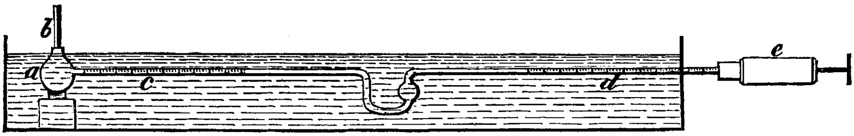
XII.—*Researches on Atomic Volume and Specific Gravity, by* JAMES P. JOULE, ESQ. *Corresponding Member of the Royal Academy of Sciences, Turin, and* LYON PLAYFAIR, F.R.S. *of the Museum of Practical Geology.*

SERIES IV.—EXPANSION BY HEAT OF SALTS IN THE SOLID STATE.

In pursuing our researches on atomic volume and specific gravity, we have thought it desirable, as has been already intimated in a previous memoir, to ascertain the expansion of the salts by heat, as well as their volume at a given temperature. In this way we hope to arrive ultimately at the solution of the apparent discrepancies between theory and experiment. We are not aware that any experiments of this kind have hitherto been made. Brunner has indeed determined the expansion of ice, and we are led to expect that Pierre, who has already given valuable results on the expansion of liquids, will extend his labours to solid salts. We hope, therefore, that our own results, as detailed in the present memoir, will be speedily confirmed. The expansion of solids by heat is a subject which although little cultivated hitherto, is of very great importance to science, and will require, in all probability, the labours of many experimenters for its complete development. It will not, therefore, be expected that we shall be able to include the expansions of the whole range of known inorganic salts in one memoir; our object being simply to examine a sufficient number of them, in order to throw light on the causes which produce variations in the sp. gr. of bodies, and thus enable us to confirm or correct our views on atomic volumes.

It was only after much consideration and some preliminary trials, that we were enabled to select what appeared to us an unexceptionable method of conducting the experiments. The first form of apparatus which suggested itself to us, consisted of a glass volumenometer, Fig. 1, in which *a* is a bulb, of two and a half cubic inches capacity, having a neck fitted with a perforated glass stopper *b*. A graduated tube *c d*, of small diameter, was attached to this bulb,

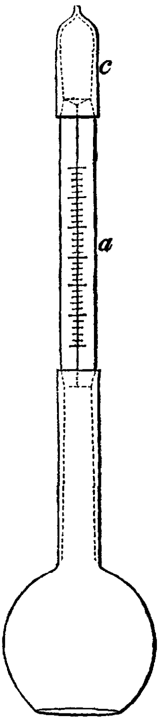
FIG 1.



having at the centre a smaller bulb, of one cubic inch capacity. A syringe was attached tightly to the extremity, and the whole was immersed in a large vessel containing water. The method of experimenting with this apparatus was as follows:—The bulb *a* was filled with turpentine or any liquid incapable of dissolving the salt, and the exact quantity was noted on the graduated stem at *c*. The piston of the syringe was then gradually withdrawn, so as to draw the liquid nearly to the end of the tube *d*, entirely filling the intermediate bulb. A known quantity of the salt was then thrown into the bulb *a*, and the stopper being re-adjusted, the liquid was driven back by the syringe till it ascended into the perforation of the stopper. By examining the position of the liquid in the graduated tube, the space occupied by the salt was rendered evident. By conducting experiments with a salt in the above manner, at different temperatures, its expansion could be made evident, regard being of course paid to the expansion of the glass tube.

Several trials were made with the above-described apparatus, the use of which appeared to offer a great advantage in not requiring an acquaintance with the expansion of the liquid employed. However, it was speedily found that there were grave inconveniences attending it, in consequence of the difficulty of drying the tube thoroughly after each experiment, as well as the danger of losing a portion of the salt whilst introducing it through the narrow neck of the bulb. But these objections might have given way to time and patience. Our chief, and with this apparatus, insurmountable difficulty, arose from the fact, that a quantity of air always remained attached to the salt after immersion. Since, therefore, it was highly probable that the quantity of adhering air varied with the temperature, the apparatus appeared liable to error, and was consequently abandoned.

FIG. 2.



After some other attempts, we at last fixed upon a plan, which appeared to combine the advantages of accuracy with great practical facility. We procured four sp. gravity bottles, made of the same sample of glass. Two of them, marked No. 1 and No. 3, were capable of containing somewhat more than 500 grs. of water, whilst the other two, No. 2 and No. 4, had a capacity for about 270 grs. of water, the latter being destined for ascertaining the volumes and expansions of weighty articles in small quantities. We have given a half-size representation of one of the larger bulbs in Fig. 2, where *a* is a stopper formed from a piece of thermometer tube of narrow bore, terminated at the upper end by a small conical cavity, over which a cap *c* is accurately fitted by grinding, so that any liquid which may have ascended through the capillary, is confined in the cap without loss. There is a fine capillary perforation at the summit of the cap, for allowing the egress of the air displaced by the liquid.

