

A STUDY OF MOLYBDENUM BLUE, ITS PROPERTIES AND COMPOSITION.—BY LLOYD ALEXANDER MUNRO, B. A., Dalhousie University, Nova Scotia.

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Introduction.—Centuries before Molybdenum was recognized as an element, the name Molybdos, “heavy” had been given by the Greeks to ores of lead. Until the middle of the eighteenth century, Graphite or “Plumbago”, as it was then called, and Molybdenite, were thought to be identical. Scheele, in 1778, proved that these were different minerals. In his “Treatise on Molybdena,” he pointed out that one of these, Molybdenite, formed a “peculiar white earth,” when treated with nitric acid. “Black Lead” did not give a similar reaction. The white precipitate from Molybdenite was found to be acidic in character. Scheele named it “Acid of Molybdena” or “Molybdic Acid.” The metal was isolated several years later (1790) by Hjelm. He reduced Molybdic acid by heating it with charcoal.

Molybdenum Blue is the name given to the blue coloration obtained when Molybdic Acid is reduced in acid solution. This reaction is one of the most characteristic tests for Molybdenum. In addition to this there are several other tests for the element. A common one is the precipitation of curdy mass in solution of Molybdate when not too dilute. This also gives a yellow-green color to the blow-pipe flame. It imparts a green color to the Borax bead.

Later work has brought to light other tests. The Chemical Abstracts (1913) give a paper on “Sensitive Reaction for the Detection of Molybdenum,” (A.C.S. 3726). The presence of Molybdenum was shown by a blood red color obtained by KCNS in a solution of molybdate reduced by calcium chloride, or zinc and sulphuric acid. The test was not dependable when stannous chloride was used.

In 1912, Melikov published a paper (Ber. 31. 2448) on “Reaction for Detection of Molybdic Acid.” The test was for

formation of a red ammonium per-molybdate similar to K_2O_2 , MoO_4 , H_2O_2 .

Although the above reactions are sensitive, the standard test for Molybdenum is the formation of Molybdenum Blue. Nearly all text books on Inorganic Chemistry *mention* the blue as a test for Molybdenum or Tin, but few tell anything about its properties. A still smaller number assign any formula to the compound which causes coloration. Formulae suggested by these writers show little agreement.

A few extracts from well known volumes will show this clearly. The "Encyclopedia Britannica," says: "ammonium molybdate $(NH_4)_{10}Mo_{24}O_{15}$ with hydrochloric acid or nitric acid gives a white precipitate; with reducing agents, such as sulphurated hydrogen, sulphuric acid and zinc, stannous chloride, etc., it gives a *blue coloration*, which turns green and finally brown."

Holleman, (translated by Cooper, 1911), states:

"A very characteristic test for molybdic acid is the following: the substance is mixed with zinc and sulphuric acid. At first a *blue coloration* (a Molybdate of Molybdic Oxide) appears."

Kolbe also merely mentions the blue as a test. "If zinc is added to a solution of molybdic acid a blue color is first produced which becomes green and finally dark brown in color, due to reduction."

Mellor, in his very readable book on "Inorganic Chemistry," does not give any definite formula. "The molybdates," he writes, "are reduced by zinc in acid solution to one of the lower oxides, *approximately* Mo_2O_3 and at the same time the color of the solution changes through various shades of violet, blue and black."

Browning of Yale, in his book "The Rarer Elements," does not suggest the formula for Molybdenum Blue.

Finally, Roscoe and Schorlemmer in their "Treatise on Chemistry," Vol. II. 1044 (1917), give the following:

“When molybdic acid is reduced in solution by sulphuretted hydrogen, sulphur dioxide, stannous chloride, nascent hydrogen, etc., a blue color is obtained, due to the formation of an oxide or oxides between the di- and the tri-oxide. The solution deposits a blue precipitate of this oxide which contains (?) water. It is termed “Molybdenum Blue.”

It will be seen from the above extracts that very little is definitely known concerning the properties or composition of Molybdenum Blue. Attempts were made by various investigators to find it's formula. A number of different formulae have been brought forth. These will be briefly noted, without giving any details of the methods by which they were obtained.

