When the conditions of the dry process are under examination, the dried materials, clay or shale with marl or limestone, are mixed and well ground together in a laboratory jar mill. The mill at present in use, which has given very satisfactory results in grinding both raw material and clinker, was furnished by the Bonnot Co., of Canton, Ohio. After mixing and grinding dry, the material is moistened with just enough water to enable it to be rolled out and cut up like that used for the wet process.

ANN ARBOR, MICH.
December 16, 1901.

THE ALLOYS OF ALUMINUM.[1]

BY WILLIAM CAMPBELL AND JOHN A. MATHEWS.

Received December 7, 1901.

THE fact that aluminum can now be classed as one of the common metals, since it can be obtained at a moderate price, and of certainly as great purity as other commercial metals, has of late years made it the subject of many researches. Its alloys with nearly all the commoner metals have been made or attempted, but their adaptability to commercial uses has rested solely upon the ordinary tests and many statements of a very unscientific nature have been published about them.

While working in Professor Sir William Roberts-Austen's laboratory, at the Royal College of Science, the authors were engaged in examining anew some of these alloys in the light of recent advancement in those methods of alloy research which Professor Roberts-Austen has done so much to promote. Through the interest in our work which he exhibited and by means of the facilities which he provided us for carrying on metallographic and pyrometric observations we now have the honor to present the following results,—not as a completed investigation, but as the beginning of one which has, of necessity, been transferred from one laboratory to another. We expect to continue work upon some of these lines in the metallurgical laboratory of Columbia University. It has been thought best, therefore, to present the results already obtained by us in the laboratories at South Kensington in the following paper.

Professor Richards, whose researches upon the industrial applications of aluminum are so well known and which entitle him to be considered as the foremost authority upon the metallurgy of

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[1] Read before the New York Section of the American Chemical Society, November 1, 1901.

aluminum and its alloys, has given us a very valuable work on the subject in his book, "Aluminum: Its History, Properties, Metallurgy, etc." In so far as this book deals with industrial topics, resting upon Professor Richards' own authority, it is no doubt the best source of information to be had. A great deal of what might be called the "pure science" of the book—particularly in regard to the alloys—is decidedly at fault and should be revised thoroughly, and many portions, almost without exception direct quotations from antiquated sources, might well be omitted.

In classifying the alloys of aluminum, Professor Richards points out that the useful ones fall into two groups.

1. Those in which small amounts of another metal are added to aluminum.

2. Those in which aluminum is added in small amounts to other metals.

Generally speaking the metal present in the smaller amount does not exceed 15 per cent., and practically, in alloys of the first class, much smaller amounts give the maximum improvement in the alloy, hardness being one of the qualities most sought. Aluminum seems to be able to take up considerable quantities of certain metals without undergoing a change in volume, though the density and probably the hardness are improved in such cases.

Aluminum seems to form intermetallic compounds more readily than almost any other single metal unless it be the alkalies. On the other hand, there are several metals with which it will neither combine nor even mix to give homogeneous alloys except when the added metal is present in very small percentages. Of this class of metals we might mention lead, bismuth, and cadmium.

Various workers have mentioned the formation of one or more compounds of aluminum with antimony, chromium, cobalt, copper, nickel, gold, manganese, magnesium, mercury, molybdenum, platinum, titanium, tungsten, and other metals. In the light of recent work we may doubt that the formulas of these compounds have been correctly given in all cases. We are positive that many of the copper-aluminum compounds so-called, that have been mentioned in past years, have no existence. They are neither indicated by metallographic nor pyrometric evidence and the fact that from many alloys of aluminum beautiful and for the most part rather stable crystals can be obtained by the use of proper solvents does not prove that these crystals consist of a single intermetallic compound. Any one who has worked much with such crystals knows that from alloys of different percentage compositions crystals may be isolated which, while entirely identical in form, give very different analyses. The crystals, granting that they contain an intermetallic compound, may also contain one or other of the constituents of this compound in solid solution. This quantity of dissolved substance will be found to increase in amount as we approach the alloy whose percentage corresponds exactly to the formula-percentage of the intermetallic compound under consideration. It seems to have been the custom in the past to assign a formula to all crystalline products which could be isolated from alloys. The result of this method and others equally faulty is that in the literature one may find mention of at least eight carbides of iron, while in iron one finds but one. Similarly, some fifteen compounds of aluminum with copper and nearly as many with molybdenum have been mentioned. Pyrometric evidence indicates but two of the former (Al-Cu), while Le Chatelier thinks he has microscopic evidence of four; certainly the latter figure is the limit. We have not studied Al-Mo alloys.