In order to ascertain the expansion of the glass of these volumenometers, the capillary tubes which served for their stoppers were carefully calibrated and graduated. They were then filled with distilled water and immersed for half an hour in a bath containing a large quantity of water, kept constantly at 38°·92 (F). The exact height of the water in the capillary tube being then noted, the water in the bath was from time to time increased in temperature. At every successive increase, the position of the water in the stem was observed. It first descended and then of course ascended, until at the temperature of 45°·82, the water stood at exactly the same point as at 38°·92. Hence it was evident that the glass had expanded exactly as much as the water, through the interval between 38°·92 and 45°·82. According to the table given by Despretz, it appears that the expansion of water through this interval is 0·0001069; so that, supposing the expansion of glass to go on at the same rate through 180°, the expansion of the bulbs of the volumenometers will be 0·002788 between the freezing and boiling points of water.

Another experiment of the same kind showed that the expansions of the glass and water were the same through the interval between $38^{0}\cdot478$ and $46^{0}\cdot218$, which placed the expansion of the volumenometers at 0·002798.

The expansion of the glass bulbs being thus known, it was easy to see how they might be employed in ascertaining the expansion of turpentine and salts. For by weighing them filled with turpentine, at different temperatures, we could obtain the expansion of that fluid. And then by weighing the bulbs filled with turpentine, and a given weight of salt at different temperatures, we could readily obtain the volume and expansion of the salt.

It need hardly be observed, that experiments of this nature require to be performed with very great accuracy. We therefore employed an excellent calibrated thermometer, in which each division was equal to $\frac{1}{12\cdot92}$ of a degree, of Fahrenheit's scale, and the freezing point, which had remained nearly stationary, for half a year stood at 16·1 divisions. It was easy to read off temperatures to within $\frac{1}{150}$th of a degree by this instrument. We also employed a very sensible balance by Dancer, which would turn well with the addition of $\frac{1}{1000}$th of a grain, when each scale was loaded with 1000 grs. The barometric pressure was always noted, in order to correct the observed weights, and before weighing, the bulbs were reduced nearly to the temperature of the apartment, to prevent the inaccuracy arising from the currents of air they would otherwise occasion in the balance case. In taking temperatures, regard was had to the temperature of that part of the stem not immersed in the bath; and, whenever necessary, the rule of the committee of the Royal Society was employed in order to supply the requisite correction.

In the first place the weights of the bulbs, both empty and filled with water, were ascertained, in order to find their exact capacity. The water employed for this purpose was distilled, and had been recently boiled. The stoppers were placed in the necks of the bulbs, causing the water to ascend through the capillary tubes into the small cavities at the tops of the stoppers. A noose of string was now placed on the neck of each of the bulbs, which were then immersed to within an inch of the tops of the stoppers in the bath of water. The thermometer in the bath stood at the 113th division, and kept as nearly as possible at that point for about three quarters of an hour, during the whole of which time the water was repeatedly agitated by a stirrer. Experience had already shown that three quarters of an hour was more than sufficient to reduce the temperature of the bulbs to the exact temperature of the bath; the water remaining in the cavities at the tops of the stoppers was therefore now removed by means of bibulous paper, and the caps were placed upon them. The bulbs were then removed in succession from the bath, reduced to the temperature of the room, dried with a soft silk handkerchief, and weighed. The results corrected for barometrical pressure were as follows:

	No. 1. Volumenometer.	No. 2. Volumenometer.	No. 3. Volumenometer.
Bulbs and water at 113 . .	623·572	882·042	922·522
Bulbs alone	349·546	377·036	397·649
Capacity in grs. of water at 113	274·026	505·006	524·873

The bulbs being now thoroughly dried, were filled with the turpentine destined for the experiments. The range of temperature fixed upon was between about 100 and 750 of the thermometer, corresponding to about $38^{0}{\cdot}5$ and $88^{0}{\cdot}8$ Fahr. The low temperature was attained by dissolving carbonate of soda in the water of the bath, adding a small quantity from time to time, to keep the temperature uniform. The high temperature was maintained by a lamp, burning underneath the bath. When, after half an hour's immersion, the turpentine had attained the exact temperature of the bath, the bulbs were successively weighed, as in the case of the trial with water already described. The bulbs were then again immersed in the bath for half an hour, and re-weighed, in order to preclude the possibility of an accidental error.

Volumenometer.	Temp.	Weight.	Mean temp.	Mean weight.	Weight of empty bulbs.	Weight of turpentine only
No. 1	120	589·648	123·5	589·616	349.546	240·070
	127	589·584				
	745.2	583·854	747·8	583·828	349·546	234.282
	750·4	583·802				
No. 2	107·6	819 779	111·8	819·710	377·036	442·674
	116·0	819·640				
	744·5	808·874	747·45	808·831	377·036	431·795
	750·4	808·788				
No. 3	106	857·852	110.5	857·773	397·649	460·124
	115	857·694				
	744·9	846·456	747·55	846·411	397·649	448·762
	750·2	846·366				

The above results were obtained on the 11th of August, 1846, and immediately afterwards the experiments on the expansion of salts were commenced, and continued until the 26th of August, when the turpentine (which was kept in a large glass bottle, holding about a gallon) was again tested, in order to ascertain whether any change had taken place in its density. Such was found to have happened, in consequence of the absorption of atmospheric air, as will be seen by the results given below.

