ignation of such a mating is 58. This will be made clear by repeating the pedigree diagram of bird *N, Diagram II.,* and adding to it the proper letters and mating designations from Table I.

The simplicity of the scheme is obvious. No argument appears necessary as to its usefulness in experimental breeding operations. The writer has found it extremely helpful and clarifying.

A word should be added in regard to the system by which the numbers have been assigned to the matings. It might at first sight appear as though the arrangement were an entirely haphazard one. It is not. On the contrary the numbers will be found to conform to the following general principles, which seem likely to be of aid in practical work, as tending to make it easy to recall from a number just what its particular pedigree looks like.

1. All even numbers refer to back-cross matings.

2. All odd numbers refer to co-fraternal or intra-generation matings (not back-crosses).

3. Matings below 2 are of parental generation individuals: between 2 and 8 inclusive are of F_1 individuals; matings over 10 are of F_2 individuals.

4. Even numbers from 10 to 36 inclusive designate back-crosses of F_2 individuals with their *grandparents,* or individuals of the grandparental generation.

5. Even numbers from 40 up designate back-crosses of F_2 individuals on F_1 individuals.

6. In the case of the odd numbers from 11 up it is, *in a general way,* true that the smaller the designating number of a mating the more closely related to each other are the two individuals entering that mating likely to be. This principle of assigning the numbers could not be so precisely followed as the preceding five, but still is perhaps worth a little.

In using this system in one's notes or writing it is of course essential to have the basic table always at hand. If the plan should appeal to any number of experimental workers it would be a simple matter to have copies of Table I. printed on heavy cardboard to be used in breeding houses and pens, in the field and at the desk.

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THE CHEMICAL COMPOSITION OF BORNITE

SINCE the analyses of crystallized material from Cornwall by Plattner,[1] bornite has generally been considered to be a cuprous sulfoferrite, $Cu_3FeS_3(3Cu_2S \cdot Fe_2S_3)$. In 1903 Harrington[2] made a critical study of the published analyses, added several new analyses, and concluded that the chemical formula of bornite is $Cu_5FeS_4(5Cu_2S \cdot Fe_2S_3)$. Recently Kraus and Goldsberry[3] made an analysis of crystallized bornite from Bristol, Conn., which gave the formula $Cu_{12}Fe_2S_9(6Cu_2S \cdot Fe_2S_3)$, and also confirmed Harrington's formula Cu_5FeS_4, of crystallized bornite from the same locality. They conclude that bornite is of variable chemical composition, and in order to explain the facts they assume a morphotropic series of minerals ranging from chalcopyrite, $CuFeS_2$, through barnhardtite, $Cu_4Fe_2S_5$, and various bornites $Cu_6Fe_2S_6$, $Cu_8Fe_2S_7$, $Cu_{10}Fe_2S_8$, $Cu_{12}Fe_2S_9$, up to $Cu_{76}Fe_2S_{41}$, finally ending with chalcocite Cu_2S, each member of the series differing from the one below it by the addition of one molecule of Cu_2S.

As a metallographic examination of the two analyzed bornites showed no foreign admixture, the work of Kraus and Goldsberry furnishes, for the first time, proof that bornite is variable in composition. It is believed, however, that there is a more rational explanation of the variability in composition of bornite than the one advanced by Kraus and Goldsberry.

The recorded analyses of bornite show a copper content varying from 77 to 55 per cent., and an iron content varying from 18 to 6 per cent. In Fig. 1 I have plotted on the triangular coordinate diagram of J. Willard Gibbs the available bornite analyses (59 in number) given in Hintze's "Handbuch" and in the

[1] *Pogg. Ann.,* 47, 351, 1839.

[2] *Amer. Jour. Sci.,* 16, 151, 1903.

