XLI.—*Action of Acids upon Metals and Alloys.*

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It has frequently occurred to us, in the course of our investigations into the physical properties of metals and alloys, that it would be interesting both in a scientific and practical point of view, if we were carefully to examine the action of some of the acids upon them. We, therefore, submitted copper, zinc, and tin, and the two classes of alloys which are obtained from these metals, viz., brasses and bronzes, to the action of sulphuric, nitric, and hydrochloric acids.

In this series of researches we have followed the same plan as when we experimented upon the "conductibility," the "specific gravity," &c., &c. of metals and alloys; viz., we first examined the action of these acids upon the pure metals, and afterwards upon the alloys composed of the pure metals melted together in equivalent and multiple proportions.

Our experiments having been very numerous, and therefore, having extended over a long period of time, we have deemed it advisable to divide our paper into two parts.

First—The action of sulphuric acid upon zinc, copper, and tin, and of nitric and hydrochloric acids on the same metals.

Secondly—The action of the same acids upon their alloys, viz., brasses and bronzes.

On the marked influence which an Oxidized Surface has on the subsequent action of Sulphuric Acid of various strengths on Zinc.

Before entering into the details of our experiments, it is necessary that we should state, that it was only after considerable time and experience that we were able to determine the exact conditions under which we were to operate, if we wished to obtain constant and correlated results, owing not only to the extreme difficulty attending the preparation of perfectly pure sulphuric acid and a few ounces of pure zinc, but especially to the irregularity of the action of sulphuric acid on zinc, depending, as we observed, upon the peculiar state of its surface. Thus we found that cubes which had been made of the same zinc, but at different times, were acted upon more or less by the same acid when placed under the same circumstances; and these observations gradually led us to the discovery of a curious fact, viz., that a perfectly clean surface of zinc will become, after a few days, sufficiently oxidized by contact with air to modify in a very marked degree the action of sulphuric acid upon it. Thus, if a cube of zinc recently filed is placed in sulphuric acid diluted with 9 eq. water, the action may be considered as null; whilst if the same cube be gently heated in contact with the air and allowed to cool, and be then placed in the same strength of acid, the attack is 10 times greater, as proved by these results.

TABLE.

Quantity of acid	50 cent. cube.
Surface of zinc acted on	1 ,,
Time of action	2 hours.

STRENGTH OF ACID USED.

	Quantity of zinc dissolved.	
$SO_3,9HO$	·31	Used a clean file carefully kept free from grease to clean surfaces of cube.
$SO_3,9HO$	·03	After filing washed with alcohol to remove grease.
$SO_3,9HO$	3·08	After filing heated in gas flame—allowed to cool before using—surface oxidized.

On the Action of Sulphuric Acid of various Strengths on Zinc.

In looking over the table following these remarks, and containing our results on the action of various strengths of sulphuric acid on pure zinc with an unoxidised surface, it will be observed, firstly, that they are contrary to the general view entertained by chemists of the action of sulphuric acid upon that metal, for this acid has no action at ordinary temperatures on zinc; also that it requires a temperature of 130° C. before concentrated acid begins to show any marked action, and that it is only at 150° C. that the action of sulphuric acid with 1 and 2 equivalents of water, is fully developed. Secondly, on perusing our results, the following curious facts will be observed, viz., that mono- and bi-hydrated sulphuric acids exercise a comparatively limited action on zinc at a temperature of 130° C. as compared with that of the tri-hydrated acid; thus, whilst SO_3,HO and $SO_3,2HO$ will dissolve only respectively 125 or 236·6 grammes zinc on a square metre surface, $SO_3,3HO$ will in the same space of time dissolve 9860 grammes or 7 to 8 times the amount. Further, the same extraordinary difference of action of these various strengths of acids is maintained when their temperature is raised to 150° C.

A similar difference of action is observed when the action of diluted sulphuric acids on the unoxidized surface of pure zinc is studied; thus when $SO_3,6HO$ acts upon such a metal, only 561·6 grammes per metre surface are dissolved in two hours, whilst $SO_3,7HO$ dissolves in the same space of time as much as 5260·8 grammes, but in this case the temperature employed was only 100° C., or that of the boiling point of the latter acid.