Volumeno-meter.	Temp.	Weight.	Mean temp.	Mean weight.	Weight of empty bulb.	Weight of tur-pentine alone.
No. 1	93	590·052	93·5	590·052	349·546	240·506
	94	590·052				
	399·9	587·214	399·7	587·220	349·546	237·674
	399·5	587·227				
	754·4	583·906	752·5	583·926	349·546	234·380
	750.6	583·946				
No. 2	93·9	820·271	95·1	820·255	377·036	443·219
	96·4	820·239				
	399·6	815·044	399·3	815·050	377·036	438·014
	399	815·056				
	752·8	808·934	751·3	808·962	377·036	431·926
	749·9	808·991				
No. 3	93·8	858·358	94·2	858.353	397·649	460·704
	94·7	858·349				
	399·9	852·905	399·7	852·907	397·649	455·258
	399·5	852·909				
	753·5	846·554	751·8	846.582	397·649	448·933
	750·2	846·610				

In the above table we have recorded observations taken at a temperature intermediate between the two extremes. The same was done in the case of a large proportion of the salts tried, with a view to ascertain whether their expansion was uniform. Such appeared to be invariably the case; at least if any discrepancy occurred, it was within the limits of experimental errors. We have not, however, thought it right to extend our paper, already too voluminous, by these details. It will be seen from the observations on the volume of turpentine at the three temperatures above given, that that fluid is remarkably uniform in its expansion, a circumstance which eminently adapts it for experiments on the expansion of salts.

Owing to the slight change which had occurred in the density of the turpentine, we calculated the expansion of the salts first tried by the first table of results on the expansion of turpentine, and that of the salts last tried by the last table, employing the mean of the two tables for the intermediate experiments.

In trying a salt, the bulb, partially filled with turpentine, was accurately weighed. A quantity of salt having been then introduced, the bulb was again weighed, the increase of weight giving the exact quantity of salt, attention being paid to the correction for barometrical pressure. The bulb was then placed under the exhausted receiver of an air-pump, until the air adhering to the salt was entirely boiled away. This done, the vacant space in the bulb was filled up with turpentine, and the stopper inserted The weights of the volumenometers and their contents at different temperatures were then ascertained, as in the case of the experiments with turpentine alone, already described. We may mention in this place that, for convenience sake, two or three bulbs containing different salts were always tried at the same time.

Exp^{t}. 1.—634·200 grs. of Powdered Red Oxide of Mercury, in No. 3 Volumenometer.

Temp.	Weight.	Mean Temp.	Mean Weight.
108 110	1442·086 1442·058	109	1442·072
747·9 749·2	1431·882 1431·844	748·5	1431·863

In calculating the volume and expansion of the red oxide of mercury from the above results, we proceeded as follows. From our first table of results for the expansion of turpentine, it appears that the weights of No. 3 volumenometer, filled with turpentine at the temperatures 110·5 and 747·55, are respectively 857·773 and 846·411. Hence, at the temperatures of the above experiment (109 and 748·5), the weights would have been 857·800 and 846·394. Subtracting the weight of oxide from the weights of the volumenometer at the two temperatures, we have 1442·072 — 634·200 = 807·872 and 1431·863 — 634·200 = 797·663. These numbers being subtracted from 857·800 and 846·394, leave 49·928 and 48·731 as the quantities of turpentine displaced by the oxide at the respective temperatures. But from the first table of the expansion of turpentine, it appears that 48·731 grs. at 748·5 are equivalent to 50·008 grs. at 109, regard being had to the expansion of glass. The expansion of the oxide for the interval of temperature between 109 and 748.5 is therefore 0·001596, which gives 0·005802 as the expansion for an interval of 2325 divisions of the thermometer corresponding to 180° Fahrenheit.

It appears also that the volume of 634·200 grs. of the oxide is equal to the volume of 49·928 grs. of turpentine at 109. But from the relative weights of the volumenometer containing water and turpentine, already given, we find that the sp. gravity of turpentine at 109 is to that of water at 107·7 as 0·87669 is to 1. Hence we readily find that the sp. gravity of the oxide at 107·7, the point of maximum density of water, is 11·136.

Exp[t]. II.—540·940 grs. of Sulphuret of Lead in powder in No. 2 Volumenometer :

Temperature.	Weight.	Mean Temp.	Mean Weight.
108·2 114·4	1292·228 1292·116	111·3	1292·172
748·2 749·6	1282·824 1282·791	748·9	1282·807

Therefore expansion for 180^0=0·01045. Sp. gr. at 39^0·1=6·9238.

Exp[t]. III.—585·500 grs. of Bichromate of Potash in small crystals in No. 3 Volumenometer :

111·2 114·2	1252·440 1252·402	112·7	1252·421
749·8 748·9	1245·290 1245·303	749·3	1245·297

Therefore expansion for 180^0=0·0122. Sp. gr. at 39^0·1=2·692.

