

XXIV.—Connection between the Atomic Weight of contained Metals, and the Magnitude of the Angles of Crystals of Isomorphous Series. A Study of the Potassium, Rubidium, and Cæsium Salts of the Monoclinic Series of Double Sulphates $R_2M(SO_4)_2 \cdot 6H_2O$.

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THE direction in which pure crystallographical research appears likely to afford results of the greatest interest and significance is that in which comparable measurements are made upon crystals of substances chemically related to each other in a definitely ascertained manner. The information on this question at present available,

particularly with regard to the goniometrical effect produced by the replacement of one metal in an isomorphous series of salts by another, is of a most meagre and insufficient character. The absence of conclusive data is, however, largely accounted for by the fact that, especially in the cases of substances crystallising in the higher systems of symmetry, the values of analogous angles upon the crystals of the various members of the series are so nearly identical that the differences frequently fall within the limits of the few minutes usually assigned to experimental and formational error.

The object of this investigation has been to examine in great detail some well defined but hitherto unattacked series of isomorphous salts crystallising in one of the systems of lesser symmetry, with the view of ascertaining whether the replacement of one metal by another of the same family group but of higher atomic weight was attended by a change in the values of the angles of sufficient magnitude to be far removed from the narrow limits of experimental and formational error. The attention of the author was at once attracted to the well known series of double sulphates crystallising in the monoclinic system with 6 mols. of water of which the salt $K_2Mg(SO_4)_2 \cdot 6H_2O$ may be considered as the first member. Measurements, not, however, sufficiently numerous and detailed for the purposes of this investigation, have been made of the potassium and ammonium salts of this series by several crystallographers, notably Brooke, Rammelsberg, and most recently Murmann and Rotter (*Sitz. Ber. der Kais. Akad. Wiss.*, **34**, 135). The salts containing rubidium and cæsium, however, first prepared by Bunsen, which are of course more directly comparable with those containing potassium than are the salts of ammonium, have never yet been subjected to measurement so far as the author has been able to ascertain. It was, therefore, determined to prepare crystals, as suitable and perfect as possible, of all the salts of the series containing potassium, rubidium, and cæsium, and to subject them to a goniometrical investigation as complete as their development would permit. The remeasurement of the potassium salts was resolved upon, firstly, because the previous measurements were not made with sufficient completeness, and, secondly, in order that the results might be more strictly comparable with those obtained in the cases of the rubidium and cæsium salts.

When a comparison is made of the angular values given by previous observers of the potassium salts of this series containing magnesium, zinc, iron, nickel, cobalt, and copper, no regular differences are observed. In a large majority of cases the differences are very small, and where larger show no relationship to the atomic weights of the dyad (or acting dyad) metals contained. Moreover, in the case of one and the same salt, the differences in the values of the angles given by

different observers are frequently of considerable magnitude, occasionally exceeding half a degree. These discrepancies in the published angles are probably partly due to the fact that an insufficient number of measurements upon different crystals belonging to distinct crops were made; for it frequently happens that apparently equally perfect crystals of the same substance, of equal purity, but of different crops and consequently deposited under different conditions, exhibit angular differences amounting to several minutes of arc. Hence measurements made upon one or two crystals, however apparently perfect, are not likely to furnish results so near the true angles which the substance would produce if all cause of disturbance could be avoided. In the present work, therefore, at least 10 crystals of each salt, selected—on account of their special perfection and suitability as regards size—from as many crops as possible, have been measured, in order that these differences might be eliminated by taking the mean of all the observed values of the same angles. Moreover, such beautifully perfect crystals of most of the salts have been obtained by working under the most favourable conditions for slow undisturbed deposition, that these differences in the values of the angles of one and the same salt have usually been far smaller than those obtained on comparing the work of previous observers. It will be shown hereafter that on inspection of the values now given, values of which the error in most cases cannot exceed four or five minutes of arc, the differences between the six potassium salts containing the dyad metals above enumerated are observed to be so small that no relations between their magnitude and the atomic weights of the respective metals can be deduced from them. In fact, in those cases where the dyad metals belong to the same family group, the values are practically identical. It would appear, therefore, that in the isomorphous series under investigation, the replacement of one dyad (or acting dyad) metal by another of the same family group is unattended by any material change of angle.

The case, however, will be shown to be very different when the alkali metal potassium is replaced by rubidium and the rubidium in turn by caesium. It will be amply demonstrated in the course of this communication that in each case the change is accompanied by an alteration in the principal angle, the axial angle β , of more than a whole degree; and what is more important still from a chemical point of view, the amount of the change bears a definite and very simple relationship to the change in atomic weight.

It will be further shown, with respect to *all* the numerous angles which have been measured, that the differences between their magnitudes in the corresponding potassium, rubidium, and caesium salts respectively, where those differences are, as is nearly always the

case, greater than such as might be attributed to experimental and formational error, also bear a direct relationship to the change in atomic weight, although such relationship is not usually of so simple a character as that which obtains in the case of the axial angle.

Other interesting relationships will also be pointed out, particularly one connecting the habitual geometrical form, the so-called "habit," of the crystals of the various salts with the atomic weight of the alkali metal present.

Method of Work.

For the purposes of this investigation, the double sulphates were prepared in every case by mixing solutions of the two simple sulphates, containing those salts in equal molecular proportions. The weighings were made with considerable care in order that there should be no appreciable excess of either of the simple sulphates present after admixture. The simple sulphates employed were of the highest obtainable degree of purity. The sulphates of rubidium and cæsium were prepared with particular care by Tromsdorff, and on spectroscopic examination were found to be remarkably free from impurity. The following numbers were obtained from determinations of their content of sulphuric acid :—

1·6837 gram of rubidium sulphate yielded 1·4815 gram of barium sulphate, corresponding to 30·20 per cent. of SO_3 . The calculated amount of SO_3 contained in Rb_2SO_4 is 30·03 per cent.

1·1905 gram of cæsium sulphate yielded 0·7780 gram of barium sulphate, corresponding to 22·43 per cent. of SO_3 . The calculated amount of SO_3 contained in Cs_2SO_4 is 22·14 per cent.

A similar determination of sulphuric acid in the potassium sulphate employed gave the following numbers :—

0·6285 gram of sulphate yielded 0·8404 gram of barium sulphate, corresponding to 45·90 per cent. of SO_3 . The calculated percentage of SO_3 in K_2SO_4 is 45·97.

Usually solutions containing 20—30 grams of each double salt were prepared, and portions poured into several crystallising vessels, perfectly cleansed small glass beakers being found most suitable, in order to obtain several distinct crops. The method of slow crystallisation from cold solutions was usually adopted, as affording crystals of more regular growth and more even faces. The crops were removed from time to time as soon as the crystals had attained the small size suitable for the goniometer, the mother liquors being

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usually decanted into fresh clean vessels and again allowed to crystallise. Each crop was stored separately in a small dry bottle until the conclusion of the work.

When a dozen or more such crops had been accumulated, 10 specially well formed and perfectly developed crystals were selected for measurement from several of the best of the crops. These crystals were then measured completely, except in a few cases where certain zones exhibited traces of distortion; these zones were discarded and additional crystals were selected and measured. Hence in the case of each salt 10 particularly good crystals have been completely measured, not only along the principal, but also along all the minor, zones, and in certain cases one or two additional crystals have been partially measured. As most of the principal angles are repeated four times on each fully developed crystal, in accordance with the symmetry of the monoclinic system, as many as 40, and sometimes more, determinations of the values of each of these principal angles have been obtained. The arithmetical mean of all the values of each angle has then been taken and recorded as the mean observed angle. By this exhaustive method of work it is probable that most of the slight deviations from the angles of the true geometrical forms of the salts, due to the influence of the surface of the crystallising vessel, to slight disturbance of the parallelism of layers during deposition, to minute traces possibly of included matter, and other disturbing causes to which the minute deviations of a few minutes of arc are to be attributed, termed in this communication "formational error," together with the still smaller instrumental errors of measurement, have been eliminated. The goniometer employed was one of the large horizontal Fuess instruments, whose accuracy has been thoroughly tested in previous work by the author and whose circle graduations, which read to 30 seconds, are certainly trustworthy to 1 minute of arc. Moreover, the measurements were almost entirely made during the quiet of the evenings, and very bright images of the signal, a "Websky" slit, were obtained by employing as the source of illumination the improved mantles supplied by the Welsbach Incandescent Light Company. Further, all readings of the circle were taken twice.

The mean observed values of the three most reliably measured angles, either on account of the large number of measurements which had been made of them, or the closer agreement of the individual values, were then employed in accordance with the requirements of the monoclinic system as basal angles, from which by the processes of spherical trigonometry all the remaining angles were calculated so as to afford a confirmation of the accuracy of the mean observed values of those angles. The close agreement between the calculated

and mean observed angles amply repays the labour involved in making so large a number of measurements, about 9500 in all.

After the potassium, rubidium, and caesium salts containing the same dyad metal have been thus fully treated, a comparison of their angles is made in a table following, so that the effect of the change from potassium to rubidium and from rubidium to caesium may be observed at a glance. A summary will be found at the close of the memoir in which the relationships, so graphically exhibited by one and all of these tables of comparison, are set forth as concisely as possible.

In order that no doubt should possibly arise as to the composition of the crystals under measurement, analyses have been made of some of the crystals of each salt belonging to one of the crops from which specimens have been measured, estimations having been carried out of the amount of one of the metals and of the sulphuric acid which they contained.

The Salts of the Series R₂M(SO₄)₂,6H₂O investigated.

The sulphates of rubidium and caesium very readily unite with the sulphates of magnesium and zinc, ferrous and manganous sulphates, and the sulphates of nickel, cobalt, copper, and cadmium, respectively, to form double sulphates crystallising with 6 mols. of water. The caesium salts are particularly fine, frequently forming crystals whose size is only limited by the bulk of the solution and the walls of the crystallising vessel. The whole of the 16 salts have been measured in the manner just described.

Potassium, however, does not appear to form salts of this series with quite the same readiness as rubidium and caesium. Excellent crystals of the potassium salts containing, as the second metal represented by M in the general formula, magnesium, zinc, iron, and nickel have been obtained; but considerable difficulty, eventually overcome however, has been experienced in procuring crystals of the degree of perfection desired of the salts containing cobalt and copper, and up to the present time, although repeated efforts have been made, under most varied conditions, all attempts to obtain crystals of the potassium salts of the series containing as the second metal manganese and cadmium have been unsuccessful. Murmann and Rotter (*loc. cit.*), and likewise Scacchi and Marignac (*Jahresb.*, 1856, 381), were also unable to prepare the double sulphate of potassium and manganese containing 6 mols. H₂O; instead of this salt crystals of a salt containing only 4 mols. H₂O, and, consequently, crystallising quite differently, were obtained. The crystals of potassium manganous sulphate invariably obtained during the course of

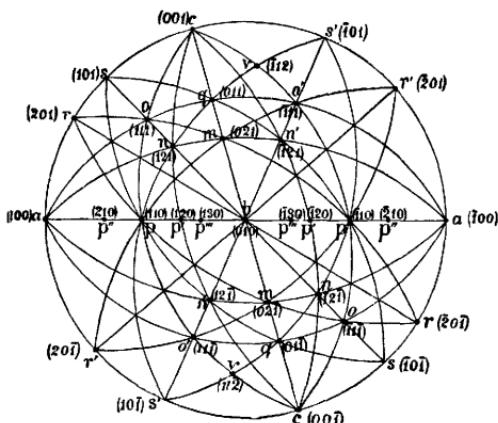
this work agreed with Marignac's description of the latter salt. Similarly, in the case of cadmium, other workers have been unsuccessful in obtaining the salt $K_2Cd(SO_4)_2 \cdot 6H_2O$. Von Hauer (*Wien. Akad. Ber.*, 1885, **15**, 42) appears to have obtained, along with crystals of two other salts, $K_2Cd(SO_4)_2 \cdot 2H_2O$ and $2K_2SO_4 \cdot CdSO_4 \cdot 3H_2O$, a few crystals of a salt containing 6 mols. H_2O , but which effloresced almost immediately after removal from the mother liquor. Up to the present time the author has been unable to obtain such crystals, but has always obtained instead crystals corresponding with the descriptions given by Von Hauer (*loc. cit.*, and *Ann. Phys. Chem.*, **133**, 176) of the two other salts just named.

Altogether, 22 salts of the series have been investigated in the manner described under the last heading, namely, the potassium, rubidium, and caesium salts, containing as the second metal magnesium, zinc, iron, nickel, cobalt, and copper respectively (18 salts, six sets of three each), and the rubidium and caesium salts containing, as the second metal, manganese and cadmium respectively (four salts, two sets of two each).

General Crystallographic Form of the Series $R_2M(SO_4)_2 \cdot 6H_2O$.

The general crystallographic form of the series is represented in the spherical projection given in Fig. 1. Inasmuch as the differences

FIG. 1.



between the angles of the various members of the series would be scarcely perceptible in a spherical projection on the scale given, the extreme limits of the differences between the angles of the salts differing most widely being only two and a half degrees, the same

spherical projection suffices for all, and is given now for general reference.

The drawing was actually made from the measurements of one of the rubidium salts, for a reason which will be apparent when the results of the investigation are discussed.

The plane of projection is the symmetry plane $b\{010\}$.

The forms $s\{101\}$ and $s'\{\bar{1}01\}$, the two complementary primary orthodomes, have never been found developed upon any of the crystals examined, but they are marked upon the spherical projection because it was considered interesting to calculate the angles formed by these possible faces with neighbouring faces for the purposes of the tables of comparison, and also because certain of these calculated angles involving the poles s and s' afford data for independently calculating, and thus checking, the axial ratios. With the exception of these two forms, s and s' , all the forms given in the spherical projection have been found actually developed, although never upon any one single crystal. The crystals of several of the salts, however, frequently exhibit a large number of these forms, and individual crystals have been measured upon which all but one or two of the forms of higher indices were developed.

Salts containing Magnesium.

Potassium Magnesium Sulphate, $K_2Mg(SO_4)_2 \cdot 6H_2O$.

Eleven of the most perfect crystals of this well-known salt were selected from two distinct particularly suitable crops, and measured as completely as their development would permit. Their size varied from prisms of about 1 mm. side and $\frac{1}{2}$ mm. depth to prisms of a little more than twice this size. The crystals were perfectly colourless and transparent, and their faces plane and very brilliant, yielding generally magnificent images of the signal. They were particularly free from striation and distortion.

Analyses of other crystals belonging to one of these crops yielded the following numbers, indicative of the purity of the crop:—

Estimation of SO_3 : 0·6893 gram of crystals gave 0·8040 gram of $BaSO_4$, corresponding to 40·04 per cent. SO_3 . The calculated percentage of SO_3 in $K_2Mg(SO_4)_2 \cdot 6H_2O$ is 39·80.

Estimation of MgO : 0·9170 gram of crystals gave 0·2550 gram of magnesium pyrophosphate, corresponding to 10·02 per cent. of MgO . Calculated percentage 9·95.

Habit: short prismatic.

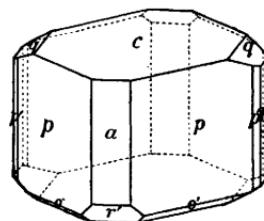
Axial angle: $\beta = 75^\circ 12'$.

Ratio of axes: $a : b : c = 0\cdot7413 : 1 : 0\cdot4993$.

Forms observed: $a = \{100\} \infty P \infty$; $b = \{010\} \infty P \infty$; $c = \{001\} oP$;
 $p = \{110\} \infty P$; $p' = \{120\} \infty P 2$; $q = \{011\} P \infty$; $o' = \{\bar{1}\bar{1}1\} + P$;
 $r' = \{\bar{2}01\} + 2P \infty$.

The habit usually assumed by the crystals of potassium magnesium sulphate which have been obtained during the course of this work is that shown in Fig. 2, consisting essentially of a short prism formed by the faces of the primary prism $p\{110\}$, and terminated by the basal plane $c\{001\}$. The edges of the prism are usually modified by the faces of the orthopinacoid $a\{100\}$ and the clinopinacoid $b\{010\}$. The comparatively large development of the orthopinacoid may, indeed, be regarded as a characteristic trait of the salt, for with the exception of the potassium iron salt, no other salt of the series has been found to exhibit this form to anything like so large an extent. The basal plane $c\{001\}$, as has been found to be the case in all the potassium salts of the series, is the largely predominating end face,

FIG. 2.



the orthodome $r'\{\bar{2}01\}$ and the clinodome $q\{011\}$ being usually developed only to the extent indicated in the figure. The reflections yielded by all these faces upon the crystals measured were generally excellent. The faces of the hemipyramid $o'\{\bar{1}\bar{1}1\}$ were, as a rule, more or less developed, but the reflections yielded by them were rarely so perfect as those afforded by the forms just enumerated. The presence of the prismatic form $p'\{120\}$ was only observed twice, but the reflections of the signal then obtained were perfectly trustworthy.

The following table (p. 346) exhibits the results of the measurements. In the second column is given the number of measurements made of each angle. This number represents the number of times the same angle has been met with, formed, of course, by different faces, in the whole of the 11 crystals subjected to measurement. As this occurred in the case of a few of the principal angles four times upon each perfectly developed crystal, in accordance with the symmetry of the monoclinic system, the maximum number of times the same angle could be observed was 44. In the third column, headed "limits," are given the highest and lowest values of the same angle which

were observed, and in the fourth column the arithmetical mean of all the values of that angle obtained. In the fifth column are given the calculated values of all the angles except the three marked by an asterisk, in which cases the mean observed angles were employed, as described under "Method of Work," being specially trustworthy, as the necessary basal angles in making the calculations. In the sixth

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$\{as = 100 : 101$	—	—	—	46° 8'	—
$sc = 101 : 001$	—	—	—	29 4	—
$ac = 100 : 001$	18	75° 0' — 75° 23'	75° 13'	75 12	1'
$\{cs' = 001 : \bar{1}01$	—	—	—	38 12	—
$s'r' = 101 : \bar{2}01$	—	—	—	25 5	—
$cr' = 001 : 201$	13	63 0 — 63 37	63 20	63 17	3
$r'a = 201 : \bar{1}00$	10	41 17 — 41 48	41 29	41 31	2
$\{ap = 100 : 110$	26	35 19 — 35 54	35 38	*	—
$pp' = 110 : 120$	2	19 28 — 19 31	19 30	19 28	2
$p'b = 120 : 010$	—	—	—	34 54	—
$pb = 110 : 010$	10	54 5 — 54 29	54 20	54 22	2
$pp = 110 : \bar{1}10$	20	71 6 — 71 29	71 18	71 16	2
$pp = 110 : \bar{1}10$	18	108 25 — 108 52	108 42	108 44	2
$\{cq = 001 : 011$	42	25 38 — 25 59	25 48	*	—
$qb = 011 : 010$	10	64 5 — 64 13	64 9	64 12	3
$qq = 011 : \bar{0}1\bar{1}$	21	128 15 — 128 38	128 23	128 24	1
$\{ao = 100 : 111$	—	—	—	49 18	—
$oq = 111 : 011$	—	—	—	27 24	—
$\{aq = 100 : 011$	4	76 35 — 77 0	76 42	76 42	0
$qo' = 011 : \bar{1}1\bar{1}$	5	34 15 — 34 37	34 26	34 27	1
$o'a = \bar{1}1\bar{1} : \bar{1}00$	4	68 49 — 68 55	68 53	68 51	2
$\{co = 001 : 111$	—	—	—	34 41	—
$op = 111 : 110$	—	—	—	43 20	—
$\{cp = 001 : 110$	44	77 50 — 78 14	78 1	*	—
$po' = 110 : \bar{1}1\bar{1}$	13	57 25 — 57 43	57 36	57 35	1
$oc' = \bar{1}1\bar{1} : 001$	13	44 8 — 44 33	44 21	44 24	3
$\{bo = 010 : 111$	—	—	—	70 12	—
$os = 111 : 101$	—	—	—	19 48	—
$\{bo' = 010 : \bar{1}1\bar{1}$	2	65 12 — 65 25	65 19	65 23	4
$o's' = \bar{1}1\bar{1} : \bar{1}01$	—	—	—	24 37	—
$o'o' = \bar{1}1\bar{1} : \bar{1}1\bar{1}$	1	—	49 18	49 14	4
$\{sq = 101 : 011$	—	—	—	38 6	—
$qp = 011 : \bar{1}10$	29	86 1 — 86 21	86 9	86 11	2
$ps = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	55 43	—
$\{s'q = \bar{1}01 : 011$	—	—	—	44 58	—
$qp = 011 : 110$	30	63 44 — 63 59	63 52	63 52	0
$ps' = 110 : \bar{1}0\bar{1}$	—	—	—	71 10	—
$\{r'o' = \bar{2}01 : \bar{1}11$	1	—	34 44	34 35	9
$o'p = \bar{1}1\bar{1} : 110$	6	92 40 — 92 55	92 48	92 54	6
$pr' = 110 : 201$	8	52 18 — 52 40	52 30	52 31	1

Total number of measurements, 350.

column are given the differences between the mean observed and the calculated values, in order to afford some idea of the general trustworthiness of the measurements.

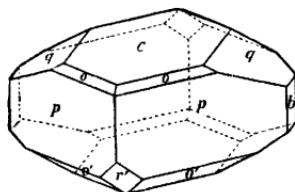
The angles given are, as is now customary, the goniometrical ones, that is, those actually represented in the spherical projection given in Fig. 1. They are the angles between the normals to the faces, and are consequently supplementary to the obtuse internal dihedral angles between the faces themselves.

The values of the few angles of this salt given by Rammelsberg, Brooke, and Murmann and Rotter (*loc. cit.*) fall within the limits of the above observations. But, inasmuch as only a very small number of measurements appear to have been made, they cannot be regarded as at all comparable with the mean values given in the above table. The value of the axial angle β given by Murmann and Rotter is $75^\circ 5'$.

Rubidium Magnesium Sulphate, $\text{Rb}_2\text{Mg}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

Very brilliant crystals of rubidium magnesium sulphate, frequently of large size, are readily obtained on evaporating a solution containing equal molecular proportions of rubidium and magnesium sulphates. Several excellent crops were obtained, and 10 crystals were selected from the two best. These 10 crystals were admirably suitable for goniometrical purposes, yielding almost throughout well defined and very bright single images of the signal. They varied in size within about the same limits as those of the potassium salt.

FIG. 3.



Determinations of sulphuric acid and magnesia in other crystals belonging to one of the two crops from which crystals were measured gave the following indications of purity :—

0·4562 gram of crystals yielded 0·4320 gram of BaSO_4 , corresponding to 32·51 per cent. SO_3 . The calculated percentage of SO_3 in the salt is 32·36.

1·2105 gram of crystals yielded 0·2765 gram of $\text{Mg}_2\text{P}_2\text{O}_7$, corresponding to 8·23 per cent. of MgO . The calculated percentage of MgO in the salt is 8·09.

Habit: slightly tabular.

Axial angle: $\beta = 74^\circ 1'$.

Ratio of axes: $a : b : c = 0.7400 : 1 : 0.4975$.

Forms observed: $b = \{010\} \infty P \infty$; $c = \{001\} oP$; $p = \{110\} \infty P$;
 $q = \{011\} P \infty$; $o = \{111\} -P$; $o' = \{\bar{1}11\} +P$; $r' = \{\bar{2}01\} +2P \infty$.

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$\{as\} = 100 : 101$	—	—	—	45° 25'	—
$sc = 101 : 001$	—	—	—	28 36	—
$ac = 100 : 001$	—	—	—	74 1	—
$\{cs'\} = 001 : \bar{1}01$	—	—	—	38 25	—
$s'r' = 101 : \bar{2}01$	—	—	—	25 37	—
$cr' = 001 : \bar{2}01$	15	63° 50' — 64° 19'	64° 6'	64 2	4'
$r'a = \bar{2}01 : \bar{1}00$	—	—	—	41 57	—
$\{ap\} = 100 : 110$	—	—	—	35 26	—
$pp' = 110 : 120$	—	—	—	19 28	—
$p'b = 120 : 010$	—	—	—	35 6	—
$pb = 110 : 010$	18	54 20 — 54 52	54 34	54 34	0
$pp = 110 : \bar{1}\bar{1}0$	20	70 46 — 70 57	70 51	*	—
$pp = 110 : \bar{1}\bar{1}0$	19	109 3 — 109 14	109 8	109 9	1
$\{cq\} = 001 : 011$	40	25 30 — 25 41	25 35	*	—
$qb = 011 : 010$	18	64 18 — 64 29	64 25	64 25	0
$qq = 011 : 011$	20	128 43 — 128 54	128 49	128 50	1
$\{ao\} = 100 : 111$	—	—	—	48 35	—
$oq = 111 : 011$	1	—	27 6	27 2	4
$aq = 100 : 011$	—	—	—	75 37	—
$qo' = 011 : \bar{1}\bar{1}1$	28	34 33 — 34 54	34 44	34 40	4
$o'a = \bar{1}\bar{1}1 : \bar{1}00$	—	—	—	69 43	—
$\{co\} = 001 : 111$	4	33 55 — 34 24	34 8	34 9	1
$op = 111 : 110$	4	42 39 — 43 3	42 53	42 53	0
$cp = 001 : 110$	40	76 58 — 77 8	77 2	*	—
$po' = 110 : 11\bar{1}$	32	58 6 — 58 26	58 16	58 21	5
$o'c = 11\bar{1} : 00\bar{1}$	32	44 31 — 44 49	44 42	44 37	5
$\{bo\} = 010 : 111$	—	—	—	70 30	—
$os = 111 : 101$	—	—	—	19 30	—
$\{bo'\} = 010 : \bar{1}11$	9	65 15 — 65 29	65 19	65 18	1
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 42	—
$o'o' = \bar{1}11 : \bar{1}\bar{1}1$	6	49 20 — 49 29	49 24	49 24	0
$\{sq\} = 101 : 011$	—	—	—	37 38	—
$qp = 011 : \bar{1}10$	30	87 7 — 87 19	87 14	87 15	1
$ps = 110 : 10\bar{1}$	—	—	—	55 7	—
$\{s'q\} = \bar{1}01 : 011$	—	—	—	45 2	—
$qp = 011 : 110$	32	63 2 — 63 12	63 6	63 5	1
$ps' = 110 : 10\bar{1}$	—	—	—	71 53	—
$\{r'o'\} = \bar{2}01 : \bar{1}11$	30	34 51 — 35 9	35 0	35 0	0
$o'p = \bar{1}11 : 110$	30	92 14 — 92 33	92 22	92 18	4
$pr' = 110 : 20\bar{1}$	33	52 33 — 52 48	52 40	52 42	2

Total number of measurements, 461.

The disposition of the faces of the comparatively simple crystals of rubidium magnesium sulphate is more or less characteristic of the whole of the eight salts of the series which contain rubidium. A typical crystal is represented in Fig. 3. The habit is distinctly more tabular than in the case of the crystals of potassium magnesium sulphate, although the prism faces $p\{110\}$ are still very largely developed. The basal plane $c\{001\}$ is not, however, so largely the predominant end face as in the latter salt, the faces of the clinodome $q\{011\}$ now assuming greater importance, and tending to point the terminations of the axis b , and, consequently, to diminish the height of the clinopinacoid $b\{010\}$. The orthodome $r'\{\bar{2}01\}$ only attains a second-rate development, as indicated in the figure, but the faces of the hemipyramid $o'\{\bar{1}11\}$ attain larger dimensions in the crystals of this salt than in those of the analogous potassium salt. Moreover, in addition, the faces of the primary hemipyramid $o\{111\}$ were occasionally observed, although on only four occasions were sufficiently trustworthy reflections obtained. With the exception of this last form, irreproachable single images of the signal were usually afforded by the whole of the faces of the ten crystals measured.

The results of the measurements are exhibited in the table (p. 348).

The excellent nature of the faces of the crystals of this salt is evident from the close agreement of the observed and the calculated angles, and from the closeness of the limits between which the observed values fell. It will be at once noticed, on comparing these values with those of the potassium salt just described, that the differences between them are real, for in few cases do even the *limiting values*, which generally represent measurements between faces of a somewhat less degree of perfection than usual, approach each other; and in those cases where the differences are greatest, these limiting values in the two salts are far removed from each other.

Cæsium Magnesium Sulphate, $\text{Cs}_2\text{Mg}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

Cæsium magnesium sulphate crystallises well in clear, transparent, and very brilliant crystals, which frequently attain large dimensions. Eleven of the most perfect individuals were selected from three different crops. Ten of these were measured completely; the remaining one only afforded two zones of the same high standard of perfection, hence the other zones of this crystal were discarded.

Analyses of specimens from one of these crops yielded the following results:—

0·4583 gram of crystals gave 0·3660 gram of BaSO_4 , corresponding to 27·42 per cent. of SO_4 . The calculated percentage of SO_3 is 27·12.

0·6448 gram of crystals gave 0·1240 gram of $Mg_2P_2O_7$, corresponding to 6·93 per cent. of MgO . The calculated percentage of MgO is 6·78.