The reactions of sulphuric acid of different strengths upon an unoxidized surface of pure zinc, are far more complicated and interesting than chemists admit. To understand them it is necessary that they should be classed under two distinct heads, viz., the action of SO_3,HO, in which case the metal is oxidized solely at the expense of the acid, sulphurous acid being produced, whilst with $SO_3,2HO$, and especially with $SO_3,3HO$, not only is sulphurous acid given off, but also simultaneously with it sulphuretted hydrogen.

It is interesting to observe two distinct chemical reactions taking place simultaneously; thus we have an action similar to that which sulphuric acid exercises on the metals of the alkalies or alkaline earths, giving rise to hydrogen and a sulphate of the metal, and that which sulphuric acid has, viz., on the fifth group, etc., viz., mercury, generating sulphurous acid and a sulphate of the metal.

Lastly, it will be observed on looking over the table that sulphurous acid gradually disappears, whilst the quantity of sulphuretted hydrogen increases, until in its turn it also disappears and is replaced by pure hydrogen.

TABLE 1.

Action of Sulphuric Acid of different strengths upon pure Zinc.

Quantity of acid .... 50 cent. cubes.
Surface acted on .... 1 „ „
Time of action .... 2 hours.

Strength of acid.	Temperature degs. cels.	1 centimetre cube.	1 sq. metre.	Remarks.
SO_3HO ..	Ordinary	"	"	
„ „ ..	130°	·075	125 ·0	SO_2 evolved.
„ „ ..	150°	·232	386 ·6	SO_2 evolved. No HS.
SO_32HO ..	Ordinary	·002	3 ·3	
„ „ ..	130°	·142	236 ·6	SO_2 evolved. A little HS.
„ „ ..	150°	·345	575 ·0	HS given off and SO_2.
SO_33HO ..	Ordinary	·002	3 ·3	
„ „ ..	130°	5 ·916	9860 ·0	Large quantity of HS. A trace of SO_2. Violent action. Large quantity of $ZnOSO_3$ undissolved.
„ „ ..	130°	4 ·916	8193 ·3	
„ „ ..	150°	5 ·450	9083 ·3	Same action as above.
SO_34HO ..	Ordinary	·005	8 ·3	
„ „ ..	130°	3 ·080	5133 ·3	Large quantity of HS given off, with a little SO_2. Violent action. Quantity of $ZnOSO_3$ not dissolved.
„ „ ..	130°	2 ·389	4731 ·6	
SO_35HO ..	Ordinary	·049	81 ·66	
„ „ ..	130°	·456	760 ·0	Acid nearly boiling. HS given off. Trace of SO_2.
SO_36HO ..	Ordinary	·027	45 ·0	
„ „ ..	130°	·337	561 ·6	Boiling point of this acid. HS evolved.
SO_37HO ..	Ordinary	·018	33 ·0	
„ „ ..	100°	3 ·161	5268 ·3	Violent action at first; after about 20 minutes stopped. ZnO,SO_3 undissolved. Surface apparently coated, with no HS. Trace of SO_2. Attack irregular.
„ „ ..	„	3 ·800	6333 ·3	
„ „ ..	„	3 ·060	5100 ·0	
SO_38HO ..	Ordinary	·035	58 ·3	
SO_39HO ..	Ordinary	·005	8 ·3	
SO_310HO	Ordinary	·033	55 ·3	

Action of Sulphuric Acid on Copper.

The following is the action of 50 cubic centimetres of sulphuric acid, of different strengths, upon 1 cent. cube of pure copper, during a period of two hours, and at the temperature of 130° and 150° C.

TABLE 2.

Action of Sulphuric Acid of different strengths upon pure Copper.

Surface acted upon....................	1 cent. cube.
Quantity of acid......................	50 „ „
Time of action	2 hours.
Temperature	130° and 150° C.

Sulphuric acid employed.	Temperature degs. cels.	Loss by 1 cent. cube.	Calculated on 1 sq. metre.	Remarks.
SO_3,HO	130°	·854	1423·3	Surface of cubes covered with CuS; SO_2 was also evolved.
„ „	„	·704	1173·3	
„ „	150°	1·678	2796·7	There was also a residue insoluble in the acid, and composed principally of CuS and CuO,SO_3.
$SO_3 2HO$	130°	·008	13·3	Very slight action.
„ „	150°	·063	105·0	
$SO_3 3HO$	130°	·004	6·6	
„ „	150°	·006	9·9	
$SO_3 4HO$	150°	·000		

These results suggest to us the following remarks: that the temperature at which copper is first attacked by sulphuric acid, SO_3HO, is 130° C., and that even at a few degrees below that temperature, copper is not acted upon; further, that at 150° C., the quantity of copper dissolved by this acid under the same circumstances is nearly the double of that which $SO_3,2HO$, $SO_3,3HO$ could dissolve, whilst $SO_3,4HO$, have little or no action upon that metal.