[3] *Amer. Jour. Sci.,* 37, 539, 1914.

articles of Harrington and Kraus and Golds-berry. (For analyses with more than two or three per cent. of gangue the percentages have been recalculated.) The small triangle fur-nishes a key to the larger diagram which rep-resents one sixth the area enlarged tenfold. The diagonal line crossing the diagram is the locus of analyses of minerals in Kraus and Goldsberry's series, $Cu_xFe_2S_{\frac{x}{2}+3}$. This ranges from $CuFeS_2$ on the left to Cu_2S on the right. Most of the analyses are ranged along this line. Those much above the line are probably

that very few of the massive bornites are en-tirely free from other minerals, but chalco-pyrite and chalcocite, the two most common impurities in bornite, tend to neutralize the effect of each other for

$$CuFeS_2 + Cu_2S = Cu_3FeS_3$$

and

$$CuFeS_2 + 2Cu_2S = Cu_5FeS_4.$$
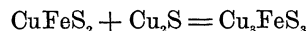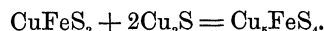
Because of this, and because the impurities are often trifling in amount, the analyses may be used with caution.
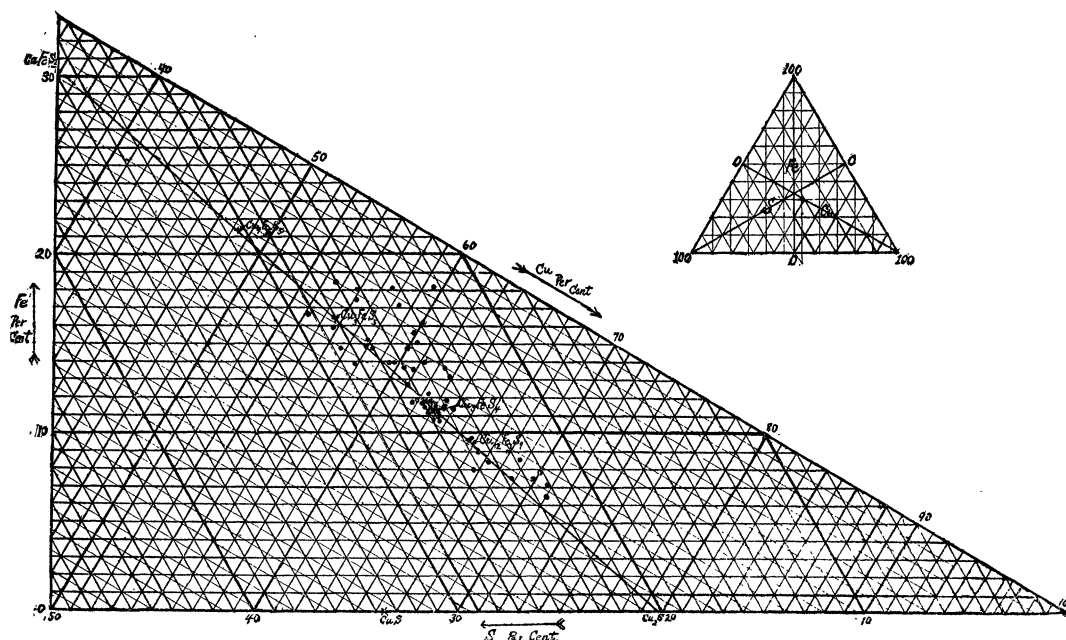

FIG. 1.

due to errors in the analyses or to the presence of oxidation products.

The only clustering of points in the diagram is around Cu_5FeS_4. Some may interpret this as evidence that bornite has the formula Cu_5FeS_4, but on the solid solution hypothesis advanced later on it may simply represent the average solubility. Most of these analyses were made upon massive material and as the study of polished sections proves, apparently pure, massive bornite usually contains small amounts of chalcopyrite, chalcocite or covellite, and occasionally other minerals. It is safe to say

The lower limit of bornite seems to be rep-resented by Cu_3FeS_3 with iron content of 16.36 per cent.; the Cornish crystals approach this formula and an artificial bornite made by Böcking[4] is very close to the theoretical for Cu_3FeS_3. Only seven analyses out of the fifty-nine show more than 16.3 per cent. iron. A slight admixture of chalcopyrite (Fe = 30.5 per cent.) will easily account for the excess iron. The lowest iron content on record is 6.4 per cent. The low iron content of some of the

[4] Hintze, ''Handbuch der Mineralogie,'' Vol. I., p. 914, 1901.

bornites is doubtless due to admixed chalcocite just as the iron content of chalcocite is usually due to admixed bornite.