Habit: prismatic.

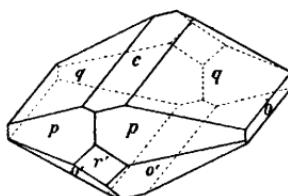
Axial angle: $\beta = 72^\circ 54'$.

Ratio of axes: $a:b:c = 0\cdot7279 : 1 : 0\cdot4946$.

Forms observed: $b = \{010\}_{\infty}\nparallel_{\infty}$; $c = \{001\}oP$; $p = \{110\}_{\infty}P$;
 $q = \{011\}\nparallel_{\infty}$; $o' = \{\bar{1}11\}+P$; $r' = \{\bar{2}01\}+2P_{\infty}$.

The crystals of cæsium magnesium sulphate differ considerably in appearance and habit from those of the potassium and rubidium salts. The prism $p\{110\}$ and the basal plane $c\{001\}$ are no longer the predominating planes. The basal plane is reduced to a mere strip, as shown in Fig. 4, and is not unfrequently absent altogether. The clinodome $q\{011\}$ is now the principal form, and is usually so largely developed that the crystals assume the form of long prisms, whose principal faces are those of q , as represented in Fig. 4. The acute

FIG. 4.



angle of the prism is modified as a rule by the clinopinacoid $b\{010\}$, while the terminations of the prism are formed by the faces of the prism $p\{110\}$ and hemipyramid $o'\{\bar{1}11\}$ more or less equally developed. The solid angle formed by the intersection of the two latter forms is generally truncated by the orthodome $r'\{\bar{2}01\}$. It not unfrequently happens, however, that the latter form is absent.

It is certainly of interest that the habitual geometrical form of the rubidium salt should be so markedly intermediate in character, as it has now been shown to be, between that of the potassium salt and that of the cæsium salt just described, and it will be hereafter seen that the same relationship obtains throughout the whole series.

The results of the measurements are set forth in the following table (p. 351).

The degree of agreement between the observed and calculated values is again satisfactory, and the same remarks apply to the differences between the rubidium and cæsium salts as were made with

respect to those between the potassium and rubidium salts. There can be no doubt, from the nature of the limiting values, that the differences between the mean observed values of the salts are real differences which are within a very few minutes, probably not exceeding three or four, in the large majority of the angles, of the truth.

Angle observed.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$\{as = 100 : 101$	—	—	—	44° 28'	—
$sc = 101 : 001$	—	—	—	28 26	—
$ac = 100 : 001$	—	—	—	72 54	—
$cs' = 001 : \bar{1}01$	—	—	—	39 3	—
$s'r' = 101 : \bar{2}01$	—	—	—	26 7	—
$cr' = 001 : \bar{2}01$	15	65° 9' — 65° 25'	65° 15'	65 10	5'
$r'a = 201 : \bar{1}00$	—	—	—	41 56	—
$\{ap = 100 : 110$	—	—	—	34 50	—
$pp' = 110 : 120$	—	—	—	19 28	—
$p'b = 120 : 010$	—	—	—	35 42	—
$pb = 110 : 010$	30	54 58 — 55 22	55 9	55 10	1
$pp = 110 : \bar{1}10$	20	69 22 — 69 50	69 40	*	—
$pp = 110 : 1\bar{1}0$	20	110 4 — 110 30	110 19	110 20	1
$\{cq = 001 : 011$	43	24 57 — 25 34	25 16	25 17	1
$qb = 011 : 010$	33	64 32 — 64 56	64 43	*	—
$qq = 011 : \bar{0}11$	19	129 15 — 129 40	129 27	129 26	1
$\{ao = 100 : 111$	—	—	—	47 35	—
$oq = 111 : 011$	—	—	—	27 0	—
$aq = 100 : 011$	—	—	—	74 35	—
$qo' = 011 : \bar{1}11$	32	35 9 — 35 34	35 22	35 17	5
$o'a = \bar{1}11 : \bar{1}00$	—	—	—	70 8	—
$\{co = 001 : 111$	—	—	—	33 49	—
$op = 111 : 110$	—	—	—	42 13	—
$cp = 001 : 110$	34	75 50 — 76 14	76 2	*	—
$po' = 110 : \bar{1}1\bar{1}$	36	58 35 — 59 7	58 47	58 52	5
$oc = 111 : 00\bar{1}$	31	44 54 — 45 25	45 12	45 6	6
$\{bo = 010 : 111$	—	—	—	70 53	—
$os = 111 : 101$	—	—	—	19 7	—
$\{bo' = 010 : \bar{1}11$	28	65 7 — 65 34	65 20	65 21	1
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 39	—
$o'o' = \bar{1}11 : \bar{1}\bar{1}1$	14	49 13 — 49 28	49 20	49 18	2
$\{sq = 101 : 011$	—	—	—	37 20	—
$qp = 011 : \bar{1}10$	35	88 26 — 88 41	88 34	88 32	2
$ps = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	54 8	—
$\{s'q = \bar{1}01 : 011$	—	—	—	45 24	—
$qp = 011 : 110$	37	62 19 — 62 38	62 29	62 28	1
$ps' = \bar{1}10 : 10\bar{1}$	—	—	—	72 8	—
$\{r'o' = \bar{2}01 : \bar{1}11$	31	35 5 — 35 34	35 19	35 18	1
$o'p = \bar{1}11 : 110$	36	92 5 — 92 36	92 24	92 20	4
$pr' = 110 : 20\bar{1}$	32	52 3 — 52 26	52 17	52 22	5

Total number of measurements, 526.

It will now be interesting to compare the angles of the potassium, rubidium, and caesium salts containing magnesium as the dyad metal with each other.

Comparison of the Angles of the three Salts containing Magnesium.

Angle.	Potassium salt.	Diff.	Rubidium salt.	Diff.	Cæsium salt.
{ $ac = 100 : 001 = \beta$	75° 12'	-71'	74° 1'	-67'	72° 54'
{ $as = 100 : 101$	46 8	-43	45 25	-57	44 28
{ $sc = 101 : 001$	29 4	—	28 36	—	28 26
{ $cr' = 001 : \bar{2}01$	63 17	+45	64 2	+68	65 10
{ $cs' = 001 : \bar{1}01$	38 12	—	38 25	—	39 3
{ $s'r' = 101 : 201$	25 5	+32	25 37	+30	26 7
{ $r'a = 201 : \bar{1}00$	41 31	—	41 57	—	41 56
{ $ap = 100 : 110$	35 38	-12	35 26	-36	34 50
{ $p\mu' = 110 : 120$	19 28	—	19 28	—	19 28
{ $p'b = 120 : 010$	34 54	+12	35 6	+36	35 42
{ $pb = 110 : 010$	54 22	—	54 34	—	55 10
{ $cq = 001 : 011$	25 48	-13	25 35	-18	25 17
{ $qb = 011 : 010$	64 12	—	64 25	—	64 43
{ $ao = 100 : 111$	49 18	-43	48 35	-60	47 35
{ $oq = 111 : 011$	27 24	—	27 2	—	27 0
{ $aq = 100 : 011$	76 42	-65	75 37	-62	74 35
{ $qo' = 011 : \bar{1}11$	34 27	—	34 40	—	35 17
{ $o'a = \bar{1}11 : \bar{1}00$	68 51	+52	69 48	+25	70 8
{ $co = 001 : 111$	34 41	-32	34 9	-20	33 49
{ $op = 111 : 110$	43 20	—	42 53	—	42 13
{ $cp = 001 : 110$	78 1	-59	77 2	-60	76 2
{ $p\mu' = 110 : 11\bar{1}$	57 35	—	58 21	—	58 52
{ $o'c = \bar{1}11 : 00\bar{1}$	44 24	+13	44 37	+29	45 6
{ $bo = 010 : 111$	70 12	+18	70 30	+23	70 53
{ $os = 111 : 101$	19 48	—	19 30	—	19 7
{ $bo' = 010 : \bar{1}11$	65 23	-5	65 18	+3	65 21
{ $o's' = \bar{1}11 : \bar{1}01$	24 37	—	24 42	—	24 39
{ $sq = 101 : 011$	88 6	-28	87 38	-18	87 20
{ $qp = 011 : \bar{1}10$	86 11	+64	87 15	+77	88 32
{ $ps = 110 : 10\bar{1}$	55 43	—	55 7	—	54 8
{ $s'q = \bar{1}01 : 011$	44 58	—	45 2	—	45 24
{ $qp = 011 : 110$	63 52	-47	63 5	-37	62 28
{ $ps' = 110 : 10\bar{1}$	71 10	+43	71 53	+15	72 8
{ $r'o' = \bar{2}01 : \bar{1}11$	34 35	+25	35 0	+18	35 18
{ $o'p = \bar{1}11 : 110$	92 54	—	92 18	—	92 20
{ $pr' = 110 : 20\bar{1}$	52 31	+11	52 42	-20	52 22

Inasmuch as the mean observed and calculated angles lie so close to each other, it is of little moment which are employed in making the comparison. The calculated values are employed in the above and all subsequent tables of comparison, as it is likely that these, being derived from the three best measured angles, are nearer the

truth in a few cases, where the angles are those formed by faces usually of a lower degree of excellence.

The angles printed in bolder type are the primary determinative angles of each zone, the remaining angles of the same zones following necessarily from them. The differences between these primary angles are given, expressed in minutes, the sign being positive when an increase of the angle occurs, and negative when a decrease is observed.

The most important of all the angles of crystals belonging to the monoclinic system of symmetry is usually considered to be that which determines the inclination of the one inclined axis a to the vertical axis c . This angle is conveniently termed the axial angle, and is represented by the symbol β , the angles α and γ between the vertical axis c and the rectangular axis b , and between the inclined axis a and the rectangular axis b , being right angles in the monoclinic system.

Upon comparing the values of this fundamental angle β given in the above table for the salts containing potassium, rubidium, and cæsium respectively, the following facts are observed :—

The difference between the values of β in the salts containing potassium and rubidium is $1^\circ 11'$, or $71'$; that between the values of β in the rubidium and cæsium salts is $1^\circ 7'$, or $67'$. These differences are approximately equal, for the $4'$ discrepancy falls within the limits of possible error in the determinations. Hence it may be stated that :—

1. *The value of the axial angle β in the rubidium salt is approximately midway between the values of the axial angles of the potassium and cæsium salts.*

The difference between the atomic weights of potassium (39) and rubidium (85) is 46; that between rubidium and cæsium (133) is 48; that is, the differences of the atomic weights are approximately equal. Hence, if the change in the inclination of the inclined to the vertical axis is directly proportional to the change in atomic weight, the amount of change brought about by substituting rubidium for potassium should be approximately equal to that produced by substituting cæsium for rubidium; or, in other words, the value of β exhibited by the rubidium salt should be approximately half way between the values of β in the potassium and cæsium salts respectively. As this has been shown to be the case, it may be further stated that :—

2. *The relative amounts of change brought about in the axial angle by replacing the alkali metal potassium by rubidium, and the rubidium in turn by cæsium, are approximately directly proportional to the relative differences in the atomic weights of the metals interchanged.*

It is likewise worthy of note that, as the angles given in the table

are, in accordance with convenient usage, the goniometrical angles between the normals to the faces of the crystals, the real angle between the vertical and inclined axes, which is directly in front of one in contemplating the crystals as given in the drawings, is the obtuse angle supplementary to the angle β given in the table. The real values of the axial angle in the potassium, rubidium, and caesium salts will therefore be $104^\circ 48'$, $105^\circ 59'$, and $107^\circ 6'$ respectively. That is :—

3. *The axial angle increases with the increase in the atomic weight of the alkali metal.*

As the axial angle is that included between the traces of the basal plane $c(001)$ and orthopinacoid $a(100)$ upon the plane of symmetry $b(010)$, the outward evidence of the operation of the above rule is the increase in the tilt of the basal plane towards the orthopinacoid as the metal of greater atomic weight is introduced.

Turning our attention now to the remaining angles, all of which are compared in the table, it will be further noticed that out of the 36 angles compared, 31 of the angles of the rubidium salt lie between the values of the corresponding angles of the potassium and caesium salts. The remaining five are cases where, owing to the change in adjacent angles of the same or neighbouring zones being of opposite sign, more or less neutrality is produced. The first case, $r'a$, is owing to the changes in the supplementary angles of the same zone [acr'] being of opposite signs. The next two cases, bo' and $o's'$, lie upon a zone of practical neutrality, and the differences are so small that they may be left out of consideration, being about the limits of possible error. The last two cases, $o'p$ and pr' , belong to a secondary cross zone [$po'r'$], where the angles are the resultants of the changes of varying sign in the values of the surrounding primary angles; it will be shown later, in other salts of the series, that sometimes the angles of this zone follow the rule, and sometimes not, and very frequently the values are so near together that the differences are within, or approach, the limits of error.

Of the 22 determinative angles printed in bolder type, 20 follow the rule; in one of the two exceptions, bo' , the differences are too small to be certain about, and the other exception, pr' , belongs to the secondary zone just referred to. It may therefore be stated that :—

4. *The values of all the angles of the rubidium salt lie between the corresponding values of the potassium and caesium salts, except in very rare cases, where more or less neutrality is produced owing to the changes in adjacent angles being of opposite sign.*

The rule of direct proportionality which applies in the case of the axial angle β does not apply in the cases of most of the other primary angles. Indeed, it is an interesting fact, which may, perhaps, be of use

hereafter in studying the influence of atomic weight in modifying the molecular forces which give rise to the geometrical conformations of crystallised substances, that the maximum deviation from direct proportionality is observed in the prism zone $[apb]$ at right angles to that $[acr']$ containing the axial angle (that is, containing the basal plane and orthopinacoid, and conveniently termed the "primitive" zone, because forming the primitive circle of the spherical projection). In this case, three times the change in the value of the angle ap , between the orthopinacoid and the primary prism faces, is observed on replacing rubidium by the heavy cæsium atom, as compared with that produced on replacing the light potassium by rubidium, the differences being $12'$ and $36'$ respectively. The differences in the zones adjacent to the primitive zone and furthest removed from the prism zone approach more nearly to the rule of direct proportionality. Thus the differences between the three values of cp , lying in the zone $[cop]$ next adjacent, and very near to the primitive zone, are actually in direct simple proportion, being $59'$ and $60'$ respectively. The differences in the case of aq upon another zone $[aoq]$ very near the primitive zone are $65'$ and $62'$ respectively. In the case of cq , nearly equally removed from both the primitive and prism zones, the differences are $13'$ and $18'$.

Hence it may be stated that:—

5. *The relative amounts of change in the angles other than the axial angle are rarely in direct simple proportion to the changes in atomic weight. The maximum deviation from direct proportionality occurs in the prism zone at right angles to the zone containing the basal plane and orthopinacoid, and the relative amounts of change here bear the ratio of one to three.*

One further fact must be noted concerning the angular differences.

6. *The magnitude of the differences between most of the angular values of the three salts is surprisingly large, exceeding a whole degree in the cases of several important angles, and indicates a preponderating influence on the part of the alkali metals in determining the geometrical form of these double salts.*

It will be interesting, in conclusion, to compare the axial ratios of the three salts. They are as follows:—

Potassium magnesium sulphate	$a : b : c = 0\cdot7413 : 1 : 0\cdot4993$	
Rubidium	$"$	$a : b : c = 0\cdot7400 : 1 : 0\cdot4975$
Cæsium	$"$	$a : b : c = 0\cdot7279 : 1 : 0\cdot4946$

It is at once apparent that, although the ratios of the rubidium salt stand between those of the potassium and cæsium salts, the changes are only of a slight character. The cause of this is not far to seek, and the author has long been of opinion that, for the reasons now

given, differences in the axial ratios of crystals belonging to the systems of lesser symmetry afford by no means such valuable indications of the effect of change of composition, especially in isomorphous series, as do the angles themselves. Consider, for instance, the ratio of the length of the axis a to that of b . This ratio is most conveniently calculated from the formula $a/b = \tan \theta$, where $\cos \theta = \cot cp \tan ac$.

Now the two angles cp and ac , which are employed in calculating θ , both diminish on the passage from the potassium to the caesium salt. But the cotangent increases with diminution of the angle, while the tangent diminishes: hence the increase of the one is more or less neutralised by the diminution of the other, and so the value of θ , and consequently of a/b , is not very materially changed. This will perhaps be more readily understood by a reference to the crystal itself. The plane which determines the relative lengths of the axes a and b is the face of the prism $p\{110\}$. On the passage from the potassium to the caesium salt, the internal inclination of this plane to the clinopinacoid $b\{010\}$, and hence to the axis a , diminishes, causing the length of that axis to become less in proportion to that of b ; that is to say, the ratio a/b diminishes. But at the same time the internal inclination of the basal plane to the orthopinacoid, and therefore that of the axis a (the inclined axis) to the vertical axis c , is increasing; this movement of the axis a causes the length of that axis intercepted by the plane p to increase, and as the symmetry axis b remains fixed at 90° , the effect is to cause an increase in the ratio a/b . It is only the difference, therefore, of these two opposing influences which is effectual in altering the axial ratios. A similar explanation holds in the case of the ratio c/b . Hence:—

7. *No indication of the full nature of the change brought about on replacing one metal by another in this isomorphous series is afforded by a comparison of the axial ratios, as simultaneous changes, which more or less neutralise each other, occur in the inclinations of the planes which determine them. The angles themselves alone furnish complete information concerning the change of external form.*

Salts containing Zinc.



Twelve crystals of this beautiful salt, selected from five different crops, were measured. Ten of these were excellent in all respects, and were measured as completely as their development would permit. Of the remaining two, only certain well-formed zones were measured; the other zones were less perfect, and were consequently discarded.

Analyses of a quantity of the crystals belonging to one of these crops yielded the following results:—

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0·7868 gram of crystals yielded 0·8215 gram BaSO₄, corresponding to 35·85 per cent. of SO₃. Calculated percentage of SO₃, 36·12. 0·7593 gram of crystals gave 0·1400 gram ZnO, corresponding to 18·44 per cent. of ZnO. Calculated percentage of ZnO, 18·28.

Habit: short prismatic.

Axial angle: $\beta = 75^\circ 12'$.

Ratio of axes: $a : b : c = 0\cdot7413 : 1 : 0\cdot5044$.

Forms observed: $b = \{010\}_{\infty}P_{\infty}$; $c = \{001\}oP$; $p = \{110\}_{\infty}P$; $p' = \{120\}_{\infty}P_2$; $q = \{011\}P_{\infty}$; $o' = \{\bar{1}11\}+P$; $r' = \{\bar{2}01\}+2P_{\infty}$.

In many of the crops of potassium zinc sulphate obtained, the crystals were remarkably simple, consisting, as shown in Fig. 5, of only a few forms. They usually assumed the form of stout, colourless, transparent prisms formed by the faces of the primary prism $p\{110\}$ and the basal plane $c\{001\}$, and slightly modified, as in the crystals of potassium magnesium sulphate, by the faces of the clinodome $q\{011\}$. The reflections yielded by all these brilliant faces

FIG. 5.

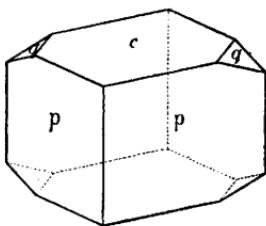
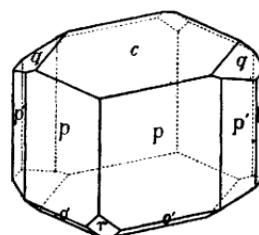


FIG. 6.



were irreproachable. The clinopinacoid $b\{010\}$ was usually present, but narrow, and frequently a mere line; the reflections from this form, when visible, were, however, uniformly good.

In other crops more forms were present, as represented in Fig. 6, but the habit was very similar. In many crystals of these crops, however, the prismatic form $p'\{120\}$ assumed considerable importance, sometimes equalling in development the faces of the primary prism itself. The images of the signal yielded by the faces of this second prism form were, moreover, particularly clear and definite. The orthodome $r'\{\bar{2}01\}$ was generally small, but brilliant. The hemipyramid $o'\{\bar{1}11\}$ was only occasionally developed, and still more rarely were the images yielded by it good.

In the following table are given the results of the measurements:—

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Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$\{as = 100 : 101$	—	—	—	45° 56'	—
$sc = 101 : 001$	—	—	—	29 16	—
$ac = 100 : 001$	—	—	—	75 12	—
$cs' = 001 : \bar{1}01$	—	—	—	38 32	—
$s'r' = 101 : \bar{2}01$	—	—	—	25 6	—
$cr' = 001 : 201$	12	63° 34' — 63° 42'	63° 38'	63 38	0'
$r'a = 201 : \bar{1}00$	—	—	—	41 10	—
$\{ap = 100 : 110$	—	—	—	35 37	—
$pp' = 110 : 120$	18	19 18 — 19 35	19 23	19 28	5
$p'b = 120 : 010$	11	34 50 — 35 5	34 58	34 55	3
$p'b = 110 : 010$	24	54 15 — 54 32	54 23	54 23	0
$pp = 110 : \bar{1}\bar{1}0$	24	71 8 — 71 26	71 14	*	—
$pp = 110 : \bar{1}10$	24	108 36 — 108 53	108 46	108 46	0
$\{cq = 001 : 011$	45	25 38 — 26 14	25 57	25 58	1
$qb = 011 : 010$	24	63 56 — 64 14	64 2	*	—
$qq = 011 : 0\bar{1}1$	20	127 56 — 128 28	128 6	128 4	2
$\{ao = 100 : 111$	—	—	—	49 10	—
$oq = 111 : 011$	—	—	—	27 34	—
$aq = 100 : 011$	—	—	—	76 44	—
$qo' = 011 : \bar{1}11$	3	34 35 — 34 45	34 40	34 42	2
$o'a = \bar{1}11 : \bar{1}00$	—	—	—	68 34	—
$\{co = 001 : 111$	—	—	—	34 54	—
$op = 111 : 110$	—	—	—	43 7	—
$cp = 001 : 110$	42	77 55 — 78 9	78 1	*	—
$po' = 110 : \bar{1}\bar{1}1$	7	57 6 — 57 38	57 18	57 14	4
$o'c = 111 : 001$	7	44 23 — 44 51	44 41	44 45	4
$\{bo = 010 : 111$	—	—	—	70 5	—
$os = 111 : 101$	—	—	—	19 55	—
$\{bo' = 010 : \bar{1}11$	1	—	65 16	65 13	3
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 47	—
$o'o' = \bar{1}11 : \bar{1}\bar{1}1$	—	—	—	49 34	—
$\{sq = 101 : 011$	—	—	—	38 21	—
$qp = 011 : \bar{1}10$	36	86 0 — 86 13	86 5	86 5	0
$ps = \bar{1}10 : 10\bar{1}$	—	—	—	55 34	—
$\{s'q = \bar{1}01 : 011$	—	—	—	45 19	—
$qp = 011 : 110$	35	63 43 — 63 57	63 49	63 47	2
$ps' = 110 : 10\bar{1}$	—	—	—	70 54	—
$\{r'o' = \bar{2}01 : \bar{1}11$	3	34 43 — 34 56	34 48	34 42	6
$o'p = \bar{1}11 : 110$	3	92 46 — 93 4	92 57	93 2	5
$pr' = 110 : 20\bar{1}$	21	52 11 — 52 22	52 15	52 16	1

Total number of measurements, 360.

A few previous measurements of crystals of this salt have been made by Rammelsberg and Teschemacher. The axial ratios given by the former observer in his *Krystallographisch-physikalischen Chemie*, are $a : b : c = 0.7446 : 1 : 0.5098$. About half of the values of the very small number of angles measured fall within the limits above given; the others are just outside.

Rubidium Zinc Sulphate, Rb₂Zn(SO₄)₂.6H₂O.

Rubidium zinc sulphate crystallises well, in individuals frequently attaining large size, and somewhat resembling in appearance the crystals of the potassium salt just described. Ten excellent specimens of suitable small size were selected for measurement from four distinct crops. Analyses of similar specimens from one of the crops yielded the following results :—

1·0740 gram of crystals gave 0·9300 gram of BaSO₄, corresponding to 29·73 per cent. of SO₃. The calculated percentage of SO₃ is 29·91.

0·8805 gram of crystals gave 0·1325 gram of ZnO, corresponding to 15·05 per cent. of ZnO. The calculated percentage of ZnO is 15·14.

Habit: tabular in certain crops, and short prismatic in others.

Axial angle: $\beta = 74^\circ 7'$.

Ratio of axes: $a : b : c = 0\cdot7373 : 1 : 0\cdot5011$.

Forms observed: $a = \{100\}_{\infty}P_{\infty}$; $b = \{010\}_{\infty}P_{\infty}$; $c = \{001\}_oP$; $p = \{110\}_{\infty}P$; $p' = \{120\}_{\infty}P_2$; $q = \{011\}R_{\infty}$; $o = \{111\}-P$; $o' = \{\bar{1}\bar{1}\bar{1}\}+P$; $r' = \{\bar{2}01\}+2P_{\infty}$; $n = \{121\}-2P_2$.

FIG. 7.

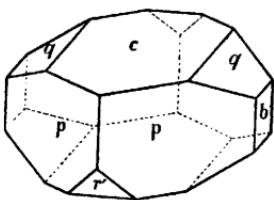
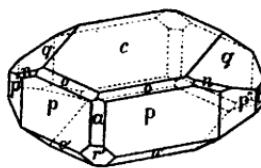


FIG. 8.



In habit, the crystals of rubidium zinc sulphate closely resemble those of potassium zinc sulphate, the primary prism $p\{110\}$ and basal plane $c\{001\}$ being generally the most largely developed forms. The faces of the basal plane are, however, usually relatively smaller in the rubidium than in the potassium salt, the faces of the clinodome $q\{011\}$ being larger in proportion. As shown in Fig. 7, the orthodome $r'\{\bar{2}01\}$ and the clinopinacoid $b\{010\}$ are also present, and are usually more largely developed than in case of the crystals of the potassium salt. The images afforded by all these forms on the crystals measured were uniformly good, being for the most part brilliant and single.

In certain crops, the crystals exhibited a more or less tabular habit, as shown in Fig. 8, owing to a shortening of the faces of the prism

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zone. The faces of the hemipyramid $o'\{1\bar{1}1\}$ were not always present, and when developed were more distorted than usual, affording images much below the average of those yielded by the other forms.

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
{ $as = 100 : 101$	—	—	—	45° 16'	—
$sc = 101 : 001$	—	—	—	28 51	—
$ac = 100 : 001$	—	—	—	74 7	—
$cs' = 001 : \bar{1}01$	—	—	—	38 45	—
$s'r' = \bar{1}01 : 201$	—	—	—	25 35	—
$cr' = 001 : 201$	17	64° 7' — 64° 25'	64° 18'	64 20	2'
$r'a = 201 : \bar{1}00$	—	—	—	41 33	—
{ $ap = 100 : 110$	8	35 15 — 35 28	35 22	*	—
$pp' = 110 : 120$	3	19 23 — 19 39	19 33	19 28	5
$p'b = 120 : 010$	1	—	35 16	35 10	6
$p\bar{b} = 110 : 010$	28	54 26 — 54 46	54 38	54 38	0
$pp = 110 : \bar{1}10$	20	70 41 — 70 49	70 44	70 44	0
$pp = 110 : 1\bar{1}0$	20	109 10 — 109 19	109 16	109 16	0
{ $cq = 001 : 011$	40	25 35 — 25 51	25 44	*	—
$qb = 011 : 010$	28	64 9 — 64 22	64 15	64 16	1
$qq = 011 : 0\bar{1}1$	20	128 24 — 128 39	128 31	128 32	1
{ $ao = 100 : 111$	3	48 23 — 48 30	48 27	48 27	0
$oq = 111 : 011$	3	27 9 — 27 23	27 17	27 17	0
$aq = 100 : 011$	3	75 39 — 75 46	75 43	75 44	1
$g'o' = 011 : \bar{1}11$	7	34 53 — 35 6	34 58	34 55	3
$o'a = \bar{1}11 : \bar{1}00$	2	69 14 — 69 19	69 17	69 21	4
{ $co = 001 : 111$	6	34 18 — 34 29	34 23	34 24	1
$op = 111 : 110$	6	42 40 — 42 49	42 43	42 42	1
$cp = 001 : 110$	40	77 0 — 77 13	77 6	*	—
$po' = 110 : 1\bar{1}\bar{1}$	15	57 43 — 58 2	57 52	57 59	7
$o'c = \bar{1}1\bar{1} : 00\bar{1}$	15	44 51 — 45 12	45 2	44 55	7
{ $bn = 010 : 121$	—	—	—	54 33	—
$no = 121 : 111$	—	—	—	15 51	—
$bo = 010 : 111$	—	—	—	70 24	—
$os = 111 : 101$	—	—	—	19 36	—
{ $bo' = 010 : \bar{1}11$	5	64 53 — 65 24	65 9	65 13	4
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 47	—
$o'o' = \bar{1}11 : \bar{1}11$	—	—	—	49 34	—
{ $sq = 101 : 011$	—	—	—	37 54	—
$qp = 011 : \bar{1}10$	40	87 1 — 87 12	87 6	87 7	1
$ps = 110 : 10\bar{1}$	—	—	—	54 59	—
{ $s'q = \bar{1}01 : 011$	—	—	—	45 22	—
$qn = 011 : 121$	4	26 25 — 26 39	26 35	26 33	2
$np = 121 : 110$	4	36 25 — 36 41	36 33	36 33	0
$qp = 011 : 110$	40	63 2 — 63 12	63 6	63 6	0
$ps' = 110 : 10\bar{1}$	—	—	—	71 32	—
{ $r'o' = \bar{2}01 : \bar{1}11$	11	34 51 — 35 1	34 57	35 1	4
$o'p = \bar{1}11 : 110$	12	92 31 — 92 41	92 36	92 36	0
$pr' = 110 : 20\bar{1}$	30	52 19 — 52 32	52 25	52 23	2

Total number of measurements, 431.

