

**Chemistry.** — *“Provisional Communication on Boric Acid Compounds of some Organic Substances containing more than one Hydroxyl-Group. Boron as a Pentavalent Element.”* By P. H. HERMANS. (Communicated by Prof. J. BÖESEKEN).

(Communicated at the meeting of December 30, 1922).

The behaviour of boric acid towards hydroxyl-containing organic substances is striking in many respects. The extra-ordinary ease and rapidity with which it forms esters of the type of  $B(OR)_3$ , with the ordinary saturated alcohols, also when a catalyst is absent, is a totally unexpected property for a weak, and for the rest mono-basic acid such as boric acid, and in this respect it is unequalled.

Still more interesting is the action of boric acid on the aqueous solutions of multi-valent alcohols and other substances rich in hydroxyl, such as some sugars. It has been known for a long time that these mixed solutions sometimes present a much greater hydrogen ion concentration than a solution of boric acid only. The alkaline reaction of a borax solution can even become an acid one by addition of substances such as mannite<sup>1)</sup>. Also the influence of boric acid or borates on the optical rotatory power of such substances rich in hydroxyl, was early observed. Undoubtedly these phenomena point to compounds which boric acid forms with the substances mentioned above. Several investigators have expressed their opinion about the nature of these compounds<sup>1)</sup>. Mostly it is assumed that acid boric acid esters are formed which possess a higher degree of acidity than free boric acid. Systematic attempts to find out more about these compounds through their isolation, have seldom been made, at least they have not been very successful.

In 1869 DUVE<sup>2)</sup> described a series of salts of different boro-tartaric acids, which however present the appearance of glassy, non-crystallizing masses or amorphous precipitates, the individuality of which is open to doubt. The same principle applies to most of the boro-citric acid

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<sup>1)</sup> We will postpone the older and more recent literature on this subject to a following publication.

<sup>2)</sup> Vierteljahrsschr. pr. Pharm. XVIII, 321.

salts described by SCHEIBER<sup>1)</sup> in 1879 and 1880, with the exception however of a potassium salt, which was considered to have the formula  $C_{12}H_{11}K(BO)_2O_{14} \cdot 2H_2O$ , crystallizes beautifully, and to which we refer below<sup>2)</sup>.

Also among the salts of boro-salicylic acid described for the first time by JAHNS in 1878<sup>3)</sup> there are some well-crystallised compounds.

The first who inquired more systematically into the influence on the acidity of boric acid by hydroxyl-containing substances, was MAGNANINI, who published a series of papers on the influence which these substances have on the conductivity (and some other physical constants) of boric acid solutions.<sup>4)</sup> The number of compounds examined by him is very large, and he pointed out the influence of the constitution in connection with the occurrence or non occurrence of an increase of conductivity. He found a.o. that this was only observed in *α*-oxy acids, and *not* when the OH-group is somewhere else, it *was* found in aromatic *o*-oxy carbonic acids, *not* in the *m*- and *p*-isomers, it *was* found in *o*-diphenols, not in *m*- and *p*-diphenols.

These researches have been continued and extended by BÖESEKEN (and collaborators)<sup>5)</sup>, who assumed, discovered, and worked out an influence of the *steric* configuration by the side of the constitutional influence.

In his hands the Magnanini "boric acid method" became an important instrument, not only for the determination of the constitution and configuration, but also for our stereo-chemical views in general. These results reached their acme in the application of the method to the sugars and their derivatives, the isomeric tartaric acids, and the saturated cyclic vic. diols.

In his "Lagerung der Atome im Raume" VAN 'T HOFF already expressed his opinion that in the compounds which are responsible for the phenomena in question, the boron atom might be part of a ring-system, and that this ring could close only when certain condi-

<sup>1)</sup> Russ. Zeitschr. f. Pharm. **18**, 257, 289, 321; **19**, 513. Pharm. Journ. and Trans. (3) **11**, 389.