We further noticed, that the decomposition of SO_3HO, by copper is far more complicated than it is generally admitted to be; for the action does not consist simply in the decomposition of the acid into oxygen which oxidizes the copper, and sulphurous acid which escapes, but the affinity of copper for oxygen is such that the whole of this gas is removed from a certain portion of the sulphuric acid, leaving free sulphur, which combines with the copper to form sulphide of copper. The reason which leads us to believe that the formation of this compound is due to the direct combination of the sulphur with the copper, and not, as in the case of zinc, to two chemical actions taking place simultaneously, is that if water were decomposed into its constituent elements, its oxygen uniting with the copper, whilst its hydrogen would combine with the sulphur of the reduced sulphuric acid to form sulphuretted hydrogen, which in its turn would act upon oxide of copper to produce the sulphuret of copper, some sulphuretted hydrogen would undoubtedly have been given off, and under the influence of heat, must have escaped, and have been easily detected. Another proof that sulphuric acid is decomposed into oxygen and sulphur, and that water does not participate in the chemical action which ensues is, that free sulphur volatilizes and condenses in the neck of the small balloons employed, which, in our experiments, were placed in an oil-bath maintained carefully at the required temperature. This remarkable reduction of sulphuric acid by a metal is further corroborated by the action of sulphuric acid upon tin, in which case sulphur is also liberated in considerable quantity, but no sulphide of tin produced, owing, probably, to the fact that sulphur has less affinity for tin than for copper.

TABLE 3.

Action of Sulphuric Acid of different strengths upon Tin.

Sulphuric acid employed.	Temperature degs. cels.	Loss by 1 cent. cube.	Calculated on 1 sq. metre.	Remarks.
SO_3HO	150°	3·010	5016·6	A large quantity of SO_2 given off. No HS. No SSn, but *some free sulphur.*
SO_32HO	150°	·640	1066·6	SO_2 given off. No HS.
SO_33HO	150°	·470	783·3	SO_2 given off and a little HS.
SO_34HO	130°	·215	358·3	A large quantity of HS given off with a little SO_2.
SO_35HO	130°	·140	233·3	Acid nearly on the foil. HS given off, and only a little SO_2.

It will be observed, in examining the results contained in this table, that the action of various strengths of sulphuric acid upon tin, differs entirely from that which they exert upon copper, and in some respects on zinc; SO_3HO exerts the maximum action upon copper, but it gradually decreases as the acid becomes more diluted; whilst with zinc, as before stated, the action is completely different according to the strength of acid; but there is still this similitude between the action of sulphuric acid upon tin and zinc, viz., that with a certain strength of acid, sulphurous acid and sulphuretted hydrogen are given off simultaneously; but this action does not take place with SO_3,HO or SO_3,2HO, as the first indication of sulphuretted hydrogen occurs with SO_3,3HO, and it is only with SO_3,5HO that large quantities of sulphuretted hydrogen are given off, and only a trace of sulphurous acid. From these results we conclude that when strong sulphuric acid acts upon tin, the metal is oxidized, like on copper, through the action of the acid, whilst with weaker acids water is decomposed, the oxygen fixing itself on the tin or zinc, whilst the hydrogen unites with the sulphur to produce sulphuretted hydrogen; therefore, the action of dilute sulphuric acid upon tin may be considered as two chemical actions occurring simultaneously; moreover sulphate of binoxide of tin is produced and not the corresponding salt of protoxide.

The action of sulphuric acid upon tin throws much light on the formation of sulphide of copper, for in the case of tin, as there is no intense affinity between sulphur and that metal, we observe the production of a large quantity of sulphurous acid, no sulphuretted hydrogen, but a large quantity of free sulphur floating in the liquid, showing a complete deoxidation of the sulphuric acid by both metals; but with this difference, that in the case of tin, sulphur remains free, whilst in that of copper, it combines with it, producing a sulphuret.