In a few crystals of this type the orthopinacoid $a\{100\}$ was present, although narrow. The prismatic form $p'\{120\}$ was likewise occasionally observed. In addition to these forms, two others of much rarer occurrence were discovered upon one or two of the crystals measured, viz., the primary hemipyramid $o\{111\}$ and the hemipyramid $n\{121\}$. In every case the reflections obtained from these rarer faces were good.

The table on p. 360 gives the measurements.

Cæsium Zinc Sulphate, $\text{Cs}_2\text{Zn}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

This salt is one of the finest of the whole series, crystallising readily from solutions containing equal molecular proportions of the two constituent sulphates in brilliant, colourless, transparent crystals, which usually take the form of flattened prisms; they frequently attain to very large size, and possess a high specific gravity.

Twelve crystals were employed in the measurements, 10 of which were excellent throughout, and were measured completely; of the remaining two, only certain zones were measured, the other zones being less perfect. These crystals were selected from five different crops. Analyses of specimens belonging to one of these crops gave the following numbers:—

0·6595 gram of crystals gave 0·4895 gram of BaSO_4 , corresponding to 25·48 per cent. of SO_3 . The calculated percentage of SO_3 is 25·36.

0·9015 gram of crystals gave 0·1165 gram of ZnO , corresponding to 12·92 per cent. of ZnO . The calculated percentage of ZnO is 12·84.

Habit: flattened prismatic.

Axial angle: $\beta = 72^\circ 59'$.

Ratio of axes: $a : b : c = 0\cdot7274 : 1 : 0\cdot4960$.

Forms observed: $b = \{010\}_{\infty}\text{P}_{\infty}$; $c = \{001\}_o\text{P}$; $p = \{110\}_{\infty}\text{P}$; $q = \{011\}_{\infty}\text{P}_{\infty}$; $o' = \{\bar{1}11\} + \text{P}$; $r' = \{\bar{2}01\} + 2\text{P}_{\infty}$; $n' = \{\bar{1}21\} + 2\text{P}_2$.

Cæsium zinc sulphate differs considerably in habit from potassium and rubidium zinc sulphates, as will be seen on comparison of Figs. 9 and 10 (p. 362) with the figures representing the crystals of the two latter salts. Owing to the comparatively lesser development of the faces of the prism $p\{110\}$, the clinodome $q\{011\}$ and the basal plane are the principal faces, and give to the crystals their flattened prismatic habit. The faces of the basal plane vary considerably in different

crops, sometimes slightly predominating as in Fig. 9, but much more frequently being reduced to narrow strips, as represented in Fig. 10. Indeed, the same general tendency for a preponderating development of the basal plane in the potassium salt, an intermediate development of it in the rubidium salt, and a habit of becoming reduced to a narrow strip in the cæsium salt, has been observed in the zinc salts, as was noticed in the cases of the three salts containing magnesium. In the cæsium zinc salt, it was further noticed that when their breadth became considerable the faces of the basal plane usually exhibited more or less curvature; in the specimens selected for measurement, however, single reflections were the rule. The faces of the clinodome $q\{011\}$ usually gave magnificent reflections, and were frequently the predominating planes. The prism faces $p\{110\}$ also yielded particularly good reflections. The faces of the hemipyramid $o'\{\bar{1}11\}$ were frequently developed to the same extent as those of the prism, but rarely gave such perfect reflections. The orthodome $r'\{\bar{2}01\}$ was usually developed to about the extent shown in the figures. The clinopinacoid $b\{010\}$ was not always present, and when developed

FIG. 9.

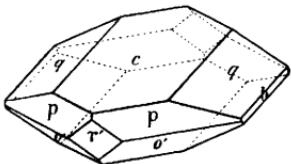
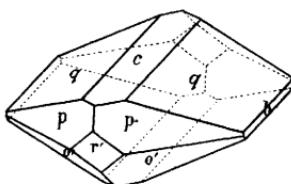


FIG. 10.



was small, but gave definite reflections. In one of the crystals measured the hemipyramid $n'\{\bar{1}21\}$ was developed, but the reflections were too much affected by striation to afford trustworthy values.

The angular measurements obtained are given in the table, p. 363.

In the same manner as in the case of the three salts containing magnesium, a comparison will now be made of the potassium, rubidium, and cæsium salts containing zinc as the second metal. It will be seen from the differences exhibited in the table, p. 364, that the rules established in the case of the three salts containing magnesium as the second metal are followed even more implicitly in the zinc salts.

The value of the axial angle β is again in the case of rubidium zinc sulphate midway between the values of the same angle in the potassium and cæsium salts; hence the differences ($65'$ and $68'$) are again directly proportional to the change in atomic weight.

Out of the remaining 35 angles, no less than 32 follow the rule

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
{ $as = 100 : 101$	—	—	—	44° 28'	—
$sc = 101 : 001$	—	—	—	28 31	—
$ac = 100 : 001$	—	—	—	72 59	—
$cs' = 001 : \bar{1}01$	—	—	—	39 9	—
$s'r' = \bar{1}01 : 201$	—	—	—	26 6	—
$cr' = 001 : 201$	18	65° 10' — 65° 20'	65° 17'	65 15	2°
$r'a = \bar{2}01 : \bar{1}00$	—	—	—	41 46	—
{ $ap = 100 : 110$	—	—	—	34 51	—
$pp' = 110 : 120$	—	—	—	19 28	—
$p'b = 120 : 010$	—	—	—	35 41	—
$p'b = 110 : 010$	16	55 3 — 55 15	55 9	55 9	0
$pp = 110 : \bar{1}10$	24	69 36 — 69 58	69 43	* —	—
$pp = 110 : \bar{1}10$	24	110 0 — 110 26	110 17	110 17	0
{ $cq = 001 : 011$	45	25 3 — 25 46	25 23	* —	—
$qb = 011 : 010$	12	64 23 — 64 56	64 36	64 37	1
$qq = 011 : 0\bar{1}1$	23	129 2 — 129 28	129 13	129 14	1
{ $ao = 100 : 111$	—	—	—	47 37	—
$og = 111 : 011$	—	—	—	27 3	—
$aq = 100 : 011$	—	—	—	74 40	—
$qo' = 011 : \bar{1}11$	31	35 14 — 35 39	35 26	35 21	5
$o'a = \bar{1}11 : \bar{1}00$	—	—	—	69 59	—
{ $co = 001 : 111$	—	—	—	33 54	—
$op = 111 : 110$	—	—	—	42 12	—
$cp = 001 : 110$	40	75 49 — 76 25	76 6	* —	—
$po' = 110 : \bar{1}11$	36	58 14 — 58 54	58 34	58 42	8
$o'c = \bar{1}11 : 00\bar{1}$	36	45 3 — 45 37	45 19	45 12	7
{ $bo = 010 : 111$	—	—	—	70 51	—
$os = 111 : 101$	—	—	—	19 9	—
{ $bo' = 010 : \bar{1}11$	11	65 4 — 65 31	65 17	65 19	2
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 41	—
$o'o' = \bar{1}11 : \bar{1}11$	12	49 19 — 49 34	49 25	49 22	3
{ $sq = 101 : 011$	—	—	—	37 27	—
$qp = 011 : \bar{1}10$	40	88 12 — 88 39	88 23	88 24	1
$ps = \bar{1}10 : 0\bar{1}1$	—	—	—	54 9	—
{ $s'q = \bar{1}01 : 011$	—	—	—	45 31	—
$qp = 011 : 110$	41	62 19 — 62 44	62 34	62 29	5
$ps' = \bar{1}10 : 10\bar{1}$	—	—	—	72 0	—
$r'o' = \bar{2}01 : \bar{1}11$	20	35 7 — 35 31	35 18	35 19	1
$o'p = \bar{1}11 : 110$	21	92 23 — 92 39	92 30	92 25	5
$pr' = 110 : 20\bar{1}$	24	52 4 — 52 18	52 10	52 16	6

Total number of measurements, 469.

that the values of the angles in the rubidium salt lie between the values of the corresponding angles in the potassium and caesium salts. Two of the three exceptions occur, as in the magnesium salts, in the angles bo' and $o's'$ lying on the zone of approximate neutrality; and the third, pr' , likewise an exception in the magnesium salts, belongs to the secondary zone referred to in discussing the latter salts.

Comparison of the Angles of the three Salts containing Zinc.

Angle.	Potassium salt.	Diff.	Rubidium salt.	Diff.	Cæsium salt.
{ $ac = 100 : 001 = \beta$	75° 12'	-65'	74° 7'	-68'	72° 59'
{ $as = 100 : 101$	45 56	-40	45 16	-48	44 28
{ $sc = 101 : 001$	29 16	—	28 51	—	28 31
{ $cr' = 001 : \bar{2}01$	63 38	+42	64 20	+55	65 15
{ $cs' = 001 : \bar{1}01$	38 32	—	38 45	—	39 9
{ $s'r' = 101 : \bar{2}01$	25 6	+29	25 35	+31	26 6
{ $r'a = \bar{2}01 : 100$	41 10	—	41 33	—	41 46
{ $ap = 100 : 110$	85 37	-15	35 22	-31	34 51
{ $pp' = 110 : 120$	19 28	—	19 28	—	19 28
{ $p'b = 120 : 010$	34 55	+15	35 10	+31	35 41
{ $pb = 110 : 010$	54 23	—	54 38	—	55 9
{ $cq = 001 : 011$	25 58	-14	25 44	-21	25 23
{ $qb = 011 : 010$	64 2	—	64 16	—	64 37
{ $ao = 100 : 111$	49 10	-43	48 27	-50	47 37
{ $oq = 111 : 011$	27 34	—	27 17	—	27 3
{ $aq = 100 : 011$	76 44	-60	75 44	-64	74 40
{ $qo' = 011 : \bar{1}11$	34 42	—	34 55	—	35 21
{ $o'a = \bar{1}11 : 100$	68 34	+47	69 21	+38	69 59
{ $co = 001 : 111$	34 54	-30	34 24	-30	33 54
{ $op = 111 : 110$	43 7	—	42 42	—	42 12
{ $cp = 001 : 110$	78 1	-55	77 6	-60	76 6
{ $po' = 110 : \bar{1}1\bar{1}$	57 14	—	57 59	—	58 42
{ $o'c = 11\bar{1} : 00\bar{1}$	44 45	+10	44 55	+17	45 12
{ $bo = 010 : 111$	70 5	+19	70 24	+27	70 51
{ $os = 111 : 101$	19 55	—	19 36	—	19 9
{ $bo' = 010 : \bar{1}11$	65 18	0	65 18	+6	65 19
{ $o's' = \bar{1}11 : \bar{1}01$	24 47	—	24 47	—	24 41
{ $sq = 101 : 011$	38 21	-27	37 54	-27	37 27
{ $qp = 011 : \bar{1}10$	86 5	+62	87 7	+77	88 24
{ $ps = \bar{1}10 : \bar{1}01$	55 34	—	54 59	—	54 9
{ $s'q = \bar{1}01 : 011$	45 19	—	45 22	—	45 31
{ $qp' = 011 : \bar{1}10$	63 47	-41	63 6	-37	62 29
{ $ps' = \bar{1}10 : 10\bar{1}$	70 54	+38	71 32	+28	72 0
{ $r'o' = \bar{2}01 : \bar{1}11$	34 42	+19	35 1	+18	35 19
{ $o'p = \bar{1}11 : 110$	93 2	—	92 36	—	92 25
{ $pr' = 110 : 20\bar{1}$	52 16	+ 7	52 23	- 7	52 16

Moreover, the differences in all three exceptions approach the limits of error, varying as they do only from 0° to 7°.

Again, the maximum deviation from direct simple proportionality occurs in the prism zone. The relative amounts of change in the angles ap and pb of this zone in case of the zinc salts bear the ratio of one to two, the difference between the potassium and rubidium salts being 15', and between the rubidium and cæsium salts 31'.

The changes in the axial ratios are again very slight, from the cause previously stated:—

In potassium zinc sulphate...	$a : b : c = 0\cdot7413 : 1 : 0\cdot5044$
„ rubidium „ „ „	$a : b : c = 0\cdot7373 : 1 : 0\cdot5011$
„ caesium „ „ „	$a : b : c = 0\cdot7274 : 1 : 0\cdot4960$

And although the ratios of the rubidium salt stand between the ratios of the potassium and caesium salts, still the actual differences are so slight that no deductions drawn from them can be regarded as possessing the same value as those derived from a comparison of the angles themselves.

Salts containing Iron.

Potassium Ferrous Sulphate, $K_2Fe(SO_4)_2 \cdot 6H_2O$.

Excellent crystals of this well known salt were obtained by slow crystallisation over oil of vitriol in a vacuum. They are liable to somewhat rapid efflorescence, and were therefore measured as soon after removal from the mother liquor as possible. Ten particularly fine crystals from four distinct crops were selected for measurement. They were perfectly clear and transparent, of a pale green colour, and exhibited very brilliant faces.

Analyses of specimens taken from one of the crops from which crystals were measured gave the following results:—

0·8657 gram of crystals gave 0·9240 gram of $BaSO_4$, corresponding to 36·65 per cent. of SO_3 . The calculated percentage of SO_3 is 36·87.

1·4250 gram of crystals gave 0·2645 gram of Fe_2O_3 , corresponding to 16·70 per cent. of FeO . The calculated percentage of FeO is 16·59.

Habit: tabular in certain crops and short prismatic in others.

Axial angle: $\beta = 75^\circ 28'$.

Ratio of axes: $a : b : c = 0\cdot7377 : 1 : 0\cdot5020$.

Forms observed: $a = \{100\} \infty P \infty$; $b = \{010\} \infty P \infty$; $c = \{001\} oP$;
 $p = \{110\} \infty P$; $p' = \{120\} \infty P 2$; $q = \{011\} P \infty$; $o = \{111\} - P$;
 $o' = \{\bar{1}11\} + P$; $r' = \{\bar{2}01\} + 2P \infty$; $n' = \{\bar{1}21\} + 2P 2$.

In the crystals of potassium ferrous sulphate examined, the faces of the basal plane $c\{001\}$ were usually the predominating planes, as represented in Fig. 11 (p. 367), and gave to the crystals their tabular habit. The prism faces $p\{110\}$ came next in importance, and the images of the signal afforded by them were particularly brilliant and sharply defined. The faces of the clinodome $q\{011\}$, as in most of the salts of the series containing potassium, were generally small, but yielded good reflections. In certain crops, however, the faces of the clino-

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dome assumed greater relative importance, as shown in Fig. 12; in these crops the orthodome $\{ \bar{2}01 \}$ was frequently developed to an extent not observed in any of the salts containing magnesium and

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$as = 100 : 101$	—	—	—	46° 9'	—
$sc = 101 : 001$	—	—	—	29 19	—
$ac = 100 : 001$	16	75° 23' — 75° 32'	75° 28'	75 28	0'
$cv' = 001 : \bar{1}01$	—	—	—	38 23	—
$s'r' = \bar{1}01 : \bar{2}01$	—	—	—	24 58	—
$cr' = 001 : \bar{2}01$	19	63 10 — 63 25	63 20	63 21	1
$r'a = 201 : \bar{1}00$	15	41 5 — 41 18	41 12	41 11	1
$ap = 100 : 110$	32	35 22 — 35 48	35 36	*	—
$pp' = 110 : 120$	1	—	19 28	19 28	0
$p'b = 120 : 010$	1	—	34 57	34 56	1
$p'b = 110 : 010$	8	54 15 — 54 31	54 23	54 24	1
$pp = 110 : \bar{1}10$	20	70 56 — 71 21	71 13	71 12	1
$pp = 110 : \bar{1}10$	20	108 40 — 109 3	108 47	108 48	1
$cq = 001 : 011$	49	25 40 — 26 6	25 56	*	—
$qb = 011 : 010$	8	63 48 — 64 17	64 4	64 4	0
$qq = 011 : \bar{0}1\bar{1}$	20	128 0 — 128 32	128 8	128 8	0
$ao = 100 : 111$	—	—	—	49 21	—
$oq = 111 : 011$	—	—	—	27 37	—
$aq = 100 : 011$	20	76 48 — 77 8	76 58	76 58	0
$qo' = 011 : \bar{1}11$	23	34 16 — 34 47	34 32	34 35	3
$o'a = 111 : \bar{1}00$	21	68 15 — 68 47	68 29	68 27	2
$co = 001 : 111$	—	—	—	34 56	—
$op = 111 : 110$	—	—	—	43 17	—
$cp = 001 : 110$	40	78 5 — 78 21	78 13	*	—
$po' = 110 : \bar{1}1\bar{1}$	34	57 0 — 57 32	57 11	57 13	2
$o'c = 11\bar{1} : 00\bar{1}$	34	44 16 — 44 59	44 35	44 34	1
$bo = 010 : 111$	—	—	—	70 6	—
$os = 111 : 101$	—	—	—	19 54	—
$bn' = 010 : \bar{1}21$	1	—	47 23	47 26	3
$n'o' = \bar{1}21 : \bar{1}11$	2	17 54 — 17 56	17 55	17 54	1
$bo' = 010 : \bar{1}11$	8	65 9 — 65 29	65 20	65 20	0
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 40	—
$o'o' = \bar{1}11 : \bar{1}1\bar{1}$	11	49 16 — 49 47	49 28	49 20	8
$sq = 101 : 011$	—	—	—	38 22	—
$qn' = 011 : \bar{1}21$	5	34 36 — 35 57	35 22	35 24	2
$n'p = \bar{1}21 : \bar{1}10$	5	50 0 — 51 9	50 32	50 31	1
$qp = 011 : \bar{1}10$	35	85 41 — 86 9	85 55	85 55	0
$ps = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	55 43	—
$s'q = \bar{1}01 : 011$	—	—	—	45 10	—
$qp = 011 : 110$	37	63 53 — 64 20	64 3	64 1	2
$ps' = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	70 49	—
$r'o' = \bar{2}01 : \bar{1}11$	32	34 21 — 34 51	34 37	34 32	5
$o'p = \bar{1}11 : 110$	33	92 56 — 93 18	93 7	93 12	5
$pr' = 110 : \bar{2}0\bar{1}$	38	52 8 — 52 26	52 16	52 16	0

Total number of measurements, 579.

zinc. In a few of the crystals measured, the faces of the hemipyramid $o\{\bar{1}11\}$ were also particularly well developed, and gave excellent images; more usually, however, the faces of this form were both unimportant and somewhat curved. The orthopinacoid $a\{100\}$ was generally present to about the extent shown in the figures, and gave good reflections, but the clinopinacoid $b\{010\}$ was only found sufficiently well developed to afford trustworthy reflections upon three crystals. Upon one crystal, faces of the primary hemipyramid $o\{111\}$ were observed, but the images obtained were too faint for accurate allocation. The prismatic form $p'\{120\}$ was also met with once, and the image afforded by it was clear and bright. Faces of the hemipyramid $n'\{\bar{1}21\}$ occurred upon several crystals, and were occasionally fairly brilliant, and yielded good reflections.

FIG. 11.

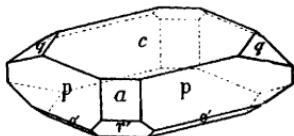
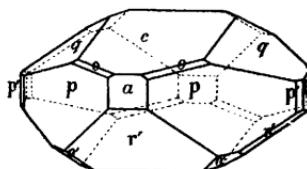


FIG. 12.



The results of the measurements are recorded in the table, p. 366.

A few measurements of this salt have previously been made by Marignac, and by Murmann and Rotter (*loc. cit.*). The values given by Marignac (*vide Rammelsberg, Kryst. phys. Chemie*) accord best with those given above; the value of the axial angle is given as $75^\circ 27'$, and the ratio of the axes $a : b : c = 0.7417 : 1 : 0.5039$.

Rubidium Ferrous Sulphate, $\text{Rb}_2\text{Fe}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

Very fine crystals of this salt are readily obtained, individuals of large size being frequently formed. The faces of the specimens examined were exceptionally perfect, even those of the largest usually giving excellent single reflections without any trace of curvature being apparent. The crystals are perfectly transparent and of a pale green colour, similar to that of potassium ferrous sulphate. They may be preserved unchanged in tightly stoppered bottles, but soon effloresce and oxidise when exposed to the air. Ten excellent crystals were measured, selected from three distinct crops. Specimens taken for analysis from one of these crops yielded the following results:—

0·8167 gram of crystals gave 0·7205 gram of BaSO₄, corresponding to 30·29 per cent. of SO₃. The calculated percentage of SO₃ is 30·42.

0·5075 gram of crystals gave 0·0785 gram of Fe₂O₃, corresponding to 13·92 per cent. of FeO. The calculated percentage of FeO is 13·69.

Habit: more or less tabular.

Axial angle: $\beta = 74^\circ 16'$.

Ratio of axes: $a : b : c = 0\cdot7377 : 1 : 0\cdot5004$.

Forms observed: $a = \{100\}_{\infty}P_{\infty}$; $b = \{010\}_{\infty}P_{\infty}$; $c = \{001\}_oP$;
 $p = \{110\}_{\infty}P$; $q = \{011\}P_{\infty}$; $o = \{111\} - P$; $o' = \{\bar{1}\bar{1}\bar{1}\} + P$;
 $r' = \{\bar{2}\bar{0}\bar{1}\} + 2P_{\infty}$.

FIG. 13.

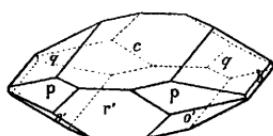
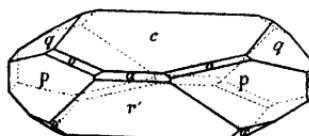


FIG. 14.



Two typical forms of the crystals of rubidium ferrous sulphate are represented in Figs. 13 and 14. The basal plane $c\{001\}$ is usually the most extensively developed plane, although not so large relatively as in the case of potassium ferrous sulphate, the faces of the clinodome $q\{011\}$, as shown in Fig. 13, being larger in proportion than they usually are in the crystals of the latter salt. The large development of the orthodome $r'\{\bar{2}01\}$ is a characteristic feature of the crystals of rubidium ferrous sulphate. The prism faces $p\{110\}$ vary considerably in their relative dimensions, but are always important faces, although usually smaller than those of the orthodome r' . The faces of the hemipyramid $o'\{\bar{1}\bar{1}\bar{1}\}$ vary very much more, being sometimes equal in extent to those of the prism, as represented in Fig. 13, but more frequently they are comparatively unimportant, as shown in Fig. 14. The primary hemipyramid $o\{111\}$ is only occasionally encountered, and then is relatively very small; in the three instances in which it was observed, however, excellent reflections were obtained. The orthopinacoid $a\{100\}$ was only once met with, and in that case was a mere line. The clinopinacoid $b\{010\}$, although occasionally absent, is generally developed to about the extent shown in the figures.

The following table gives the results of the measurements:—

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Angle observed.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
{ $as = 100 : 101$	—	—	—	45° 24'	—
$sc = 101 : 001$	—	—	—	28 52	—
$ac = 100 : 001$	1	—	74° 15'	74 16	1'
$cs' = 001 : \bar{1}01$	—	—	—	38 38	—
$s'r' = \bar{1}01 : 201$	—	—	—	25 30	—
$cr' = 001 : 201$	20	64° 3° — 64° 18'	64 9	64 8	1
$r'a = 201 : \bar{1}00$	1	—	41 34	41 36	2
{ $ap = 100 : 110$	—	—	—	35 23	—
$pp' = 110 : 120$	—	—	—	19 28	—
$p'b = 120 : 010$	—	—	—	35 9	—
$p'b = 110 : 010$	12	54 26 — 54 40	54 37	54 37	0
$pp = 110 : \bar{1}10$	19	70 42 — 70 53	70 46	* —	—
$pp = 110 : \bar{1}10$	19	109 6 — 109 20	109 14	109 14	0
{ $cq = 001 : 011$	40	25 36 — 25 52	25 43	* —	—
$qb = 011 : 010$	16	64 8 — 64 38	64 17	64 17	0
$qq = 011 : \bar{0}1\bar{1}$	20	128 28 — 128 46	128 34	128 34	0
{ $ao = 100 : 111$	—	—	—	48 35	—
$oq = 111 : 011$	1	—	27 7	27 17	10
$aq = 100 : 011$	—	—	—	75 52	—
$qo' = 011 : \bar{1}11$	26	34 36 — 35 0	34 48	34 51	3
$o'a = \bar{1}11 : \bar{1}00$	—	—	—	69 17	—
{ $co = 001 : 111$	3	34 22 — 34 33	34 27	34 26	1
$op = 111 : 110$	3	42 43 — 42 50	42 46	42 48	2
$cp = 001 : 110$	38	77 8 — 77 23	77 14	* —	—
$po' = 110 : \bar{1}1\bar{1}$	35	57 51 — 58 12	58 1	57 57	4
$o'c = \bar{1}1\bar{1} : 00\bar{1}$	36	44 34 — 44 57	44 45	44 49	4
{ $bo = 010 : 111$	—	—	—	70 23	—
$os = 111 : 101$	—	—	—	19 37	—
{ $bo' = 010 : \bar{1}11$	12	65 1 — 65 31	65 15	65 15	0
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 45	—
$o'o' = \bar{1}11 : \bar{1}\bar{1}1$	12	49 22 — 49 42	49 31	49 30	1
{ $sq = 101 : 011$	—	—	—	37 55	—
$qp = 011 : \bar{1}10$	36	86 54 — 87 8	87 1	87 1	0
$ps = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	55 4	—
{ $s'q = \bar{1}01 : 011$	—	—	—	45 16	—
$qp = 011 : 110$	37	63 6 — 63 27	63 15	63 14	1
$ps' = \bar{1}10 : 10\bar{1}$	—	—	—	71 30	—
{ $r'o' = \bar{2}01 : \bar{1}11$	36	34 48 — 35 17	35 0	34 57	3
$o'p = \bar{1}11 : 110$	36	92 15 — 92 48	92 34	92 37	3
$pr' = 110 : 20\bar{1}$	39	52 16 — 52 34	52 25	52 26	1

Total number of measurements, 498.

Cæsium Ferrous Sulphate, Cs₂Fe(SO₄)₂.6H₂O.

Cæsium ferrous sulphate likewise forms brilliant, transparent crystals of a pale green colour, slightly paler than that of the potassium and rubidium salts; they exhibit faces of a high order of perfection. It also resembles the two latter salts in efflorescing and oxidising on

exposure to the atmosphere, but is quite permanent when stored in tightly stoppered bottles.

Eleven of the best formed individuals were measured, belonging to three different crops. A portion of one of these crops was submitted to analysis with the following results:—

0·9230 gram of crystals gave 0·6965 gram of BaSO_4 , corresponding to 25·91 per cent. of SO_3 . The calculated percentage of SO_3 is 25·72.

1·0102 gram of crystals gave 0·1320 gram of Fe_2O_3 , corresponding to 11·76 per cent. of FeO . The calculated percentage of FeO is 11·58.

Habit: prismatic to pyramidal.

Axial angle: $\beta = 73^\circ 8'$.

Ratio of axes: $a : b : c = 0\cdot7261 : 1 : 0\cdot4953$.

Forms observed: $b = \{010\}_{\infty}\text{P}_{\infty}$; $c = \{001\}_{\infty}\text{P}$; $p = \{110\}_{\infty}\text{P}$; $q = \{011\}_{\infty}\text{P}$; $o' = \{\bar{1}11\} + \text{P}$; $r' = \{\bar{2}01\} + 2\text{P}_{\infty}$.

FIG. 15.