Exp[t]. IV.—146·355 grs. of pounded Muriate of Ammonia in No. 2 Volumenometer :

111·8 115·8	882·348 882·310	113·8	882·329
750 748·8	873·149 873·150	749·5	873·149

Therefore expansion for 180^0=0·0191. Sp. gr. at 39^0·1=1·5333.

Exp[t]. V.—376·520 grs. of Peroxide of Tin in powder. No. 1 Volumenometer :

109·2 113	917·088 917·058	111·1	917·073
750 749	912·379 912·383	749·5	912·381

Therefore expansion for 180^0=0·00172. Sp. gr. at 39^0·1=6·7122.

Exp[t]. VI.—405·131 grs. of Sulphate of Iron, prepared by pounding, and pressing between bibulous paper, in No. 3 Volumenometer :

104 111	1074·826 1074·758	107·5	1074·792
749·4 750·6	1077·586 1077·567	750	1077·576

Therefore expansion for 180^0=0·01153. Sp. gr. at 39^0·1=1·8889.

Exp[t]. VII.—426·672 grs. of Sulphate of Copper, prepared by pressing the pounded salt between folds of bibulous paper. No. 2 Volumenometer :

Temperature.	Weight.	Mean Temp.	Mean Weight.
104·5	1083·046	108·2	1083·004
112	1082·963		
749·6	1075·777	750	1075·776
750·4	1075·775		

Therefore expansion for 180^0=0·009525. Sp. gr. at 39^0·1=2·2901.

Expt. VIII.—552·605 grs. of Protoxide of Lead in powder in No. 1 Volumenometer:

103·5	1090·670	106·4	1090·649
109·4	1090·629		
749 6	1085·902	750	1085·900
750·4	1085·898		

Therefore expansion for 180^0=0·00795. Sp. gr. at 39^0·1=9·3634.

Expt. IX.—327·760 grs. of Sulphate of Magnesia, prepared by pressing the pounded salt between folds of bibulous paper. No. 3 Volumenometer:

90	1014·948	93·3	1014·913
96 6	1014·879		
750	1007·181	749·5	1007·182
749	1007·182		

Therefore expansion for 180^0=0·01019. Sp. gr. at 39^0·1=1·6829.

Expt. X.—417·706 grs. of Nitrate of Potash in No. 2 Volumenometer:

89·4	1063·822	93·4	1063·776
97·4	1063·731		
750 3	1056·109	749·4	1056·114
748·6	1056·119		

Therefore expansion for 180^0=0·01967. Sp. gr. at 39^0·1=2·1078.

Expt. XI.—287·080 grs. of Copper, prepared from the oxide by passing hydrogen over it at a red heat, in No. 1 Volumenometer:

89	846·962	92·3	846·932
95·6	846·903		
401.2	844·420	400·6	844·426
400	844·432		

Therefore expansion for 180^0=0·0055. Sp. gr. at 39^0·1=8·367.

Expt. XII.—621·528 grs. of Yellow Chromate of Potash in No. 3 Volumenometer:

91·4	1278·445	95·2	1278·402
99	1278·360		
752·5	1271·323	752·8	1271.304
753·2	1271·285		

Therefore expansion for 180^0=0·01134. Sp. gr. at 39^{0}1=2·7110.

Expt. XIII.—531·794 grs. of Nitrate of Soda in No. 2 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
92	1145·372	95·8	1145·323
99·6	1145·274		
752·4	1138·724	752·7	1138·720
753	1138·715		

Therefore expansion for 180° = 0·0128. Sp. gr. at 39°·1 = 2·2606.

Expt. XIV.—133·131 grs. of Red Oxide of Manganese in No. 1 Volumenometer:

91·2	696·149	94·6	696·113
98	696·077		
753·4	690·654	753·2	690·660
753	690·666		

Therefore expansion for 180° = 0·00522. Sp. gr. at 39°·1 = 4·325.

Expt. XV.—424·298 grs. of Sugar Candy, coarsely pounded. No. 3 Volumenometer:

102·6	1048·504	107·0	1048·472
111·5	1048·440		
752·6	1042·251	753·8	1042·244
755	1042·238		

Therefore expansion for 180° = 0·01116. Sp. gr. at 39°·1 = 1·5927.

Expt. XVI.—546·662 grs. of Nitrate of Lead in No. 1 Volumenometer:

99·4	1029·299	104·1	1029·280
108·8	1029·261		
753·4	1025·773	753·9	1025·772
754·4	1025·771		

Therefore expansion for 180° = 0·00839. Sp. gr. at 39°·1 = 4·472.

The above experiments were, as we have already stated, completed before the commencement of September 1846, and a variety of circumstances prevented our resumption of the research before March in the succeeding year. However, previously to the commencement of the new series, we provided ourselves with a large quantity of turpentine, which after having been well mixed, was decanted into small bottles and preserved over mercury. In this way the turpentine was kept without material change, as will be seen from the following series of results obtained with it before the commencement of the experiments, and after their completion.