Alloys of Aluminum with Lead, Bismuth, and Cadmium.—Aluminum, like zinc, will not mix in all proportions with lead or bismuth to form homogeneous alloys, but separates into two layers. Unlike zinc, it does not mix in all proportions with cadmium. Dr. Alder Wright has studied several such pairs of metals[1] and his results show that in every case each of the resulting layers of metal consists of a primary constituent holding in solid solution a small amount of the other metal of the pair under examination. Thus lead and aluminum, after heating together, separate into layers, lead, of course, at the bottom containing 0.07 per cent. aluminum, while the upper layer consisted of aluminum containing 1.92 per cent. of lead. Our experiments agree with Dr. Wright's in the main. With regard to the Al-Cd alloys we found the top portion to be aluminum and the base cadmium, but in the cadmium could be seen bright minute crystals, whose specific gravity was less than that of cadmium and hence the crystals were found mostly at the junction between the two layers. The alloy was slowly cooled. According to Wright, cadmium dissolves 0.22 per cent. of aluminum and aluminum dissolves 3.39

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[1] *J. Soc. Chem. Ind.*, 1892, p. 492.

per cent. of cadmium when these metals are heated in contact for eight hours at about 750° C.

Aluminum and Platinum.—Tissier Brothers state that an alloy containing 5 per cent. of platinum approaches in color gold containing 5 per cent. of silver. We made such an alloy, also one of 10 per cent. platinum, but were unable to detect any change in color. The metals seem to unite chemically and by dissolving away the excess of aluminum, long needle-shaped crystals remained. These gave by analysis, 4.35 per cent. aluminum and 95.65 per cent. platinum, which corresponds closely to the formula $AlPt_4$; we do not state, however, that such a compound exists. The freezing-point curves of those series of aluminum alloys which have been completely ascertained show that the intermetallic compounds of aluminum are numerous but they also lead us to doubt the existence of many of those which have been mentioned in the past. When platinum is present in large amount, say from 30 to 50 per cent., the alloy is decidedly yellow. Mr. George S. Newth showed us some alloy of this kind made several years ago in the electric furnace. Indeed, the production of this alloy was probably the first instance of a colored alloy from colorless or "white" metals. In this case we may almost assume that the color is an evidence of chemical combination, just as it is in Roberts-Austen's purple alloy, $AuAl_2$. In the formation of this beautiful compound the heat evolved during the reaction is said to be so great that when once the reaction is started it proceeds without application of external heat.

Aluminum and Tungsten.—As has been known for a long time, these two metals readily unite. In working with alloys containing from 3 to 17 per cent. tungsten, we obtained in every case except one, large, thin monoclinic crystals. In a single instance some very beautiful hexagonal crystals terminating in hexagonal pyramids were obtained. All efforts to obtain a further production of these crystals were unsuccessful, except that in one alloy both kinds occurred (see Figs. 1 and 2). We were not aware that in the chance production of them in these two cases, any peculiar conditions were operating which were absent in the instances in which only monoclinic crystals resulted. A number of very curious chemical properties were noted in studying these crystals. The analyses resulted as follows:

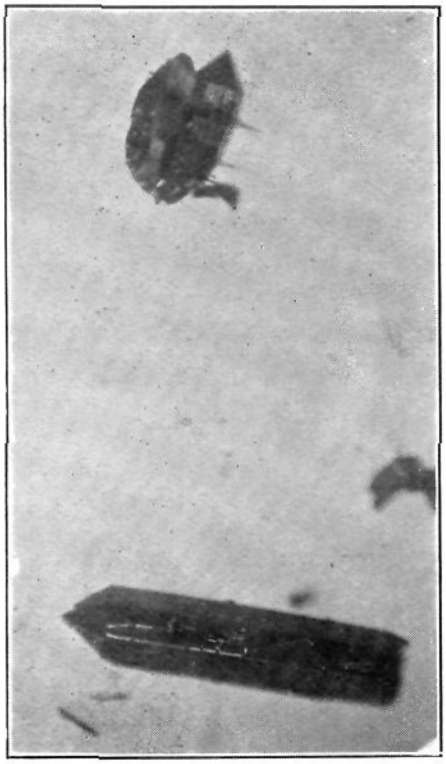

Fig. 1.

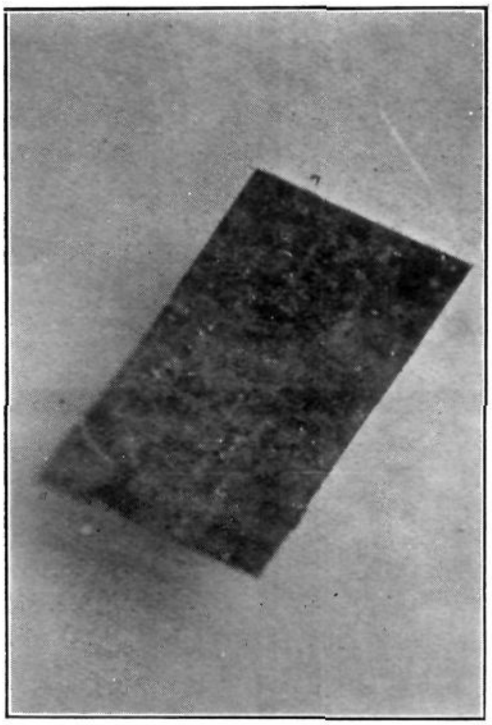

Fig. 2.