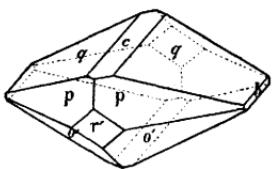
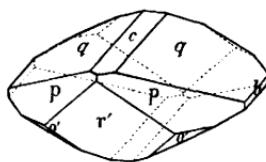


FIG. 16



The crystals of caesium ferrous sulphate obtained exhibit, in conformity with the caesium magnesium and caesium zinc salts, an entirely different habit from those of the corresponding salts containing potassium and rubidium. The basal plane $c\{001\}$, which is so largely developed in the potassium salt and still retains considerable importance in the rubidium salt, is reduced to a narrow strip, and frequently to a mere line. The clinodome $q\{011\}$ is now the predominating form, endowing the crystals with their prismatic habit; its faces usually gave magnificent single reflections upon the crystals measured. The prisms thus formed, however, are usually about as broad as long, and the ends are formed by the faces of the prism $p\{110\}$, hemipyramid $o'\{\bar{1}11\}$, and orthodome $r'\{\bar{2}01\}$. Sometimes, owing to the shortening of the faces of the zone $[cq b]$, a pyramidal habit is exhibited, the faces of the pyramids being those of the prism and clinodome. The faces of the prism p and hemipyramid o' vary considerably in their relative development in different crops. Sometimes they are approximately equal in extent, as represented in

Fig. 15. In other crops the prism faces are much more largely developed at the expense of the hemipyramid, whose faces are reduced to comparatively small dimensions, as shown in Fig. 16. Both these forms gave excellent reflections, those of the hemipyramid being far above the usual average for this form throughout the series. The orthodome $r'\{\bar{2}01\}$ is usually a prominent form, and the

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$\{as = 100 : 101$	—	—	—	44° 34'	—
$sc = 101 : 001$	—	—	—	28 34	—
$ac = 100 : 001$	—	—	—	73 8	—
$cs' = 001 : \bar{1}01$	—	—	—	39 7	—
$s'r' = 101 : \bar{2}01$	—	—	—	26 1	—
$cr' = 001 : \bar{2}01$	21	65° 5' — 65° 21'	65° 12'	65 8	4'
$r'a = \bar{2}01 : \bar{1}00$	—	—	—	41 44	—
$\{ap = 100 : 110$	—	—	—	34 49	—
$pp' = 110 : 120$	—	—	—	19 28	—
$p'b = 120 : 010$	—	—	—	35 43	—
$pb = 110 : 010$	40	54 58 — 55 29	55 11	55 11	0
$pp = 110 : \bar{1}10$	22	69 26 — 69 49	69 37	*	—
$pp = 110 : \bar{1}10$	22	110 13 — 110 35	110 23	110 23	0
$\{cq = 001 : 011$	44	25 5 — 25 28	25 21	*	—
$qb = 011 : 010$	40	64 28 — 64 56	64 39	64 39	0
$qq = 011 : 011$	22	129 9 — 129 31	129 18	129 18	0
$\{ao = 100 : 111$	—	—	—	47 42	—
$oq = 111 : 011$	—	—	—	27 6	—
$aq = 100 : 011$	—	—	—	74 48	—
$qo' = 011 : \bar{1}11$	30	35 11 — 35 35	35 4	35 20	4
$o'a = \bar{1}11 : \bar{1}00$	—	—	—	69 52	—
$\{co = 001 : 111$	—	—	—	33 57	—
$op = 111 : 110$	—	—	—	42 16	—
$cp = 001 : 110$	36	76 5 — 76 25	76 13	*	—
$po' = 110 : \bar{1}11$	34	58 17 — 58 46	58 33	58 38	5
$o'c = \bar{1}11 : 001$	31	44 59 — 45 30	45 14	45 9	5
$\{bo = 010 : 111$	—	—	—	70 50	—
$os = 111 : 101$	—	—	—	19 10	—
$\{bo' = 010 : \bar{1}11$	28	65 15 — 65 29	65 21	65 22	1
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 38	—
$o'o' = \bar{1}11 : \bar{1}\bar{1}1$	14	49 11 — 49 24	49 18	49 16	2
$\{sq = 101 : 011$	—	—	—	37 28	—
$qp = 011 : \bar{1}10$	37	88 0 — 88 26	88 18	88 20	2
$ps = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	54 12	—
$\{s'q = \bar{1}01 : 011$	—	—	—	45 29	—
$qp = 011 : 110$	40	62 31 — 62 51	62 38	62 38	0
$ps' = \bar{1}10 : 10\bar{1}$	—	—	—	71 53	—
$\{r'o' = \bar{2}01 : \bar{1}11$	35	34 58 — 35 21	35 11	35 13	2
$o'p = 111 : 110$	36	92 26 — 92 55	92 38	92 34	4
$p'r' = 110 : 201$	40	51 55 — 52 24	52 11	52 13	2

Total number of measurements, 572.

prominence given to it in Fig. 16 is characteristic of many of the crops obtained. It has, however, occasionally been found reduced to microscopic dimensions. The faces of the clinopinacoid $b\{010\}$ are generally present, and not unfrequently attain even larger relative proportions than those attributed to them in the figures.

The goniometrical results obtained are tabulated on p. 371.

As previously with respect to the salts containing magnesium and zinc, a table is now given in which the respective values of the various angles of the three salts just described are compared.

Comparison of the Angles of the three Salts containing Iron.

Angle.	Potassium salt.	Diff.	Rubidium salt.	Diff.	Cæsium salt.
$\{ac = 100 : 001 = \beta$	75° 28'	-72'	74° 16'	-68'	73° 8'
$as = 100 : 101$	48 9	-45	45 24	-50	44 34
$sc = 101 : 001$	29 19	—	28 52	—	28 34
$cr' = 001 : \bar{2}01$	63 21	+47	64 8	+60	65 8
$cs' = 001 : \bar{1}01$	38 23	—	38 38	—	39 7
$s'r' = \bar{1}01 : \bar{2}01$	24 58	+32	25 30	+31	26 1
$r'a = \bar{2}01 : \bar{1}00$	41 11	—	41 36	—	41 44
$\{ap = 100 : 110$	35 38	-13	35 28	-34	34 49
$pp' = 110 : 120$	19 28	—	19 28	—	19 28
$p'b = 120 : 010$	34 56	+13	35 9	+34	35 43
$pb = 110 : 010$	54 24	—	54 37	—	55 11
$\{cq = 001 : 011$	25 56	-13	25 43	-22	25 21
$qb = 011 : 010$	64 4	—	64 17	—	64 39
$\{ao = 100 : 111$	49 21	-46	48 35	-53	47 42
$oq = 111 : 011$	27 37	—	27 17	—	27 6
$aq = 100 : 011$	76 58	-66	75 52	-64	74 48
$qo' = 011 : \bar{1}11$	34 35	—	34 51	—	35 20
$o'a = \bar{1}11 : \bar{1}00$	68 27	+50	69 17	+35	69 52
$\{co = 001 : 111$	34 56	-30	34 26	-29	33 57
$op = 111 : 110$	43 17	—	42 48	—	42 16
$cp = 001 : 110$	78 13	-59	77 14	-61	76 13
$po' = 110 : \bar{1}11$	57 13	—	57 57	—	58 38
$o'c = 111 : 001$	44 34	+15	44 49	+20	45 9
$\{bo = 010 : 111$	70 6	+17	70 23	+27	70 50
$os = 111 : 101$	19 54	—	19 37	—	19 10
$\{bo' = 010 : \bar{1}11$	65 20	-5	65 15	+7	65 22
$o's' = \bar{1}11 : \bar{1}01$	24 40	—	24 45	—	24 38
$\{sq = 101 : 011$	38 22	-27	37 55	-27	37 28
$qp = 011 : \bar{1}10$	85 55	+66	87 1	+79	88 20
$ps = \bar{1}10 : \bar{1}01$	55 43	—	55 4	—	54 12
$\{s'q = \bar{1}01 : 011$	45 10	—	45 16	—	45 29
$qp = 011 : 110$	64 1	-47	63 14	-36	62 38
$ps' = 110 : 101$	70 49	+41	71 30	+23	71 53
$\{r'o' = \bar{2}01 : \bar{1}11$	34 32	+25	34 57	+16	35 13
$o'p = \bar{1}11 : 110$	93 12	—	92 37	—	92 34
$pr' = 110 : \bar{2}01$	52 16	+10	52 26	-13	52 13

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The relationships deduced from the comparisons of the potassium, rubidium, and caesium salts containing as the second metal magnesium and zinc respectively are again exhibited by the three salts containing iron as the second metal.

The differences between the values of the axial angle ($72'$ and $68'$) are again approximately equal, and consequently proportional to the increments in atomic weight.

Out of the other 35 angles compared, 32 again follow the rule that the values of the rubidium salt lie between those of the potassium and caesium salts. Moreover, the three exceptions are the same (bo' , $o's'$, and pr') as in the salts containing magnesium and zinc, and therefore capable of the same ready explanation. Again, the maximum deviation from simple proportionality occurs in the prism zone. The relative amounts of change in the angles ap and pb of this zone bear a relation between $1 : 2$, the ratio found in the case of the zinc salts, and $1 : 3$, the ratio found for the magnesium salts, and lying nearer to the latter ratio (the differences being $13'$ and $34'$).

The changes in the axial ratios are again slight, and afford very little indication of the change of form of the crystals.

For potassium ferrous sulphate.. $a : b : c = 0\cdot7377 : 1 : 0\cdot5020$

„ rubidium „ „ .. $a : b : c = 0\cdot7377 : 1 : 0\cdot5004$

„ caesium „ „ .. $a : b : c = 0\cdot7261 : 1 : 0\cdot4953$

Salts containing Manganese.

As explained in the introductory paragraph, "The Salts of the Series investigated" (p. 342), attempts to prepare crystals of the double sulphate of potassium and manganese containing 6 mols. H_2O have so far been unsuccessful.

Rubidium Manganous Sulphate, $Rb_2Mn(SO_4)_2 \cdot 6H_2O$.

Rubidium manganous sulphate, unlike the potassium salt, crystallises readily from solutions containing equal molecular proportions of rubidium and manganous sulphates, in large, transparent, and very brilliant crystals of a pale pink colour. Ten crystals, chosen from five different crops on account of their comparative freedom from the curvature and distortion which many of the crystals of this salt were found to exhibit, were measured.

Estimations of the sulphuric acid and manganese in a quantity of crystals taken from one of these crops yielded the following numbers:—

0·8490 gram of crystals gave 0·7550 gram of $BaSO_4$, corresponding to 30·53 per cent. of SO_3 . The calculated percentage of SO_3 is 30·48.

The manganese was determined in the filtrate from the barium sulphate after removal of the excess of barium by dilute sulphuric acid. The manganese was precipitated by pure sodium hydrate and weighed as Mn_3O_4 . The weight of Mn_3O_4 obtained was 0·1250, corresponding to 13·69 per cent. of MnO . The calculated percentage of MnO is 13·52.

Habit: tabular to short prismatic.

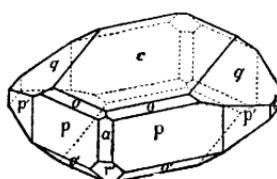
Axial angle: $\beta = 74^\circ 3'$.

Ratio of axes: $a : b : c = 0\cdot7382 : 1 : 0\cdot4950$.

Forms observed: $a = \{100\} \infty P \infty$; $b = \{010\} \infty R \infty$; $c = \{001\} oP$;

$p = \{110\} \infty P$; $p' = \{120\} \infty R2$; $q = \{011\} R \infty$; $o = \{111\} - P$;
 $o' = \{\bar{1}11\} + P$; $r' = \{\bar{2}01\} + 2P \infty$.

FIG. 17.



The crystals of rubidium manganous sulphate usually exhibit a more or less tabular habit, as represented in Fig. 17, owing to the predominance of the basal plane $c\{001\}$, but not unfrequently are much thicker and almost prismatic in habit. Although as a rule the predominating end form, the faces of the basal plane are not so large compared with those of the clinodome $q\{011\}$ as in the potassium salts previously described, but resemble more the other rubidium salts, the clinodome being sometimes quite as largely developed as the basal plane. The prism $p\{110\}$ is always an important form, but its faces vary considerably, being short in the tabular, and almost as long as broad in the crystals of short prismatic habit. The reflections obtained from the faces of these three forms in the 10 crystals measured were usually very brilliant and definite. The faces of the remaining forms were all small, and rarely all present on any one crystal. The orthopinacoid $a\{100\}$ was only represented by one narrow face upon each of the six crystals upon which it was found. The clinopinacoid $b\{010\}$ was only observed upon the crystals of a few crops. The hemipyramid $o'\{\bar{1}11\}$, however, was universally present, but small, and frequently distorted. The faces of the orthodome $r'\{\bar{2}01\}$ were likewise generally developed, but particularly small compared with their relative dimensions on most of the other salts of the series, and the reflections afforded were below the average. Upon two of the crystals measured, small faces of the

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primary hemipyramid $o\{111\}$ were discovered, and faces of the prismatic form $p'\{120\}$ upon four of the crystals examined.

The results of the measurements and calculations are tabulated below:—

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$as = 100 : 101$	—	—	—	45° 27'	—
$sc = 101 : 001$	—	—	—	28 36	—
$ae = 100 : 001$	6	73° 57'— 74° 5'	74° 2'	74 3	1'
$cs' = 001 : \bar{1}01$	—	—	—	38 23	—
$s'r' = \bar{1}01 : \bar{2}01$	—	—	—	25 35	—
$cr' = 001 : \bar{2}01$	15	64 2— 64 12	64 7	63 58	9
$r'a = \bar{2}01 : \bar{1}00$	5	41 48— 41 56	41 51	41 59	8
$ap = 100 : 110$	6	35 14— 35 23	35 18	35 20	2
$pp' = 110 : 120$	4	19 11— 19 36	19 24	19 28	4
$p'b = 120 : 010$	—	—	—	35 12	—
$pb = 110 : 010$	4	54 40— 54 45	54 42	54 40	2
$pp = 110 : \bar{1}10$	20	70 31— 70 52	70 40	*	—
$pp = 110 : \bar{1}10$	20	109 7— 109 27	109 20	109 20	0
$cq = 001 : 011$	39	25 13— 25 43	25 30	*	—
$qb = 011 : 010$	4	64 24— 64 37	64 30	64 30	0
$qq = 011 : \bar{0}1\bar{1}$	19	128 50— 129 14	128 59	129 0	1
$ao = 100 : 111$	1	—	48 39	48 34	5
$og = 111 : 011$	1	—	27 0	27 4	4
$aq = 100 : 011$	3	75 38— 75 41	75 39	75 38	1
$qo' = 011 : \bar{1}11$	13	34 36— 34 54	34 46	34 40	6
$o'a = \bar{1}11 : \bar{1}00$	2	69 35— 69 37	69 36	69 42	6
$co = 001 : 111$	3	34 3— 34 19	34 11	34 6	5
$op = 111 : 110$	3	42 45— 42 57	42 53	42 57	4
$cp = 001 : 110$	39	76 54— 77 12	77 3	*	—
$po' = 110 : \bar{1}1\bar{1}$	23	58 7— 58 29	58 18	58 25	7
$o'c = \bar{1}1\bar{1} : 00\bar{1}$	23	44 24— 44 54	44 38	44 32	6
$bo = 010 : 111$	—	—	—	70 34	—
$os = 111 : 101$	—	—	—	19 26	—
$bo' = 010 : \bar{1}11$	2	65 20— 65 20	65 20	65 25	5
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 35	—
$o'o' = \bar{1}11 : \bar{1}\bar{1}1$	8	49 13— 49 26	49 19	49 10	9
$sq = 101 : 011$	—	—	—	37 35	—
$qp = 011 : \bar{1}10$	39	87 14— 87 27	87 20	87 20	0
$ps = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	55 5	—
$s'q = \bar{1}01 : 011$	—	—	—	44 58	—
$qp = 011 : 110$	39	63 6— 63 18	63 10	63 10	0
$ps' = \bar{1}10 : 10\bar{1}$	—	—	—	71 52	—
$r'o' = \bar{2}01 : \bar{1}11$	21	34 39— 35 6	34 56	34 54	2
$o'p = \bar{1}11 : 110$	21	92 22— 92 43	92 30	92 26	4
$pr' = 110 : \bar{2}01$	30	52 26— 52 44	52 34	52 40	6

Total number of measurements, 413.

Owing to the fact, previously alluded to, that the faces of the hemipyramid $o'\{\bar{1}11\}$ and of the orthodome $r'\{\bar{2}01\}$ were some-

what affected by distortion, the differences between the calculated and observed values of the angles which involve these forms are somewhat greater than those usually observed during the course of this work. The calculated values in these cases are probably nearer the truth, being calculated from angles involving faces free from this defect.

Cæsium Manganous Sulphate, $\text{Cs}_2\text{Mn}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

Cæsium manganous sulphate likewise crystallises with facility, forming large, transparent, brilliant individuals of the same pale pink colour as the rubidium salt. Twelve crystals selected from four different crops were measured. Two of these crystals were only partially measured, certain zones being unsuitable, owing to slight distortion; the remaining 10 crystals were measured completely.

Analyses of other crystals belonging to one of these crops afforded the following data as to purity :—

0·7488 gram of crystals gave 0·5675 gram of BaSO_4 , corresponding to 26·02 per cent. of SO_3 . The calculated percentage of SO_3 is 25·77.

The determination of manganese in the filtrate, as in the case of the rubidium salt, gave 0·0940 gram of Mn_3O_4 , corresponding to 11·67 per cent. of MnO . The calculated percentage of MnO is 11·43.

Habit: prismatic or pyramidal.

Axial angle: $\beta = 72^\circ 53'$.

Ratio of axes: $a : b : c = 0\cdot7274 : 1 : 0\cdot4913$.

Forms observed: $b = \{010\} \infty P \infty$; $c = \{001\} oP$; $p = \{110\} \infty P$;
 $p' = \{120\} \infty P 2$; $q = \{011\} P \infty$; $o' = \{\bar{1}11\} + P$; $r' = \{\bar{2}01\} + 2P \infty$.

The commonest habit of the crystals of cæsium manganous sulphate is shown in Fig. 18 (p. 378). The principal faces are those of the clinodome $q\{011\}$ and the prism $p\{110\}$, and the relation of these two forms determines the habit. Sometimes the clinodome faces are so elongated in the direction of the zone axis (that is, in the direction of the edge cq) that long prisms are the result, the faces of $p\{110\}$ being then the principal end faces. In other crystals, the faces of the prism are so high (elongated in the direction of the edge pp) that prisms are again produced, but whose principal end faces are those of the clinodome q . The crystal drawn represents the commonly occurring case when the faces of the prism and clinodome are about equally developed. Such pyramidal crystals have been obtained of large size and considerable weight, and owing to their perfect transparency and pale pink colour, are very beautiful objects.

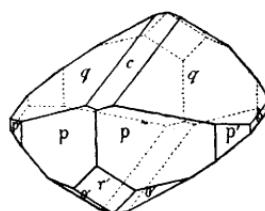
Again, in caesium manganous sulphate, as in the caesium salts containing magnesium, zinc, and iron, the basal plane, fairly broad in the rubidium salt, is reduced to a narrow strip and often a mere line. The orthodome $r'\{2\bar{0}1\}$ is usually much larger, although scarcely more free from distortion, than in the crystals of the rubidium salt, and the prismatic form $p'\{120\}$ is almost universally pre-

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$as = 100 : 101$	—	—	—	44° 37'	—
$sc = 101 : 001$	—	—	—	28 16	—
$ac = 100 : 001$	—	—	—	72 53	—
$cs' = 001 : \bar{1}01$	—	—	—	38 48	—
$s'r' = \bar{1}01 : 201$	—	—	—	26 7	—
$cr' = C01 : 201$	18	64° 32' — 65° 12'	65° 4'	64 55	9'
$r'a = 201 : \bar{1}00$	—	—	—	42 12	—
$ap = 100 : 110$	—	—	—	34 51	—
$pp' = 110 : 120$	39	19 5 — 19 45	19 24	19 28	4
$p'b = 120 : 010$	31	35 6 — 36 5	35 44	35 41	3
$pb = 110 : 010$	26	54 54 — 55 19	55 9	55 9	0
$pp = 110 : \bar{1}\bar{1}0$	24	69 33 — 69 54	69 42	* —	—
$pp = 110 : 1\bar{1}0$	24	110 6 — 110 33	110 17	110 18	1
$cq = 001 : 011$	48	24 48 — 25 29	25 11	* —	—
$qb = 011 : 010$	30	64 31 — 65 19	64 50	64 49	1
$qq = 011 : 0\bar{1}\bar{1}$	23	129 32 — 129 45	129 38	129 38	0
$ao = 100 : 111$	—	—	—	47 43	—
$oq = 111 : 011$	—	—	—	26 50	—
$aq = 100 : 011$	—	—	—	74 38	—
$q'o' = 011 : \bar{1}\bar{1}1$	28	35 1 — 35 23	35 14	35 5	9
$o'a = \bar{1}\bar{1}1 : \bar{1}00$	—	—	—	70 22	—
$co = 001 : 111$	—	—	—	33 38	—
$op = 111 : 110$	—	—	—	42 23	—
$cp = 001 : 110$	39	75 41 — 76 21	76 1	* —	—
$po' = 110 : 1\bar{1}\bar{1}$	28	58 42 — 59 8	58 56	59 8	12
$o'c = \bar{1}\bar{1}1 : 00\bar{1}$	29	44 42 — 45 25	45 3	44 51	12
$bo = 010 : 111$	—	—	—	70 58	—
$os = 111 : 101$	—	—	—	19 2	—
$bo' = 010 : \bar{1}11$	21	65 12 — 65 38	65 24	65 27	3
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 33	—
$o'o' = \bar{1}11 : \bar{1}\bar{1}1$	11	49 6 — 49 18	49 10	49 6	4
$sq = 101 : 011$	—	—	—	37 9	—
$qp = 011 : \bar{1}10$	39	88 24 — 88 46	88 36	88 36	0
$ps = \bar{1}10 : 10\bar{1}$	—	—	—	54 15	—
$s'q = \bar{1}01 : 011$	—	—	—	45 9	—
$qp = 011 : 110$	40	62 19 — 62 38	62 28	62 30	2
$ps' = \bar{1}10 : 10\bar{1}$	—	—	—	72 21	—
$r'o' = \bar{2}01 : \bar{1}11$	27	34 51 — 35 34	35 13	35 14	1
$o'p = \bar{1}11 : 110$	29	92 5 — 92 40	92 18	92 13	5
$pr' = 110 : 201$	35	52 11 — 52 54	52 28	52 33	5

Total number of measurements, 589.

sent, and frequently attains considerable prominence. The faces of the hemipyramid $o'\{111\}$ are, however, but small, and their reflections as imperfect as in the case of the rubidium salt. The clinopinacoid $b\{010\}$ is usually present, and is often developed to an extent equal to that of the basal plane c .

FIG. 18.



The results of the measurements are given in the table, p. 377.

As in the case of rubidium manganous sulphate, owing to the presence of more or less distortion the reflections yielded by the faces of the hemipyramid o' and those of the orthodome r' were inferior to those usually obtained in other salts of the series, and the differences between the calculated and mean observed values of the angles involving these faces are consequently larger than will be generally found in this memoir.

Owing to the inability to prepare the potassium manganous salt containing 6 mols. H_2O , a complete comparison of the angles cannot be effected, but it will nevertheless be interesting to see if the relationships discovered between the rubidium and cæsium salts containing magnesium, zinc, and iron are repeated in those containing manganese.

It will be at once evident, upon comparing the differences (p. 379) with those shown in the previous tables of comparison, that precisely the same relationships hold between the rubidium and cæsium manganous salts as were found between the rubidium and cæsium salts containing as the second metal magnesium, zinc, and iron respectively. The differences are all of the same order, very close in actual value, and all of the same sign. Indeed there is no room for doubt that if the corresponding potassium salt could only be prepared, the three salts containing manganese would follow the rules which apply so remarkably in the cases previously discussed. Moreover, the differences between the axial ratios are of the same order as those between the rubidium and cæsium salts of the series.

For rubidium manganous sulphate... $a : b : c = 0.7382 : 1 : 0.4950$
,, cæsium , , .. $a : b : c = 0.7274 : 1 : 0.4913$

Comparison of the Angles of the two Salts containing Manganese.

Angle.	Rubidium salt.	Diff.	Cæsium salt.
$\{ac = 100 : 001 = \beta$	74° 3'	-70'	72° 58'
$as = 100 : 101$	45 27	-50	44 37
$sc = 101 : 001$	28 36	—	28 16
$cr' = 001 : 2\bar{0}1$	63 58	+57	64 55
$cs' = 001 : \bar{1}01$	38 23	—	38 48
$s'r' = \bar{1}01 : 201$	25 35	+32	26 7
$r'a = 2\bar{0}1 : \bar{1}00$	41 59	—	42 12
$\{ap = 100 : 110$	35 20	-29	34 51
$pp' = 110 : 120$	19 28	—	19 28
$p'b = 120 : 010$	35 12	+29	35 41
$pb = 110 : 010$	54 40	—	55 9
$\{cq = 001 : 011$	25 30	-19	25 11
$qb = 011 : 010$	64 30	—	64 49
$\{ao = 100 : 111$	48 34	-51	47 43
$oq = 111 : 011$	27 4	—	26 50
$aq = 100 : 011$	75 38	-65	74 33
$qo' = 011 : \bar{1}11$	34 40	—	35 5
$o'a = \bar{1}11 : \bar{1}00$	69 42	+40	70 22
$\{co = 001 : 111$	34 6	-28	33 38
$op = 111 : 110$	42 57	—	42 23
$cp = 001 : 110$	77 3	-62	76 1
$po' = 110 : 11\bar{1}$	58 25	—	59 8
$o'c = 11\bar{1} : 001$	44 32	+19	44 51
$\{bo = 010 : 111$	70 34	+24	70 58
$os = 111 : 101$	19 26	—	19 2
$\{bo' = 010 : \bar{1}11$	65 25	+2	65 27
$o's' = \bar{1}11 : \bar{1}01$	24 35	—	24 33
$\{sq = 101 : 011$	37 35	-26	37 9
$qp = 011 : \bar{1}10$	87 20	+76	88 36
$ps = \bar{1}10 : \bar{1}01$	55 5	—	54 15
$\{s'q = \bar{1}01 : 011$	44 58	—	45 9
$qp = 011 : 110$	63 10	-40	62 30
$ps' = 110 : 10\bar{1}$	71 52	+29	72 21
$\{r'o' = \bar{2}01 : \bar{1}11$	34 54	+20	35 14
$o'p = \bar{1}11 : 110$	92 26	—	92 13
$pr' = 110 : 20\bar{1}$	52 40	-7	52 33

*Salts containing Nickel.**Potassium Nickelous Sulphate, K₂Ni(SO₄)₂, 6H₂O.*

Excellent crystals of this well-known bright green salt were obtained by slow evaporation. Ten of the most perfect, selected from three different crops, were measured. Analyses of a few other crystals belonging to one of these crops gave the following numbers:—

0·9667 gram of crystals gave 1·0245 gram of BaSO₄, corresponding to 36·39 per cent. of SO₃. The calculated percentage is 36·61. 0·8398 gram of crystals gave 0·1455 gram of NiO, corresponding to 17·32 per cent. of NiO. The calculated percentage of NiO is 17·16.

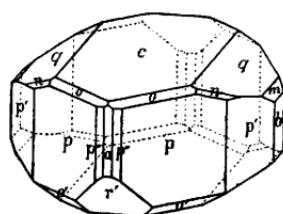
Habit: varying between prismatic and tabular.

Axial angle: $\beta = 75^\circ 0'$.

Ratio of axes: $a : b : c = 0·7379 : 1 : 0·5020$.

Forms observed: $a = \{100\} \infty P \infty$; $b = \{010\} \infty P \infty$; $c = \{001\} oP$; $p = \{110\} \infty P$; $p' = \{120\} \infty P 2$; $p'' = \{210\} \infty P 2$; $q = \{011\} P \infty$; $m = \{021\} 2P \infty$; $o = \{\bar{1}11\} - P$; $o' = \{\bar{1}\bar{1}1\} + P$; $n = \{121\} - 2P 2$; $v = \{\bar{1}12\} + \frac{1}{2}P$; $r' = \{\bar{2}01\} + 2P \infty$.

FIG. 19.