SERIES I. *Experiments on the Expansion of Turpentine, on March* 20, 1847.

Volumeno-meter.	Tempe-rature.	Weight.	Mean Tempe-rature.	Mean Weight.	Weight of Bulb.	Weight of Turpentine alone.
No. 1.	89·5 87·0	590·119 590·136	88·2	590·127	349·546	240·581
	747·6	584·024	747·6	584·024	349·546	234·478
No. 2.	89·4 87·0	820·472 820·512	88·2	820·492	377·036	443·456
	746·6	809·169	746·6	809·169	377·036	432·133
No. 3.	89 87	858·553 858·584	88	858·568	397·649	460·918
	734·1 745·7	847·030 846·806	739·9	846·918	397·649	449·269

SERIES II. *Experiments on the Expansion of Turpentine, on January* 21, 1848.

Volumeno-meter.	Tempe-rature.	Weight.	Mean Tempe-rature.	Mean Weight.	Weight of Bulb.	Weight of Turpentine alone.
No. 2.	73 70	820·752 820·805	71·5	820·778	377·036	443·742
	754·6 754·6	809·031 809·032	754·6	809·031	377·036	431·995
No. 3.	70·8 73·2 70·2	858·871 858·831 858·886	71·4	858·863	397.649	461·214
	754·6 754·6 754·6	846·645 846·641 846·647	754·6	846·644	397·649	448·995

In calculating the expansion of the salts, the mean of the above two series was employed, viz.:

Volumenometer.	Temperature.	Weight.	Weight of Volumeno-meter alone.	Weight of Tur-pentine alone.
No. 1.	88·2	590·127	349·546	240·581
	747·6	584·024	349·546	234·478
No. 2.	79·85	820·635	377·036	443·599
	750·6	809·100	377·036	432·064
No. 3.	79·7	858·715	397·649	461·066
	747·25	846·781	397·649	449·132

Expt. XVII.—466·202 grs. of Nitrate of Potash in large crystals. No. 3 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
75 78	1129·601 1129·578	76·5	1129·589
739·3 746·5	1121·954 1121·920	742·9	1121·937

Therefore expansion for 180°=0·017237. Sp. gr. at 39°·1=2·09584.

Expt. XVIII.—654·992 grs. of Sulphate of Potash in small crystals. No. 2 Volumenometer:

74·6 78·0	1259·066 1259·054	76·3	1259·060
738·4 746·6	1252·752 1252·690	742·5	1252·721

Therefore expansion for 180°=0·010697. Sp. gr. at 39°·1=2·65606.

Expt. XIX.—302·609 grs. of Copper prepared from the oxide by passing hydrogen gas over it at a red heat. No. 1 Volumenometer:

74 77·8	861·271 861·256	75·9	861·263
740 747·4	855·884 855·816	743·7	855·850

Therefore expansion for 180°=0·00767. Sp. gr. at 39°·1=8·41613.

Expt. XX.—501·286 grs. of Nitrate of Potash, pounded small. No. 3 Volumenometer:

60 62·8	1151·237 1151·197	61·4	1151·217
736·6 743	1143·634 1143·558	739·8	1143·596

Therefore expansion for 180°=0·019487. Sp. gr. at 39°·1=2·10657.

Expt. XXI.—427·790 grs. of Sulphate of Copper and Ammonia, in large crystals. No. 2 Volumenometer:

60·8 63·2	1050·197 1050·167	62	1050·182
736 743	1043·559 1043·499	739·5	1043·529

Therefore expansion for 180°=0·0066113. Sp. gr. at 39°·1=1·89378.

Expt. XXII.—429·784 grs. of Sulphate of Magnesia and Ammonia, in good crystals. No. 3 Volumenometer:

76·0 77·2	1068·645 1068·643	76·6	1068·644
739·0 735·6	1062·177 1062·227	737·3	1062·202

Therefore expansion for 180°=0·007161. Sp. gr. at 39°·1=1·71686.

Exp^t. XXIII.—507·958 grs. of Sulphate of Potash and Zinc, in good crystals. No. 2 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
75·0	1129·497	75·8	1129·480
76·6	1129·463		
738·7	1122·899	736·6	1122·920
734·5	1122·941		

Therefore expansion for 180^0=0·008235. Sp. gr. at 39^0·1=2·24034.

Exp^t. XXIV.—444·494 grs. of Sulphate of Magnesia and Potash, in good crystals. No. 3 Volumenometer:

75·0	1113·108	75·4	1113·101
75·8	1113·095		
747·9	1105·678	748·0	1105·683
748·1	1105·688		

Therefore expansion for 180^0=0 009372. Sp. gr. at 39^0·1=2·05319.

Exp^t. XXV.—456·314 grs. of Sulphate of Copper and Potash, in good crystals. No. 2 Volumenometer:

74·9	1091·772	75·4	1091·761
75·9	1091·750		
748·3	1084·695	748·0	1084·698
747·7	1084·701		

Therefore expansion for 180^0=0·009043. Sp. gr. at 39^0·1=2·16376.