The formula of lowest molecular weight is that given by Rammelsberg. He assigns to the Blue the formula $\text{Mo}_2 \text{O}_5 = \text{MoO}_2 \cdot \text{MoO}_3$. Others regard it as $\text{Mo}_3 \text{O}_8 = \text{MoO}_2 \cdot 2\text{MoO}_3$.

Guichard suggests $\text{Mo}_5\text{O}_{14} \cdot 6\text{H}_2\text{O} = \text{MoO}_2 \cdot 4 \text{MoO}_3 \cdot 6\text{H}_2\text{O}$. Zsigmondy says “The formula *is supposed to be* $\text{Mo}_3 \text{O}_8 \cdot 5\text{H}_2\text{O}$. According to Klassen, it consist of complex derivatives of an oxide Mo_2O_5 and Molybdic acid, analogous to phosphomolybdic acid.

Since 1917, no further work has been published on the question of its composition. This research was undertaken with the object of determining the correct formula for Molybdenum Blue and to make a study of its properties.

DEMONSTRATION

A solution of ammonium molybdate was the first requisite. This was made according to the method given by Noyes. A solution of stannous chloride was also made. This was obtained by dissolving pure tin shot in concentrated hydrochloric acid and diluting it to required strength. Some metallic tin was kept in the bottom of the flask.

On attempting to obtain Molybdenum Blue by adding a portion of the SnCl_2 solution to some of the solution of ammonium molybdate, a blue coloration was first obtained. but

it soon changed to green and finally pale yellow. It was thought that this bleaching action might be due to the nitric acid in the molybdate solution. This was found to be the case. Hence neutral solutions of molybdate were used. These were made by dissolving 5 grams of the salt in 500 c c of distilled water.

Molybdenum Blue was obtained by the action of SnCl_2 in the presence of HCl , by Hydrogen sulphide from hot acid solution, nascent hydrogen, sulphur dioxide, and oxalic acid. Quantities of the blue were obtained by stannous chloride and Dumanski's method. These were by far the most satisfactory. Dumanski dissolved 15 g of ammonium molybdate in 400 c c water. To this solution 100 c c of 3 N or 4 N. H_2SO_4 was added. The boiling solution was reduced with H_2S . Samples of the blue obtained by these two methods were dried at 40° for some hours, put in a sealed bottle and labelled according to their mode of preparation.

In the preparation of the Blue it was found that, if the amount of stannous chloride added to a constant amount of the molybdate solution, were varied, the precipitated Blue and the filtrate varied in color. It was noted that as the amount of stannous chloride was increased, the precipitated Blue became darker in color while the filtrate, instead of being blue, was green or almost colorless. By adding molybdate solution to this filtrate the blue color and further precipitate was obtained. This suggested that green was further reduction product as SnCl_2 was evidently in excess.

To prove this a few drops of hydrogen peroxide were added. A blue color was obtained. Same result was obtained with FeCl_3 as oxidizing agent. When more SnCl_2 instead of H_2O_2 was added to the green solution, a brown color appeared. When the green solution obtained with sulphur dioxide was allowed to stand exposed to the air, it became blue. This property was shown by the colorless solution obtained by reduction with Oxalic acid.



FIG. 1

A test tube containing a brown solution obtained by reduction by zinc and H_2SO_4 was treated with three drops of H_2O_2 . A green color appeared in two thirds of the tube. Another drop of peroxide was then added. This gave a blue solution in the upper part of the tube. These experiments show conclusively that the green and browns are successive reduction products.

The colloidal nature of the blue was confirmed by adding an electrolyte (NaCl) to the clear filtrate. The mixture was shaken. A precipitate formed. After allowing the solution to stand for a few hours, the precipitate was removed by filtration. The filtrate was still blue. More electrolyte was added but no further precipitate was obtained. The fact that the filtrate was blue would suggest that Molybdenum Blue exists in the crystalloidal form also.