The crystals of this salt are exceptionally rich in faces. A common type is represented in Fig. 19, in which the faces of the clinopinacoid $b\{010\}$ and the prism $p\{110\}$ form a more or less equally developed, short, six-sided prism. It frequently happens, however, that one pair of the faces of the prism p are much more largely developed than the other pair, giving to the crystal a tabular habit. The prism faces, moreover, are usually much striated parallel to the edge pp , and curved, but the 10 crystals measured were chosen on account of their greater freedom from this disturbing influence, many of the prism faces on these particular specimens being absolutely plane, yielding brilliant single reflections. Of the end faces, the basal plane $c\{001\}$ usually predominates, as in most of the salts of the series containing potassium, but the faces of the clinodome $q\{011\}$ frequently attain the importance attached to them in the figure, and generally yield excellent images of the signal. The orthodome $r'\{\bar{2}01\}$ is usually smaller, but also well-formed and plane. The faces of the prismatic form $p'\{120\}$ are rarely absent, and often assume considerable relative importance. The hemipyramid $o'\{\bar{1}\bar{1}1\}$ is only, as a rule, developed to the extent shown in the figure. The remaining forms were all small upon the specimens examined; their reflections, however, were all good. In addition to the ortho-

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Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$as = 100 : 101$	—	—	—	45° 48'	—
$sc = 101 : 001$	—	—	—	29 12	—
$ac = 100 : 001$	3	74° 53' — 74° 55'	74° 54'	75 0	6'
$cs' = 001 : \bar{1}01$	—	—	—	38 33	—
$s'r' = \bar{1}01 : 201$	—	—	—	25 11	—
$cr' = 001 : \bar{2}01$	15	63 45 — 63 59	63 51	63 44	7
$r'a = 201 : \bar{1}00$	3	41 11 — 41 15	41 13	41 16	3
$ap'' = 100 : 210$	—	—	—	19 37	—
$p''p = 210 : 110$	1	—	15 56	15 52	4
$ap = 100 : 110$	8	35 16 — 35 44	35 29	35 29	0
$pp' = 110 : 120$	18	19 19 — 19 36	19 28	19 28	0
$p'b = 120 : 010$	13	34 49 — 35 11	35 3	35 3	0
$pb = 110 : 010$	26	54 22 — 54 40	54 31	54 31	0
$pp = 110 : \bar{1}10$	16	70 56 — 71 1	70 58	*	—
$pp = 110 : \bar{1}10$	16	108 59 — 109 6	109 2	109 2	0
$cq = 001 : 011$	39	25 39 — 25 59	25 52	*	—
$qm = 011 : 021$	—	—	—	18 15	—
$mb = 021 : 010$	—	—	—	45 53	—
$qb = 011 : 010$	31	64 0 — 64 22	64 7	64 8	1
$qq = 011 : 01\bar{1}$	19	128 5 — 128 28	128 15	128 16	1
$ao = 100 : 111$	1	—	49 6	48 59	7
$oq = 111 : 011$	3	27 26 — 27 32	27 30	27 33	3
$aq = 100 : 011$	1	—	76 32	76 32	0
$q'o' = 011 : \bar{1}11$	8	34 43 — 34 53	34 48	34 46	2
$o'a = 111 : \bar{1}00$	2	68 30 — 68 52	68 41	68 42	1
$co = 001 : 111$	8	34 33 — 34 54	34 47	34 46	1
$op = 111 : 110$	8	42 54 — 43 12	43 3	43 4	1
$cp = 001 : 110$	40	77 43 — 77 57	77 50	*	—
$po' = 110 : 11\bar{1}$	12	57 12 — 57 28	57 22	57 26	4
$o'v = 11\bar{1} : 112$	1	—	20 30	20 37	7
$vc = 112 : 00\bar{1}$	1	—	24 10	24 7	3
$o'c = 11\bar{1} : 00\bar{1}$	12	44 45 — 44 55	44 49	44 44	5
$bn = 010 : 121$	—	—	—	54 15	—
$no = 121 : 111$	—	—	—	15 57	—
$bo = 010 : 111$	—	—	—	70 12	—
$os = 111 : 101$	—	—	—	19 48	—
$bo' = 010 : \bar{1}11$	10	65 10 — 65 18	65 14	65 17	3
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 43	—
$o'o' = 111 : \bar{1}\bar{1}1$	5	49 28 — 49 38	49 32	49 26	6
$sq = 101 : 011$	—	—	—	38 13	—
$qp = 011 : \bar{1}10$	33	86 12 — 86 32	86 23	86 22	1
$ps = \bar{1}10 : 101$	—	—	—	55 25	—
$s'v = \bar{1}01 : 112$	—	—	—	23 16	—
$vq = 112 : 011$	5	21 56 — 22 9	22 2	22 1	1
$s'q = \bar{1}01 : 011$	—	—	—	45 17	—
$qn = 011 : 121$	1	—	26 43	26 50	7
$np = 121 : 110$	1	—	36 51	36 53	2
$qp = 011 : 110$	33	63 32 — 63 51	63 40	63 43	3
$ps' = 110 : 10\bar{1}$	—	—	—	71 0	—
$r'o' = 201 : \bar{1}11$	19	34 39 — 34 57	34 46	34 43	3
$o'm = \bar{1}11 : 021$	8	36 40 — 36 53	36 46	36 45	1
$mp = 021 : 110$	8	56 12 — 56 20	56 15	56 16	1
$o'p = 111 : 110$	18	92 56 — 93 4	93 1	93 1	0
$pr' = 110 : 20\bar{1}$	29	52 6 — 52 24	52 13	52 16	3

Total number of measurements, 475.

pinacoid $a\{100\}$, the primary hemipyramid $o\{111\}$, and the hemipyramid $n\{121\}$, three forms not observed upon the crystals of the salts previously discussed were discovered. These are the prismatic form $p'\{210\}$, the clinodome $m\{021\}$, and the pyramidal form $v\{\bar{1}12\}$. The last two forms were almost universally present upon the crystals of one crop, and occasionally upon those of the other crops examined.

The table on p. 381 exhibits the results of the measurements.

The values of the crystallographical constants and of the very few measured angles given by Rammelsberg, Brooke, and Murmann and Rotter (*loc. cit.*), are fairly close to those given above. The ratio of the axes given by the latter observers is

$$a : b : c = 0.7374 : 1 : 0.4965,$$

and the axial angle as determined by the same observers $74^\circ 57'$.

Rubidium Nickelous Sulphate, $\text{Rb}_2\text{Ni}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

The crystals of rubidium nickelous sulphate resemble those of the potassium nickel salt in being of a deep green colour. Among others, several crops were obtained consisting of small crystals admirably adapted for goniometrical purposes, about $\frac{1}{2}$ mm. diameter, and exhibiting very brilliant and plane faces. Ten perfect little individuals were selected from four of these crops and measured.

Analyses of other crystals belonging to one of these crops yielded the following numbers:—

1.0560 gram of crystals gave 0.9325 gram of BaSO_4 , corresponding to 30.32 per cent. of SO_3 . The calculated percentage of SO_3 is 30.25.

0.8770 gram of crystals gave 0.1255 gram of NiO , corresponding to 14.31 per cent. of NiO . The calculated percentage of NiO is 14.18.

Habit: varying from tabular to prismatic.

Axial angle: $\beta = 73^\circ 57'$.

Ratio of axes: $a : b : c = 0.7350 : 1 : 0.5022$.

Forms observed: $b = \{010\}_{\infty}\mathbb{P}_{\infty}$; $c = \{001\}_0\mathbb{P}$; $p = \{110\}_{\infty}\mathbb{P}$; traces of $p' = \{120\}_{\infty}\mathbb{P}^2$; $q = \{011\}\mathbb{P}_{\infty}$; $o' = \{\bar{1}11\} + \mathbb{P}$; $r' = \{\bar{2}01\} + 2\mathbb{P}_{\infty}$.

The habit usually assumed by the crystals in the various crops obtained is shown in Fig. 20 (p. 384). The predominating forms are the prism $p\{110\}$ and basal plane $c\{001\}$. It very frequently happens, however, that one pair of prism faces are much more largely developed

than the other pair, giving to the crystals a prismatic habit as shown in Fig. 21. The faces of the clinodome $q\{011\}$ are generally well developed, especially in the larger crystals, but occasionally are small, as represented in Fig. 21; these faces were particularly perfect upon the individuals measured, the images of the signal which they afforded being uniformly sharp and single. Moreover,

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
{ as = 100 : 101 sc = 101 : 001 ac = 100 : 001 cs' = 001 : 101 s'r' = 101 : 201 cr' = 001 : 201 r'a = 201 : 100	— — — — — 12 —	— — — — — $64^\circ 28'$ — $64^\circ 40'$ —	— — — — — $64^\circ 34'$ —	$45^\circ 4'$ 28 53 73 57 38 57 25 39 64 36 41 27	— — — — — 2' —
{ ap = 100 : 110 pp' = 110 : 120 p'b = 120 : 010 pb = 110 : 010 pp = 110 : 110 pp = 110 : 110	— — — 32 20 20	— — — $54 34$ — $54 55$ $70 26$ — $70 41$ $109 16$ — $109 40$	— — — $54 43$ $70 34$ $109 25$	$35 17$ 19 28 35 15 * 70 34 109 26	— — — — 0 1
{ eq = 001 : 011 qb = 011 : 010 qq = 011 : 011	38 32 17	$25 39$ — $25 51$ $64 9$ — $64 20$ $128 25$ — $128 40$	$25 44$ $64 16$ $128 31$	* 64 16 128 32	— 0 1
{ ao = 100 : 111 oq = 111 : 011 aq = 100 : 011 q'o' = 011 : 111 o'a = 111 : 100	— — — 17 —	— — — $34 55$ — $35 6$ —	— — — $35 2$ —	$48 16$ 27 19 75 35 35 5 69 20	— — — 3 —
{ eo = 001 : 111 op = 111 : 110 cp = 001 : 110 po' = 110 : 111 o'c = 111 : 001	— — 40 22 22	— — $76 52$ — $77 2$ $57 55$ — $58 5$ $44 57$ — $45 9$	— — $76 57$ $58 1$ $45 2$	$34 25$ 42 32 * 57 57 45 6	— — 4 4 4
{ bo = 010 : 111 os = 111 : 101	— —	— —	— —	$70 25$ 19 35	— —
{ bo' = 010 : 111 o's' = 111 : 101 o'o' = 111 : 111	21 — 8	$65 6$ — $65 20$ — $49 29$ — $49 37$	$65 13$ — $49 34$	65 11 24 49 49 38	2 — 4
{ sq = 101 : 011 qp = 011 : 110 ps = 110 : 101	— 35 —	— $87 11$ — $87 26$ —	— $87 17$ —	37 56 87 17 54 47	— 0 —
{ s'q = 101 : 011 qp = 011 : 110 ps' = 110 : 101	— 32 —	— $62 51$ — $63 5$ —	— $62 59$ —	45 32 63 0 71 28	— 1 —
{ r'o' = 201 : 111 o'p = 111 : 110 pr' = 110 : 201	15 20 19	$35 3$ — $35 16$ $92 27$ — $92 39$ $52 13$ — $52 25$	$35 7$ $92 33$ $52 19$	$35 6$ 92 38 52 16	1 5 3

Total number of measurements, 422.

the prism faces were almost entirely free from striation in the small crystals measured, and yielded very trustworthy values. On the other hand, the faces of the basal plane were almost universally striated or curved parallel to the axis a , so that the reflections when the crystal was adjusted for measuring the zone $[cq\bar{b}]$ were usually double or multiple. The mean position, however, of these various images afforded a fairly accurate approximation to the position of c . Moreover, as the definition of the images given by the q faces was particularly perfect, any slight uncertainty respecting the position of c disappears on taking the mean of the whole of the values of the angle cq obtained. When the crystal was adjusted for measuring the zone $[acr']$, the multiple reflections of c coincided into one single image, affording accurate readings.

FIG. 20.

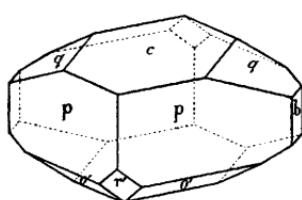
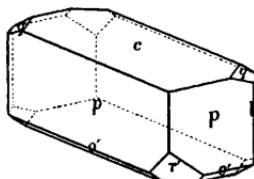


FIG. 21.



The faces of the clinopinacoid $b\{010\}$, orthodome $r'\{\bar{2}01\}$, and the hemipyramid $r\{\bar{1}11\}$ are usually present, but small. Faces of the prismatic form $p'\{120\}$ were observed upon one crystal, but the images of the signal reflected from them were too faint for accurate allocation.

The results of the measurements and calculations are tabulated on p. 383.

Cæsium Nickelous Sulphate, $\text{Cs}_2\text{Ni}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

The crystals of cæsium nickelous sulphate are bright green and perfectly clear and transparent, like the corresponding potassium and rubidium salts. They readily grow to large size. Ten small crystals were measured, selected from five different crops.

Estimations of the sulphuric acid and nickel contained in other crystals belonging to one of these crops yielded the following numbers:—

0·6645 gram of crystals gave 0·5000 gram of BaSO_4 , corresponding to 25·84 per cent. of SO_3 . The calculated percentage of SO_3 is 25·60.

0·6775 gram of crystals gave 0·0810 gram of NiO , corresponding to 11·95 per cent. of NiO . The calculated percentage of NiO is 12·00.

Habit: prismatic.

Axial angle: $\beta = 72^\circ 58'$.

Ratio of axes: $a : b : c = 0.7270 : 1 : 0.4984$.

Forms observed: $b = \{010\}_{\infty}P_{\infty}$; $c = \{001\}_oP$; $p = \{110\}_{\infty}P$;
 $q = \{011\}P_{\infty}$; $o' = \{\bar{1}11\}+P$; $r' = \{\bar{2}01\}+2P_{\infty}$.

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$as = 100 : 101$	—	—	—	44° 21'	—
$sc = 101 : 001$	—	—	—	23 37	—
$ac = 100 : 001$	—	—	—	72 58	—
$cs' = 001 : \bar{1}01$	—	—	—	39 22	—
$s'r' = \bar{1}01 : \bar{2}01$	—	—	—	26 6	—
$cr' = 001 : \bar{2}01$	8	65° 20' — 65° 32'	65° 26'	65 28	2'
$r'a = \bar{2}01 : 100$	—	—	—	41 34	—
$ap = 100 : 110$	—	—	—	34 48	—
$pp' = 110 : 120$	—	—	—	19 28	—
$p'b = 120 : 010$	—	—	—	35 44	—
$pb = 110 : 010$	32	55 5 — 55 21	55 12	*	—
$pp = 110 : \bar{1}10$	20	69 30 — 69 40	69 35	69 36	1
$pp = 110 : \bar{1}10$	20	110 15 — 110 32	110 25	110 24	1
$cq = 001 : 011$	40	25 22 — 25 34	25 28	*	—
$qb = 011 : 010$	18	64 26 — 64 36	64 32	64 32	0
$qq = 011 : 01\bar{1}$	20	128 58 — 129 9	129 4	129 4	0
$ao = 100 : 111$	—	—	—	47 32	—
$oq = 111 : 011$	—	—	—	27 8	—
$aq = 100 : 011$	—	—	—	74 40	—
$qo' = 011 : \bar{1}11$	24	35 22 — 35 39	35 32	35 31	1
$o'a = \bar{1}11 : 100$	—	—	—	69 49	—
$co = 001 : 111$	—	—	—	34 0	—
$op = 111 : 110$	—	—	—	42 5	—
$cp = 001 : 110$	26	75 45 — 76 16	76 5	*	—
$po' = 110 : 11\bar{1}$	22	58 19 — 58 44	58 30	58 31	1
$o'c = 111 : 00\bar{1}$	21	45 14 — 45 41	45 24	45 24	0
$bo = 010 : 111$	—	—	—	70 48	—
$os = 111 : 101$	—	—	—	19 12	—
$bo' = 010 : \bar{1}11$	17	65 8 — 65 20	65 17	65 15	2
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 45	—
$o'o' = 111 : 111$	10	49 18 — 49 35	49 25	49 30	5
$sq = 101 : 011$	—	—	—	37 35	—
$qp = 011 : \bar{1}10$	32	88 12 — 88 29	88 21	88 23	2
$ps = 110 : 10\bar{1}$	—	—	—	54 2	—
$s'q = \bar{1}01 : 011$	—	—	—	45 44	—
$qp' = 011 : 110$	33	62 19 — 62 39	62 30	62 27	3
$ps' = 110 : 10\bar{1}$	—	—	—	71 49	—
$r'o' = \bar{2}01 : \bar{1}11$	11	35 6 — 35 29	35 20	35 22	2
$o'p = \bar{1}11 : 110$	20	92 29 — 92 46	92 37	92 32	5
$pr' = 110 : 20\bar{1}$	13	51 55 — 52 15	52 4	52 6	2

Total number of measurements, 387.

The caesium nickel salt crystallises very similarly to the caesium salts of the series containing as the second metal magnesium, zinc, iron, and manganese, the basal plane $c\{001\}$ being only narrow, whilst the clinodome $q\{011\}$ is so largely developed, and its faces frequently so long, as to endow the crystals with a prismatic habit. In some crops, the prisms thus formed by the faces of the clinodome are compact, as in Fig. 22; in others, they are elongated, as represented in Fig. 23. The narrow faces of the basal plane were usually

FIG. 22.

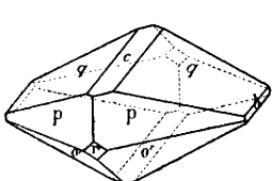
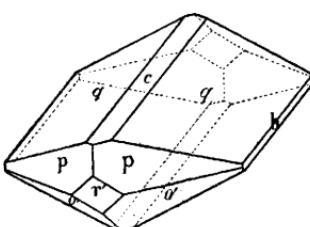


FIG. 23.



curved and striated parallel to the edges cq , but most of the crystals measured were almost free from this imperfection. The faces of the clinodome were uniformly plane, yielding brilliant, single reflections. The ends of the prisms are formed mainly by the faces of the prism $p\{110\}$ and hemipyramid $o'\{\bar{1}11\}$, more or less equally developed, and both forms gave good single reflections. Together with narrow clinopinacoid faces $b\{010\}$, these were the only forms usually present, the orthodome $r'\{\bar{2}01\}$ being generally either absent or very small. But upon several of the specially well-developed crystals employed in making the measurements, the faces of the latter form were sufficiently large and brilliant to yield good images of the signal.

The table on p. 385 represents the results of the measurements.

In the next table (p. 387), the respective values of the angles of the three salts just described are placed side by side for comparison, as before in the cases of the salts containing magnesium, zinc, iron, and manganese.

The angular relationships between the three nickel salts follow the same rules as were observed to apply in the cases of the salts containing as the second metal magnesium, zinc, iron, and manganese respectively.

The differences in the axial angle are again approximately equal ($63'$ and $59'$), and in the cases of 33 out of the 36 angles compared the values for the rubidium salts lie between the corresponding values for the potassium and caesium salts. The three exceptions occur in the cases of the same angles (bo' , $o's'$, and pr') as in the salts pre-

Comparison of the Angles of the three Salts containing Nickel.

Angle.	Potassium salt.	Diff.	Rubidium salt.	Diff.	Cæsium salt.
{ $ac = 100 : 001 = \beta$	75° 0'	-63'	73° 57'	-59'	72° 58'
{ $as = 100 : 101$	45 48	-44	45 4	-43	44 21
{ $sc = 101 : 001$	29 12	—	28 53	—	28 37
{ $cr' = 001 : \bar{2}01$	63 44	+52	64 36	+52	65 28
{ $cs' = 001 : 101$	38 33	—	38 57	—	39 22
{ $s'r' = \bar{1}01 : \bar{2}01$	25 11	+28	25 39	+27	26 6
{ $r'a = \bar{2}01 : \bar{1}00$	41 16	—	41 27	—	41 34
{ $ap = 100 : 110$	35 29	-12	35 17	-29	34 48
{ $pp' = 110 : 120$	19 28	—	19 28	—	19 28
{ $p'b = 120 : 010$	35 3	+12	35 15	+29	35 44
{ $pb = 110 : 010$	54 31	—	54 43	—	55 12
{ $cq = 001 : 011$	25 52	-8	25 44	-16	25 28
{ $qb = 011 : 010$	64 8	—	64 16	—	64 32
{ $ao = 100 : 111$	48 59	-43	48 16	-44	47 32
{ $oq = 111 : 011$	27 33	—	27 19	—	27 8
{ $aq = 100 : 011$	76 32	-57	75 35	-55	74 40
{ $qo' = 011 : \bar{1}11$	34 46	—	35 5	—	35 31
{ $o'a = \bar{1}11 : \bar{1}00$	68 42	+38	69 20	+29	69 49
{ $co = 001 : 111$	34 46	-21	34 25	-25	34 0
{ $op = 111 : 110$	43 4	—	42 32	—	42 5
{ $cp = 001 : 110$	77 50	-53	76 57	-52	76 5
{ $po' = 110 : \bar{1}1\bar{1}$	57 26	—	57 57	—	58 31
{ $o'c = \bar{1}1\bar{1} : 00\bar{1}$	44 44	+22	45 6	+18	45 24
{ $bo = 010 : 111$	70 12	+13	70 25	+23	70 48
{ $os = 111 : 101$	19 48	—	19 35	—	19 12
{ $bo' = 010 : \bar{1}11$	65 17	-6	65 11	+ 4	65 15
{ $o's' = \bar{1}11 : \bar{1}01$	24 43	—	24 49	—	24 45
{ $sq = 101 : 011$	38 13	-17	37 56	-21	37 35
{ $qp = 011 : \bar{1}10$	86 22	+55	87 17	+66	88 28
{ $ps = \bar{1}10 : \bar{1}0\bar{1}$	55 25	—	54 47	—	54 2
{ $s'q = \bar{1}01 : 011$	45 17	—	45 32	—	45 44
{ $qp' = 011 : 110$	63 43	-43	63 0	-33	62 27
{ $ps' = \bar{1}10 : 10\bar{1}$	71 0	+28	71 28	+21	71 49
{ $r'o' = \bar{2}01 : \bar{1}11$	34 43	+23	35 6	+16	35 22
{ $o'p = \bar{1}11 : 110$	93 1	—	92 38	—	92 32
{ $pr' = 110 : 20\bar{1}$	52 16	0	52 16	-10	52 6

viously compared; the differences in these cases are very small, and the same explanation, that they are due to more or less neutralisation being produced owing to the change on either side being of opposite signs, is applicable to them.

Once more the maximum deviation from direct proportionality occurs in the prism zone, the differences for the angle ap being 12' and 29' respectively, thus bearing the ratio of about 1 : 2.5.

The changes in the axial ratios are again very slight, especially in the case of the ratio $b : c$.

In potassium nickelous sulphate	$a : b : c = 0.7379 : 1 : 0.5020$
„ rubidium „ „	$a : b : c = 0.7350 : 1 : 0.5022$
„ caesium „ „	$a : b : c = 0.7270 : 1 : 0.4984$

Salts containing Cobalt.

Potassium Cobaltous Sulphate, $K_2Co(SO_4)_2 \cdot 6H_2O$.

The colour of the crystals of this salt varies in different crops from ruby-red to reddish-brown. Their faces are usually deeply striated and distorted, so that accurate measurement has hitherto been found extremely difficult. During the course of this work one crop, however, was eventually obtained entirely free from this defect. It consisted of brownish-red, plane-faced individual crystals of small size (ranging from very minute to crystals 3–4 mm. diameter), which yielded sharply defined and very brilliant images of the "Websky" signal, and consequently enabled perfectly trustworthy measurements to be obtained. Eight crystals of this crop were completely measured. The best-formed zones of two more crystals, selected from two other crops for their comparative freedom from distortion, were also measured and found to give values confirmatory of those derived from the eight crystals of the exceptionally good crop.

The following results were obtained from analyses of other specimens belonging to the good crop above referred to:—

0.8505 gram of crystals gave 0.9015 gram of $BaSO_4$, corresponding to 36.39 per cent. of SO_3 . The calculated percentage of SO_3 is 36.61.

1.3375 gram of crystals, on precipitation of the hydrated oxide by pure sodium hydrate and reduction of the ignited oxide to metallic cobalt in a current of hydrogen, gave 0.1780 gram of metallic cobalt, corresponding to 16.92 per cent. of CoO . The calculated percentage of CoO is 17.16.

Habit: varying from prismatic to tabular.

Axial angle: $\beta = 75^\circ 5'$.

Ratio of axes: $a : b : c = 0.7404 : 1 : 0.5037$.

Forms observed: $a = \{100\} \infty P \infty$; $c = \{001\} oP$; $p = \{110\} \infty P$; $p' = \{120\} \infty P 2$; $q = \{011\} P \infty$; $o' = \{\bar{1}11\} + P$; $r' = \{\bar{2}01\} + 2P \infty$.

The habit of the eight crystals belonging to the excellent crop above mentioned is represented in Fig. 24 (p. 390). The predominating

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forms are, as in the potassium salts previously described, the basal plane $c\{001\}$ and the prism $p\{110\}$. The faces of the clinodome $q\{011\}$ and orthodome $r'\{\bar{2}01\}$ were invariably present, but relatively small, and these four forms were usually the only ones developed. Upon a few crystals of this crop, however, the faces of the hemipyramid $o'\{\bar{1}11\}$ and orthopinacoid $a\{100\}$ were discovered. The

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$\{as = 100 : 101$	—	—	—	45° 53'	—
$sc = 101 : 001$	—	—	—	29 12	—
$ac = 100 : 001$	—	—	—	75 5	—
$es' = 001 : \bar{1}01$	—	—	—	38 29	—
$s'r' = \bar{1}01 : \bar{2}01$	—	—	—	25 9	—
$cr' = 001 : \bar{2}01$	18	63° 29' — 63° 45'	63° 37'	63 38	1'
$r'a = \bar{2}01 : \bar{1}00$	—	—	—	41 17	—
$\{ap = 100 : 110$	2	35 28 — 35 49	35 38	35 37	1
$pp' = 110 : 120$	3	19 18 — 19 26	19 23	19 28	5
$p'b = 120 : 010$	—	—	—	34 55	—
$pb = 110 : 010$	—	—	—	54 23	—
$pp = 110 : \bar{1}\bar{1}0$	20	71 2 — 71 28	71 14	*	—
$pp = 110 : \bar{1}\bar{1}0$	20	108 30 — 108 59	108 46	108 46	0
$\{eq = 001 : 011$	37	25 51 — 26 0	25 55	*	—
$q\bar{b} = 011 : 010$	—	—	—	64 5	—
$qq = 011 : 01\bar{1}$	19	128 2 — 128 28	128 11	128 10	1
$\{ao = 100 : 111$	—	—	—	49 6	—
$oq = 111 : 011$	—	—	—	27 31	—
$aq = 100 : 011$	—	—	—	76 37	—
$qo' = 011 : \bar{1}11$	4	34 25 — 35 2	34 42	34 41	1
$o'a = \bar{1}11 : \bar{1}00$	—	—	—	68 42	—
$\{co = 001 : 111$	—	—	—	34 50	—
$op = 111 : 110$	—	—	—	43 5	—
$cp = 001 : 110$	35	77 50 — 77 59	77 55	*	—
$po' = 110 : 11\bar{1}$	3	57 12 — 57 27	57 20	57 22	2
$o'c = 11\bar{1} : 00\bar{1}$	3	44 34 — 44 54	44 44	44 43	1
$\{bo = 010 : 111$	—	—	—	70 7	—
$os = 111 : 101$	—	—	—	19 53	—
$\{bo' = 010 : \bar{1}11$	—	—	—	65 13	—
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 47	—
$o'o' = \bar{1}11 : \bar{1}\bar{1}1$	1	—	49 30	49 34	4
$\{sq = 101 : 011$	—	—	—	38 16	—
$qp = 011 : \bar{1}10$	28	86 3 — 86 22	86 12	86 12	0
$ps = \bar{1}10 : 10\bar{1}$	—	—	—	55 32	—
$\{s'q = \bar{1}01 : 011$	—	—	—	45 15	—
$qp = 011 : 110$	29	63 32 — 63 52	63 44	63 43	1
$ps' = 110 : 10\bar{1}$	—	—	—	71 2	—
$\{r'o' = \bar{2}01 : \bar{1}11$	3	34 35 — 34 46	34 41	34 44	3
$o'p = \bar{1}11 : 110$	2	92 54 — 93 3	92 58	92 55	3
$pr' = 110 : 20\bar{1}$	32	52 13 — 52 29	52 21	52 21	0

Total number of measurements, 259.

habit of one of the other two crystals measured, typical of the crystals of several of the ruby-red crops obtained, is shown in Fig. 25. It is characterised by the large relative development of the orthodome $r\{\bar{2}01\}$. In other crops, the crystals were reduced to thin plates, parallel to the basal plane, owing to the shortening of the prism faces. One face of the prismatic form $p'\{120\}$ was observed upon three individual crystals. Although many crystals were examined besides those subjected to measurement, no traces of the clinopinacoid $b\{010\}$ were ever observed.

FIG. 24.

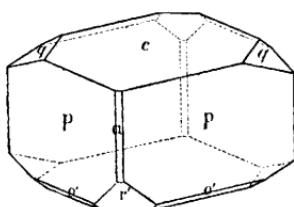
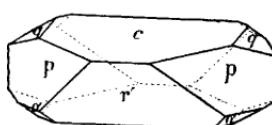


FIG. 25.



The results of the measurements are exhibited in the table, p. 389.

The values of the few measured angles of this salt given by Murrmann and Rotter (*loc. cit.*) differ rather considerably from those given above. The axial angle given by these observers is $75^\circ 17'$, and the ratio of the axes, $a : b : c = 0.7327 : 1 : 0.4705$. They state, however, that the values are somewhat uncertain, owing to imperfections in the crystals employed.

Rubidium Cobaltous Sulphate, $\text{Rb}_2\text{Co}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

The crystals of rubidium cobaltous sulphate are coloured ruby-red or reddish-brown like those of the potassium salt. They also resemble those of the latter salt in being usually much striated and distorted. Ten crystals were measured, and of these nine were selected from two crops which alone, out of the many prepared, showed no appreciable distortion. The tenth crystal was chosen from one of the other crops, and only the measurements yielded by faces free from distortion were accepted. The nine crystals above mentioned were particularly perfect, and gave sharply-defined and brilliant reflections.