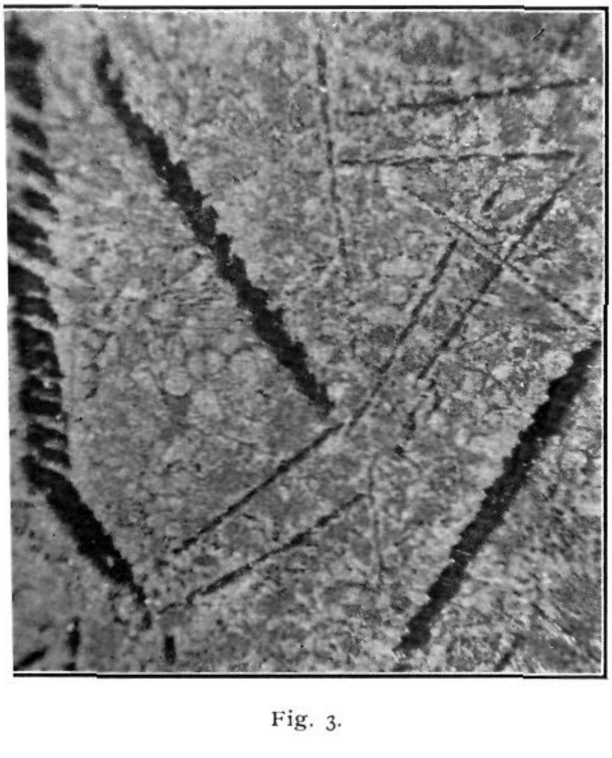

Fig. 3.

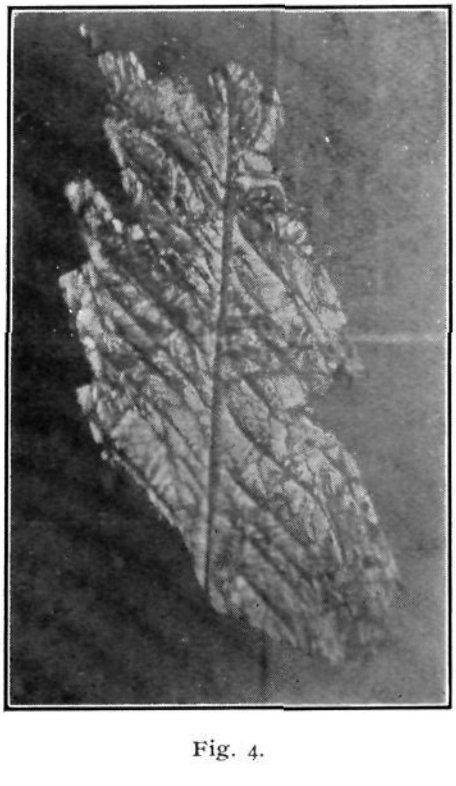

Fig. 4.

Monoclinic crystals.	Tungsten. Per cent.	Aluminum. Per cent.	Possible formula.
Sample 1	57.1	....	....
" 2	57.97	41.97	WAl_5
" 3	60.43	39.62	?

The third sample was in the form of very fine siftings and the crystals may have been somewhat acted upon by the dilute hydrochloric acid used in removing the excess of aluminum.

Hexagonal crystals.	Tungsten. Per cent.	Aluminum. Per cent.	Possible formula.
Sample 4	50.91	....	....
" 5	49.19	50.52	WAl_7

Now, whether these are true chemical compounds of the formulas given or not, they certainly differ as distinctly in chemical behavior as they do in crystalline form. The monoclinic crystals are readily attacked by aqua regia, while the hexagonal ones are not. A mixture of nitric, hydrochloric and sulphuric acids is without effect on them and when fused with mixed alkaline carbonate plus a little nitrate in a nickel crucible, the crucible suffered much more than the crystals. With potassium bisulphate they are decomposed with deflagration at a very moderate temperature. We supposed that this fusion would give a mixture of alkali tungstate and aluminate, but were surprised to find that upon treating the fusion with water, a white, more or less flocculent insoluble residue remained. This residue was about as difficult to deal with as the original substance. It was insoluble in aqua regia, slightly soluble in ammonia, but soluble in caustic potash. The monoclinic crystals by fusion with bisulphate gave the same white residue. This we believe is somewhat impure aluminum tungstate, $Al_2(WO_4)_3.5H_2O$. It loses by ignition 10.4 per cent. water, and one analysis gave 66.3 per cent. tungsten; theory for $Al_2(WO_4)_3$ requires 69.17 per cent.