Exp^t. XXVI.—449·535 grs. of Sulphate of Copper, in small crystals, prepared by stirring the cupreous solution while cooling. This specimen contained 5·112 equivalents of water, or an excess, due to a mechanical admixture of water. No. 3 Volumenometer.

83·7	1132·089	83·9	1132·094
84·1	1132·099		
746·2	1124·632	746·2	1124·653
746·2	1124·674		

Therefore expansion for 180^0=0·005315. Sp. gr. at 39^0·1=2·2422.

Exp^t. XXVII.—320·027 grs. of Sulphate of Ammonia, in fine small crystals. No. 3 Volumenometer:

89·4	1019· 9	85·3	1019 095
81·2	1019·141		
746·2	1011·018	746·1	1011·011
746·0	1011·005		

Therefore expansion for 180^0=0·010934. Sp. gr. at 39^0·1=1·76147.

Exp^t. XXVIII.—377·686 grs. of Sulphate of Chromium and Potash, in good crystals. No. 2 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
89·0 81·2	1019·481 1019·571	85·1	1019·526
746 2 746·2	1012·614 1012·620	746·2	1012·617

Therefore expansion for $180^0=0{\cdot}005242$. Sp. gr. at $39^0{\cdot}1=1{\cdot}85609$.

Exp^t. XXIX.—517·725 grs. of Sulphate of Copper, pounded and well pressed between folds of bibulous paper. No. 3 Volumenometer:

86·0 88·0	1176·752 1176·734	87·0	1176·743
745·3 742·1	1169·776 1169·812	743·7	1169·794

Therefore expansion for $180^0=0{\cdot}00812$. Sp. gr. at $39^0{\cdot}1=2{\cdot}2781$.

Exp^t. XXX.—600·594 grs. of Yellow Chromate of Potash, in fine small crystals. No. 2 Volumenometer:

86·0 88·0	1227·440 1227·427	87·0	1227·433
745·3 742·3	1220·612 1220·656	743·8	1220·634

Therefore expansion for $180^0=0{\cdot}011005$. Sp. gr. at $39^0{\cdot}1=2{\cdot}72309$.

Exp^t. XXXI.—467·184 grs. of Potash Alum, in good crystals. No. 2 Volumenometer:

80·0 80·0	1053·484 1053·480	80·0	1053·482
748·0 744·8	1047·995 1048·042	746·4	1048·018

Therefore expansion for $180^0=0{\cdot}003682$. Sp. gr. at $39^0{\cdot}1=1{\cdot}75125$.

Exp^t. XXXII.—402·116 grs. of Binoxalate of Potash, in good crystals. No. 3 Volumenometer:

80·0 80·0	1088·032 1088·034	80·0	1088·033
748·2 745·0	1080·146 1080·194	746·6	1080·170

Therefore expansion for $180^0=0{\cdot}011338$. Sp. gr. at $39^0{\cdot}1=2{\cdot}04401$.

Exp^t. XXXIII.—447·312 grs. of Oxalate of Potash, in good crystals. No. 2 Volumenometer:

61·6 65·0	1083·389 1083·359	63·3	1083·374
752·2 751·0	1075·978 1076·014	751·6	1075·996

Therefore expansion for $180^0=0{\cdot}01162$. Sp. gr. at $39^0{\cdot}1=2{\cdot}12657$.

Expt. XXXIV.—406·552 grs. of Chloride of Potassium. coarsely pounded. No. 3 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
60.8	1084·916	63·2	1084·886
65·6	1084·856		
752·5	1076·959	751·9	1076·970
751·3	1076·981		

Therefore expansion for 180⁰=0·010944. Sp. gr. at 39⁰·1=1·97756.

Expt. XXXV.—292·039 grs. of Oxalate of Ammonia, in fine small crystals. No. 3 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
79·2	979·728	80·8	979·713
82·4	979·698		
752·0	971·874	750·9	971·890
749·8	971·907		

Therefore expansion for 180⁰=0·00876. Sp. gr. at 39⁰·1=1·49985.

Expt. XXXVI.—621·193 grs. of Nitrate of Barytes, in small crystals. No. 2 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
85·8	1269·101	87·9	1269·085
90·0	1269·069		
745·8	1262·089	746·4	1262·086
747·0	1262·083		

Therefore expansion for 180°=0·004523. Sp. gr. at 39°1=3·16052.

Expt. XXXVII.—450·560 grs. of Bisulphate of Potash, pounded. No. 3 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
86·9	1149·461	88·5	1149·445
90·1	1149·429		
746·0	1141·345	746·5	1141·339
747·0	1141·333		

Therefore expansion for 180⁰=0·012287. Sp. gr. at 39⁰·1=2·47767.

Expt. XXXVIII.—373·783 grs. of Oxalic Acid, in good crystals. No. 2 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
89·2	994·334	87·8	994·346
86·4	994·359		
744·9	986·783	744·8	986·784
744·7	986·785		

Therefore expansion for 180⁰=0·027476. Sp. gr. at 39⁰·1=1·64138.