Analyses of specimens from one of the two good crops gave the following results:—

0·8690 gram of crystals gave 0·7715 gram of BaSO_4 , corresponding to 30·48 per cent. of SO_3 . The calculated percentage of SO_3 is 30·25.

0.7220 gram of crystals gave 0.0800 gram of metallic cobalt, corresponding to 14.09 per cent. of CoO. The calculated percentage of CoO is 14.18.

Habit: tabular to prismatic.

Axial angle: $\beta = 73^\circ 59'$.

Ratio of axes: $a : b : c = 0.7391 : 1 : 0.5011$.

Forms observed: $b = \{010\}_{\infty}P\infty$; $c = \{001\}_oP$; $p = \{110\}_{\infty}P$;
 $p' = \{120\}_{\infty}P2$; $q = \{011\}\infty$; $o = \{111\}-P$; $o' = \{\bar{1}11\}+P$; $r = \{\bar{2}01\}+2P\infty$; $v = \{\bar{1}12\}+\frac{1}{2}P$.

The crystals of this salt varied very considerably in habit in the various crops obtained. Sometimes, as portrayed in Fig. 26, the faces of the basal plane $c\{001\}$ are relatively so large and the prism faces $p\{110\}$ so short in the vertical direction as to render the crystal tabular parallel to c . It frequently happens, however, in crystals of this type, that the faces of the clinodome $q\{011\}$ are relatively much larger, as represented in Fig. 20, in the description

FIG. 26.

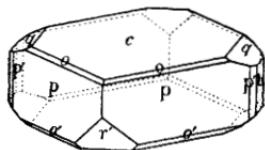
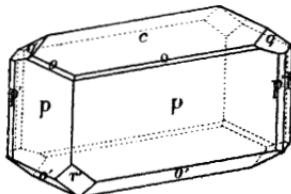


FIG. 27.



of rubidium nickelous sulphate. At other times, the crystals assume quite a different habit, in which the prism faces are vertically much longer, and there is usually a considerable difference in the relative width of adjacent faces of this form, so that, as delineated in Fig. 27, the crystals assume the appearance of an elongated prism whose principal faces are those of the basal plane and a pair of faces of the prism p . The crystals of these two types are usually reddish-brown, and nine of the individuals measured belonged to them. These nine crystals exhibited remarkably perfect faces of the prism p , clinodome q , orthodome $r'\{\bar{2}01\}$, and hemipyramid $o'\{\bar{1}11\}$, all of which forms reflected brilliant single images of the signal. The faces of the clinopinacoid $b\{010\}$ were small, but also gave good reflections. The faces of the basal plane were slightly distorted, giving in the zone $[cq\bar{b}]$ a sheaf of images close together, the mean of the two outside of which afforded a fairly good approximation to the position of c . As the q images, however, were so well defined, any doubt as

to the value of cq disappears on taking the mean of all the values of cq obtained. This distortion does not affect the zone [acr'], the c images coinciding. The angle cp is but slightly affected, and all doubt disappears on taking the mean of all the values of this angle

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
{ $as = 100 : 101$	—	—	—	45° 11'	—
{ $sc = 101 : 001$	—	—	—	28 48	—
{ $ac = 100 : 001$	—	—	—	73 59	—
{ $cs' = 001 : \bar{1}01$	—	—	—	38 47	—
{ $s'r' = 101 : \bar{2}01$	—	—	—	25 37	—
{ $cr' = 001 : \bar{2}01$	18	64° 14'— 64° 28'	64° 19'	64 24	5'
{ $r'a = 201 : \bar{1}00$	—	—	—	41 37	—
{ $ap = 100 : 110$	—	—	—	35 21	—
{ $pp' = 110 : 120$	2	19 17— 19 31	19 24	19 28	4
{ $p'b = 120 : 010$	1	—	35 4	35 11	7
{ $pb = 110 : 010$	28	54 29— 54 48	54 39	* —	—
{ $pp = 110 : \bar{1}10$	20	70 36— 70 49	70 42	70 42	0
{ $\bar{p}p = 110 : \bar{1}10$	20	109 11— 109 25	109 18	109 18	0
{ $cq = 001 : 011$	40	25 37— 25 49	25 43	* —	—
{ $qb = 011 : 010$	30	64 9— 64 26	64 17	64 17	0
{ $qq = 011 : 0\bar{1}\bar{1}$	20	128 25— 128 39	128 34	128 34	0
{ $ao = 100 : 111$	—	—	—	48 23	—
{ $oq = 111 : 011$	3	27 5— 27 31	27 18	27 13	5
{ $aq = 100 : 011$	—	—	—	75 36	—
{ $qo' = 011 : \bar{1}11$	20	34 48— 35 4	34 56	34 59	3
{ $o'a = \bar{1}11 : \bar{1}00$	—	—	—	69 25	—
{ $co = 001 : 111$	3	34 2— 34 41	34 22	34 20	2
{ $op = 111 : 110$	3	42 19— 42 58	42 38	42 40	2
{ $cp = 001 : 110$	35	76 52— 77 7	77 0	* —	—
{ $po' = 110 : \bar{1}1\bar{1}$	30	57 55— 58 16	58 4	58 3	1
{ $o'c = \bar{1}1\bar{1} : 00\bar{1}$	30	44 46— 45 4	44 56	44 57	1
{ $bo = 010 : 111$	—	—	—	70 26	—
{ $os = 111 : 101$	—	—	—	19 34	—
{ $bo' = 010 : \bar{1}11$	30	65 5— 65 22	65 13	65 12	1
{ $o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 48	—
{ $o'o' = \bar{1}11 : \bar{1}\bar{1}\bar{1}$	14	49 29— 49 40	49 34	49 36	2
{ $sq = 101 : 011$	—	—	—	37 51	—
{ $qp = 011 : \bar{1}10$	34	87 5— 87 24	87 14	87 14	0
{ $ps = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	54 55	—
{ $s'v = \bar{1}01 : \bar{1}12$	—	—	—	23 28	—
{ $vq = \bar{1}12 : 011$	1	—	21 50	21 55	5
{ $s'q = \bar{1}01 : 011$	—	—	—	45 23	—
{ $qp = 011 : 110$	34	62 48— 63 8	63 0	63 0	0
{ $ps' = \bar{1}10 : 10\bar{1}$	—	—	—	71 37	—
{ $r'o' = \bar{2}01 : \bar{1}11$	29	34 54— 35 17	35 3	35 4	1
{ $o'p = \bar{1}11 : 110$	30	92 21— 92 36	92 29	92 30	1
{ $pr' = \bar{1}10 : 20\bar{1}$	32	52 14— 52 38	52 27	52 26	1

Total number of measurements, 507.

obtained. In addition to these faces, the primary hemipyramid $\{111\}$, the prismatic form $p'\{120\}$, and the pyramidal form $v\{\bar{1}12\}$ were occasionally observed. The crystals of many other crops of this salt were of the same type as those of potassium cobaltous sulphate represented in Fig. 25, and were, like those, ruby-red. The tenth crystal measured was of this type, and in those cases where the measurements were made upon faces unaffected by distortion, the values were similar to those yielded by the other nine crystals. The crystals of this type are characterised by the relatively large development of the orthodome r' , and they very rarely exhibit faces of the clinopinacoid b .

The results of the measurements are set forth in the table, p. 392.

Cæsium Cobaltous Sulphate, $\text{Cs}_2\text{Co}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

The crystals of cæsium cobaltous sulphate are coloured brownish-red similarly to the corresponding potassium and rubidium salts. Large and apparently well formed crystals are deposited from solutions containing equal molecular proportions of the constituent simple sulphates, but the faces usually exhibit more or less distortion, although not to so great an extent as the potassium and rubidium salts containing cobalt. Ten crystals from five different crops were selected on account of their comparative immunity from this defect.

Analyses of other crystals belonging to one of these crops gave the following numbers:—

0·8725 gram of crystals gave 0·6565 gram of BaSO_4 , corresponding to 25·83 per cent. of SO_3 . The calculated percentage of SO_3 is 25·60.

0·6260 gram of crystals gave 0·0585 gram of metallic cobalt, corresponding to 11·88 per cent. of CoO . The calculated percentage of CoO is 12·00.

Habit: prismatic.

Axial angle: $\beta = 72^\circ 52'$.

Ratio of axes: $a : b : c = 0\cdot7270 : 1 : 0\cdot4968$.

Forms observed: $b = \{010\}_{\infty}\text{P}_{\infty}$; $c = \{001\}_{\infty}\text{P}$; $p = \{110\}_{\infty}\text{P}$; $q = \{011\}\text{P}_{\infty}$; $o' = \{\bar{1}11\} + \text{P}$; $r' = \{\bar{2}01\} + 2\text{P}_{\infty}$.

The habit usually assumed by the crystals of cæsium cobaltous sulphate is represented in Fig. 28 (p. 395). In common with the habitual outward forms of the other cæsium salts of the series previously described, it is characterised by the large relative development of the

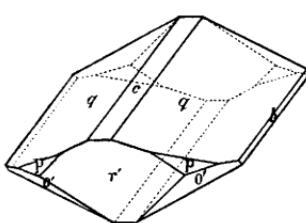
faces of the clinodome $q\{011\}$ and the consequent narrowing of those of the basal plane $c\{001\}$. Owing to the elongation of the faces of the zone $[cgb]$, the crystals take the form of prisms, usually about one and a half times to twice as long as broad. The crystals of this caesium salt are distinguished from those of the other caesium salts of the series yet described in the largely preponderating development among

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$\{as = 100 : 101$	—	—	—	44° 20'	—
$sc = 101 : 001$	—	—	—	28 32	—
$ac = 100 : 001$	—	—	—	72 52	—
$\{cs' = 001 : \bar{1}01$	—	—	—	39 15	—
$s'r' = \bar{1}01 : \bar{2}01$	—	—	—	26 9	—
$cr' = 001 : \bar{2}01$	17	65° 14' — 65° 30'	65° 24'	65 24	0'
$r'a = 201 : \bar{1}00$	—	—	—	41 44	—
$\{ap = 100 : 110$	—	—	—	34 48	—
$pp' = 110 : 120$	—	—	—	19 28	—
$p'b = 120 : 010$	—	—	—	35 44	—
$p'b = 110 : 010$	6	55 6 — 55 16	55 10	55 12	2
$pp = 110 : \bar{1}10$	17	69 25 — 69 48	69 36	*	—
$pp = 110 : \bar{1}10$	17	110 12 — 110 39	110 24	110 24	0
$\{cq = 001 : 011$	40	25 17 — 25 31	25 24	*	—
$qb = 011 : 010$	6	64 30 — 64 42	64 36	64 36	0
$qq = 011 : \bar{0}1\bar{1}$	20	129 7 — 129 16	129 12	129 12	0
$\{ao = 100 : 111$	—	—	—	47 30	—
$oq = 111 : 011$	—	—	—	27 4	—
$aq = 100 : 011$	—	—	—	74 34	—
$qo' = 011 : \bar{1}1\bar{1}$	16	35 16 — 35 30	35 23	35 26	3
$o'a = \bar{1}1\bar{1} : \bar{1}00$	—	—	—	70 0	—
$\{co = 001 : 111$	—	—	—	33 54	—
$op = 111 : 110$	—	—	—	42 6	—
$\{cp = 001 : \bar{1}10$	22	75 53 — 76 8	76 0	*	—
$po' = 110 : \bar{1}1\bar{1}$	18	58 34 — 58 50	58 42	58 42	0
$o'c = \bar{1}1\bar{1} : 001$	18	45 7 — 45 28	45 18	45 18	0
$\{bo = 010 : 111$	—	—	—	70 52	—
$os = 111 : 101$	—	—	—	19 8	—
$\{bo' = 010 : \bar{1}11$	4	65 18 — 65 21	65 19	65 17	2
$o's' = \bar{1}1\bar{1} : \bar{1}01$	—	—	—	24 43	—
$o'o' = \bar{1}1\bar{1} : \bar{1}\bar{1}\bar{1}$	10	49 19 — 49 34	49 24	49 26	2
$\{sq = 101 : 011$	—	—	—	37 29	—
$qp = 011 : \bar{1}10$	20	88 17 — 88 39	88 28	88 29	1
$ps = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	54 2	—
$\{s'q = \bar{1}01 : 011$	—	—	—	45 37	—
$qp = 011 : 110$	20	62 22 — 62 38	62 26	62 24	2
$ps' = \bar{1}10 : 10\bar{1}$	—	—	—	71 59	—
$\{r'o' = \bar{2}01 : \bar{1}11$	14	35 13 — 35 29	35 22	35 22	0
$o'p = \bar{1}1\bar{1} : 110$	13	92 19 — 92 38	92 26	92 25	I
$pr' = 110 : \bar{2}0\bar{1}$	17	52 6 — 52 22	52 13	52 13	0

Total number of measurements, 295.

the end faces of the orthodome $r'\{\bar{2}01\}$, the faces of the prism $p\{110\}$ and hemipyramid $o'\{\bar{1}11\}$ being rarely more prominent than is represented in the figure, the prism faces p being particularly small and not unfrequently scarcely visible. The clinopinacoid $b\{010\}$ is only occasionally developed, by far the greater number of crystals examined showing either no sign of it or only mere traces.

FIG. 28.



The table, p. 394, represents the results of the measurements.

Having now described the three salts containing cobalt as the second metal, a table, in which the three respective values of the various angles are arranged side by side, is appended (p. 396) in order to permit of their ready comparison.

It is remarkable how similar in their nature and magnitude are the differences presented by each set of three salts. Here again in the case of the cobalt salts the value of the axial angle in the one containing rubidium is midway between the values in those containing potassium and cæsium, the differences being $66'$ and $67'$, thus following the rule of simple direct proportion to the change in atomic weight observed with respect to the axial angle in the sets of three salts previously discussed.

Moreover, as also found with regard to the salts before described, the rule that the values of all the angles of the rubidium salt lie somewhere between those of the potassium and the cæsium salts again applies in 33 out of the 36 angles compared; also, the three exceptions are identical with those previously described, namely, the angles bo' , $o's'$, and pr' , and are cases where the change is practically *nil*, owing to the changes in the zones or angles upon opposite sides of them being in opposite directions.

Again, the maximum deviation from direct simple proportionality occurs in the angles of the prism zone, the differences of the angle ap being $16'$ and $33'$ or approximately in the ratio $1 : 2$.

The changes in the axial ratios are again of the same slight order, but it will be remarked that those of the rubidium salt lie between those of the potassium and cæsium salts.

For potassium cobaltous sulphate $a : b : c = 0\cdot7404 : 1 : 0\cdot5037$
 „ rubidium „ „ $a : b : c = 0\cdot7391 : 1 : 0\cdot5011$
 „ caesium „ „ $a : b : c = 0\cdot7270 : 1 : 0\cdot4968$

Comparison of the Angles of the three Salts containing Cobalt.

Angle.	Potassium salt.	Diff.	Rubidium salt.	Diff.	Cæsium salt.
{ $ac = 190 : 001 = \beta$	75° 5'	-66'	73° 59'	-67'	72° 52'
{ $as = 100 : 101$	45 53	-42	45 11	-51	44 20
{ $sc = 101 : 001$	29 12	—	28 48	—	28 32
{ $cr' = 001 : 201$	63 38	+46	64 24	+60	65 24
{ $cs' = 001 : \bar{1}01$	38 29	—	38 47	—	39 15
{ $s'r' = \bar{1}01 : 201$	25 9	+28	25 37	+32	26 9
{ $r'a = 201 : 100$	41 17	—	41 37	—	41 44
{ $ap = 100 : 110$	35 37	-16	35 21	-33	34 48
{ $pp' = 110 : 120$	19 28	—	19 28	—	19 28
{ $p'b = 120 : 010$	34 55	+16	35 11	+33	35 44
{ $pb = 110 : 010$	54 23	—	54 39	—	55 12
{ $cq = 001 : 011$	25 55	-12	25 43	-19	25 24
{ $qb = 011 : 010$	64 5	—	64 17	—	64 36
{ $ao = 100 : 111$	49 6	-43	48 28	-53	47 30
{ $oq = 111 : 011$	27 31	—	27 13	—	27 4
{ $aq = 100 : 011$	76 37	-61	75 36	-62	74 34
{ $q'o' = 011 : \bar{1}11$	34 41	—	34 59	—	35 26
{ $o'a = \bar{1}11 : 100$	68 42	+43	69 25	+35	70 0
{ $co = 001 : 111$	34 50	-30	34 20	-26	33 54
{ $op = 111 : 110$	43 5	—	42 40	—	42 6
{ $cp = 001 : 110$	77 55	-55	77 0	-60	76 0
{ $po' = 110 : 111$	57 22	—	58 3	—	58 42
{ $o'c = 111 : 001$	44 43	+14	44 57	+21	45 18
{ $bo = 010 : 111$	70 7	+19	70 26	+26	70 52
{ $os = 111 : 101$	19 53	—	19 34	—	19 8
{ $bo' = 010 : \bar{1}11$	65 13	-1	65 12	+ 5	65 17
{ $o's' = \bar{1}11 : 101$	24 47	—	24 48	—	24 43
{ $sq = 101 : 011$	38 16	-25	37 51	-22	37 29
{ $qp = 011 : \bar{1}10$	86 12	+62	87 14	+75	88 29
{ $ps = \bar{1}10 : 101$	55 32	—	54 55	—	54 2
{ $s'q = \bar{1}01 : 011$	45 15	—	45 23	—	45 37
{ $qp' = 011 : 110$	63 43	-43	63 0	-36	62 24
{ $ps' = \bar{1}10 : 101$	71 2	+35	71 37	+22	71 59
{ $r'o' = \bar{2}01 : \bar{1}11$	34 44	+20	35 4	+18	35 22
{ $o'p = \bar{1}11 : 110$	92 55	—	92 30	—	92 25
{ $pr' = 110 : 201$	52 21	+ 5	52 26	-13	52 13

Salts containing Copper.

Potassium Copper Sulphate, K₂Cu(SO₄)₂, 6H₂O.

The crystals of potassium copper sulphate are of a light greenish-blue. The most perfect crystals, formed by slow evaporation of solu-

tions containing the two constituent sulphates in equal molecular proportions, are clear and transparent, but somewhat difficult to obtain, and rarely attain any considerable size without losing their perfection. Crystals more quickly grown are more or less turbid and semi-opaque, and the faces dull. Ten exceptionally well formed crystals were measured, selected from three different crops.

Estimations of the sulphuric acid and copper contained in other crystals of one of these three crops afforded the following numbers:—

0·8770 gram of crystals gave 0·9110 gram of BaSO_4 , corresponding to 35·67 per cent. of SO_3 . The calculated percentage of SO_3 is 36·28.

0·8613 gram of crystals gave 0·1525 gram of CuO , corresponding to 17·76 per cent. of CuO . The calculated percentage of CuO is 17·91.

It will be observed that the amount of SO_3 found is 0·6 per cent. too low. A second estimation gave an almost identical result. This is the only case of the kind which has been met with among the whole of the 22 salts investigated, and would appear to be connected with the difficulty experienced in obtaining transparent crystals of this salt, for most of the crystals taken to make up the amount required for the analysis were more or less opaque. Indeed, of all the six potassium salts of the series, the potassium copper salt has been by far the most difficult to obtain in suitable crystals. It will be afterwards shown that the rubidium salt and particularly the caesium salt containing copper as the second metal are much more readily formed in good crystals, which give practically theoretical numbers on analysis. It is improbable, however, that the slight discrepancy in the content of SO_3 observed in the case of the potassium salt will have any appreciable effect on the geometrical form of the crystals. For, as the simple sulphates of potassium and copper employed in preparing the salt were pure, the cause of this slight discrepancy cannot be the presence of any other salt crystallising isomorphically with it, but is more likely to be due to a minute quantity of foreign matter mechanically included, possibly traces of a salt containing a different number of molecules of water, which produces the turbidity, but which has no influence whatever on the angles of the crystals.

Habit: more or less tabular.

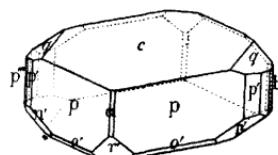
Axial angle $\beta = 75^\circ 32'$.

Ratio of axes: $a : b : c = 0\cdot7490 : 1 : 0\cdot5088$.

Forms observed: $a = \{100\} \infty P \infty$; $b = \{010\} \infty P \infty$; $c = \{001\} \delta P$; $p = \{110\} \infty P$; $p' = \{120\} \infty P 2$; $p''' = \{130\} \infty P 3$; $q = \{011\} P \infty$; $o' = \{\bar{1}11\} + P$; $n' = \{121\} + 2P2$; $r' = \{\bar{2}01\} + 2P \infty$.

The usual habit of the crystals of potassium copper sulphate is delineated in Fig. 29. It will be observed to follow the rule of the potassium salts of the series in exhibiting a relatively largely developed basal plane $c\{001\}$, parallel to which faces the crystals are usually more or less tabular, according to the comparative vertical height of the faces of the prism $p\{110\}$. Upon the crystals chosen for measurement, the short but wide faces of the latter form were uniformly brilliant, and gave irreproachable single images of the signal. The faces of the basal plane were generally deeply grooved, parallel to the trace of the symmetry plane; but this curious grooving did not interfere with the definition of the reflections. The faces of the clinodome $q\{011\}$, however, which have, as a rule, been found so well formed and bright in the other salts of the series, were very poor upon most of the large number of crystals examined; in some crops they were so small (carrying the characteristic of the potassium salt to an extreme) and dull as to afford no definite images. Occasionally crystals were found which did exhibit good clinodome faces, and several of the crystals measured were chosen on this account. In these somewhat rare cases, good single images were obtained.

FIG. 29.



The faces of the orthodome $r'\{\bar{2}01\}$ and of the hemipyramid $o'\{\bar{1}11\}$ were likewise small in comparison with those of the prism and basal plane; but the images were fairly good in the crystals measured. The chief characteristic, however, of this salt is the comparatively large and perfect development of the hemipyramid $n'\{\bar{1}21\}$, which was almost always present, and its faces frequently the largest and most brilliant after those of the basal plane and primary prism. The faces of the prismatic form $p'\{120\}$ were always found more or less developed, and yielded good reflections. In addition to this prismatic form, another, $p''\{130\}$, was observed upon one crystal. Of the two pinacoids, the clinopinacoid $b\{010\}$ was usually observed, but the orthopinacoid $a\{100\}$ was only developed upon two of the crystals measured.

The results of the measurements are tabulated on p. 399.

The previous measurements of the crystals of this salt are quite untrustworthy. Brooke appears to have made measurements of four angles (v. Rammelsberg, *Kryst. Phys. Chemie*), but the values ascribed

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Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
{ as	= 100 : 101	—	—	46° 11'	—
sc	= 101 : 001	—	—	29 21	—
ac	= 100 : 001	—	—	75 32	—
cs'	= 001 : 101	—	—	38 22	—
s'r'	= 101 : 201	—	—	24 57	—
cr'	= 001 : 201	8	63° 7'— 63° 31'	63° 18'	63 19 1'
r'a	= 201 : 100	—	—	41 9	—
{ ap	= 100 : 110	4	35 50— 36 8	35 59	35 59 0
pp'	= 110 : 120	19	19 16— 19 38	19 26	19 28 2
p'b	= 120 : 010	10	34 24— 34 52	34 38	34 33 5
p'p'''	= 120 : 130	1	—	10 9	9 54 15
p''b	= 130 : 010	1	—	24 28	24 39 11
pb	= 110 : 010	16	53 45— 54 19	54 1	54 1 0
pp	= 110 : 110	23	71 54— 72 3	71 58	* —
pp	= 110 : 110	20	107 57— 108 6	108 2	108 2 0
{ cq	= 001 : 011	12	26 7— 26 14	26 11	* —
qb	= 011 : 010	9	63 48— 63 58	63 54	63 49 5
qq	= 011 : 011	3	127 42— 127 48	127 45	127 38 7
{ ao	= 100 : 111	—	—	—	49 28 —
og	= 111 : 011	—	—	—	27 35 —
aq	= 100 : 011	—	—	—	77 3 —
go'	= 011 : 111	1	—	34 40	34 30 10
o'a	= 111 : 100	—	—	—	68 27 —
{ co	= 001 : 111	—	—	—	35 6 —
op	= 111 : 110	—	—	—	43 14 —
cp	= 001 : 110	37	78 13— 78 27	78 20	* —
po'	= 110 : 111	6	56 50— 56 58	56 54	56 58 4
o'c	= 111 : 001	6	44 34— 44 52	44 43	44 42 1
{ bo	= 010 : 111	—	—	—	69 50 —
os	= 111 : 101	—	—	—	20 10 —
{ bn'	= 010 : 121	3	47 1— 47 14	47 6	47 4 2
n'o'	= 121 : 111	1	—	17 56	17 59 3
bo'	= 010 : 111	1	—	65 0	65 3 3
o's'	= 111 : 101	—	—	—	24 57 —
o'o'	= 111 : 111	1	—	49 57	49 54 3
{ sq	= 101 : 011	—	—	—	38 32 —
qn'	= 011 : 121	3	35 18— 35 32	35 27	35 21 6
n'p	= 121 : 110	10	50 0— 50 21	50 12	50 11 1
qp	= 011 : 110	11	85 27— 85 45	85 39	85 32 7
ps	= 110 : 101	—	—	—	55 56 —
{ s'q	= 101 : 011	—	—	—	45 17 —
qp	= 011 : 110	9	63 40— 63 51	63 46	63 51 5
ps'	= 110 : 101	—	—	—	70 52 —
{ r'o'	= 201 : 111	3	34 45— 34 50	34 47	34 43 4
o'p	= 111 : 110	3	92 43— 92 52	92 47	92 49 2
pr'	= 110 : 201	11	52 18— 52 40	52 30	52 28 2

Total number of measurements, 232.

to them are so different from the extreme limits of the values given above, and so out of keeping with those of the ammonium salt as

determined by Miller, that grave doubts must be entertained concerning the purity of the salt measured by Brooke. The axial angle he gives as $71^\circ 56'$, and the ratio of the axes as $a : b : c = 0.7701 : 1 : 0.4932$, values utterly at variance with those now given. The untrustworthiness of these few older values is rendered very probable indeed, when they are compared with Miller's angles for ammonium copper sulphate. From the most trustworthy measurements made of the ammonium salts of this series, the value of the axial angle in these salts would appear to be about 2° lower than in the corresponding potassium salts of the series, and curiously enough almost identical with the values of the analogous caesium salts given in this communication. Now, Miller's value of β for ammonium copper sulphate is $73^\circ 54'$, almost identical with the value of β ($73^\circ 50'$) found by the author for caesium copper sulphate. It would be expected, therefore, that the value of β in potassium copper sulphate would be over $75\frac{1}{2}^\circ$, which the author finds to be the case, namely, $75^\circ 32'$. It is evident, therefore, that Brooke's value, $71^\circ 56'$, is altogether erroneous.

Rubidium Copper Sulphate, $\text{Rb}_2\text{Cu}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

Rubidium copper sulphate is more readily obtained in crystals possessing bright faces than its potassium analogue; they are pale greenish-blue, like those of the latter salt. Eleven crystals were measured, selected from three different crops. Of these, nine belonged to a specially well-developed crop, the crystals of which were particularly brilliant and free from distortion. All the other crops obtained were more or less affected by distortion, and the two remaining crystals employed were only measured along certain zones in which the distortion was insignificant. The values obtained from these two crystals were similar to those observed upon the nine excellent crystals of the crop previously referred to.

Estimations of the content of sulphuric acid and copper in one of these crops yielded the following results:—

0.7780 gram of crystals gave 0.6800 gram of BaSO_4 , corresponding to 30.01 per cent. of SO_3 . The calculated percentage of SO_3 is 30.02.

0.6395 gram of crystals gave 0.0955 gram of CuO , corresponding to 14.93 per cent. of CuO . The calculated percentage of CuO is 14.82.

Habit: tabular to short prismatic.

Axial angle: $\beta = 74^\circ 42'$.

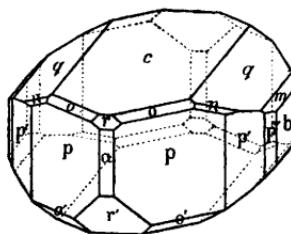
Ratio of axes: $a : b : c = 0.7490 : 1 : 0.5029$.

Forms observed : $a = \{100\} \infty P \infty$; $b = \{010\} \infty P \infty$; $c = \{001\} oP$;
 $p = \{110\} \infty P$; $p' = \{120\} \infty P 2$; $p''' = \{130\} \infty P 3$; $q = \{011\} P \infty$;
 $m = \{021\} 2P \infty$; $o = \{111\} - P$; $o' = \{\bar{1}11\} + P$; $n = \{121\} - 2P 2$;
 $r = \{201\} - 2P \infty$; $r' = \{\bar{2}01\} + 2P \infty$.