A simple dialyzer was made by covering the mouth of a funnel tube 2" in diameter, with a membrane of sheepskin. Solutions of the Blue, the filtrates from the preparation by SnCl_2 and H_2S , were placed in the dialyzer and the latter kept immersed in distilled water for five days. The water was changed every twelve hours. After twelve hours dialysis, some of the water was evaporated over microscopic slides. Examination under the microscope revealed large amount of stannous chloride crystals. Slides prepared after thirty hours dialysis showed stannous chloride needles, and a little Blue. At the end of four days continuous dialysis, the water in which the dialyzer had been immersed for twelve hours, gave almost no deposit on the slide. This slight deposit consisted of tint patches of Blue with a mere trace of stannous chloride. That some Blue passes through the membrane would suggest that it might be crystalloidal as well as colloidal. The blue patches might well be aggregations of ultramicroscopic crystals.

The bleaching action of animal charcoal on solution of Molybdenum Blue was tried. The blue solution was soon bleached by the charcoal. Concerning this phenomenon Zsig-

mondy says: "Colloids can be completely removed from a liquid by porous bodies. As a lecture experiment the author has used the absorption of Molybdenum Blue by animal charcoal. As in other cases the absorption was quantitative and irreversible."

It was found however, that if the solution was filtered as soon as it became colorless and the filtrate treated with SnCl_2 , a slight blue coloration was obtained. This shows that it is incorrect to assume, as Zsigmondy evidently does, that the bleaching action is wholly due to absorption. The action is also one of oxidation, although to a much smaller extent.

The oxidizing power of charcoal was shown by treating the brown solution obtained from the extreme reduction of Blue by Zinc. The supernatant liquid gradually changed to blue.

Vectoriality.—Some liquids are vectorial in character. They form "crystals" while still in the liquid, i. e., they assume definite shapes. Extensive research has been done on this property of liquids. The question as to whether, or not, colloid phases exhibit vectorial properties, has apparently not been settled to the satisfaction of all, as yet. However, men who have worked upon this problem usually support the affirmative. To quote Lincoln ("Physical Chemistry," 1920):

"Von Weimarn even believes vectoriality is manifested by gaseous substances and in addition, has presented evidence which he considers to be direct proof of the vectoriality of the colloid phases. In the case of colloid iodine and certain colloid dyes, L. Pelet and Wild claim to have observed the fusion of ultra-microscopic particles which assumed definite crystalline shapes."

An attempt was made to obtain crystalline Molybdenum Blue and thus confirm the work of Von Weimarn and Pelet and Wild.

Microscopic slides were placed in shallow evaporating basin, containing filtrate from Blue prepared with SnCl_2 . The solution was allowed to evaporate at room temperature. When slide became exposed it was removed and allowed to dry. It was examined under the microscope.

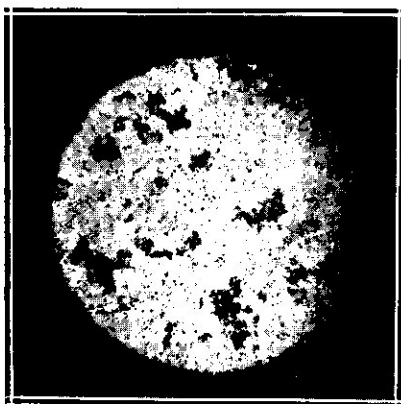


FIG. 2

the diagonals of the square. This cross pattern reminded one of similar pattern found in a variety of the minerals, Andalusite, Chiastolite. The crosses in the mineral are supposed to be caused by "impurities on crystallization" (Butler). It seems more reasonable in the case of a Molybdenum compound that they are the edges of an octahedron. If this be so, they are molybdc oxide.

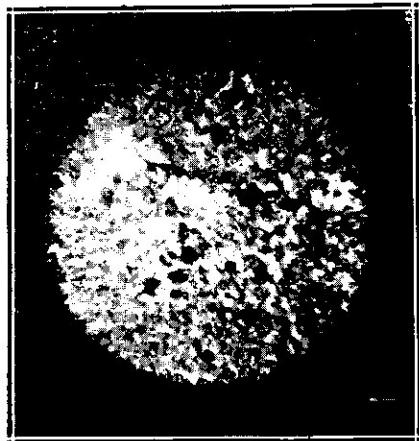


FIG. 3

The first slide showed a blue gel with little colorless crosses here and there. These little crosses were found to be incipient crystals, for, on the second slide examined, cross and square crystals, derived from these, were found side by side. The third slide (Fig. 2) showed these crystals in large numbers. In many cases the cross could be seen, forming

A few colorless hexagonal crystals were also noticed. These were recognized as ammonium molybdate. The photograph shows these crystals, some hexagonal ones, as well as gel and amicros.