Expt. XXXIX.—393·044 grs. of Chlorate of Potash, in small crystals. No. 3 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
89·2	1103·259	87·9	1103·269
86·6	1103·279		
744·7	1094·718	744·7	1094·722
744·7	1094·726		

Therefore expansion for 180°=0·017112. Sp. gr. at 39⁰·1=2·32643.

Expt. XL.—541·833 grs. of Chloride of Barium, in small crystals. No. 2 Volumenometer:

Temperature.	Weight.	Mean Temp.	Mean Weight.
64·8	1206·826	67·1	1206·800
69·4	1206·774		
755·4	1198·800	755·8	1198·797
756·2	1198·794		

Therefore expansion for $180^0 = 0·009873$. Sp. gr. at $39^0·1 = 3·05435$.

Expt. XLI.—326·462 grs. of Sugar of Milk, pounded. No. 3 Volumenometer:

65·0	998·393	67·2	998·383
69·4	998·373		
755·6	990·721	755·9	990·720
756·2	990·719		

Therefore expansion for $180^0 = 0·009111$. Sp. gr. at $39^0·1 = 1·53398$.

Expt. XLII.—307·866 grs. of Binoxalate of Ammonia in good crystals. No. 2 Volumenometer:

81·8	960.874	83·6	960·862
85·4	960·850		
750·8	953·203	750·9	953·210
751·0	953·217		

Therefore expansion for $180^\circ = 0·013718$ sp. gr. at $39^\circ·1 = 1·61341$.

Expt. XLIII.—234·865 grs. of Bichromate of Chloride of Potassium in good crystals. No. 3 Volumenometer:

81·6	1010·939	83·4	1010·914
85·2	1010·889		
750·7	1000·808	750·9	1000·816
751·1	1000·824		

Therefore expansion for $180^\circ = 0·015902$. Sp. gr. at $39^0·1 = 2·49702$.

Expt. XLIV.—392·901 grs. of Quadroxalate of Potash in good crystals. No. 2 Volumenometer:

74·5	1026·945	75·3	1026·940
76·1	1026·935		
751·0	1019·509	752·2	1019·502
753·4	1019·494		

Therefore expansion for $180^\circ = 0·015916$. Sp. gr. at $39^\circ 1 = 1·84883$.

Expt. XLV.—396·646 grs. of Quadroxalate of Ammonia in good crystals. No. 3 Volumenometer:

74.9	1044·521	75·6	1044·518
76·3	1044·515		
751·0	1037·270	752·2	1037·263
753·4	1037·256		

Therefore expansion for $180^\circ = 0·014347$. Sp. gr. at $39^0·1 = 1·65194$.

The foregoing results are collated in the following Table:

No. of Exp^t.	Name of Salt.	Formula.	Atomic weight.	Expansion for 180°.	Sp. gravity at 39°·1.	Atomic Volume.	Atomic Volume, divided by 1·225.
11	Copper	Cu	31·66	0·0055	8·367	3·7839	3·0889
19	Ditto	ditto	ditto	0·00767	8·41613	3·7618	3·0709
1	Red Oxide of Mercury . .	HgO	108·07	0·005802	11·136	9·7046	7·9221
8	Protoxide of Lead . . .	PbO	111·56	0·00795	9.3634	11·887	9·7037
14	Red Oxide of Manganese . .	$Mn_3 O_4$	115·0	0·00522	4·325	26·590	21·706
5	Peroxide of Tin	$Sn O_2$	74·82	0·00172	6·7122	11·147	9·0995
2	Sulphuret of Lead . . .	Pb S	119·56	0·01045	6·9238	17·268	14·096
34	Chloride of Potassium . . .	K Cl	74·5	0·010944	1·97756	37·673	30·753
40	Chloride of Barium . . .	Ba Cl + 2HO	122·14	0·009873	3·05435	39·989	32·644
4	Chloride of Ammonium . .	$NH_4 Cl$	53·5	0·0191	1·5333	34·892	28·483
13	Nitrate of Soda	NaO, NO_5	85·0	0·0128	2·2606	37·601	30·694
10	Nitrate of Potash	KO, NO_5	101·0	0·01967	2·1078	47·917	39·116
17	Ditto	ditto	ditto	0·017237	2·09584	48·191	39·339
20	Ditto	ditto	ditto	0·019487	2·10657	47·945	39·139
16	Nitrate of Lead	PbO, NO_5	165·56	0·00839	4·472	37·021	30·222
36	Nitrate of Barytes	BaO, NO_5	130·64	0·004523	3·16052	41·335	33·743
39	Chlorate of Potash	$KO, Cl O_5$	122·5	0·017112	2·32643	52·656	42·984
12	Chromate of Potash	$KO, Cr O_3$	99·15	0·01134	2·711	36·573	29·856
30	Ditto	ditto	ditto	0·011005	2·72309	36·411	29·723
3	Bichromate of Potash	$KO, 2Cr O_3$	151·3	0·0122	2·692	56·204	45·880
43	Bichromate of Chloride of Potassium	$K Cl + 2Cr O_3$	178·8	0·015902	2·49702	71·605	58·453
38	Oxalic Acid	$HO, C_2 O_3 + 2HO$	63·0	0·027476	1·64138	38·382	31·332
33	Oxalate of Potash	$KO, C_2 O_3 + HO$	92·0	0·01162	2·12657	43·262	35·316