Aluminum and Nickel.—The most commonly used metal for hardening aluminum is nickel. For this purpose, from 2 to 5 per cent. of nickel is employed, often in conjunction with copper, tungsten, and other hardeners. When the combined percentage of these hardeners is from 7 to 10 per cent., an alloy is obtained which casts exceedingly well and is very tough. We made up alloys containing 2.12, 3.14, 4.15, and 7.97 per cent. nickel. The first of these contained a few bright crystals, while the last consisted of a network of skeleton crystals. On isolating these by the use of dilute hydrochloric acid, beautiful single crystals were obtained, each crystal being made up of numberless minute dendritic plates. The groundmass in which these crystals lie is isomorphous with aluminum and melts at a slightly lower temperature. An alloy containing 7.97 per cent. of nickel, and a single crystalline mass isolated from it, are shown in Figs. 3 and 4.

Aluminum and Tin.—Heycock and Neville, in their work upon the depression of the freezing-point of metals by the presence of other metals in them in solution, state that 0.48 per cent. aluminum gives the lowest freezing-point, *viz.*, 3° C. below that of pure tin. Further additions of aluminum to tin cause a rapid rise in the melting-point of the alloy ; ten per cent. of aluminum raises the melting-point nearly 300° C. Our own freezing-point curve (Fig. 5) shows that beginning at pure aluminum (m. p., 655° C.) the addition of tin causes a gradual lowering of the freezing-point up to 74 per cent. tin (570° C.), when there is a sudden drop to 80 per cent. tin at 490°, followed by a rise to 85 per cent. tin at 550° and then a regular fall to the eutectic-point,

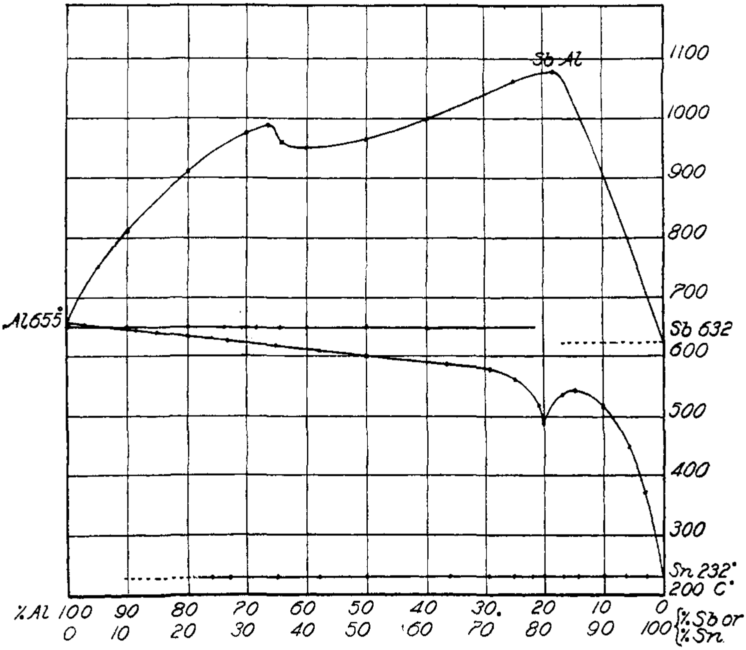

Fig. 5.

99.52 per cent. tin (229°). Microscopic examination of this series of alloys, while not yet completed, shows grains and dendrites of aluminum, or aluminum containing tin in solid solution, in a groundmass of tin (containing 0.48 per cent. aluminum). As the alloys become richer in aluminum, the grains of aluminum increase while the groundmass decreases in amount and disappears altogether at about 90 per cent. aluminum; that is, aluminum containing up to 10 per cent. tin consists of a single solid solution crystallizing isomorphously with pure aluminum. The eutectic[1] in this series of alloys differs apparently from most eutectics in that it has not as yet been resolved into two microscopically visible constituents and, indeed, seems to crystallize isomorphously with pure tin. It seems like a single solid solution rather than two juxtaposited saturated solid solutions of tin in aluminum and aluminum in tin which would be expected from analogy with other eutectic alloys. The idea of either a pure metal or single solid solution constituting a eutectic is not contrary to the definition of a eutectic. We wish to work further on this subject. The meaning of the sudden break in the freezing-point and curve is as yet unsettled. Its existence is even disputed by Anderson and McClean (Brit. Asso., Glasgow, 1901). Gautier's curve, while not identical with ours, does show an irregularity in the symmetry of the curve between 15 and 25 per cent. aluminum. We determined the freezing-points between these percentages in duplicate and upon different series of alloys made by different methods. In all our freezing-point curves, the alloys which we actually examined are indicated in the curves by heavy dots occurring at the percentage composition of the alloys examined. In the same vertical line with these dots, are indicated other breaks occurring in the cooling curves at temperatures below the initial freezing-point.

Aluminum and Antimony.—In Richards' "Aluminum" we find a short summary of the conclusions of several workers on these alloys.