A portion of dialyzed hydrosol was evaporated, at 18°. The deposit on slide was examined under microscope. A beautiful back ground of blue gel was seen. This gel con-

tained a few dark blue opaque particles of regular outline. They were almost cubic in shape. Fig. 3 shows the slide under low power. The hydrosol was treated with NH_4Cl . Precipitate was separated from solution by filtration. The blue filtrate was allowed to evaporate over slides. Crystals were found as shown in Fig. 5 and 6. As can be readily seen, they belong to the cubic system. It will also be noticed that the corners are truncated. These little faces do not appear on crystals on slide No. 2. These crystals (No. 4) are pale blue in color. They are certainly not ammonium chloride crystals.

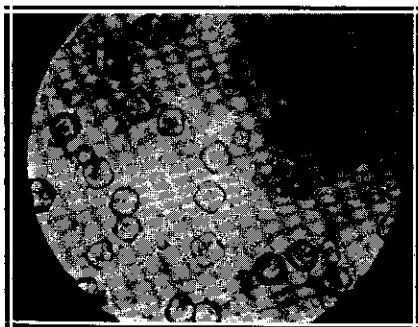


FIG. 4

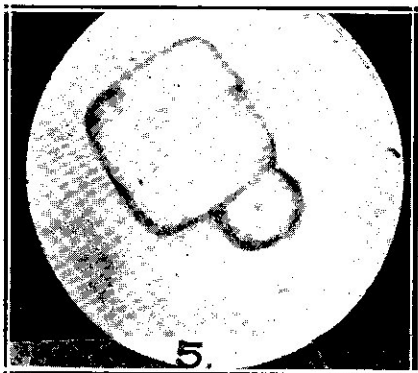


FIG. 5

They are different from either molybdic oxide or ammonium Molybdate. It is therefore probable that they are crystals of crystalloidal Blue.

Fig. 5 shows a crystal under high power. The truncated corners can be seen quite distinctly. The cross in centre appears quite plainly.

As will be noted more fully later, the hydrogel was found to be soluble in absolute alcohol.

A concentrated solution of the Alcosol was made. It was concentrated further by slow evaporation. Fig. 3 shows a section of the slide obtained. The

particles are cubes varying in color from lightblue to very dark blue, according to their thickness. The light blue ones were examined under crossed nicols. They are isotropic. A basal section of a cubic crystal would give this effect.

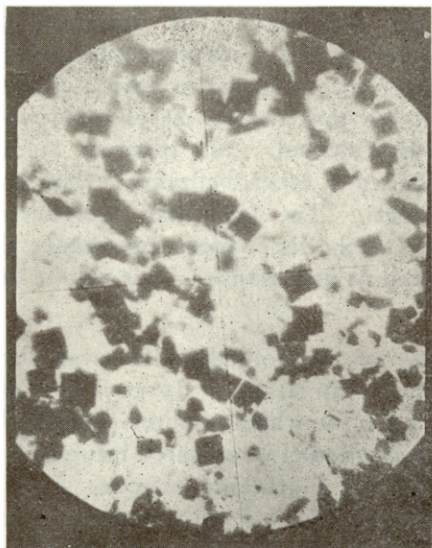


FIG. 6

diluted by adding more alcohol. A few drops of this solution were added to the molybdate. A brownish precipitate was obtained. The same experiment was tried with HCl added to the molybdate solution. The same result was obtained.

The alcohol solution was treated with zinc and sulphuric acid with no apparent reaction. Sulphuretted hydrogen was passed into the solution. A colloidal solution resulted. This solution was fluorescent, giving blueish grey and red by reflected and transmitted light, respectively. After standing for some hours the solution became a fawn color and a flocculent brownish precipitate similar in color to that obtained by adding

The writer can see no valid reason for considering these crystals other than crystal of colloidal Molybdenum Blue. This fact would lend strength to Wiemarn's and Pelet's supposition that colloids have the property of vectoriality.