Action of Nitric and Hydrochloric Acids on Tin, Zinc, and Copper.—We shall reserve details of our experiments until we describe the results obtained by acting with the same acids on the two classes of alloys formed by these metals, viz., brasses and bronzes; for it was found by direct experiment that to arrive at any correct data, it was necessary to employ acids of peculiar strength, or otherwise the reactions were so complicated that no comparative results could be obtained of the action of these acids on the various groups of alloys. The following facts will, we believe, illustrate these statements:—

TABLE 4.

Action of Nitric Acid upon an Alloy of Copper and Zinc.

Surface acted upon.............	1 cent. cube.
Quantity of acid...............	100 ,,
Time of action................	24 hours.
Composition of Brass { 1 eq. copper....	49·059
1 eq. zinc......	50·941
	100·000

Strength of nitric acid employed.	Total quantity dissolved on 1 c.c.	Composed of	Per cent.	Average per cent.
Sp. gr.				
Strong acid. 1·14	6·421	3·093 Cu 3·328 Zn 6·421	48·232 Cu 51·768 Zn 100·000	48·258 Cu 51·742 Zn 0 ·000
Strong acid. 1·14	3 936	1·898 Cu 2·038 Zn 3·936	48·283 Cu 51 717 Zn 100·000	
Weak acid. 1·08	1·504	0·252 Cu 1·243 Zn 1·495	16·856 Cu 83·144 Zn 100·000	16·741 Cu 83·259 Zn 100·000
Weak acid. 1·08	2·034	0·340 Cu 1·705 Zn 2·045	16·626 Cu 83·374 Zn 100·000	

In perusing the above table, it will be seen that whilst nitric acid of sp. gr. 1·14 dissolves the metals composing the brass in the exact proportions in which they exist in the alloy employed, whilst an acid of about half the strength, or of sp. gr. 1·08, dissolves nearly the whole of the zinc contained in the alloy, and only a small quantity of copper. This result, among others, showed us the necessity of employing a given strength of acid in order to conduct a series of comparative experiments on various alloys, and we consider the action of nitric acid of sp. gr. 1·14 a normal action, as it attacks both zinc and copper in the proportions in which they exist in the alloy, whilst that of a stronger or weaker acid is abnormal, as it acts according to its strength, more or less, on each of the metals composing a brass alloy. These results were further confirmed by a cube of an alloy composed of equal parts of zinc and copper, being left for several days in hydrochloric acid of full strength, the whole of the zinc, or nearly so, of the alloy, being dissolved, leaving a cube which had the same diameter as if it had only been experimented upon, and was composed of nearly pure copper.

The following table illustrates this fact:—

TABLE 5.

Action of Strong Hydrochloric Acid on the Alloy ZnCu.

1 eq. copper	49·059
1 eq. zinc........................	50·941
	100·000

Strength of acid used.	Weight of cube.	Amount of zinc dissolved 1 c.c.	Amount of Zn left in cube.	Remarks.
	grammes.	grammes.	grammes.	
1·20	Cu 4·409 Zn 4·577 8·986	4·443	·130	The cubes, after the experiment, have copper-like colour, and have the same diameter as before, but are quite soft.
1·20	Cu 4·467 Zn 4·638 9·105	4·330	·308	A trace only of copper dissolved.

Action of weak Nitric Acid on Brasses.

We shall now proceed to describe the action of weak nitric acid sp. gr. 1·100 on various alloys of zinc and copper, combined in equivalent and multiple proportions. We decided to use this strength of acid, as we found, after many experiments, that this was the best strength of acid that could be employed to obtain constant results.

The table which follows these remarks contains a summary of our results, and gives an idea how varied is the action of the same strength of nitric acid on the same class of alloys, and what an extraordinary influence a few per cent. of copper or zinc, more or less, exerts in preventing or promoting the action of this acid.

Further, in perusing the table, it will be observed that the action of the acid is comparatively violent on all the alloys containing an excess of zinc, and that it is nearly 1,000 times less active on all those in which there is an excess of copper; and we cannot in this case refrain from drawing special attention to the action of the acid on the alloy ZnCu, as compared with that which it exerts upon Zn_2Cu, although there is only a difference of 17 % of zinc.

It is necessary that we should explain how we have arrived at the data found in the fourth column. The figures represent the calculated results of the amount of metals which should have been dissolved had the metals been free, and had not the presence of one of the metals interfered with the chemical action. It will be observed, in comparing these figures with those which represent the quantity of alloy actually dissolved, that in the first four alloys of the table, viz., those which contain an excess of zinc, the quantity of alloy dissolved is in excess of that which theory indicates, whilst in the alloy composed of equivalents of each metal, and those which contain an excess of copper, the action is 40 or 50 times less. These facts appear to us not only interesting in a scientific point of view, but important in their applications to manufactures, especially for brass taps, pipes, &c.