Alder Wright[2] came to the conclusion that antimony formed no commercially valuable alloy with aluminum. He found that when antimony is dropped into molten aluminum, it falls to the bottom and melts. No combination takes place until they are

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[1] For an explanation of cooling curves, freezing-point curves, how they are obtained, etc., see Mathews: *J. Franklin Inst.*, Jan. and Feb., 1902, or *Eng. Min. J.*, Dec. 1901.

[2] *J. Soc. Chem. Ind.*, June, 1892.

stirred, when part of them unite and form an alloy which immediately solidifies on account of its high melting-point. The remainder stays molten because its melting-point is comparatively low. The solidified alloy has the composition 81.6 per cent. antimony, 18.4 per cent. aluminum. SbAl is a gray mass with an iridescent luster. Its melting-point is above 1000° C. which is most remarkable, considering that the melting-points of its ingredients are 625° and 426°, respectively (the melting-points should be 655° and 632°). The alloys low in aluminum look like antimony, while those low in antimony are somewhat spongy. They all slowly disintegrate in the air and disengage hydrogen in water.

Roche[1] confirms the existence of the alloy AlSb with its abnormally high melting-point, but he claims that aluminum containing less than 5 per cent. antimony is malleable and superior in hardness, tenacity, and elasticity to pure aluminum. As the percentage of antimony is increased, the hardness and tenacity diminish until at 10 per cent. antimony, the alloy crystallizes in brilliant laminae. The melting-point and ease with which moist air attacks the alloy, increase up to 81.6 per cent. antimony, which in moist air or water crumbles to a black powder.

Richards says "The only useful alloy claimed by Roche is the one with less than 5 per cent. antimony. This, it is true, can be made apparently quite homogeneous, casts and rolls perfectly, and is apparently superior in many ways to pure aluminum, as remarked by Roche. But after a few months' standing it will be found that the alloy has disintegrated to such an extent as to be worthless, a point which has probably been discovered by this time." Our own experience has been the same as that of Richards.

Dr. Gautier, in his paper on the fusibility of metallic alloys,[2] points out that the curve of fusibility of these alloys is remarkable since nearly all its points correspond to temperatures higher than those of the fusion of the two metals. He says that the curve indicates the existence of the compound SbAl, whose fusing-point is slightly lower than that of pure copper.

On repeating this work with a recording pyrometer, we obtained a "complete freezing-point curve" of the series, which shows the lower breaks as well as the points of initial solidifica-

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[1] *Mon. Sci.*, p. 265 (1893).

[2] *Bull Soc. d'Enc.* [5], 1, Oct. (1896).

tion. Our curve differed from that of Dr. Gautier only at the point where the maximum occurs: whereas he placed it at about 85 per cent. antimony, 15 per cent. aluminum, we found it near 82 per cent. antimony, 18 per cent. aluminum. The compound SbAl ought to occur at 81.6 per cent. antimony. In the case of the alloys containing from 82–95 per cent. antimony we had great difficulty in taking pyrometric readings. The pipe-clay casing for the thermocouple was found to be quite pervious to part at least of the alloy, which by alloying with the platinum spoiled the record. On glazing the tube, this difficulty was only partially overcome, the method being far from safe. Glass was tried without success, for on cooling and solidifying, great strains are set up in the alloy and the glass was shattered. We were content to leave this part of the curve incomplete for the time being, because our microscopic examination was sufficient to fill in the missing parts. On a microscopic examination, these alloys fall into two groups:

1. 0 to 81.6 per cent. antimony, in which increasing amounts of the compound SbAl crystallize out in a groundmass of aluminum, or aluminum containing some antimony in solid solution, and having the same structure as pure aluminum.

2. 81.6 to 100 per cent. antimony, in which we pass from the compound SbAl, through a series of alloys composed of crystals of the compound in an increasing groundmass till we reach pure antimony. The groundmass of this group could not be resolved into two constituents and probably consists of antimony containing some aluminum (in the form of AlSb) in solid solution for it melts 2° lower than pure antimony;[1] that is, in the first series we have mixtures of aluminum and the compound SbAl, but no free antimony; in the second we are dealing with alloys made up of aluminum antimonide and antimony, but no free aluminum. The series is remarkable in many ways. When the antimony reaches about 60 per cent., the alloys rapidly disintegrate in air into a fine powder. Gautier points out that this is due to oxidation, for if the alloy be weighed before and after disintegration it will be found to have gained weight, and if the fresh alloy be sealed *in vacuo* no change takes place. When the antimony in the alloy is between 50 and 85 per cent. a great expansion takes place during solidification, and part of the liquid interior of these alloys is squeezed out and solidifies as a button on top of the alloy.

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[1] Gautier, see *ante*.