Pure crystals of Stannous chloride were dissolved in absolute alcohol. A saturated solution of Ammonium Molybdate in alcohol was also prepared. Portions of the stannous chloride solution were

SnCl_2 , separated out. Three weeks later the solution was filtered. The precipitate formed a gel on the filter. It turned a darker brown. Lack of time prohibited further investigation. The experiments showed that Blue could not be obtained except in water solution.

The Gel.—Solubility in solvents: The hydrogel prepared by action of stannous chloride and sulphuretted hydrogen was dried. The solubility of the dried gel in various solvents was ascertained. It was found that the gel dissolved in water, absolute alcohol and methyl alcohol. No apparent solution took place when gel was shaken in ether, benzene, carbon bisulphide, acetone and chloroform. The fact that Molybdenum blue is soluble in absolute alcohol is of more importance than would, perhaps, be recognized at first glance. This will be dealt with later.

The negative character of the colloidal Blue was shown by a modification of Cohen's apparatus. It consisted of a U-tube partly filled with agar, in which sodium chloride had been dissolved. The dialyzed hydrosol was poured into each arm, the levels in each being the same. Platinum electrodes were immersed in the hydrosol. A current of 1-2 mil amperes and pressure 4 volts was passed through tube for 16 hours. At the end of that time it was found that blue solution had become colorless. The level of water in the cathode arm had risen. Solutions in each arm were tested for oxidation or reduction. The cathode arm gave negative tests. The solution from the anode tube showed oxidation, due to chlorine liberated from the electrolyte (NaCl).

A solution of the hydrosol in agar was now placed in a U-tube. Electrodes were immersed in gel. Potential was raised to 10 volts. A current of 3 milamperes was passed through tube for 16 hours. The blue migrated towards the anode. This proved that hydrosol carried a negative charge.

An experiment was undertaken to find whether the hydrosol and alcosol had the same rate of migration. Solutions of

Blue were made by dissolving equal quantities in equal volumes of water and of alcohol. These solutions were placed in tubes over agar. The tubes were connected in parallel. It was found that the migration of hydrosol was greater than that of the alcohol. Results were of little value, however, on account of the unequal diameter of the tubes. Since resistance, and therefore amount current varies with the area of cross section, and rate of migration depends on amount of current, the difference might have been partly due to difference in tubes. The resistance of the solutions was so great that the current could not be measured with mil-ammeter.

Analysis of Blue.—Samples of "hydrogel" were pulverised and dried at temperature of 105°-110°C until three weighings, taken at intervals of one hour, gave the same weight.

Apparatus.—Apparatus for reduction of an oxide was set up. It consisted of a hydrogen generator; wash bottle containing C. P. sulphuric acid; short length of hard glass tubing, small platinum boat and a U-tube containing sulphuric acid over glass beads. The platinum boat, which had been ignited, cooled in a desiccator and weighed, was partially filled

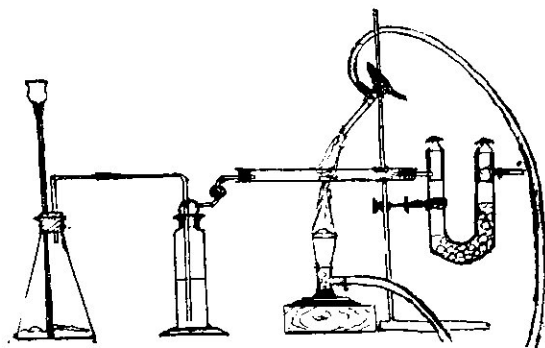


FIG. 7

with the prepared Blue. The amount of Blue taken for analysis was recorded. The boat and Blue were placed in the hard glass tube, the apparatus connected. When a stream

of hydrogen had been passing through the apparatus for ten minutes, heat was applied to the boat. It was heated at red heat for eight hours. The boat was weighed as quickly as possible and

reduction and heating continued for four hours more. At the end of that time the boat containing the residue was again weighed. The boat was allowed to cool in a stream of hydrogen. Weighing was done as rapidly as possible. It was found that the Blue lost very little or no weight during the final four hours heating. The gain in weight of the U tube served as a check.