No. of Expt.	Name of Salt.	Formula.	Atomic weight.	Expansion for 180°	Sp. gravity at 39°·1.	Atomic Volume	Atomic Volume, divided by 1·225.
32	Binoxalate of Potash	$KO, 2C_2O_3 + 3HO$	146·0	0·011338	2·04401	71·428	58·309
44	Quadroxalate of Potash	$KO, 4C_2O_3 + 7HO$	254·0	0·015916	1·84883	137·384	112·150
35	Oxalate of Ammonia	$NH_4O, C_2O_3 + HO$	71·0	0·00876	1·49985	47·338	38·643
42	Binoxalate of Ammonia	$NH_4O, 2C_2O_3 + 3HO$	125·0	0·013718	1·61341	77·476	63·245
45	Quadroxalate of Ammonia	$NH_4O, 4C_2O_3 + 7HO$	233·0	0·014347	1·65194	141·046	115·140
18	Sulphate of Potash	KO, SO_3	87·0	0·010697	2·65606	32·755	26·739
37	Bisulphate of Potash	$KO, SO_3 + HO, SO_3$	136·0	0·012287	2.47767	54·890	44·808
27	Sulphate of Ammonia	$NH_4O, SO_3 + HO$	75·0	0·010934	1·76147	42·578	34·758
7	Sulphate of Copper	$CuO, SO_3 + 5HO$	124·66	0·009525	2·2901	54·434	44·436
26	Ditto	ditto	ditto	0·005315	2·2422	55·597	45·385
29	Ditto	ditto	ditto	0·00812	2·2781	54·721	44·670
6	Sulphate of Iron	$FeO, SO_3 + 7HO$	139·0	0·01153	1·8889	73·588	60·072
9	Sulphate of Magnesia	$MgO, SO_3 + 7HO$	123·67	0·01019	1·6829	73·486	59·989
21	Sulphate of Copper and Ammonia	$CuO, SO_3 + NH_4O, SO_3 + 6HO$	199·66	0·0066113	1·89378	105·430	86·065
25	Sulphate of Copper and Potash	$CuO, SO_3 + KO, SO_3 + 6HO$	220·66	0·009043	2·16376	101·980	83·249
24	Sulphate of Magnesia and Potash	$MgO, SO_3 + KO, SO_3 + 6HO$	201·67	0·009372	2·05319	98·223	80·182
28	Sulphate of Chromium and Potash	$Cr_2O_3, 3SO_3 + KO, SO_3 + 24HO$	503·3	0·005242	1·85609	271·161	221·356
31	Potash Alum	$Al_2O_3, 3SO_3 + KO, SO_3 + 24HO$	476·38	0·003682	1·75125	272·023	222·060
23	Sulphate of Potash and Zinc	$ZnO, SO_3 + KO, SO_3 + 6HO$	221·0	0·008235	2·24034	98·646	80·527
22	Sulphate of Magnesia and Ammonia	$MgO, SO_3 + NH_4O, SO_3 + 6HO$	180·67	0·007161	1·71686	105·233	85·904
15	Cane Sugar	$C_{12}H_{11}O_{11}$	171·0	0·011160	1·5927	107·365	87·645
41	Sugar of Milk	$C_{12}H_{12}O_{12}$	180·0	0·009111	1·53398	117·342	95·789

On a cursory inspection of the above table, it will be observed that considerable discrepancy occurs in the results obtained with salts of the same name. This must not throw doubt on the accuracy of the experiments, as it arose from the state in which the salts were tried. The specific gravity of copper in the 19th experiment is somewhat greater than that in the 11th experiment; the reason for which is, that the copper in the former case was exposed to hydrogen at a red heat for a considerable time after the oxygen had been removed from the oxide. In the case of nitrate of potash, the 17th experiment was made with large crystals, averaging $\frac{3}{16}$ of an inch in diameter, whilst in experiment 20 we employed another portion of the same salt pounded very small, so as to free it from mechanical water, and in experiment 10 a different specimen was used in small crystals. It will be observed, that a very considerable difference exists between the results of the three trials. The large crystals were lighter and in a more coerced state, as shown by their smaller expansion. Of the three specimens of sulphate of copper tried, that employed in experiment 26 had, as we have stated, a larger quantity of water than 5 equivalents attached to it, and hence we observe a great difference in its expansion and specific gravity, the decrease of gravity being, as before, accompanied by a decrease of expansion. With regard to the expansions, we may call attention to the close approximation of the highly hydrated salts to 0·01125, or the expansion of ice as determined by Brunner. The expansion of oxalic acid is remarkable as being greater, and that of peroxide of tin as being less than those of any solid bodies on record. In all cases of hydrated salts, it is extremely difficult to obtain them in their exact normal state of hydration, and therefore the results of experiment with different specimens are subject to variation.