On examination, this part of the alloy which squeezed out was found to contain much less antimony than the original alloy. Edmond von Aubel[1] states that the compound SbAl melts at 1078°–1080° C., and has a specific gravity of 4.2176 at 16°/4°, whereas the calculated specific gravity is 5.2246. Therefore the formation of this compound is accompanied by a relatively large increase in volume which manifests itself at the moment of solidification. The outer layer in the crucible or mold solidifies, expansion takes place, and the still liquid inner portions of the alloy are squeezed out in nodular masses. The nodules may in turn behave in the same way and a second part be squeezed out of their still liquid centers. It would naturally be supposed that the formation of these squeeze-buttons would alter the composition of the residual alloy so that analyses would have to be made of each. However, the largest buttons obtained were from alloys containing 60 and 75 per cent. antimony. When micro-sections of the buttons were made they corresponded closely with known alloys containing 50 and 60 per cent. antimony respectively, and the buttons constituted less than 10 per cent of the whole mass. By a simple calculation it is found that the residual alloys are probably not altered by more than 1 per cent. or 1.5 per cent. respectively, or at most by 2 per cent.

From the accompanying freezing-point curve (Fig. 5) it will be seen that a rise from aluminum (100 per cent.) to aluminum 67 per cent., antimony 33 per cent., is followed by a fall to antimony 37 per cent., after which the freezing-point rises uniformly to 81.6 per cent. antimony. The reason for the irregularity in the curve between antimony 33 per cent. and antimony 40 per cent., has not been found and the microscopic examination of these alloys offers no explanation. It may be that the difference is one of composition of the crystals, for it was noticed on etching, that the crystals in the 33 per cent. alloy were more easily attacked than those before or after it. It must be remembered in this connection that although the crystals consist primarily of the compound SbAl yet that need not be the sole constituent. Crystals isolated from series of alloys, though identical in form, are usually not definite in composition.

In the accompanying microphotographs examined in connection with the freezing-point curve it will be seen how the

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[1] *Compt. rend.*, **132**, 1266–7 (1901).

crystals of SbAl increase toward the alloy whose freezing-point constitutes the summit of the curve. In those containing crystals plus aluminum, the groundmass decreases from aluminum 100 per cent. to aluminum 18.4 per cent., when it disappears; in those alloys which consist of crystals plus antimony, the groundmass decreases from antimony 100 per cent. to antimony 81.6 per cent. At the percentage corresponding to the summit in the freezing-point curve we should have a perfectly homogeneous mass consisting of pure crystals of the compound SbAl. Our figure, antimony 82 per cent., aluminum 18 per cent., shows nearly this condition. These are the two most reliable evidences of an intermetallic compound; *viz.*, a summit in the freezing-point curve which is afforded by an alloy which solidifies as a whole to a homogeneous mass at a single definite temperature. Alloys on either side of the summit consist of crystals of the compound decreasing in amount according to the distance they occur from the alloy of formula percentage, and disappearing entirely when the branch of the freezing curve in which the summit occurs disappears.

Fig. 6 shows an alloy containing 5 per cent. antimony, 95 per cent. aluminum, magnified 33 diameters and obliquely illuminated. Dark crystals of more or less pure SbAl, lath-like in shape, are seen in a granular groundmass consisting of aluminum or aluminum containing some antimony in solid solution.

Fig. 7 shows the alloy, 25 per cent. antimony, 75 per cent. aluminum. Similar to the above, but the crystals have increased in amount and size (33 diameters oblique).

Fig. 8 shows the alloy, 40 per cent. antimony, 60 per cent. aluminum. The dark crystals have become much larger and show a tendency toward parallel growth, thus forming large composite crystals. The groundmass is granular as before (33 diameters oblique).

Figs. 9 and 10 show, respectively, the alloy 60 per cent. antimony, 40 per cent. aluminum, and the squeeze-button resulting during the cooling of the original alloy. These and all the other alloys of the series are vertically illuminated. In these two, the compound appears bright and the groundmass of aluminum dark. The groundmass is decreasing rapidly and the crystals are beginning to interfere with each other, forming large masses of the compound. In the crystals of the squeeze-button we see a number of skeleton triangles.

Fig. 11 is practically pure SbAl plus a little antimony which appears bright.

Fig. 12 shows 90 per cent. antimony, 10 per cent. aluminum, 33 diameters. It is very friable and difficult to polish, and it is almost impossible to get rid of small pittings in the surface. Small crystals of SbAl are seen in a bright groundmass of antimony.

Fig. 13 shows 95 per cent. antimony, 5 per cent. aluminum, unetched. The crystals are much smaller and more regular than those of a 3 per cent. aluminum alloy but not so minute as those of a 10 per cent. aluminum alloy. Thus in passing from the compound SbAl to pure antimony, we find first the compound breaking up into very minute crystals, while, as the temperature of initial solidification decreases, we find the crystals increasing in size, but of course decreasing in number. This is just the reverse of what happens in the alloys on the aluminum side of the summit. So far we have found no solvent suitable for isolating the crystals. All those tried attack the crystals and even water decomposes them slowly. When a solvent is found, the crystals from the region of the irregularity in the freezing-point curve will be analyzed and their compositions compared. The etching of the alloys between 40 and 60 per cent. antimony generates considerable heat; in some cases this was sufficient to soften the cementing material used to fix the alloy upon glass for photographic purposes.