Three determinations were made. The results agreed very well considering the possible experimental error, due to sublimation of Molybdenum, moisture absorbed by blue during first weighing, and also variation in amount of water in hydrogel. In discussing the various formulae that have been suggested the average results obtained will be considered.

<u>Average time of reduction</u>	<u>Average Wt. of hydrogel</u>	<u>Wt. of residue</u>	<u>Average Loss in Wt.</u>
12.2 hrs.	.2669 g	.1785 g	.0884 g

The residue was blueish grey. It was taken to be Molybdenum with a trace of oxide. As no further loss in weight resulted between weights at the end of eight and twelfth hours of treatment the residue could not be $\text{Mo}_2\text{O}_3\text{MoO}$, MoO_2 , MoO_3 , for these oxides are broken down below bright red heat. When the heat was increased, a metallic mirror was deposited in the tube. This would show that the residue was Molybdenum. In the following calculations it will be treated as such:

Let us consider the first formula suggested, Mo_2O_5 . If this were the formula residue would weigh $\frac{\text{Mo}_2 \text{O}_5}{\text{Mo}_2 \text{O}_3} \times 2669 = \frac{192}{272} \times 2669 = 1884$ g.

This is more than $5\frac{1}{3}\%$ greater than actual weight of residue. According to this formula the loss in weight would be:

$$\frac{\text{O}_5}{\text{Mo}_2 \text{O}_3} \times .2669 = \frac{80}{272} \times .2669 = .08045.$$

This is 10% smaller than experimental result. The formula Mo_2O_5 must therefore be considered incorrect.

Considering Guichard's formula—

$\text{Mo}_5\text{O}_{14}, 6\text{H}_2\text{O}$ it is calculated that residue should weigh

$$\frac{\text{Mo}_5}{\text{Mo}_5 \text{O}_{14} 6 \text{H}_2 \text{O}} \times .2669 \text{ g} = .1980 \text{ g. This } 10\% \text{ too great.}$$

The "loss in weight" as calculated by the formula, would be correspondingly small.

The formula given in Zsigmondy's "Colloids" is $\text{Mo}_3\text{O}_8, 5\text{H}_2\text{O}$. This would give a residue weighing .1517 g, as calculated by

$$\frac{\text{Mo}_3}{\text{Mo}_3\text{O}_8 5 \text{H}_2\text{O}} = \frac{288}{506} \times .2669 = .1517 \text{ g, or } 85.1\% \text{ of experimental value.}$$

According to this formula the weight of gas and water-vapor given off would be $\frac{\text{O}_8 5 \text{H}_2 \text{O}}{\text{Mo}_3 \text{O}_8 5\text{H}_2 \text{O}} \times .2669 = \frac{218}{506} \times .2669 = 1150 \text{ g, which is over } 10\% \text{ greater than experimental value.}$

The formula most generally given is Mo_3O_8 . According to this the residue would be $\frac{\text{Mo}_3}{\text{Mo}_3 \text{O}_8} \times .2669 = \frac{288}{416} \times .2669 = 1848\text{g}$

This is 3.5% greater than actual weight of residue.

Calculating the weight of oxygen given off; weight of oxygen equals $\frac{\text{O}_8}{\text{Mo}_3 \text{O}_8} \times .2669 = \frac{128}{416} \times .2669 = .0831 \text{ g.}$

which is 6½% less than the "loss in weight" of sample.

From the relation of weight of residue and weight of gas given off, it was thought that the formula would be $\text{Mo}_3\text{O}_8 \text{H}_2 \text{O}$.

Calculations were made.

Weights of residue equals—

$$\frac{\text{Mo}_3}{\text{Mo}_3 \text{O}_8 \text{H}_2 \text{O}} \times .2669 = \frac{288}{434} \times .2669 = .1771 \text{ g.}$$

This agrees with experimental values within 4-5%.

The wt. of gas given off $\frac{\text{O}_8 \text{H}_2 \text{O}}{\text{Mo}_3 \text{O}_8 \text{H}_2 \text{O}} \times .2669 = .0898 \text{ g.}$

This agrees within 1-1/3% of experimental result.

The formula $\text{Mo}_3\text{O}_8\text{H}_2 \text{O}$ was tried, but gave poor agreement.