There are four possible explanations of the variability in chemical composition of bornite, viz: (1) Mechanical mixture, (2) isomorphous mixture, (3) morphotropic series (Kraus and Goldsberry), (4) solid solution.

1. While it is certain that mechanical mixtures explain part of the variability, some other factor is involved, as we know from the analytical results of Kraus and Goldsberry.

2. The isomorphism of bornite and chalcocite does not seem at all probable for there is not much similarity in chemical composition; moreover, one is isometric, the other orthorhombic.

3. The term morphotropy was introduced by Groth[5] to indicate the change in crystalline form brought about by substituting in a chemical compound an atom or group of atoms for a similar atom or group. The best examples of morphotropy are furnished by organic compounds. The only clear case of morphotropy (in its original restricted sense as distinct from isomorphism) among minerals is the humite group. Kraus and Goldsberry contend that there are various bornites each with a definite formula. As far as known bornite is isometric and, if so, it is difficult to conceive of any crystallographic change that can be brought about by the addition of the Cu_2S molecule. Complex formulæ like $Cu_{34}Fe_2S_{20}$, $Cu_{40}Fe_2S_{23}$ and $Cu_{76}Fe_2S_{41}$ are very improbable and it is probably a coincidence that the percentage compositions of the crystallized bornite from Bristol are so close to the theoretical values of $Cu_{10}Fe_2S_8$ and $Cu_{12}Fe_2S_9$.

4. In order to explain the variable chemical composition of bornite, the hypothesis of solid solution is advanced by the writer. As the lower limit of bornite seems to be Cu_3FeS_3, the variation in composition can be explained by assuming that *bornite is a solid solution of* Cu_2S *in* Cu_3FeS_3 which may be indicated thus: $Cu_3FeS_3(Cu_2S)_x$. This makes an indefinite upper limit for the copper content. There is proof that it is as high as $Cu_{12}Fe_2S_9$, and it

[5] *Pogg. Ann.*, 141, 31, 1870.

probably goes still higher. The composition of bornites listed on page 547 of Kraus and Goldsberry's paper is as easily explained by the solid solution hypothesis as by any other and from a chemical standpoint it seems far more reasonable. The solid solution hypothesis also helps to explain the fact that chalcocite rarely occurs as an original hypogene[6] mineral for it seems probable that cuprous sulfoferrite (Cu_3FeS_3) can take up or dissolve appreciable amounts of cuprous sulfid, and hence chalcocite is not formed until a later stage when a change of conditions is brought about by decrease of temperature. It may also explain the readiness with which bornite alters to chalcocite. There is very little microscopic evidence to show that bornite and chalcocite are formed simultaneously except perhaps locally in the so-called intergrowths. The origin of these graphic intergrowths will be discussed by the writer in a forthcoming paper.

The long series of sulfo-salt minerals given by Kraus and Goldsberry fails to convince me of the general application of morphotropy in this group. Minerals represented by some of the formulæ in the series are doubtless examples of solid solutions, and some of these minerals are undoubtedly mechanical mixtures. Imagine what a bewildering lot of transparent minerals might have been recognized if mineralogists had had no microscopic check on their chemical work. A revision of the opaque sulfo-salt minerals seems necessary. In such work the metallographic microscope will be of great assistance.

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STUDIES IN THE MEASUREMENT OF THE ELECTRICAL CONDUCTIVITY OF SOLUTIONS[1]

It is a striking fact that very few investigators of conductivity have striven to make the measurements with an accuracy approach-

[6] This useful term is used by Ransome for minerals or ores formed by ascending solutions.