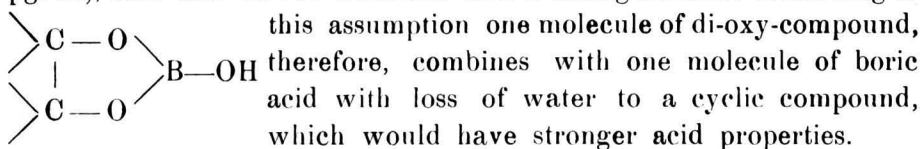
<sup>2)</sup> We have not yet been able to test entirely the records given by KLEIN in 1878 on mannite-boric acid salts of rather complicated constitution. Probably we have to do with not accurately defined substances also here.

<sup>3)</sup> Arch. der Pharm. (3) **12**, 212.

<sup>4)</sup> Z. phys. Ch. **6**, 58. Gazz. chim. Ital. **20**, 441, 448, 453; **21**, 134, 215; **22**, 541; **23**, 197. Acad. dei Lincei Rend. (4) **6a**, 411, 457.

<sup>5)</sup> E.g. These Proc. Vol. XV, p. 216 (1912); Vol. XVIII, p. 1647, 1654 (1915); Vol. XXI, p. 80 (1918); Vol. XXIII, p. 69 (1920); Verslag van de gewone vergaderingen K. Akad. v. Wet. Amsterdam Dl. XXIX, p. 368, 924 (1921). Chem. Weekbl. **19**, 207. Recueil **40**, 354, 558.

tions were fulfilled. The accompanying formula was the simplest, and was used by different investigators (see e.g. ABEGG's Handboek III pg. 43), and also served BÖESEKEN as a working-scheme. According to



Different investigators have supposed other relations as to the number of molecules combining than these to account for the physico-chemical behaviour of the mixed boric acid-polyoxyderivative-solutions, but the grounds on which these suppositions were based, are generally uncertain, and often conflicting. Up till now nothing could be said with certainty about the general type on which the acid complexes are based. The observations agree with each other only in so far that these compounds are almost completely dissociated in aqueous solution, and that their formation is favoured by increase of the concentration of the components. It further appeared from different investigations that in some cases (a.o. with substances like mannite and dulcitol); several compounds of different composition must be present in the solution, of which however, it can, not be ascertained which are the typically acid ones.

In 1911 FOX and GAUGE<sup>1)</sup> described the first compound of boric acid with a multi-valent alcohol which is well crystallized. From an alcoholic solution they obtained a mannito boric acid  $\text{C}_6\text{H}_{14}\text{O}_8\text{B}$ . They do not however, say, anything about the constitution. A second compound was described by DERX<sup>2)</sup>, viz. the crystallized cis-cycloheptane diol boric acid. He determined the boron content by titration and gave the following formula based on that  $\text{C}_7\text{H}_{14} : \begin{array}{c} \text{O} \\ \diagup \\ \diagdown \\ \text{O} \end{array} \text{BOH}, \text{H}_2\text{O}$ .

We might consider the mannito boric acid in an analogous way as  $\text{C}_6\text{H}_{14}\text{O}_4 : \begin{array}{c} \text{O} \\ \diagup \\ \diagdown \\ \text{O} \end{array} \text{BOH}, \text{H}_2\text{O}$ . Both alcohols increase the conductivity of the boric acid in a high degree. There were, as we see, reasons to look upon these compounds as being the strong complex acids that bring about these phenomena. The impetus for making a new attempt to ascertain the nature of the strongly acid boric acid compounds was given by the following accidental discovery. The 2.4. dimethyl pentane 2.4. diol<sup>3)</sup> when reacting on boric acid (even in very diluted

<sup>1)</sup> Soc. 99, 1075.

<sup>2)</sup> Recueil 41, 340 (1922).