From these calculations, it has been shown that the formula $\text{Mo}_3 \text{O}_8 \text{H}_2 \text{O}$ agrees most closely with actual weights of analysis. It should be noted also, that this formula comes the nearest to the molecular weight as determined by Dumanski. He found it to be 440. This formula $\text{Mo}_3 \text{O}_8 \text{H}_2 \text{O}$ gives molecular weight of 434; $\text{Mo}_3 \text{O}_8$ 416 and $\text{Mo}_3 \text{O}_8 5\text{H}_2 \text{O} = 506$.

It has been found, as noted above, that the dried hydrogel is soluble in absolute alcohol. Now Zsigmondy, in his "Chemistry of Colloids," "(T. Spear, 1917)" discussing Silicic Acid Organogels, states: "The fact that water may be replaced by other substances as solvents, without any marked change in the character of the gel, points clearly, as Van Bemmelen has noted, to the assumption, *that water is not there as a hydrate chemically combined, but is absorbed water that fills the spaces between the ultramicros.*" He gives G. Tschermak; (Zeit. f. phys. Chemie. 53, 349-367), (1905); G. Tammann; (Zeit f. Anorg Chemie. 71, 375), (1911); as references.

It is obvious, then, that the formula for Molybdenum Blue given, in the same volume, is incorrect. If we accept the work of Bemmelen, any formula which shows one or more molecules of water of hydration must be discarded. This leaves just Mo_2O_5 , or $\text{Mo}_3 \text{O}_8$. Of these $\text{Mo}_3 \text{O}_8$ is the better.

Ostwald in his "Inorganic Chemistry," says: "Between this (Mo O_2) and trioxide are the readily formed Blue compounds, the composition of which *varies*, and cannot be characterized with sufficient sharpness." This variation may be due to the different formula-weights of water enclosed by the ultramicros. Certainly the formula $\text{Mo}_3\text{O}_8 \text{H}_2\text{O}$ best expresses the

composition of the sample of Blue analyzed, but for the anhydrous gel, the formula is, no doubt, Mo_3O_8 .

It would be interesting to note whether the variation in composition of the precipitated ammonium phosphomolybdates, which "seem to violate the constancy of composition test for distinguishing compounds from mixtures," could not be explained in a similar manner. Possibly the variation is due to the adsorption of water or an oxide by the ultramicrons, the amount of which varies with conditions.

The formation of Molybdenum Blue by the action of ammonium molybdate and a stannous salt is a sensitive test for tin. An attempt was made to determine the sensitiveness of the test for tin.

Stannous chloride was obtained by dissolving .2138 g of pure tin in C.P. HCl. The solution was diluted to 500 cc and 50.01 cc of this solution diluted to 500 cc. A tin bead was dropped into the resulting solution and the solution immediately titrated against an approximately 1/5% solution of Ammonium molybdate.

$$\text{Average ratio} = \frac{1 \text{ cc tin}}{60.1 \text{ cc sol. AM}}$$

$$\text{Sensitivity} = \frac{.2138}{5000} \times \frac{1}{600} = \frac{1}{1.423.000},$$

(Some error due to $\text{SnCl}_2 \rightarrow \text{Sn Cl}_4$.)

Sensitivity of test for Molybdenum was also tried. It could not be determined with any degree of accuracy, owing to the formation of the green solution, when Sn Cl_2 was in excess. This faint green color was very hard to detect.

SUMMARY OF FINDINGS OR CONFIRMATIONS

1. Blue is most readily prepared by action of SnCl_2 and H_2S .
2. Green and brown colors are due to further reduction com-

pound. Action is reversible.

3. Blue only obtained in acid solution.
4. Negative colloid.
5. Exists as crystalloid also.
6. Forms cubic crystals from alcohol, and transparent cubes bearing face of octahedron from blue filtrate after gel has been precipitated by NH_4Cl .
7. Insoluble in ether, chlorform, benzene, carbon bi-sulphide and acetone.
8. Soluble in water, absolute alcohol and methyl alcohol.
9. Formula of hydrogel as obtained from analysis = $\text{Mo}_3\text{O}_8 \cdot \text{H}_2\text{O}$. Formula of Blue = Mo_3O_8 .
10. Sensitivity of test for tin is 1 part in 1,423,000.