and ammonia after the air had been swept out. This cell was not connected to a high vacuum pump, but alternately filled with ammonia gas and pumped out with a water-jet pump. Finally, the system was swept out by closing stopcock I and allowing the ammonia gas to circulate through from the bottom of the cell and out through the manometer tube J. This same devise was used for stirring the solution. The height of the mercury column was adjustable so that there was no condensation of ammonia in the cell.

As soon as the solution had come to equilibrium, which was within two days, owing to the large surface of metal and the efficient stirring, a series of electrolyses were carried out. A 110-volt storage battery current was shunted across a lamp bank to give a current of from two to four milliamperes. The electricity passed was measured by two copper voltameters in series, except for the first electrolysis, when a silver voltameter was used. In the earlier runs the electrodes were weighed and immediately immersed in the solution and the electrolysis begun. The air contained in the antimony was a source of trouble which was partly overcome by placing the electrodes in the limbs of the cell and circulating ammonia gas through the system to remove the air. This was done for a half hour before lowering the electrodes into the cell for the electrolysis.

The deposit on the anode was in the form of crystalline scales of antimony which did not adhere firmly enough to allow stirring of the solution or rotating the electrode.

The electrolyses were run from five to twelve hours. Then the electrodes were raised into the limbs of the cell and there washed by condensing ammonia on them. This was done by opening the stopcock I and allowing the ammonia to enter through the connections at the limbs. The anode was very readily washed, but it was impossible to completely wash the cathode. The cathode was always covered with a heavy black deposit. Various methods of washing were tried. The most successful was to immerse the electrode in water and then dry.

It was found that if the electrodes were short-circuited after electrolysis there was a back current. If this current was allowed to spend

TABLE II.

Voltameter. G. Cu.	Cathode loss.	Anode gain.	Gram atoms of Sb per Faraday.		Vol. Cc.	Time. Hours.	Current. Mil. amps.
			Cathode.	Anode.			
			Series A.				
0.0230[1]	0.0313	0.0336	1.22	1.46[2]	...	..	...
0.0169	0.0841	0.1014	1.315	1.605	...	10.0	2.0
0.0208	0.0360	0.1136	...	1.444[2]	...	5.0	4.0
0.0207	0.0807	0.1862	...	2.375	...	12.0	2–1.5
0.0074	0.0334	0.0678	...	2.419	100	5.0	2.0
0.0264	0.0720	0.3002	...	3.008	120	12.0	4–1
			Series B.				
			0.2652 g. Na used.				
0.01752	0.0122	0.1220	...	1.842	60	..	4.8
0.01280	0.0492[3]	0.0145	1.016	...	120	13.0	2.7
0.05504	....	0.2618	...	1.258	...	11.5	5.5
0.01534	0.0737[3]	....	1.270	...	100	12.5	5.0
0.06662	0.1623	0.3415[2]	...	1.294[2]	95	12.0	6.0—
0.04657	0.2533[3]	0.2732	1.438	1.551	125	11.5	4.0—
0.02984	0.1018[3]	0.1696	0.902	1.503	110	11.0	3.0—
0.02730	0.1041[3]	0.1376	1.009	1.333	100	11.0	2.5
0.02223	....	0.1476	...	1.756	110	7.0	4.0—

[1] Silver voltameter used.

[2] Some deposit lost.

[3] Cathode in good condition.

itself, most of the black deposit on the cathode was removed. The results of the electrolyses are shown in Table II. In Series A are given the results of two preliminary runs in which the amount of sodium used was not known. The first run was the only one obtained from the first solution. A silver voltameter was used for this run, but the copper voltameters were used in all other runs.

It was noticed that the first runs on these solutions gave the least black deposit on the cathode. This was not found to be true for the first electrolysis on the first solution, Series B, probably because equilibrium had not been attained. The procedure for handling the electrodes had not been developed in Series A, so there was the widest variations in the values for the two electrodes.

There was an abnormal behavior in this series in that the antimony deposit on the anode increased with increase in dilution of the solution to the extraordinary value of 3.0008. A similar value was obtained in the analysis of one of the bombs. The concentration at which these two results were obtained were widely different. The solution in which the electrolysis value was obtained was so dilute that the color intensity was reduced to a point where the solution was transparent even in the large cell. This must have been a concentration a hundred-fold less than for the solution analyzing to Sb/Na = 3.14.

In Series B, which was much more skilfully handled, there was still no close agreement between the two electrodes. Those cathode values indicated with the reference 3 were in good condition, such that an agreement of at least 10% might be expected. This was found in only a few cases, which shows that the process of electrolysis was affected by sources of error which could not be accounted for by the black deposit on the cathode. The possible causes of these irregular values for both electrolysis and the one analysis are so numerous that no definite factor will be discussed until further work has been done.

In spite of the lack of accuracy of these electrolyses, Series B appeared to bear out the results of the analysis that the anions decrease in antimony content with increasing dilution. The results to the contrary and the abnormally high value for the one analysis are no doubt not representative of equilibrium conditions.

VII. Summary.

The results of this investigation show that antimony and solutions of sodium in liquid ammonia react to form a series of compounds. These metallic compounds are electrolytic in nature and their equilibrium is a function of the concentration. In dilute solution, there is a great change of the ratio Sb/Na with the concentration, which at higher concentrations becomes nearly constant, decreasing slightly beyond 0.4 N with respect to sodium. This decrease may be due to lack of equilibrium in the viscous concentrated solutions, or it may be due to the fact that the density of the solutions was neglected in calculating the values of the concentrations. The equilibrium must involve not less than two compounds, one of which has a ratio of antimony to sodium greater than two, and one less than two. In dilute solution the compound of low antimony content is present in relatively larger quantities. While the electrolyses have not yielded any conclusive quantitative results, they do show that antimony is present in solution as anion and that more than one atom of antimony is associated with each negative charge. The only compounds previously investigated which bear any resemblance to those just described, aside from the corresponding lead compounds, are the polyiodides.

In conclusion, I wish to express my appreciation of interest and assistance of Professor Charles A. Kraus, under whose direction this work was carried out.

WORCESTER, MASS.

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF CLARK UNIVERSITY I, 2.]

THE ELECTRICAL CONDUCTANCE OF SOLUTIONS IN BROMINE.

BY EDWARD H. DARBY.

Received October 11, 1917.

Introduction.—The dielectric constant of a solvent is largely determinative of its power to ionize substances dissolved in it, the ionizing power increasing with the dielectric constant according to the Thomsen-Nernst hypothesis. This influence is very marked at low concentrations, but at higher concentrations solvents of low dielectric constant appear to possess an ionizing power comparable with that of solvents of high dielectric constant.

Solutions of strong electrolytes do not obey the mass-action law at higher concentrations and consequently a direct comparison between ionizing power and dielectric constant for different solvents is impossible. According to Kraus and Bray,[1] however, the ionization of a binary electrolyte in any solvent may be expressed as a function of its concentration by the equation

$$\frac{(c\gamma)^2}{c(1-\gamma)} = D(c\gamma)^m + K.$$

Where D, m and K are constants, γ is the degree of ionization and c the concentration. It is thus possible to relate the effect of the dielectric constant on the ionization of a given electrolyte in different solvents by means of the values of the constants D, m and K. Since the relation between ionization and dielectric constant is a very involved one, it is obvious

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[1] Kraus and Bray, THIS JOURNAL, 35, 1315 (1913).