As will be seen from the list of forms given above, the crystals of rubidium copper sulphate are particularly rich in faces. Moreover, several of the rarer forms frequently attain considerable size, as represented in Fig. 30. The disposition of the more commonly occurring forms is that more or less characteristic of the other rubidium salts of the series, the most peculiar feature observed being the occasional relatively large development of the clinopinacoid $b\{010\}$. The basal plane $c\{001\}$ may, perhaps, be considered as the predominating form, the crystals of some crops being tabular parallel to it, but it is frequently equalled in size in other crops by the prism faces, the crystals then assuming a short prismatic habit.

The clinodome $q\{011\}$ is likewise an important form, as in the other rubidium salts of the series, and the images of the signal yielded by it were particularly brilliant and well defined, quite different in this

FIG. 30.



respect from those afforded by the corresponding faces upon the crystals of potassium copper sulphate. The faces of the rarer form $m\{021\}$ were frequently as relatively large as shown in the figure, and occasionally still more prominent. The orthodome $r'\{\bar{2}01\}$ is usually somewhat small, but bright and plane.

For the first time in the course of this work, the complementary orthodome $r\{201\}$ was found developed upon one crystal, of about the relative size indicated in the figure. The primary hemipyramid $o\{111\}$ is frequently as largely developed as the more commonly occurring complementary form $o'\{\bar{1}11\}$, both forms yielding trustworthy reflections. The prismatic forms $p'\{120\}$ and $p''\{130\}$ were both found well formed upon a few crystals, and their faces reflected bright images of the signal. The orthopinacoid $a\{100\}$ and the hemipyramid $n\{121\}$ were likewise observed developed upon one crystal to about the extent shown in the figure.

The following table exhibits the results of the measurements :—

402 TUTTON: ATOMIC WEIGHT OF CONTAINED METALS

Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
{ $ar = 100 : 201$	1	—	30° 53'	30° 59'	6'
$rc = 201 : 001$	1	—	43 35	43 43	8
{ $as = 100 : 101$	—	—	—	45 53	—
$sc = 101 : 001$	—	—	—	28 49	—
{ $ac = 100 : 001$	1	—	74 34	74 42	8
$cs' = 001 : \bar{1}01$	—	—	—	38 12	—
$s'r' = 101 : 201$	—	—	—	25 18	—
{ $cr' = 001 : \bar{2}01$	16	63° 18' — 63° 43'	63 32	63 30	2
$r'a = 201 : 100$	1	—	41 56	41 48	8
{ $ap = 100 : 110$	2	35 51 — 35 54	35 52	35 52	0
$pp' = 110 : 120$	4	19 17 — 19 41	19 33	19 28	5
{ $p'b = 120 : 010$	3	34 23 — 34 55	34 37	34 40	3
$p'b'' = 120 : 130$	2	9 46 — 10 4	9 55	9 55	0
{ $p''b = 130 : 010$	4	24 41 — 24 51	24 45	24 45	0
$p'b = 110 : 010$	32	54 2 — 54 13	54 8	*	—
{ $pp = 110 : 1\bar{1}0$	18	71 37 — 71 55	71 44	71 44	0
$pp = 110 : \bar{1}10$	18	108 9 — 108 20	108 16	108 16	0
{ $cq = 001 : 011$	40	25 43 — 26 0	25 54	*	—
$qm = 011 : 021$	3	18 15 — 18 21	18 17	18 16	1
{ $mb = 021 : 010$	3	45 45 — 45 51	45 48	45 50	2
$qb = 011 : 010$	34	63 58 — 64 13	64 6	64 6	0
{ $qq = 011 : 01\bar{1}$	20	128 4 — 128 30	128 12	128 12	0
{ $ao = 100 : 111$	—	—	—	49 5	—
$oq = 111 : 011$	3	27 8 — 27 9	27 9	27 11	2
{ $aq = 100 : 011$	—	—	—	76 16	—
$qo' = 011 : \bar{1}11$	4	34 22 — 34 32	34 28	34 24	4
{ $o'a = \bar{1}11 : \bar{1}00$	—	—	—	69 20	—
{ $co = 001 : 111$	6	34 18 — 34 36	34 28	34 31	3
$op = 111 : 110$	6	43 2 — 43 20	43 9	43 8	1
{ $cp = 001 : 110$	36	77 35 — 77 44	77 39	*	—
$po' = 110 : 11\bar{1}$	14	57 26 — 58 7	57 47	57 50	3
{ $o'c = 11\bar{1} : 00\bar{1}$	14	44 11 — 44 58	44 34	44 31	3
{ $bu = 010 : 121$	1	—	54 12	54 9	3
{ $no = 121 : 111$	1	—	16 3	15 59	4
{ $bo = 010 : 111$	2	70 15 — 70 15	70 15	70 8	7
$os = 111 : 101$	—	—	—	19 52	—
{ $bo' = 010 : \bar{1}11$	5	65 0 — 65 6	65 4	65 8	4
{ $o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 52	—
{ $o'o' = \bar{1}11 : \bar{1}\bar{1}1$	—	—	—	49 44	—
{ $sq = 101 : 011$	—	—	—	37 59	—
{ $qp = 011 : \bar{1}10$	34	86 17 — 86 31	86 22	86 22	0
{ $ps = \bar{1}10 : \bar{1}01$	—	—	—	55 39	—
{ $s'q = \bar{1}01 : 011$	—	—	—	45 1	—
$qn = 011 : 121$	1	—	26 34	26 32	2
{ $np = 121 : 110$	2	36 46 — 36 51	36 48	36 50	2
{ $qp = 011 : 110$	36	63 14 — 63 29	63 23	63 22	1
{ $ps' = 110 : 10\bar{1}$	—	—	—	71 37	—
{ $r'o' = \bar{2}01 : \bar{1}11$	11	34 40 — 35 2	34 51	34 53	2
{ $o'm = \bar{1}11 : 021$	1	—	36 31	36 27	4
{ $mp = 021 : 110$	4	55 42 — 55 51	55 48	55 50	2
{ $o'p = \bar{1}11 : 110$	11	92 11 — 92 28	92 20	92 17	3
{ $p'r' = 110 : 20\bar{1}$	31	52 42 — 52 57	52 49	52 50	1

Total number of measurements, 426.

Cæsium Copper Sulphate, Cs₂Cu(SO₄)₂·6H₂O.

Cæsium copper sulphate is readily obtained in perfectly transparent pale greenish-blue crystals, exhibiting very brilliant faces. It is one of the most beautiful salts of the series, and individuals may be grown of large size without any diminution of clearness and brilliance. They appear, at first sight, to resemble octahedral pyramids, modified by numerous smaller faces. Ten crystals were measured, selected from six different crops. Analyses of other crystals belonging to one of these crops gave the annexed results :—

0·8442 gram of crystals gave 0·6300 gram of BaSO₄, corresponding to 25·62 per cent. of SO₃. The calculated percentage of SO₃ is 25·42.

0·6430 gram of crystals gave 0·0795 gram of CuO, corresponding to 12·37 per cent. of CuO. The calculated percentage of CuO is 12·56.

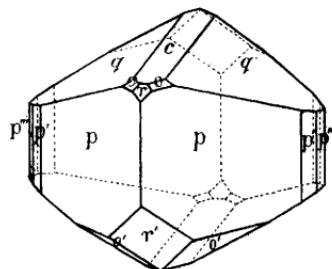
Habit: more or less pyramidal.

Axial angle: $\beta = 73^\circ 50'$.

Ratio of axes: $a : b : c = 0\cdot7429 : 1 : 4946$.

Forms observed: $b = \{010\} \infty P \infty$; $c = \{001\} oP$; $p = \{110\} \infty P$; $p' = \{120\} \infty P 2$; $p''' = \{130\} \infty P 3$; $q = \{011\} P \infty$; $o = \{111\} - P$; $o' = \{\bar{1}11\} + P$; $r = \{201\} - 2P \infty$; $r' = \{\bar{2}01\} + 2P \infty$.

FIG. 31.



The usual habit of the crystals of cæsium copper sulphate is represented in Fig. 31. The predominating faces are those of the prism $p\{110\}$ and clinodome $q\{011\}$, the relative proportions of which vary somewhat in the different crops, sometimes one and sometimes the other being the larger; it frequently happens, however, that they are equally developed, the crystals then assuming an octahedral pyramidal appearance. The clinopinacoid $b\{010\}$ is absent, except in very rare cases, in which it is just sufficiently developed to reflect an image of the signal. Hence the pyramids either terminate in sharp points or,

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Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
$\{ar = 100 : 201$	—	—	—	$30^\circ 49'$	—
$rc = 201 : 001$	1	—	$43^\circ 7'$	43 1	6'
$as = 100 : 101$	—	—	—	45 29	—
$sc = 101 : 001$	—	—	—	28 21	—
$ac = 100 : 001$	—	—	—	73 50	—
$es' = 001 : \bar{1}01$	—	—	—	38 9	—
$s'r' = 101 : \bar{2}01$	—	—	—	25 41	—
$cr' = 001 : \bar{2}01$	15	$63^\circ 46' - 64^\circ 4'$	63 58	63 50	8
$r'a = 201 : 100$	—	—	—	42 20	—
$\{ap = 100 : 110$	—	—	—	35 30	—
$pp' = 110 : 120$	1	—	19 28	19 28	0
$p'b = 120 : 010$	1	—	35 2	35 2	0
$p'p''' = 120 : 130$	1	—	10 0	9 59	1
$p'''b = 130 : 010$	1	—	25 2	25 3	1
$pb = 110 : 010$	2	54 30 — 54 38	54 34	54 30	4
$pp = 110 : \bar{1}10$	25	70 48 — 71 14	71 0	*	—
$pp = 110 : \bar{1}10$	25	108 37 — 109 15	109 0	109 0	0
$\{cq = 001 : 011$	38	25 16 — 25 30	25 24	*	—
$qb = 011 : 010$	2	64 31 — 64 35	64 33	64 36	3
$qq = 011 : 01\bar{1}$	20	129 6 — 129 23	129 12	129 12	0
$\{ao = 100 : 111$	—	—	—	48 36	—
$oq = 111 : 011$	1	—	26 54	26 50	4
$aq = 100 : 011$	—	—	—	75 26	—
$qo' = 011 : \bar{1}11$	15	34 24 — 34 45	34 33	34 28	5
$o'a = \bar{1}11 : \bar{1}00$	—	—	—	70 6	—
$\{co = 001 : 111$	2	33 55 — 34 2	33 58	33 55	3
$op = 111 : 110$	2	42 51 — 42 58	42 54	42 59	5
$cp = 001 : 110$	27	76 47 — 76 59	76 54	*	—
$po' = 110 : 11\bar{1}$	20	58 20 — 58 53	58 39	58 44	5
$o'c = 11\bar{1} : 00\bar{1}$	19	44 14 — 44 43	44 28	44 22	6
$\{bo = 010 : 111$	—	—	—	70 34	—
$os = 111 : 101$	—	—	—	19 26	—
$\{bo' = 010 : \bar{1}11$	2	65 13 — 65 30	65 21	65 22	1
$o's' = \bar{1}11 : \bar{1}01$	—	—	—	24 38	—
$o'o' = \bar{1}11 : \bar{1}\bar{1}1$	10	49 12 — 49 34	49 20	49 16	4
$\{sq = 101 : 011$	—	—	—	37 21	—
$qp = 011 : \bar{1}10$	31	87 15 — 87 36	87 26	87 27	1
$ps = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	55 12	—
$\{s'q = \bar{1}01 : 011$	—	—	—	44 44	—
$qp = 011 : 110$	31	62 52 — 63 8	63 1	63 0	1
$ps' = \bar{1}10 : \bar{1}0\bar{1}$	—	—	—	72 16	—
$\{ro' = \bar{2}01 : \bar{1}11$	19	34 49 — 35 10	35 1	35 1	0
$o'p = \bar{1}11 : 110$	21	91 54 — 92 8	92 3	91 59	4
$pr' = 110 : 20\bar{1}$	29	52 46 — 53 18	52 57	53 0	3

Total number of measurements, 361.

when the prism faces are vertically longer, in short, sharp edges. The basal plane $c\{001\}$, as in all the other caesium salts of the series, is usually narrow, not unfrequently a mere line. The faces of the

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orthodome $r'\{\bar{2}01\}$ and of the hemipyramid $o'\{\bar{1}11\}$ are generally present to somewhere about the extent shown in the figure. Many crystals exhibit no other faces than those above mentioned. Occasionally, however, the faces of the complementary orthodome $r\{201\}$ and the primary hemipyramid $o\{111\}$ are developed, forming three beautiful little faces, modifying the solid angle formed by the faces of the prism, basal plane, and clinodome. The two prismatic forms $p'\{120\}$ and $p''\{130\}$, bevelling the terminations of the pyramids, are only of rare occurrence, and never attain large proportions.

The results of the measurements are presented in the table, p. 404.

As before in the cases of the other sets of three salts, a comparison will now be made of the values of the analogous angles in the three salts of copper containing as the alkali metal potassium, rubidium, and caesium, respectively (see table, p. 406).

As might be expected from the somewhat different nature of copper, the crystals of the three salts above compared, containing that metal, exhibit differences of a somewhat different order from those presented by the other sets of three salts compared. The influence of the second metal here makes itself appreciably felt in altering the absolute values of the angles and the absolute magnitudes of the differences between analogous angles. But, which is a point of the first importance, and indicates that the relative nature of the differences observed in the other sets of salts is not accidental, *the relations of the differences established for the potassium, rubidium, and caesium salts of the series containing other second metals apply with even greater rigour to those containing copper as the second metal.*

Thus, although the influence of the second metal is apparent in reducing the absolute magnitudes of the differences in the axial angle from about 70' (as found in the other salts) to about 50', the relative magnitudes of those differences (50' and 52') are again proportional to the relative changes of atomic weight in passing from potassium to rubidium (a change of 46), and from rubidium to caesium (a change of 48). The law of simple proportionality is thus seen to apply with the utmost rigour in the case of the axial angles of the three salts containing copper.

Again, out of 38 angles compared, 37 follow the rule that the values in the case of the rubidium salt lie between those of the corresponding angles upon the crystals of the potassium and caesium salts. The only exception occurs in the case of the angle qo' , where the differences of -6' and +4' are very small, and the change is practically *nil*, owing to the large changes of about 50' magnitude in the adjacent angles aq and $o'a$ being in opposite directions.

Moreover, the maximum deviation from direct simple proportion-

Comparison of the Angles of the three Salts containing Copper.

Angle.	Potassium salt.	Diff.	Rubidium salt.	Diff.	Cæsium salt.
{ $ac = 100 : 001 = \beta$	75° 32'	-50'	74° 42'	-52'	73° 50'
{ $as = 100 : 101$	46 11	-18	45 53	-24	45 29
{ $sc = 101 : 001$	29 21	-	28 49	-	28 21
{ $cr' = 001 : \bar{2}01$	63 19	+11	63 30	+20	63 50
{ $cs' = 001 : \bar{1}01$	38 22	-	38 12	-	*38 9
{ $s'r' = 101 : \bar{2}01$	24 57	+21	25 18	+23	25 41
{ $r'a = \bar{2}01 : \bar{1}00$	41 9	-	41 48	-	42 20
{ $ap = 100 : 110$	35 59	- 7	35 52	-22	35 30
{ $pp' = 110 : 120$	19 28	-	19 28	-	19 28
{ $p'b = 120 : 010$	34 33	+ 7	34 40	+22	35 2
{ $p'p''' = 120 : 130$	9 54	-	9 55	-	9 59
{ $p''b = 130 : 010$	24 39	+ 6	24 45	+18	25 3
{ $pb = 110 : 010$	54 1	-	54 8	-	54 30
{ $eq = 001 : 011$	26 11	-17	25 54	-30	25 24
{ $qb = 011 : 0\bar{1}0$	63 49	-	64 6	-	64 36
{ $ao = 100 : 111$	49 28	-23	49 5	-29	48 36
{ $oq = 111 : 011$	27 35	-	27 11	-	26 50
{ $aq = 100 : \bar{1}11$	77 3	-47	78 16	-50	75 26
{ $gq' = 011 : \bar{1}\bar{1}1$	34 30	-	34 24	-	34 28
{ $o'a = \bar{1}11 : \bar{1}00$	68 27	+53	69 20	+46	70 6
{ $eo = 001 : 111$	35 6	-35	34 31	-36	33 55
{ $op = 111 : 110$	43 14	-	43 8	-	42 59
{ $cp = 001 : 110$	78 20	-41	77 39	-45	76 54
{ $po' = 110 : 11\bar{1}$	56 58	-	57 50	-	58 44
{ $o'c = 11\bar{1} : 001$	44 42	-11	44 31	- 9	44 22
{ $bo = 010 : 111$	69 50	+18	70 8	+26	70 34
{ $os = 111 : 101$	20 10	-	19 52	-	19 26
{ $bo' = 010 : \bar{1}\bar{1}1$	65 3	+ 5	65 8	+14	65 22
{ $o's' = \bar{1}\bar{1}1 : \bar{1}01$	24 57	-	24 52	-	24 38
{ $sq = 101 : 011$	38 32	-33	37 59	-38	37 21
{ $qp = 011 : \bar{1}10$	85 32	+50	86 22	+65	87 27
{ $ps = \bar{1}10 : \bar{1}0\bar{1}$	55 56	-	55 39	-	55 12
{ $s'q = \bar{1}01 : 011$	45 17	-	45 1	-	44 44
{ $qp = 011 : 110$	63 51	-29	63 22	-22	63 0
{ $ps' = \bar{1}10 : 10\bar{1}$	70 52	+45	71 37	+39	72 16
{ $r'o' = \bar{2}01 : \bar{1}\bar{1}1$	84 43	+10	84 53	+ 8	85 1
{ $o'p = \bar{1}\bar{1}1 : 110$	92 49	-	92 17	-	91 59
{ $pr' = 110 : 20\bar{1}$	52 28	+22	52 50	+10	53 0

ality to the change in atomic weight occurs as before in the angles of the prism zone, where the ratio of the differences is 1 : 3. It is noticeable, however, that the absolute amounts of the differences between the values of the angle ap (7' and 22') are much less in the copper salts than in the sets of three salts previously compared, although their ratio is the same as was observed in the magnesium salts, where the actual differences were 12' and 36'. Further, the

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absolute differences between the values of the angle cq , in the zone inclined nearly equally to both the zone [acr'] containing the axial angle and the prism zone [apb], are correspondingly larger in the three copper salts than in the other sets of three salts, being $17'$ and $30'$, but the ratio is about the same as in the iron salts, where the actual differences were found to be $13'$ and $22'$.

Hence the individuality of the second metal, in this case copper, only affects the *absolute* magnitudes of the differences, their *relative* magnitudes following precisely the same rules as were found to apply in the cases of all the other sets of potassium, rubidium, and caesium salts described.

The axial ratios of the three salts containing copper bear similar relationships to those before observed, lying very close together, owing to the balancing of the angular changes previously discussed.

For potassium copper sulphate..	$a : b : c = 0.7490 : 1 : 0.5088$
„ rubidium „ ..	$a : b : c = 0.7490 : 1 : 0.5029$
„ caesium „ ..	$a : b : c = 0.7429 : 1 : 0.4946$

Salts containing Cadmium.

As previously explained in the introductory paragraph, entitled "The Salts of the Series investigated," attempts to prepare the salt $K_2Cd(SO_4)_2 \cdot 6H_2O$ have so far proved unavailing.

Rubidium Cadmium Sulphate, $Rb_2Cd(SO_4)_2 \cdot 6H_2O$.

More difficulty has been found in obtaining good crystals of rubidium cadmium sulphate than in the case of any other of the salts described in this communication. They so rapidly effloresce that the faces only retain their brilliancy for a short time after removal from the mother liquor, and the whole of the crystal rapidly becomes opaque. Three crops, however, of fairly well developed individual crystals were eventually obtained, and 10 crystals selected from them were measured as soon after removal from the mother liquor as possible.

Estimations of their content of sulphuric acid and cadmium gave the following numbers:—

1.0980 gram of crystals gave 0.8785 gram of $BaSO_4$, corresponding to 27.47 per cent. of SO_3 . The calculated percentage of SO_3 is 27.49.

0.8570 gram of crystals gave 0.1860 gram of CdO , corresponding to 21.70 per cent. of CdO . The calculated percentage of CdO is 21.99.

Habit: more or less tabular.

Axial angle: $\beta = 74^\circ 7'$.

Ratio of axes: $a : b : c = 0.7346 : 1 : 0.4931$.

Forms observed: $a = \{100\}_{\infty}P_{\infty}$; $b = \{010\}_{\infty}P_{\infty}$; $c = \{001\}_{\infty}P$;
 $p = \{110\}_{\infty}P$; $p' = \{120\}_{\infty}P_2$; $p'' = \{210\}_{\infty}P_2$; $p''' = \{130\}_{\infty}P_3$;
 $q = \{011\}_{\infty}P$; $o = \{111\}-P$; $o' = \{\bar{1}11\}+P$;
 $r' = \{\bar{2}01\}+2P_{\infty}$.

The crystals of the three crops examined differed considerably in habit. Those of the first crop were of the type represented in Fig. 32, in which the principal faces, those of the basal plane $c\{001\}$, clinodome $q\{011\}$, primary prism $p\{110\}$, orthodome $r'\{\bar{2}01\}$, and hemipyramid $o'\{\bar{1}11\}$, were more or less equally developed. Those of the second crop were similar to the crystal of rubidium nickel sulphate represented in Fig. 20, in which the basal plane and primary prism predominated. The crystals of the third crop, a typical one of which is delineated in Fig. 33, were peculiar in exhibiting a relatively very large development of the orthodome r' , so large indeed as to impart to the crystals a tabular habit formed by the faces of that form. The

FIG. 32.

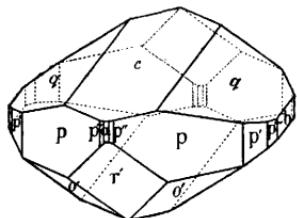
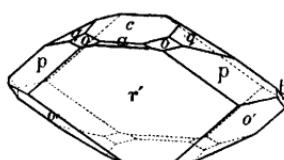


FIG. 33.



only other prominent planes were those of the hemipyramid o' , which were frequently of exceptionally large dimensions for this form, and to a less extent those of the basal plane c , primary prism p , and clinodome q . The two last forms were usually relatively so small that it was not at all unusual for some of the faces to be absent altogether.

In all these types of crystals, the faces of the remaining forms were generally small, but occasionally the prisms $p'\{120\}$ and $p''\{130\}$, and the primary hemipyramid $o\{111\}$, were well developed, and gave excellent reflections.

The appended table exhibits the results of the measurements:—

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Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
{ as = 100 : 101	—	—	—	45° 29'	—
sc = 101 : 001	—	—	—	28 38	—
ac = 100 : 001	2	74° 8'— 74° 11'	74° 9'	74 7	2'
cs' = 001 : 101	—	—	—	38 22	—
s'r' = 101 : 201	—	—	—	25 34	—
cr' = 001 : 201	15	64 1— 64 13	64 6	63 56	10
r'a = 201 : 100	2	41 40— 41 48	41 44	41 57	13
{ ap'' = 100 : 210	1	—	19 15	19 27	12
p''p = 210 : 110	2	15 47— 15 53	15 50	15 47	3
ap = 100 : 110	8	35 0— 35 45	35 16	35 14	2
pp' = 110 : 120	14	19 4— 19 57	19 26	19 28	2
p'b = 120 : 010	9	34 55— 35 30	35 19	35 18	1
p'p''' = 120 : 130	6	9 45— 10 14	9 55	10 2	7
p''b = 130 : 010	7	25 4— 25 34	25 19	25 16	3
pb = 110 : 010	20	54 25— 54 55	54 46	*	—
pp = 110 : 110	20	70 18— 70 45	70 29	70 28	1
pp = 110 : 110	18	109 12— 109 41	109 31	109 32	1
{ eq = 001 : 011	37	25 17— 25 34	25 24	*	—
qb = 011 : 010	19	64 18— 64 50	64 36	64 36	0
qq = 011 : 011	15	129 1— 129 24	129 12	129 12	0
{ ao = 100 : 111	—	—	—	48 35	—
oq = 111 : 011	1	—	27 7	27 6	1
aq = 100 : 011	2	75 45— 75 48	75 46	75 41	5
q'o' = 011 : 111	9	34 17— 35 25	34 43	34 41	2
o'a = 111 : 100	2	69 14— 69 55	69 34	69 38	4
{ co = 001 : 111	3	34 10— 34 14	34 12	34 6	6
op = 111 : 110	3	42 50— 42 53	42 51	42 59	8
cp = 001 : 110	32	77 0— 77 11	77 5	*	—
po' = 110 : 111	18	58 12— 58 58	58 28	58 26	2
o'c = 111 : 001	23	43 53— 44 59	44 27	44 29	2
{ bo = 010 : 111	4	70 30— 70 45	70 39	70 38	1
os = 111 : 101	—	—	—	19 22	—
oo = 111 : 111	2	38 42— 38 44	38 43	38 44	1
{ bo' = 010 : 111	4	65 15— 65 36	65 26	65 30	4
o's' = 111 : 101	—	—	—	24 30	—
o'o' = 111 : 111	2	48 58— 49 6	49 2	49 0	2
{ sq = 101 : 011	—	—	—	37 33	—
qp = 011 : 110	18	87 14— 87 34	87 24	87 23	1
ps = 110 : 101	—	—	—	55 4	—
{ s'q = 101 : 011	—	—	—	44 54	—
qp = 011 : 110	18	63 0— 63 27	63 17	63 18	1
ps' = 110 : 101	—	—	—	71 48	—
{ r'o' = 201 : 111	18	34 29— 35 13	34 59	34 50	9
o'p = 111 : 110	19	92 16— 92 58	92 30	92 35	5
pr' = 110 : 201	25	52 23— 52 48	52 31	52 35	4

Total number of measurements, 398.

Cæsium Cadmium Sulphate, $\text{Cs}_2\text{Cd}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

Cæsium cadmium sulphate crystallises much more readily than rubidium cadmium sulphate from solutions containing equal molecular proportions of the constituent sulphates. The crystals, moreover, are more perfectly transparent and more permanent than those of the rubidium salt. They do, however, eventually effloresce and become opaque if not preserved in tightly stoppered bottles. Ten crystals were measured, selected from three different crops.

Analyses of other crystals belonging to one of these crops gave the following results:—

0·9300 gram of crystals gave 0·6450 gram of BaSO_4 , corresponding to 23·81 per cent. of SO_3 . The calculated percentage of SO_3 is 23·60.

1·0195 gram of crystals gave 0·1900 gram of CdO , corresponding to 18·64 per cent. of CdO . The calculated percentage of CdO is 18·88.

Habit: prismatic.

Axial angle: $\beta = 72^\circ 49'$.

Ratio of axes: $a : b : c = 0\cdot7259 : 1 : 0\cdot4906$.

Forms observed: $a = \{100\}\infty\text{P}\infty$; $b = \{010\}\infty\text{P}\infty$; $c = \{001\}o\text{P}$; $p = \{110\}\infty\text{P}$; $p' = \{120\}\infty\text{P}2$; $p'' = \{210\}\infty\text{P}2$; $p''' = \{130\}\infty\text{P}3$; $q = \{011\}\text{P}\infty$; $m = \{021\}2\text{P}\infty$; $o = \{111\} - \text{P}$; $o' = \{\bar{1}11\} + \text{P}$; $n = \{121\} - 2\text{P}2$; $r' = \{\bar{2}01\} + 2\text{P}\infty$.

FIG. 34.

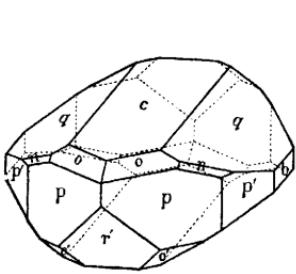
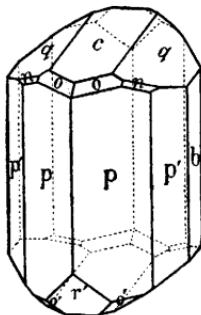


FIG. 35.



The habit usually assumed by the crystals of the various crops examined is that shown in Fig. 34. They are at once distinguished from the crystals of the other double sulphates of the series described in the foregoing pages by the comparatively large development of the faces of the primary hemipyramid $o\{111\}$, and of the prism $p'\{120\}$.