<sup>3)</sup> Obtained from  $\text{CH}_3\text{MgJ}$  and diacetone alcohol. Mr. LANGEDIJK drew my attention to a new method of preparation, which renders this latter substance very easily accessible. (ADAMS, Organic Syntheses 1921, p. 45).

aqueous solutions) gives a beautifully crystallizing and only slightly soluble compound, to which the following formula must be assigned as a result of analysis and examination of properties:

$  \begin{array}{c}  (\text{CH}_3)_2 = \text{C} - \text{O} \\  \text{CH}_2 \left\langle \begin{array}{l} \diagdown \\ \diagup \end{array} \right. \text{BOH} \\  (\text{CH}_3)_2 = \text{C} - \text{O}  \end{array}  $	<table style="border: none;"> <tr> <td></td> <td style="text-align: center;">C</td> <td style="text-align: center;">H</td> <td style="text-align: center;">B</td> </tr> <tr> <td style="padding-right: 10px;">Calculated</td> <td style="text-align: center;">53,16</td> <td style="text-align: center;">9,17</td> <td style="text-align: center;">6,90</td> </tr> <tr> <td style="padding-right: 10px;">Found</td> <td style="text-align: center;">53,10</td> <td style="text-align: center;">9,07</td> <td style="text-align: center;">6,80</td> </tr> <tr> <td></td> <td style="text-align: center;">53,27</td> <td style="text-align: center;">9,12</td> <td style="text-align: center;">6,95</td> </tr> </table>		C	H	B	Calculated	53,16	9,17	6,90	Found	53,10	9,07	6,80		53,27	9,12	6,95
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	53,27	9,12	6,95														

The compound has an exceedingly great crystallizing power, melts not entirely sharply at 100—102°, is somewhat volatile, and has a pleasant odour strongly reminiscent of saffron. It is, however, by no means a strong acid, and like boric acid it hardly colours blue litmuspaper red, and in accordance with this the said diol (which is readily soluble in water) does not bring about any increase of conductivity of the boric acid, as was to be expected from such a 1.3 diol according to the data collected by BÖESEKEN up till now.

As a result of this I believed that the really stronger acid boron-complexes must possess another structure than had been assumed so far, and this was soon confirmed. I succeeded, though only after some more difficulties, in isolating analogous and likewise only exceedingly weakly acid boron-compounds of 2.4.dimethyl hexane 2.4.diol, 2.4.pentane diol, and pinacone, likewise diols which do not appreciably influence the conductivity of boric acid. In the case of tri-methylene glycol, ordinary glycol, and cis-1.2.cyclo hexane diol the existence of compounds could be shown, but attempts to isolate them in a pure state failed<sup>1)</sup>. It is probable that all the 1.2 and 1.3 diols are able to form such compounds with boric acid, that in many cases, however, they can be separated only with great difficulty, if at all, in consequence of unfavourable solubility conditions and similar difficulties. In aqueous solution they are partially split up into their components. The compound described first, at 0° in 0,1 normal solution for 75 %. The readiness with which this compound is obtained, is owing to its slight solubility in water (4,46 g. in 100 cc. solution at 25°), which is still smaller than that of boric acid. It dissolves in diluted alkalis, probably accompanied by formation of a potassium salt, which is, however, also dissociated, as pure diol is withdrawn from the solution by ether. The liquid free diol is salted out by strong potassium hydroxide; the potassium salt itself could not be isolated as yet. In the cis. 1.2 cyclo hexane diol, however, the corresponding potassium salt is slightly soluble in an excess of strong potassium hydroxide, and crystallizes out,

<sup>1)</sup> I hope to discuss the details of the preparation in my doctor's dissertation.

before the limit of solubility of the free diol is reached. It can be obtained pure by sucking off and washing with alcohol of 96 %. It is a compound that was discovered already before by BÖESEKEN and VAN GIFFEN<sup>1)</sup> but which was not isolated and more closely examined then.

The aqueous solution of this potassium salt has an alkaline reaction, and the potassium can be determined quantitatively by titration with methyl orange, which proves anew that the corresponding complex boric acid is an exceedingly weak acid. Besides this compound  $C_6H_{11}O_3BK_2$ , a dipotassium compound  $C_6H_{13}O_4BK$  was obtained from very strong potassium hydroxide.

Under the same circumstances crystalline compounds can also be obtained from cis-1.2 hydridene diol, cis 1.2 cyclopentane diol, and cis-1.2 and cis 2.3 tetrahydronaphthalene diols. These compounds consist of potassium salts of either of the two types or of both, some of which could, however, not yet be obtained pure and free from potassium hydroxide being sometimes (o.a. in the case of hydridene diol) too easily soluble, both in water and in alcohol, so that they cannot be washed with one of these solvents.