The following is a summary of our experiments:—

TABLE 6.

Action of Nitric Acid, sp. gr. 1·100, *on Alloys of Copper and Zinc* (*Brasses*).

Surface acted upon..............	1 cent. cube.
Quantity of acid................	25 ,, ,,
Time of action..................	15 minutes.
Temperature	20° C.

Metals and composition of alloys.	Loss by 1 c.c.	Calculated loss on 1 sq. metre.	Loss calculated according to the composition of the alloys.
Copper	0·009	15·000	15·000
Zinc	1 760	2933·3	2933 3
Zn_5Cu			
Zn 83·70	2·025	3375·0	2457·645
Cu 16·30			
100 00			

TABLE 6—*Continued.*

Metals and composition of alloys.	Loss on 1 c.c.	Calculated loss on 1 sq. metre.	Loss calculated according to the composition of the alloys.
Zn_4Cu Zn 80·43 Cu 19·57 100·00	1·740	2900·0	2362·2
Zn^3Cu Zn 75·36 Cu 24·64 100·00	1·695	2825·0	2214·25
Zn_2Cu Zn 67·26 Cu 32·74 100·00	1·530	2550·0	1977·8
ZnCu Zn 50·95 Cu 49·05 100 00	0·027	45·000	1494·0
$ZnCu_2$ Zn 33·94 Cu 66·06 100·00	0·015	25·000	1005·48
$ZnCu_3$ Zn 25·52 Cu 74·48 100·00	0·013	21·66	759·75
$ZnCu_4$ Zn 20·44 Cu 79·56 100·00	0·015	25·00	611·50
$ZnCu_5$ Zn 17·05 Cu 82·95 100·00	0·010	16·66	512·57

Action of Hydrochloric Acid, sp. gr. 1·05 *on Alloys of Zinc and Copper (Brasses).*

It will be observed, in perusing the results consigned in the table following, that the action of this acid is nearly equal to that which theory indicates on the alloys Zn_5Cu and Zn_4Cu, whilst in the next alloy, Zn_3Cu, which contains only 5 % more copper than the preceding one, the attack is only half of that indicated by theory. But certainly the most unexpected result arrived at, is the complete inaction of hydrochloric acid upon all the alloys containing an excess of copper, and especially on the alloy composed of equivalent proportions of each metal; and it is very remarkable that whilst half the cube of the alloy Zn_5Cu is dissolved in the space of one hour, the alloy with equal equivalents of each of the metals remains perfectly unattacked.

The fourth column in this table also gives the theoretical quantity that should have been dissolved if the metals had been free, and not alloyed.

TABLE 7.

Surface acted upon	1 centimetre cube.
Quantity of acid................	50 „ „
Time of action	1 hour.

Metals and composition of alloys.	Loss on 1 c.c.	Calculated loss on 1 sq. metre.	Loss calculated according to the composition of the alloys.
Copper	0·000	0 000	0·000
Zinc	0 200	333·33	333 33
Zn_5Cu			
Zn 83·70	0·155	258·334	279 00
Cu 16 30			
100·00			
Zn_4Cu			
Zn 80·43	0·155	258·334	268·0
Cu 19 57			
100·00			
Zn_3Cu			
Zn 75·36	0·065	108 334	251·2
Cu 24·64			
100·00			

TABLE 7—*Continued.*

Metals and composition of alloys.	Loss on 1 c.c.	Calculated loss on 1 sq. metre.	Loss calculated according to the composition of the alloys.
Zn_2Cu Zn 67·26 Cu 32·74 100·00	0·050	83·334	224·2
ZnCu Zn 50·68 Cu 49·32 100·00	0·000	0·000	168·933
$ZnCu_2$ Zn 33·94 Cu 66·06 100·00	0·000	0·000	113·133
$ZnCu_3$ Zn 25·52 Cu 74·48 100·00	0·000	0·000	85·066
$ZnCu_4$ Zn 20·44 Cu 79·56 100·00	0·000	0·000	68·133
$ZnCu_5$ Zn 17·05 Cu 82·95 100·00	0·000	0·000	56·83

Action of Sulphuric Acids SO_3HO *and* SO_33HO *on Alloys of Copper and Zinc.*

We now pass on to the action exerted by the two above mentioned strengths of sulphuric acid upon brasses, the results of which are not less instructive than those already referred to. But before drawing attention to the leading facts observed, it is necessary that we should give the reason why we employed in preference SO_3,HO and SO_3,3HO for our experiments. They are that SO_3,HO is the only acid which attacks copper, in any marked degree; SO_3,3HO, the only one which has a corresponding action upon zinc, and therefore by employing these successively upon the same alloy at a temperature of 150° C., we were acting under favourable circumstances for appreciating the exact mode of action of these acids on both metals entering into the composition of the alloy.