Aluminum and Copper.—In Gautier's curve of the melting-points of these alloys, we find maxima at about 50 and 88 per cent. copper, and minima at 33 per cent., 54 per cent., and about 92 per cent. Definite compounds certainly occur at the maxima, namely Al_3Cu_2 containing 48.4 per cent. copper, and $AlCu_3$ containing 87.6 per cent. copper. The fall in melting-point at 7.5 per cent. aluminum seems to indicate combination at this point, $AlCu_5 = AlCu_3 + Cu_2$. Le Chatelier[1] has detected our compounds, *viz.*, $AlCu_3$, and probably Al_2Cu_3, $AlCu$ and Al_2Cu. He prepared the series of alloys by placing molten aluminum on molten copper and allowed the two to alloy at the junction and to

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[1] *The Metallographist*, Jan., 1901.

Fig. 6.

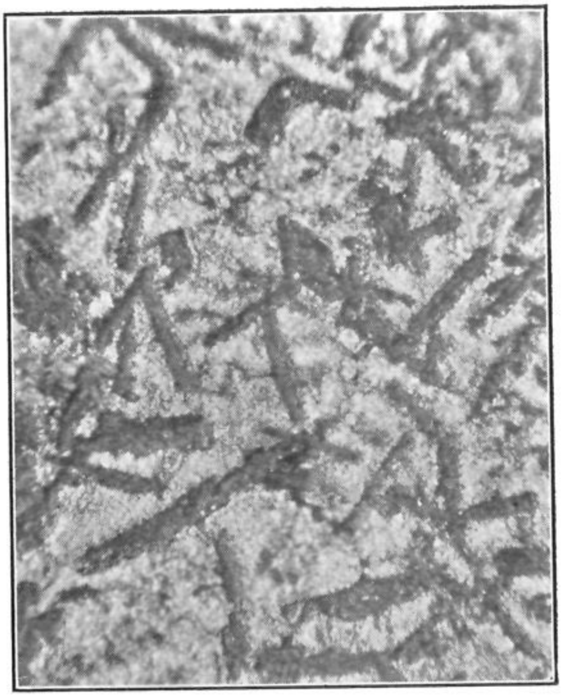

Fig 7.

Fig. 8.

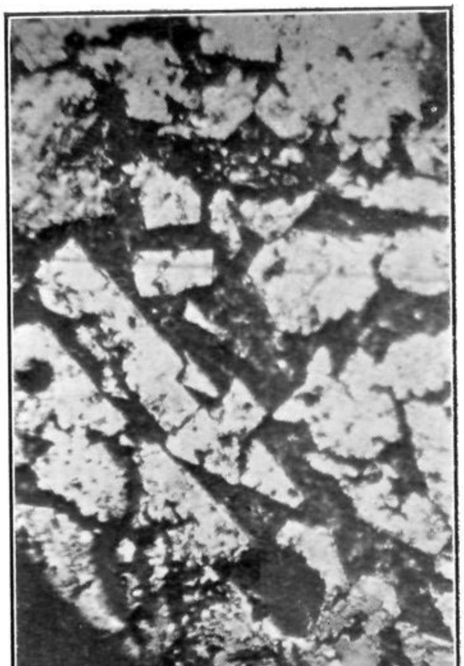

Fig. 9.

Fig. 10.

Fig. 11.

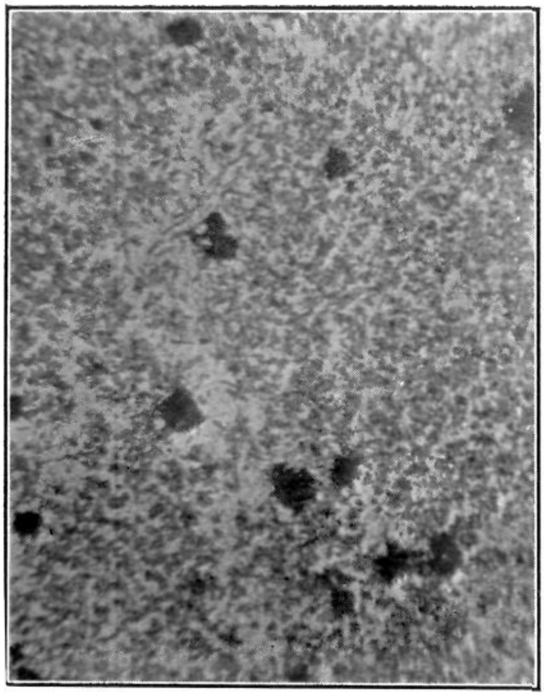

Fig. 12.