It is remarkable that in the di-potassium compound of cis-cyclohexane diol boric acid both potassium atoms can be titrated with methyl orange and HCl, but that in the corresponding compound of cis-cyclopentane diol only one of the two potassium atoms can thus be titrated. We reserve a further discussion of this point till some future occasion.

We may point out here that these compounds supply us with a method to separate isomer cis- and trans- cyclic 1.2 diols from each other, the latter not giving such compounds. For in many cases the beautiful method of separation with the aid of acetone compounds found by VAN LOON<sup>2)</sup> is attended with important drawbacks, as has appeared from another investigation (to which I hope to refer later on.<sup>3)</sup>)

The fact that the formation of these cyclic and only exceedingly weakly acid compounds seems to be a general property of the 1.2 and 1.3 diols, leads to the conclusion that the more strongly acid boro-complexes, which arise in appreciable quantities only in poly

<sup>1)</sup> Recueil **39**, 183 (1920).

<sup>2)</sup> These Proc. Vol. XXIII p. 60 (1920), and proefschrift Delft p. 59; of BÖESEKEN and DERX, Recueil **40**, 519.

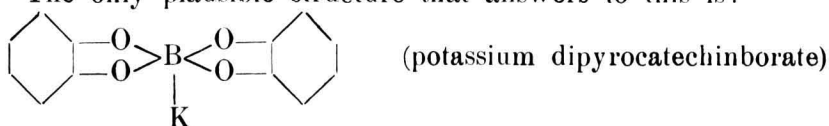
<sup>3)</sup> The new method of separation has already been successfully applied by Mr. MAAN to the methyl 1. cyclohexane 1.2 diols. The cis-diol was obtained in a much purer state than by the acetone method, as the action of acids is now fully eliminated.

oxy derivatives with "favourably" orientated OH-groups, belong to another group. In 1917 BÖESEKEN (in collaboration with OBREEN and Miss VAN HAEFTEN, Recueil **37**, 184) described several salts of pyro catechin boric acids of pretty complicated constitution. As the former had already for some time considered the analysis values found to be uncertain, and as the boric acid compounds described above appeared to be by no means particularly complex, there was sufficient occasion to subject the beautifully crystallized salts of pyro catechin boric acid to a renewed investigation, the more so because pyro-catechin greatly increases the conductivity of boric acid, so that accordingly the other type of compounds might be expected here. This expectation was confirmed: the potassium salt appeared to possess the formula  $C_{12}H_8O_4BK$  <sup>1)</sup>.

The carbon was determined by the wet way according to the method of MEISENHEIMER, the hydrogen according to a simplified method worked out by myself, about which more will be given later. The following values were found :

C	54,28; 54,26	H	3,03	B	4,3	K	14,7
Calculated	54,14		3,00		4,1		14,7

The only plausible structure that answers to this is:



The boron is here pentavalent, or has (according to WERNER'S nomenclature) the coordination value four, just as in the well-known compounds  $KBF_4$  and  $Na[B(OC_2H_5)_4]$ . The latter was obtained from  $NaOC_2H_5$  and boric acid triethyl ester <sup>2)</sup>.

The free dipyro catechin boric acid can be obtained by heating the anilin salt in a vacuum of some mm. Hg. at 100—120°, in which the aniline escapes quantitatively. Mr. MEULENHOF (who has undertaken a closer investigation of these derivatives at Prof. BÖESEKEN'S request), found that the acid obtained in this way can be prepared in perfectly pure condition by sublimation in vacuum at about 200°.

The potassium salt described is very little soluble in cold water, and this solution gives an alkaline reaction, probably in consequence of the fact that a dissociation in pyrocatechin and potassiumborate (possibly first in pyro catechin and mono-pyro catechin borate) sets in.

<sup>1)</sup> The erroneous constitution, given in the last-mentioned paper is owing, partly to an error of calculation that has crept in, partly to the fact that substances containing boron and being rich in C, are not easily combustible.