TABLE 8.

Action of Monohydrated Sulphuric Acid on Brasses.

Surface acted upon	1 cent. cube.
Quantity of acid employed	50 ,,
Time of action	2 hours.
Temperature....................	150° C.
	O sq. metre.
Action on 1 c. c. of copper	1·678 = 2797
,, ,, 1 ,, zinc	·232 = 3367

Composition of alloys.	Loss on 1 c. c.	Calculated loss 1 sq. metre on surface.	Theoretical loss.	Remarks.
$CuZn_5$ 83·7 Zn 16·3 Cu 100·0	·098	163·33	779·5	So_2 given off. No HS, and only Zn dissolved.
$CuZn_4$ 80·43 Zn 19·57 Cu 100·00	·074	123·33	858·3	SO_2 given off. No HS, and only Zn dissolved.
$CuZn_3$ 75·36 Zn 24·64 Cu 100·00	·180	300·0	980·5	SO_2 given off. No HS, and only Zn dissolved.
$CuZn_2$ 67·26 Zn 32·74 Cu 100·00	·083	183·3	1175·8	SO given off.
CuZn 50·68 Zn 49·32 Cu 100·00	1 297	2161·6	1375·7	SO, given off. No HS. Strong action. Insoluble residue consists of ZnO, SO_2,CuO,SO_3. Also a small quantity of CuS and S. The quantities of the metals dissolved were found to be in the exact proportion of those in the alloys.

TABLE 8—*Continued.*

Composition of alloys.	Loss on 1 c. c.	Calculated loss 1 sq. metre on surface.	Theoretical loss.	Remarks.
Cu_2Zn 33·94 Zn 66·06 Cu				SO_2 given off. No HS. A small quantity of free S and CuS.
100·00	1·292	2158·3	2015·0	
Cu_3Zn 25·52 Zn 74·48 Cu				
100·00	1·747	2211·66	2182·01	Ditto
Cu_4Zn 20·44 Zn 79·56 Cu				
100·00	1·328	2213·0	2304·47	Ditto
Cu_5Zn 17·05 Zn 82·95 Cu	·605	1008·33	2386·19	Ditto

In examining the results contained in this table, several interesting data are brought out, viz., that in all the alloys in which there is an excess of zinc over the quantity of copper, the attack is exceedingly limited, whilst in all those in which there is an excess of copper, the action is most marked, and very similar, in fact, to that which acid exerts on pure copper.

It is certainly interesting to observe the extraordinary preventive influence which a metal like zinc has on the action of such a powerful acid as SO_3,HO on copper; and certainly, *a priori*, such a result could have been expected. And we cannot help drawing attention to the striking difference between the action of SO_3,HO on the alloys ZnCu and Zn_2Cu, and, therefore, the influence which only 17 % of zinc exercises in preventing the action of the acid, the action on ZnCu being nearly 15 times as violent as on Zn_2Cu.

It may be further observed that when SO_3,HO acts upon the above alloys, in all those containing an excess of zinc, not only does the zinc prevent the action of the acid upon the alloy itself, but it so thoroughly preserves the copper from the action of the acid, that whatever may be the amount dissolved, it is represented by zinc only; whilst in the alloys containing an excess of copper, the copper is attacked also, and dissolved in large quantities. As to the general result of the chemical action of SO_3,HO on the same group of alloys, we may add that the secondary products are the same as when SO_3,HO acts upon copper itself.