Fig. 13.

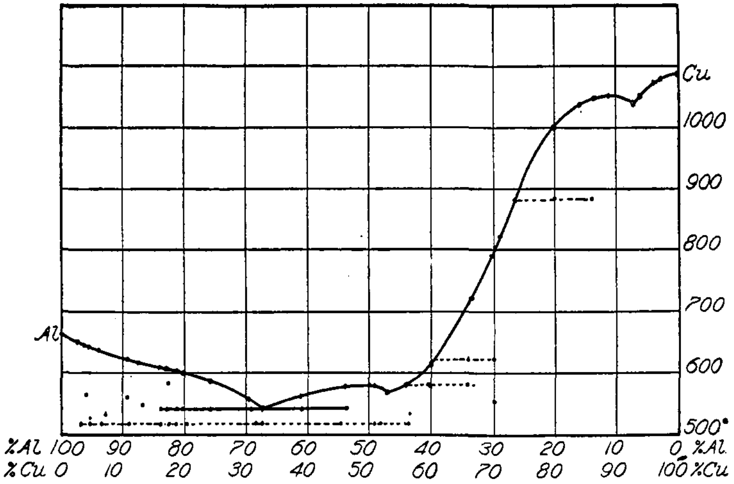

Fig. 14.

diffuse, thus obtaining the whole series of alloys between pure aluminum and pure copper. In connection with the drop in melting-point of the alloy at 56 per cent. we noticed also a corresponding irregularity of the specific gravity as compared with those alloys which precede and follow it. There is one well-marked eutectic (Fig. 14) melting at 535° and extending from about 10 per cent. copper to 48 per cent. copper. Between 0 and 10 per cent. copper we got a great number of minor points below the initial freezing-point, the meaning of which we have not determined. That the eutectic does not extend beyond 10 per cent. copper is due to the fact that aluminum can hold a considerable amount of copper in solid solution, which copper imparts certain advantageous properties to the aluminum. Beyond 50 per cent. copper the curve becomes very complicated, and we find three rows of subsidiary points indicated in the cooling curves. Their meaning will be revealed on microscopic examination if eutectics, or by a series of quenchings if changes in the solid.

At 88 per cent. we find a summit, corresponding to $AlCu_3$ and between this point and pure copper, no lower points on the cooling curves were observed. Yet the 93 per cent. alloy solidifies at a much lower temperature than either $AlCu_3$ or pure copper. If, as LeVerrier surmises, there is a compound at 93 per cent. (or rather at 92.5 per cent. copper), then the alloys between this and $AlCu_3$ are solid solutions of one compound in the other, and those between 92.5 and 100 per cent. copper are solid solutions of $AlCu_5$ in copper. We have only commenced work upon the micro-structure of these alloys. We hope ultimately to explain all the points in this curve which, as yet, are not understood. The long line of horizontal points below the eutectic line is as yet unexplained. As a basis for further study, we shall consider that all the alloys of aluminum and copper belong to three groups as shown by our curve: (1) From 0 to 48.4 per cent. copper, the alloys consist of aluminum and Al_5Cu_2; (2) from 48.4 to 87.6 per cent. copper the alloys consist of the compounds Al_5Cu_2 and $AlCu_3$: alloys within this range contain neither free aluminum nor free copper; (3) from 87.6 to 100 per cent. copper, the alloys consist of $AlCu_3$ and pure copper. These three pairs of constituents mixed or dissolved in various proportions probably compose all the possible alloys. The other compounds mentioned by LeChatelier seem to give no indications of their existence so far as pyrometric evidence is concerned.

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ROYAL COLLEGE OF SCIENCE AND
SCHOOL OF MINES,
LONDON.

[CONTRIBUTIONS FROM THE HAVEMEYER LABORATORIES OF COLUMBIA UNIVERSITY, NO. 48.]

ON THE TEMPERATURE REACTION OF OILS WITH SULPHURIC ACID—MAUMENE'S TEST.[1]

BY H. C. SHERMAN, J. L. DANZIGER AND L. KOHNSTAMM.

Received October 28, 1901.

MAUMENÉ in 1852[2] showed that the rise of temperature on mixing with strong sulphuric acid is considerably greater with drying than with non-drying oils and that the difference may be of practical value in testing olive oil for the presence of poppy or other seed oils with which it may be adulterated. This method has generally been known as the Maumené test. As originally described and generally carried out, it consists in adding to 50 grams of the oil in a beaker, 10 cc. of strong sulphuric acid (according to Maumené, 66° Bé.), stirring with a thermometer, and observing the rise in temperature. Obviously it is essential that the test be always carried out under similar

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[1] Read at the meeting of the New York Section of the American Chemical Society, June 7, 1901.

[2] *Compt. rend.*, 35, 572.