<sup>2)</sup> COPEAU C.r. **127**, 721 (1898) e.g. LIVIO CAMBI, Acad. dei Lincei Rend (5), **23a**, p. 244.

The potassium can, however, *not* be determined quantitatively by titration, from which it appears that we have to do here with an acid that is stronger than the mono diol boric acids described. Unchanged pyro catechin can again be withdrawn with ether from the aqueous solution.

The other complexes stronger than boric acid are probably also built up according to the type of di-pyro catechin boric acid.

So far, however, the separation of a derivative that probably belongs to this type, has succeeded only in one diol of abiphatic character, i. e. in the cis-cyclo heptane 1.2 diol. This diol was first prepared by DERX from suberic acid; he ascertained that it increases the conductivity of boric acid in a great degree, and states that he has succeeded in separating a solid boric acid compound, the B-content of which agrees with the formula  $C_7H_{14} : \begin{matrix} O \\ \text{O} \end{matrix} > BOH.H_2O^1$ ). As only 0.2 gramme of this diol were available (prepared by DERX), I have carried out the following experiments on micro-chemical scale under the microscope.

With an almost saturated boric acid solution the diol gives rise to the formation of an oil which is only soluble in much water.<sup>2)</sup> This oil is probably the liquid dicisycloheptanediolboric acid, from which more or less accidentally DERX obtained the mono cisyclo heptanediolboric acid as a solid substance. On addition of a little strong potassium hydroxide an aqueous suspension of this oil gives crystals of a potassium salt, while also a drop of aniline is dissolved with separation of beautiful crystal needles, which are, however, pretty readily soluble in water and other solvents.

In connection with the small quantity of material available it was better to abandon the idea of an examination of the liquid compound itself, and to try and separate one of the salts. For this purpose I chose the aniline salt to avoid the possibility that with KOH, as with the other cyclic diols, a compound of the monotype would again crystallize out. It might, however, be expected of aniline that it would give a crystallized salt only with a stronger acid.

Only a few tenths of milligrammes of the aniline salt were obtained in a sufficiently pure condition with a melting-point of about 50°. Mr. H. GRAVESTEN was so kind as to take the execution

<sup>1)</sup> Proefschrift Delft and Recueil **43**, 340 (1922).

<sup>2)</sup> As Mr. DERX communicated to me in a conversation, this oil was also observed by him, but considered as an impurity. He has obtained the solid boric acid compound described by him in a small quantity from a pretty large quantity of this oil and through rather complicated manipulations.



of a micro-elementary analysis upon him. The combustion of this boron-containing compound requires, however, special preliminary experiments, and has not yet been accomplished; the results will be published later. A determination of the boron-content yielded the following results: 9,76 mgr. were dissolved with 1 gr. of pure mannite in 10 cc. of water, and titrated with 0,0097 N barite water (under similar circumstances tested by pure boric acid) and phenolphthalein as indicator. Consumed 2,60 cc. Calculated for  $C_{10}H_{16}O_4NB$  ... 2,99 % B; found 2,8 % B.

To all probability we have here actually to do with dicisycloheptane diol boric acid aniline.

In this compound the aniline is bound still more loosely than in aniline dipyro catechin boric acid. In vacuum at room temperature it already escapes, the remaining part becoming liquid. The liquid residue becomes solid again by the addition of aniline. Also on evaporation of the aqueous solution over concentrated sulphuric acid an oil remains behind, which becomes solid again by the addition of aniline. Beside a dish with pumice saturated with aniline the salt can, however, be regained unchanged by evaporation of the aqueous solution in vacuum.

Di-cisycloheptanediol-boric acid is, therefore probably a much weaker acid than dipyrocatechin-boric acid, and the great increase of conductivity of boric acid by pyro-catechin must, therefore, be put to the account not only of the favourable orientation of the OH-groups, but also partially to the account of the acidifying influence of pyro-catechin as such. This admonishes to caution in making comparisons with regard to the orientation of the HO-groups between diols that are not very much alike in structure, exclusively on the ground of measurements of the conductivity. This point was, indeed, already foreseen by BÖESEKEN, and was a.o. mentioned by VAN LOON<sup>1)</sup> and LIEMPT<sup>2)</sup>.