Action of $SO_3 3HO$ *on Brasses.*

It will be seen, in perusing the results contained in the table which follows these remarks, how very different is the action of SO_3,3HO as compared with SO_3,HO on the same alloys when placed under identical circumstances, for all the alloys which contain an excess of zinc are those most attacked, whilst this strength of sulphuric (SO_3,3HO) acid exerts little or no action upon the alloys containing an excess of copper; and what enhances the value of these results is, that all the alloys which contain an excess of either copper or zinc are attacked more or less, whilst the alloy CuZn is not acted on, and therefore this alloy could be employed with marked advantages for many purposes, the more so that when well prepared it has a fine and rich brass appearance, notwithstanding the large proportion of zinc; it contains about 15 % more than the poorest brass alloys usually found in commerce.

Lastly, it will be observed, that among the secondary products formed during the chemical action of SO_3,3HO, there is no sulphide of zinc produced, as in the case when SO_3,HO acts upon the same alloys of zinc and copper.

TABLE 9.

Surface acted upon	1 centimetre cube
Quantity of acid	50 ,, ,,
Time of action	2 hours
Temperature	150° C.
	on sq. metre of surface.
Action on 1 c. c. of copper	·006 = 10·000
,, ,, 1 ,, zinc	5·450 = 9085·150

TABLE 9—*Continued.*

Composition of alloys.	Loss on 1 c. c.	Calculated on 1 sq. metre.	Theoretical quantity.	Remarks.
$CuZn_5$	·135	225·0	7605·73	SO_2 given off. No HS. deposits. CuS.
$CuZn_4$	·130	216·0	7308·95	Ditto. A trace of HS.
$CuZn_3$	·120	200·0	6848·86	Ditto
$CuZn_2$	·115	191·6	6113·77	Ditto
CuZn	·000	—	4609·2	—
Cu_2Zn	·119	198·33	3090·05	SO_2 given off.
Cu_3Zn	·006	10·0	2325 95	Ditto
Cu_4Zn	·007	11·6	1864·95	Ditto
Cu_5Zn	·006	10·0	1557 29	Ditto

Action of Acids on Bronzes, or Alloys of Copper and Tin.

We shall follow the same order in examining the action of various acids upon bronzes as we have done in describing their action upon brasses; thus we shall first examine the action of nitric acid, then that of hydrochloric acid, and, finally, that of sulphuric acids; and it is easy to conceive that the action of these various acids upon bronze alloys must be very different, *nitric* acid possessing the property of acting upon both metals, *hydrochloric acid* of acting only upon tin and not upon copper, whilst *sulphuric acid* only acts upon both metals, but under the influence of heat.

We shall now proceed to examine the action of each acid separately.

TABLE 10.

Action of Nitric Acid, sp. gr. 1·25, on Alloys of Copper and Tin (Bronzes).

Surface acted upon .... 1 cent. cube
Quantity of acid .... 25 „
Time of action .... 15 minutes

Metals and composition of alloys.	Loss on 1 c.c.	Calculated on 1 sq. metre.	Calculated loss according to the composition of the alloys.
Copper..........	1·920	3200·0	3200·0
Tin............	0·505	841·667	841·667
Sn_5Cu			
Sn .. 90·27			
Cu .. 9·73			
100·00	1·130	1883·33	1071·132

TABLE 10—*Continued.*

Metals and composition of alloys.	Loss on 1 c.c.	Calculated on 1 sq. metre.	Calculated loss according to the composition of the alloys.
Sn_4Cu			
Sn .. 88·14			
Cu .. 11·86			
100·00	0·725	1208 33	1121·36
Sn_3Cu			
Sn .. 84·79			
Cu .. 15 21			
100·00	0·590	983·33	1200·36
Sn_2Cu			
Sn .. 78·79			
Cu .. 21·21			
100 00	0 240	400 00	1341·869
SnCu			
Sn .. 65·02			
Cu .. 34 98			
100 00	0 110	183·334	1666 6
$SnCu_2$			
Sn .. 51 83			
Cu .. 48·17			
100·00	0·125	208·334	1977·676
$SnCu_3$			
Sn .. 38 21			
Cu .. 61·79			
100·00	0 560	933·334	2298·88
$SnCu_4$			
Sn .. 31·73			
Cu .. 68 27			
100·00	0·910	1516·66	2453·384
$SnCu_5$			
Sn .. 27 10			
Cu .. 72 90			
100·00	0·485	808 334	2577·725

The first result which attracts attention is that none of the alloys are acted on to the same extent as pure copper; therefore the presence of tin in the alloys counteracts to a certain extent the action of nitric acid on bronzes; but the preventive influence of tin presents this particularity, that the action of the acid increases as the proportion of tin increases; thus the alloy $CuSn_5$ is attacked ten times more than the alloy CuSn.