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Angle measured.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.
as = 100 : 101	—	—	—	44° 31'	—
sc = 101 : 001	—	—	—	28 18	—
ac = 100 : 001	1	—	72° 47'	72 49	2'
cs' = 001 : 101	—	—	—	38 54	—
$s'r'$ = 101 : 201	—	—	—	26 11	—
cr' = 001 : 201	18	65° 2' — 65° 15'	65 8	65 5	3
$r'a$ = 201 : 100	1	—	42 7	42 6	1
ap'' = 100 : 210	—	—	—	19 7	—
$p''p$ = 210 : 110	1	—	15 32	15 37	5
ap = 100 : 110	2	34 44 — 34 45	34 44	34 44	0
pp' = 110 : 120	30	19 16 — 19 43	19 27	19 28	1
$p'b$ = 120 : 010	30	35 30 — 35 58	35 48	35 48	0
$p'p'''$ = 120 : 130	1	—	10 9	10 7	2
$p'''b$ = 130 : 010	1	—	25 35	25 41	6
$p'b$ = 110 : 010	32	55 2 — 55 25	55 16	* —	—
pp = 110 : 110	17	69 22 — 69 34	69 28	69 28	0
pp = 110 : 110	16	110 23 — 110 41	110 32	110 32	0
cq = 001 : 011	40	25 3 — 25 17	25 8	* —	—
qm = 011 : 021	1	—	17 56	18 3	7
mb = 021 : 010	1	—	46 54	46 49	5
qb = 011 : 010	30	64 43 — 64 57	64 52	64 52	0
qq = 011 : 011	18	129 34 — 129 50	129 44	129 44	0
ao = 100 : 111	1	—	47 38	47 37	1
oq = 111 : 011	11	26 43 — 27 4	26 54	26 52	2
aq = 100 : 011	1	—	74 23	74 29	6
qo' = 011 : 111	15	35 3 — 35 26	35 15	35 11	4
$o'a$ = 111 : 100	1	—	70 22	70 20	2
co = 001 : 111	20	33 20 — 33 53	33 34	33 38	4
op = 111 : 110	22	42 10 — 42 40	42 23	42 19	4
cp = 001 : 110	31	75 45 — 76 11	75 57	* —	—
po' = 110 : 111	23	58 55 — 59 20	59 5	59 8	3
$o'c$ = 111 : 001	25	44 40 — 45 19	44 58	44 55	3
bn = 010 : 121	—	—	—	55 28	—
no = 121 : 111	—	—	—	15 33	—
bo = 010 : 111	5	71 3 — 71 9	71 5	71 1	4
os = 111 : 101	—	—	—	18 59	—
oo = 111 : 111	1	—	37 59	37 58	1
lo' = 010 : 111	8	65 19 — 65 38	65 29	65 30	1
$o's'$ = 111 : 101	—	—	—	24 30	—
$o'o'$ = 111 : 111	3	48 55 — 49 10	49 3	49 0	3
sq = 101 : 011	—	—	—	37 9	—
qp = 011 : 110	26	88 32 — 88 53	88 44	88 43	1
ps = 110 : 101	—	—	—	54 8	—
$s'q$ = 101 : 011	—	—	—	45 12	—
qn = 011 : 121	1	—	26 14	26 11	3
np = 121 : 110	1	—	36 13	36 19	6
qp = 011 : 110	27	62 18 — 62 41	62 29	62 30	1
ps' = 110 : 101	—	—	—	72 18	—
$r'o'$ = 201 : 111	19	34 59 — 35 27	35 16	35 15	1
$o'm$ = 111 : 021	1	—	36 49	36 52	3
mp = 021 : 110	1	—	55 25	55 27	2
$o'p$ = 111 : 110	18	92 13 — 92 36	92 20	92 19	1
pr' = 110 : 201	24	52 12 — 52 35	52 24	52 26	2

Total number of measurements, 525.

The faces of the basal plane often attain the breadth indicated in the figure, but equally often are much narrower, as in all the other cæsium salts of the series. The faces of the clinodome $q\{011\}$ are always largely developed, and frequently predominate. The faces of the two prisms $p\{110\}$ and $p'\{120\}$ are generally about equally developed; indeed it is not at all unusual to find the p' faces considerably larger than those of the primary prism p . The clinopinacoid $b\{010\}$ is also, as a rule, well developed, and, as represented in the figure, the whole of the faces of the zone $[bqc]$ are frequently somewhat elongated, imparting to the crystals their prismatic habit. The orthodome $r'\{\bar{2}01\}$ likewise usually attains considerable importance. All these faces gave, with few exceptions, excellent reflections. The faces of the hemipyramid $o'\{\bar{1}11\}$ were developed ordinarily to nearly the same extent as those of the primary hemipyramid $o\{111\}$, but the reflections were rarely equal to those afforded by the latter form, owing to roughness, dulness, or distortion. The remaining forms, the two prisms $p''\{210\}$ and $p'''\{130\}$, the orthopinacoid $a\{100\}$, the clinodome $m\{021\}$, and the hemipyramid $n\{121\}$, are only of rare occurrence, and in the cases observed were very small.

Occasionally crystals are found in which the faces of the prism zone are so elongated as to confer a prismatic habit upon the crystals in this direction. A drawing of one such crystal, one of the 10 particularly good crystals measured, is reproduced in Fig. 35.

The table, p. 411, represents the results of the measurements.

A comparison will now be made of the values of corresponding angles in the rubidium and cæsium salts containing cadmium as the second metal (see table, p. 413).

On comparing the differences shown in the above table with those between the other rubidium and cæsium salts previously described, they are found to be very similar to those between rubidium zinc sulphate and cæsium zinc sulphate, although a little higher in absolute magnitude, owing possibly to the much higher atomic weight of cadmium. They are all of the same sign and order. It is evident, too, that the angles bo' and $o's'$ exhibit no appreciable change, as observed in all the other tables of comparison for the other salts, except those containing copper.

There is, in fact, every reason to believe that if the double sulphate of potassium and cadmium containing 6 mols. H₂O could only be obtained, the differences between the three salts would follow the rules which have been found generally applicable throughout the series.

The axial ratios differ slightly in the same direction, and to about the extent observed in the cases of the other rubidium and cæsium salts of the series.

AND ANGLES OF CRYSTALS OF ISOMORPHOUS SERIES. 413

For rubidium cadmium sulphate $a : b : c = 0.7346 : 1 : 0.4931$
 „ cæsium „ „ $a : b : c = 0.7259 : 1 : 0.4906$

Comparison of the Angles of the Salts containing Cadmium.

Angle.	Rubidium salt.	Diff.	Cæsium salt.
$\{ ac = 100 : 001 = \beta$	74° 7'	-78'	72° 49'
$as = 100 : 101$	45 29	-58	44 31
$sc = 101 : 001$	28 38	—	28 18
$cr' = 001 : 201$	63 56	+69	65 5
$cs' = 001 : 101$	38 22	—	38 54
$s'r' = \bar{1}01 : 201$	25 34	+37	26 11
$ra' = 201 : 100$	41 57	—	42 6
$\{ ap'' = 100 : 210$	19 27	-20	19 7
$p''p = 210 : 110$	15 47	—	15 37
$ap' = 100 : 110$	35 14	-30	34 44
$pp' = 110 : 120$	19 28	—	19 28
$p'b = 120 : 010$	35 18	+30	35 48
$p'p''' = 120 : 130$	10 2	—	10 7
$p''b = 130 : 010$	25 16	+25	25 41
$p'b = 110 : 010$	54 46	—	55 16
$\{ cq = 001 : 011$	25 24	-16	25 8
$qb = 011 : 010$	64 36	—	64 52
$\{ ao = 100 : 111$	48 35	-58	47 37
$oq = 111 : 011$	27 6	—	26 52
$aq = 100 : 011$	75 41	-72	74 29
$qo' = 011 : \bar{1}11$	34 41	—	35 11
$o'a = \bar{1}11 : 100$	69 38	+42	70 20
$\{ co = 001 : 111$	34 6	-28	33 38
$op = 111 : 110$	42 59	—	42 19
$cp = 001 : 110$	77 5	-68	75 57
$po' = 110 : 11\bar{1}$	58 26	—	59 8
$o'c = 11\bar{1} : 001$	44 29	+26	44 55
$\{ bo = 010 : 111$	70 38	+23	71 1
$os = 111 : 101$	19 22	—	18 59
$\{ bo' = 010 : \bar{1}11$	65 30	0	65 30
$o's' = \bar{1}11 : \bar{1}01$	24 30	—	24 30
$\{ sq = 101 : 011$	37 38	-24	37 9
$qp = 011 : \bar{1}10$	87 23	+80	88 43
$ps = \bar{1}10 : \bar{1}01$	55 4	—	54 8
$\{ s'q = \bar{1}01 : 011$	44 54	—	45 12
$qp = 011 : 110$	63 18	-48	62 30
$ps' = 110 : 101$	71 48	+30	72 18
$\{ r'o' = \bar{2}01 : \bar{1}11$	34 50	+25	35 15
$o'p = 111 : 110$	92 35	—	92 19
$pr' = 110 : 20\bar{1}$	52 35	-9	52 26

Discussion of Results.

The conclusions to be drawn from the facts presented in the foregoing pages may conveniently be considered in sections.

1. Relative Facility of Formation of the Salts of the Series containing Potassium, Rubidium, and Cæsium respectively.—Cæsium has been found throughout to form the double sulphates containing 6 mols. H₂O with the greatest readiness; special evidence of this is afforded by the salts containing cobalt, copper, manganese, and cadmium as the second metal. Of those containing cobalt, great difficulty was experienced in obtaining well-formed crystals of the potassium salt, and considerable, though less, trouble was required to obtain crystals of rubidium cobaltous sulphate sufficiently free from distortion, whilst large and much better formed crystals of the cæsium salt were deposited under the same conditions. Similar remarks apply even more strongly to the three salts containing copper, and it was specially noticed that whilst the crystals of potassium copper sulphate, so very difficult to obtain of any use for goniometrical purposes, were usually quite turbid, or even opaque, those of the analogous cæsium salts were not only obtained with the greatest facility, but were always beautifully clear and transparent. This point is shown even more conclusively by the failure up to the present to prepare crystals of potassium manganous sulphate and potassium cadmium sulphate containing 6 mols. H₂O. Moreover, the intermediate position of the rubidium salts with respect to facility of formation is again indicated by the fact that whilst crystals of cæsium cadmium sulphate are readily obtained, and are quite clear and transparent, the corresponding rubidium salt usually forms crystals which are more or less turbid, and effloresce rapidly on removal from the mother liquor. It may therefore be stated that:—

The salts of the series R₂M(SO₄)₂.6H₂O containing cæsium as the alkali metal exhibit the greatest facility of formation and deposition in the form of crystals, and those containing potassium least, whilst the salts containing rubidium occupy an intermediate position in this respect.

2. Relations between the "Habits" of the Potassium, Rubidium, and Cæsium Salts.—It is a somewhat striking fact that, although the whole of the 22 salts investigated, crystallising isomorphically in the monoclinic system, exhibit more or less of the same planes inclined to each other at angles which differ at most by 2½°, yet each individual salt is characterised by some peculiarity of habit, or by the advent of certain rarely occurring forms, which distinguishes it from all the others. This will be at once apparent on inspection of the reproductions of the drawings representing typical crystals of the various salts, no two of which are alike.

Although this is the case, however, there is a very marked similarity in the relative development of the more commonly occurring planes between the crystals of all the salts containing potassium, between all

those containing rubidium, and between all those containing cæsium. This is particularly well shown with regard to the relative development of the end forms. In the potassium salts, the basal plane $c\{001\}$ is always the predominating end face, the faces of the clinodome $q\{011\}$ being relatively very small. In the rubidium salts, the faces of the latter form have usually been found much more largely developed, the faces of the basal plane being now curtailed, but still slightly predominating. On the other hand, in the cæsium salts, the basal plane has been generally found to be reduced to a narrow strip, and on many crystals to a mere line, whilst the faces of the clinodome have assumed such large relative dimensions as to be largely preponderating, and not unfrequently the only faces of this zone at first sight visible. The rubidium salts thus occupy an intermediate position with regard to the relative development of the end faces. This interesting fact has been observed in all the eight sets of salts examined. It is very strikingly shown by the three drawings (Figs. 2, 3, and 4) of the potassium, rubidium, and cæsium salts containing magnesium; by Figs. 6, 8, and 10, representing typical crystals of the corresponding zinc salts; and by Figs. 29, 30, and 31, representing crystals of the three salts containing copper.

The effect of this difference in the relative development of the end faces is to completely alter the habits of the three classes of salts. The large development of the basal plane in the potassium salts causes the crystals to be either tabular parallel to this plane if the prism faces are vertically short, or to assume the habit of a stout prism with broad flat ends if the prism faces are longer. On the other hand, the large preponderance of the faces of the clinodome in the cæsium salts causes the crystals to assume the habit of prisms whose faces are those of the clinodome, and as it usually happens that the clinodome faces are also much longer in the direction cq , these prisms are frequently twice as long as broad, and their ends are formed by (along with other subsidiary forms) the faces of the prism p , which themselves are of course the prism faces in the potassium salts.

When the faces of the clinodome are not so long, as in cæsium copper sulphate, a pyramidal habit is exhibited somewhat resembling an octahedron, and quite different from the habit of the potassium salts. The rubidium salts always exhibit a habit of an intermediate character, sometimes approaching that of the potassium salts, at other times more nearly approximating to that of the cæsium salts, but most frequently about halfway between the two.

It has, therefore, been established that—

The crystals of the potassium, rubidium, and cæsium salts of the series $R_2M(SO_4)_2 \cdot 6H_2O$, though bounded by the same common planes, exhibit

specific characteristic habits; the characteristic habit of the crystals of the potassium salts is widely different from that exhibited by the crystals of the caesium salts, and the habit usually assumed by the crystals of the rubidium salts is intermediate between the two. The relations between the characteristic habits of the potassium, rubidium, and caesium salts respectively are thus found to be directly dependent on the relations between the atomic weights of the alkali metals.

3. *Relations between the Magnitudes of the Axial Angle β in the Potassium, Rubidium, and Caesium Salts.*—One of the most striking results of the present investigation is the simple relation which has been shown to exist in every case between the differences in the magnitudes of this fundamental angle for the potassium, rubidium, and caesium salts respectively, and the differences in the atomic weights of the three alkali metals. These differences in the magnitudes of the axial angle may now be summarised in the following table:—

Second metal present.	Value of β for potassium salt.		Difference.	Value of β for rubidium salt.		Difference.	Value of β for caesium salt.	
Magnesium..	75°	12'	-71'	74°	1'	-67'	72°	54'
Zinc.....	75	12	-65	74	7	-68	72	59
Iron	75	28	-72	74	16	-68	73	8
Manganese..	—	—	—	74	3	-70	72	53
Nickel	75	0	-63	73	57	-59	72	58
Cobalt	75	5	-66	73	59	-67	72	52
Copper	75	32	-50	74	42	-52	73	50
Cadmium ...	—	—	—	74	7	-78	72	49

In every set of three salts, the value of β for the rubidium salt stands approximately midway between the values for the potassium and caesium salts, the differences on either side being about equal. That this is not a fortuitous circumstance, repeated in the magnesium, zinc, iron, nickel, and cobalt salts because of the small effect of these second metals in altering the crystallographic form, is rendered most probable by the fact that in the three copper salts, where, owing to the different nature of the metal copper, the differences are smaller and the absolute values considerably different, the same relation is preserved between the differences, which are again approximately equal. There can also be little doubt that if the potassium salts containing as the second metals manganese and cadmium could be prepared, the differences would follow the same rule.

It will be remembered that the difference between the atomic

weights of potassium (39) and rubidium (85) is 46, and that the difference between the atomic weights of rubidium and caesium (133) is 48, or, in other words, that the differences between the atomic weights are approximately equal; and also that the real angles between the vertical and inclined axes are the supplements of the goniometrical angles above given (as explained in the comparison of the magnesium salts) so that the real angles increase from potassium to caesium.

The rules which have been shown to be followed so closely by all the sets of salts investigated may now, therefore, be stated in general terms applicable to the whole series as follows:—

In crystals of the salts of the monoclinic series $R_2M(SO_4)_2 \cdot 6H_2O$, the axial angle β increases with the increase in the atomic weight of the alkali metal R contained, and its magnitude in any rubidium salt of the series is approximately midway between that in the potassium and that in the caesium salt containing the same second metal.

The differences, therefore, between the magnitudes of the axial angle in crystals of this series containing potassium, rubidium, or caesium respectively as the alkali metal are in direct simple proportion to the differences between the atomic weights of these metals. The latter statement may also be expressed from another point of view as follows:—

The relative amounts of change brought about in the magnitude of the axial angle by replacing the alkali metal potassium by rubidium, and the rubidium subsequently by caesium, are approximately in direct simple proportion to the relative differences between the atomic weights of the metals interchanged.

These changes in the magnitude of the axial angle on passing from a potassium to a rubidium salt, and from a rubidium to a caesium salt, are very considerable, usually exceeding a whole degree in each case; they are therefore far removed from the widest limits which can possibly be assigned to experimental and formational error.

4. *Relations between the other Angles in corresponding Potassium, Rubidium, and Caesium Salts.*—It has been shown in comparing the values of the corresponding angles upon the crystals of the potassium, rubidium, and caesium salts belonging to each of the eight sets, that the magnitudes of the angles of the crystals of the rubidium salts lay between those of the corresponding angles upon the crystals of the potassium and caesium salts respectively, in all those cases where the change was appreciable.

In the case of the three magnesium salts, of 36 angles compared, 31 followed the rule. In the cases of the four sets of three salts each, containing as the second metals zinc, iron, nickel, and cobalt respectively, 33 out of the 36 angles followed the rule. And in the case of the three salts containing copper as the second metal, no less than

37 out of the 38 angles compared followed the rule. Moreover, in the cases of the salts containing as the second metals manganese and cadmium, it was demonstrated from the nature of the differences between the rubidium and caesium salts investigated, these differences being of the same order as those exhibited between the other rubidium and caesium salts of the series, that if the potassium salts containing manganese and cadmium respectively could only be prepared, there could be no doubt that the angles of these two sets of salts would likewise exhibit the same relationships.

It has further been amply demonstrated that the very few exceptions occurred in the cases where the change was almost inappreciable, where the differences approached the limits of possible error; they were, in fact, shown to be cases in which the angles remained more or less constant owing to the changes in the magnitudes of the angles on either side of them being in opposite directions.

The rule may now, therefore, be finally stated in the following general terms:—

The magnitudes of all the angles between the faces of the crystals of the salts of the series $R_2M(SO_4)_2 \cdot 6H_2O$ containing rubidium as the alkali metal lie between the magnitudes of the corresponding angles upon the crystals of the salts containing potassium and caesium respectively.

It has been further shown, however, that the rule of direct simple proportionality to the relative changes in the atomic weight in passing from potassium to rubidium, and from rubidium to caesium, which has been found to obtain in the case of the axial angle, does not apply to the majority of the other angles. The maximum deviation from simple proportionality has in each set of salts, there being no exception, been found to occur in the angles of the prism zone. The ratio of the differences for the principal (determinative) angle of this zone *ap* (or its complement *bp*), between the orthopinacoid and primary prism faces, varies in the different sets of salts from 1 : 2 to 1 : 3, according to the nature of the second metal present. The ratio for the three salts containing magnesium is 1 : 3, for those containing zinc 1 : 2, for those containing iron 1 : 2·6, for those containing nickel 1 : 2·4, for those containing cobalt 1 : 2, and for those containing copper 1 : 3.

It has further been observed, as regards each set of salts, that the angles of the zones lying nearest to the zone perpendicular to the symmetry plane (the zone which contains the axial angle) and furthest removed from the prism zone exhibit differences which approach most closely to the rule of simple proportionality. Thus the differences between the values of the angles *cp* and *aq* for the potassium and rubidium and for the rubidium and caesium salts are always nearly equal, that is, in the proportion of 1 : 1, whilst the

angle cq of the zone [cqb] inclined not far from equally to the zone containing the axial angle and to the prism zone exhibits differences of an intermediate character, generally about 1 : 1·6.

These facts may be expressed in the following general statement :—

The differences between the magnitudes of the angles, other than the axial angle, in crystals of the series $R_2M(SO_4)_2 \cdot 6H_2O$ containing potassium, rubidium, and cæsium respectively as the alkali metal are not generally in direct simple proportion to the differences between the atomic weights of these metals. The maximum deviation from simple proportionality occurs in the prism zone, where the ratio of the differences varies, according to the nature of the second metal present, from 1 : 2 to 1 : 3.

The fact that the differences between the magnitudes of many of the angles of the cæsium and rubidium salts are so much larger than those between the rubidium and potassium salts would appear to indicate that as the atomic weight becomes higher it exercises an influence on these angles greater than in mere numerical proportion to its increase. This influence is most apparent in the angles of the prism zone, and becomes less and less evident in the zones approaching more and more nearly to the plane of symmetry, until at length, in the case of the axial angle lying in the symmetry plane itself, all evidence of it disappears, and the differences are then directly proportional to the numerical differences in atomic weight.

5. *Comparative Influence of the Alkali Metal and of the Second (Dyad or Acting-Dyad) Metal.*—The foregoing results will have rendered it quite evident that the replacement of one alkali metal by the next higher or lower is attended with considerable change in the angular magnitudes of the crystals; in the cases of several of the angles, such change exceeding a whole degree. On the other hand, it is found that the changes brought about by replacing the second (dyad) metal are usually so very small as to approach the limits of error. Indeed, if we confine our attention to comparing the angles of the crystals of those salts which are more strictly comparable, as containing dyad metals belonging as strictly to the same family group as do potassium, rubidium, and cæsium, the change is seen to be almost, and in some cases quite, inappreciable.

Thus, if we compare the axial angles of the salts containing magnesium, zinc, and cadmium, belonging to the odd series of the second vertical group in the periodic classification of Mendeléeff, we observe the following remarkable similarity, and almost identity, in the angles :—

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Second metal. present.	Value of β for potassium salt.	Value of β for rubidium salt.	Value of β for caesium salt.
Magnesium....	75° 12'	74° 1	72° 54'
Zinc.....	75 12	74 7	72 59
Cadmium	—	74 7	72 49

This similarity is again observed on comparing the salts containing nickel and cobalt :—

Nickel.....	75° 0'	73° 57'	72° 58'
Cobalt.....	75 5	73 59	72 52

It is quite evident from these comparisons that the influence of the second (dyad) metal, so long as our comparisons are made between the salts whose second metals are strictly comparable, is inappreciable as far as the axial angle is concerned, one such dyad metal being replaceable by another without materially altering the magnitude of that angle.

The same observation applies to many of the other angles, and even in those zones where the differences brought about by replacing one second metal by another of the same family group are more apparent such differences are still very small, and only have the effect of slightly modifying the ratio of the differences between the angles of the potassium and rubidium salts and the rubidium and caesium salts respectively, as described in the last paragraph. They are, in fact, so small that in many cases they approach the limits of error.

A difference, however, is apparent when the dyad metal belongs to a different group and is of a different chemical nature. This is most noticeable in the isolated case of copper, the absolute magnitudes of the angles of the three salts containing this metal differing considerably, sometimes by a whole degree, from the others of the series. Although this is the case, however, it is a most significant fact, which goes far to prove that the general rules laid down in the previous paragraphs, 3 and 4, are not accidental, that those rules are followed with the utmost rigour in the cases of the three salts containing copper.

The above observations lead to the following general conclusions :—

The alkali metals exert a preponderating influence in determining the geometrical form of the crystals of the salts of the series $R_2M(SO_4)_2 \cdot 6H_2O$, the magnitudes of the angles being altered on replacing one alkali metal, R, by the next higher or lower to an extent attaining a maximum in certain angles of more than a whole degree, whilst the replacement of the second (dyad) metal, M, by any other of the same family group is unattended by any material change in the angular magnitudes.

6. *Relations between the Axial Ratios.*—For a reason which was fully discussed in paragraph 6 of the comparison of the three salts con-

taining magnesium, the axial ratios do not afford information concerning the change in the geometrical form of the crystals of this series of such value as that derived from a comparison of the angles themselves. It has been shown that as the angles which determine the axial ratios change simultaneously on replacing one alkali metal by another, it is only the difference between these simultaneous changes which is effective in altering the ratio of the lengths of the axes. This difference is sometimes so small that the axial ratio remains practically unaltered, and very frequently the differences exhibited between the axial ratios are so small that they approach the limits of error.

As a matter of fact, out of the 12 series of axial ratios compared, in the sets containing as the second metal magnesium, zinc, iron, nickel, cobalt, and copper respectively, nine follow the rule that the ratios of the rubidium salts lie between those of the corresponding potassium and caesium salts, and in the three exceptions one minute of arc (an amount within the limits of error) difference in the angle from which they were calculated would cause them to follow the rule. One point, however, in connection with the ratios of the axes is particularly worthy of notice. It has been always found that the ratios for corresponding potassium and rubidium salts are nearer together than those of the rubidium and caesium salts, a fact which is probably connected with the same cause as the phenomenon described in the latter portion of the last paragraph but one (paragraph 4).

The above observations may be summarised as follows:—

The importance of the axial ratios as indicative of the change of geometrical form on replacing one alkali metal in any salt of the series $R_2M(SO_4)_2 \cdot 6H_2O$ by another is greatly diminished by the fact that simultaneous changes, more or less neutralising each other, occur in the angles which determine them, thus causing the differences to be small. It is generally observed, however, that in any set of three salts containing the same second metal the ratios for the rubidium salt lie between those of the potassium and caesium salts, and somewhat nearer to those of the potassium salt. The changes in the crystallographical angles themselves afford the only complete information concerning the change of geometrical form.

Summary of Conclusions.

1. The salts of the monoclinic series $R_2M(SO_4)_2 \cdot 6H_2O$ containing caesium as the alkali metal exhibit the greatest facility of formation and deposition in the form of crystals, and those containing potassium least; the salts containing rubidium occupy an intermediate position in this respect.

2. The crystals of the potassium, rubidium, and caesium salts of this series, though bounded by the same common planes, exhibit specific characteristic habits; the characteristic habit of the crystals of the potassium salts is widely different from that exhibited by the crystals of the caesium salts, and the habit usually assumed by the crystals of the rubidium salts is intermediate between the two. The relations between the characteristic habits of the potassium, rubidium, and caesium salts respectively, are thus found to be directly dependent on the relations between the atomic weights of the alkali metals.

3. In the crystals of the salts of this series, the axial angle β increases with the increase in the atomic weight of the alkali metal contained, and its magnitude in any rubidium salt of the series is approximately midway between that in the potassium and that in the caesium salt containing the same second metal. The differences, therefore, between the magnitudes of the axial angle in crystals of this series containing potassium, rubidium, and caesium respectively as the alkali metal are in direct simple proportion to the differences between the atomic weights of these metals.

This last statement may be framed from another point of view as follows. The relative amounts of change brought about in the magnitude of the axial angle by replacing the alkali metal potassium by rubidium, and the rubidium subsequently by caesium, are approximately in direct simple proportion to the relative differences between the atomic weights of the metals interchanged.

These changes in the magnitude of the axial angle on passing from a potassium to a rubidium salt, and from a rubidium to a caesium salt, are very considerable, usually exceeding a whole degree in each case; they are therefore far removed from the widest limits which can possibly be assigned to experimental and formational error.

4. The magnitudes of all the angles between the faces of the crystals of the salts of this series containing rubidium as the alkali metal lie between the magnitudes of the corresponding angles upon the crystals of the salts containing potassium and caesium respectively.

The differences between the magnitudes of the angles, other than the axial angle, in crystals of this series containing potassium, rubidium, and caesium respectively as the alkali metal are not generally in direct simple proportion to the differences between the atomic weights of these metals. The maximum deviation from simple proportionality occurs in the prism zone, where the ratio of the differences varies, according to the nature of the second metal present, from 1 : 2 to 1 : 3.

The fact that the differences between the magnitudes of many of the angles of the caesium and rubidium salts are so much larger than

those between the rubidium and potassium salts would appear to indicate that, as the atomic weight becomes higher, it exercises an influence on these angles greater than in mere numerical proportion to its increase. This influence is most apparent in the angles of the prism zone, and becomes less and less evident in the zones approaching more and more nearly to the plane of symmetry, until at length in the case of the axial angle lying in the plane of symmetry all evidence of it disappears, and the differences are then directly proportional to the numerical differences in atomic weight.

5. The alkali metals exert a preponderating influence in determining the geometrical form of the crystals of the salts of this series, the magnitudes of the angles being altered on replacing one alkali metal, R, by the next higher or lower to an extent attaining a maximum in certain angles of more than a whole degree, whilst the replacement of the second (dyad) metal, M, by any other of the same family group is unattended by any material change in the angular magnitudes.

6. The importance of the axial ratios, as indicative of the change of geometrical form on replacing one alkali metal in any salt of this series by another, is greatly diminished by the fact that simultaneous changes, more or less neutralising each other, occur in the angles which determine them, thus causing the differences to be small. It is generally observed, however, that in any set of three salts containing the same second metal, the ratios for the rubidium salt lie between those of the potassium and caesium salts, and from the cause stated in paragraph 4 somewhat nearer to those of the potassium salt. The changes in the crystallographical angles themselves afford the only complete information concerning the change of geometrical form.

It is intended to follow this communication by another, in which the crystallographical optical properties of the salts of this series will be treated in a similar manner, with the view of ascertaining whether the replacement of the alkali metal potassium by rubidium and caesium is accompanied by corresponding changes in the optic axial angle and other optical constants.