That also the increase of conductivity caused by the  $\alpha$ -oxy acids in the boric acid is probably to be attributed to the formation of complex acids built in an analogous way, we have been able to make plausible by showing that the analyses of the SCHEIBE's boro dicitric acid potassium<sup>3)</sup> and of the zincous salt of JAHNS' boro disalicic acid are in agreement with the formulae:

<sup>1)</sup> Proefschrift Delft, p. 56.

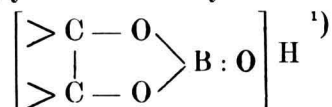
<sup>2)</sup> Recueil **39**, 359.

<sup>3)</sup> Also the free acid has been separated crystalline by SCHEIBE and by me. It is, however, difficult to purify and dry. SCHEIBE's analysis, which I have not yet checked, is in harmony with my view.



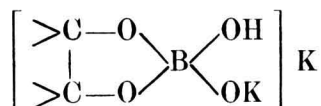


This enables the  $[(HO)_2B : O] H$  present in water to form compounds with a number of glycols and  $\alpha$ -oxy acids, of the following type:



Like boric acid these acids are very weak.

4. On the other side of the boron atom a compound can now be formed with a second molecule of diol or oxy acid with loss of water. Whether then a molecule of water is first admitted, may be left undecided for the present. The existence of dipotassium salts, to which we can assign the structure:



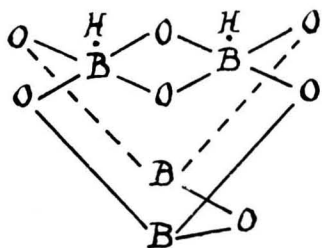
may possibly plead in favour of this, like the presence of an extra molecule of water in DERX's solid mono cyclo heptane diol boric acid and FOX and GAUGE's mono mannite boric acid.

A second molecule of dioxy compound is, however, received in diluted aqueous solution in appreciable quantities only when certain favourable conditions are realized, i.e. with a favourable steric situation of the hydroxyl groups in the diol or oxy acid. The tendency to the formation of a di-compound is, accordingly, smaller than that to the formation of the mono-derivatives, and the former seems, therefore, to be very sensitive to the value of the ring-tension in the ring to be formed. This fact constitutes the hypothetical foundation of BÖESEKEN's boric acid method.

5. It is known that the poly-boric acids whose presence must be assumed in alkaline solutions, are stronger acids than ortho-boric acid. Plausible structure formulae could not be drawn up for this large series of acids as yet on the basis of trivalent boron. Possibly they too possess the grouping  $\begin{array}{c} -O \\ -O \end{array} > B < \begin{array}{c} O- \\ O- \end{array}$ . Maintaining the assumption that to each H-atom that can be replaced by metals belongs one pentavalent B-atom, the other B-atoms being trivalent, a structure schema may be constructed for a great number of poly boric acids. Tetra borix acid, which forms the foundation of borax, possesses e.g. the scheme: <sup>2)</sup>

<sup>1)</sup> In this connection it will be of importance to examine whether in the saponification of  $B(OR)_3$  by water the presence of a relatively stable intermediate product  $(RO)_2BOH$  can be shown.

<sup>2)</sup> This representation does not lay claim, of course, to be anything more than a scheme.



In conclusion it may still be mentioned that the question what place three remarkable "acid boric acid esters" described by WOHL and NEUBERG<sup>1)</sup> and also the boric acid complexes<sup>2)</sup> found by GRÜN and NOSSOWITCH, occupy in this respect must still be made a subject of investigation.

I may still be allowed to express my great indebtedness to Prof. BÖESEKEN for the kind interest which he evinced in this investigation carried out in his laboratory.

*Delft*, December, 1922.      *Organic Lab. of the Technical Univ.*

<sup>1)</sup> Ber **32**, 3488 (1899).

<sup>2)</sup> Sitz. Ber der Akad. der Wiss. Wien M. N. Cl. **125**, 2B, 171 (1916).