It should also be noticed that the quantity of metals dissolved is less in all the alloys containing an excess of copper, as well as in the two alloys Sn_2Cu and Sn_3Cu, than theory indicates, but it is especially with the alloys Sn_2Cu and SnCu that this result is observed.

TABLE 11.

Action of Hydrochloric Acid, sp. gr. 1·10, *on Alloys of Copper and Tin* (*Bronzes*).

Surface acted upon	1 cent. cube.
Quantity of acid................	50 „
Time of action	1 hour.

Metals and composition of alloys.	Loss on 1 c.c.	Calculated on 1 sq. metre.	Calculated loss according to the composition of the alloys.
Copper	0·002	3·334	3·334
Tin	0·011	18·334	18·334
Sn_5Cu	0·017	28·334	16·874
Sn_4Cu	0·016	26·667	16·554
Sn_3Cu	0·015	25·000	16·052
Sn_2Cu	0·012	20·000	15·152
SnCu	0·006	10·000	13·086
$SnCu_2$	0·006	10·000	11·107
$SnCu_3$	0·005	8·334	9·065
$SnCu_4$	0·004	6·667	8·093
$SnCu_5$	0·003	5·000	7·398

In this series of experiments, the action of hydrochloric acid upon tin is marred by the presence of copper, the action of acid on the bronzes decreasing as the quantity of copper in the alloy increases.

TABLE 12.

Action of Sulphuric Acid (SO^3HO) *upon Bronze.*

Surface acted on	1 cent. cube
Quantity of acid	50 ,,
Time of action	2 hours
Temperature.................	150° C.

Action upon 1 c. c. Cu = 1·678 = 2797·2 sq. metre.
,, ,, Sn = 3·010 = 50·17·6

Composition of alloys.	Loss on 1 cent. cube.	Calculated on 1 square metre.	Calculated loss according to the composition of the alloy.	Remarks.
$CuSn_5$ 9·73 Cu 90·27 Sn 100·00	·656	1093·3	4801·55	SO_2 given off. No HS.
$CuSn_4$ 11·86 Cu 88·14 Sn 100·00	·546	910·0	4754·26	Ditto Ditto
$CuSn_3$ 15·55 Cu 84·45 Sn 100·00	·634	1056·6	4672·32	Ditto Ditto
$CuSn_2$ 21·21 Cu 78·79 Sn 100·00	·525	875·0	4546 65	Ditto Ditto
CuSn 34·98 Cu 65·02 Sn 100·00	·632	1053·3	4240·9	Ditto Ditto
Cu_2Sn 51·83 Cu 48·17 Sn 100·00	·797	1328·3	3866·76	Ditto Ditto

TABLE 12—*Continued.*

Composition of alloys.	Loss on 1 cent. cube.	Calculated loss on 1 square metre.	Calculated loss according to the composition of the alloy.	Remarks.
Cu_3Sn 61·79 Cu 38·21 Sn 100·00	·820	1366·6	3645·6	SO_2 given off. No HS.
Cu_4Sn 68·27 Cu 31·73 Sn 100·00	·450	750·0	3501·33	Ditto Ditto
Cu_5Sn 72·9 Cu 27·1 Sn 100·00	·372	620·0	3391·93	Ditto Ditto

In examining the results contained in this table, it will be observed that copper retards the action of the acid upon tin, none of the alloys being attacked in the ratio of the quantity of tin it contains compared with that of copper; in fact, an alloy Sn_5Cu, although it contains 90 % tin and only 10 % copper, is not attacked more than an alloy SnCu, which contains 65 % tin, and 35 % copper. Again two of the alloys which contain a great excess of copper, viz., $SnCu_4$ and $SnCu_5$, are less attacked than any of the other alloys comprised in the series, and it is difficult to understand why the two alloys $SnCu_2$ and $SnCu_3$ should be attacked with such violence as compared with the two bronzes which contain a larger amount of copper; the only explanation we shall offer of this exceptional result is, that in our experiments on the "conductibility for heat by metals and alloys," we found that those two alloys had conducting power which differed from all the rest of the alloys of copper and tin, and we submitted at that time the opinion, that it was highly probable that those two alloys were not simply mixtures of metals, but definite compounds, and the exceptional action which SO_3HO has on these alloys, as compared with that it exerts upon the rest of the series, appears to substantiate this view.