

"On the Absorption of Carbonic Acid by Saline Solutions."

By J. Y. BUCHANAN, Chemist on board H.M.S. 'Challenger.'

Communicated by Professor A. W. WILLIAMSON, For. Sec. R.S.

Received December 11, 1873*.

In the examination of sea-water, whether it be regarded from a chemical or from a zoological point of view, the determination of and the variations in the amount of carbonic acid in different parts of ocean must always be an object of importance. This is more especially so when a parallel series of observations on the quantity of oxygen present is carried out. At the surface we should expect to find the quantities of these gases following the law of partial pressures; at greater depths, however, where the water for long periods only comes in contact with water, we should expect to find the quantity of oxygen decreasing and that of carbonic acid increasing with the amount of animal life. The investigation from this point of view of the bottom-water, at greater and smaller depths, presents perhaps a more interesting field of observation than that of intermediate depths. Down to nearly 2000 fathoms life is still abundant; below this depth, however, the amount rapidly decreases till, at about 2800 fathoms, it is, for carbonic-acid producing purposes, practically extinct. We have, then, to settle the variation of the carbonic acid with latitude and longitude, with depth, with nature of bottom, and with nature of atmosphere.

In order to solve these problems, it is before all necessary to have a reliable method for the determination of the carbonic acid. For the discovery of a cause of error in the old method, and for the invention of a new one, we are indebted to Dr. Jacobsen, of Kiel. Dr. Jacobsen found that sea-water could not, as had been till then assumed, be thoroughly freed from its dissolved carbonic acid by merely boiling *in vacuo*†. He found that it was necessary to boil down almost to dryness before the last traces of carbonic acid could be expelled. Being particularly interested in the matter, I immediately commenced a series of experiments to determine, if possible, the salt or salts to which sea-water owes this peculiar property. A short *résumé* of the results of these experiments have been published as an appendix to Professor Wyville Thomson's 'Depths of the Sea.'

I purpose here to give a detailed account of the experiments performed. They consisted of two series—the one analytical, the other synthetical. In the former I was ably assisted by Mr. George Macdougald, in the latter by Mr. Robert Romanes, junior assistant in Professor Crum Brown's

* Read February 19, 1874. See *antè*, p. 192.

† Dr. Andrews informs me that he had observed a similar phenomenon when attempting to determine the amount of atmospheric gases in sea-water, by boiling it in the Torricellian vacuum after the manner of vapour-density determinations.

laboratory in the University of Edinburgh, and I gladly avail myself of this opportunity to thank them both.

The analytical series consisted of experiments on solutions of the different salts saturated with carbonic acid. A certain quantity of each was distilled almost to dryness, the steam being condensed in an ordinary Liebig's condenser, to which was fitted a tubulated receiver, having a bulbed V-tube attached containing baryta-water. The distillation was interrupted and the baryta-water changed after the passage of every eighth of the distillate, the amount of carbonic acid passed being roughly estimated by the apparent turbidity of the baryta-water. The object of these experiments being to find out which of a number of saline solutions had the property of retaining carbonic acid, and to ascertain roughly what length of time one must boil in order thoroughly to expel it, an accurate determination of the carbonic acid actually passing during the intervals would have been superfluous. Besides these, a number of quantitative determinations were made of the amount of carbonic acid actually absorbed by different solutions.

The synthetical series consisted of experiments for the determination of the absorption-coefficients of two solutions—the one of sulphate of magnesia, the other of sulphate of lime.

Let us take the analytical series first. As before remarked, it is subdivided into two sets, which we shall treat in their order. In the one observations were made on the elimination of the carbonic acid as the distillation proceeded; in the other an attempt was made to determine how much carbonic acid, in a saline solution saturated with the gas, was actually retained or bound, or at least kept from freely exercising its properties as a gas, by the presence of the salt in the solution.

First Experiment.—In order to have a certain standard of comparison in judging the retardation caused by salts in the escape of carbonic acid from solutions on boiling, distilled water was saturated with the gas and distilled in the manner indicated above. During the passage of the first eighth of distillate the gas evolution was of course abundant, during the second a perceptible quantity passed, after which no more could be detected. It may be assumed, then, that, in the experiments which followed, the carbonic acid held *simply in solution* by the water passes almost entirely in the first eighth part of the distillate, and that whatever passes afterwards has been retained, in some way or other, by the salt in solution. In conducting these experiments no baryta-water was put in the receiver itself, but only in the V-tube. The water collected was always tested with baryta-water, and with the general result that in the first fraction carbonic acid was present in abundance, while in the latter ones there was rarely a trace to be detected. That the distillate consisting of pure water should contain not a trace of the gas, whose presence in the atmosphere above it is attested by the precipitate

in the exit-tube, shows that, at feeble pressures, the solution of carbonic acid requires considerable time for its completion.

Second Experiment.—A chloride-of-sodium solution containing 2 per cent. Na Cl had a strong stream of CO_2 passed through it for about ten minutes and was then distilled. During the passage of the second* eighth there was still a considerable quantity, during that of the third a very slight trace, and after that none.

Third Experiment.—A chloride-of-magnesium solution containing 0.25 per cent. Mg Cl_2 was treated in the same way as the chloride-of-sodium solution, when the whole of the CO_2 passed in the first fraction.

Fourth Experiment.—A solution containing 4 per cent. Mg Cl_2 and 10 per cent. Na Cl was saturated with CO_2 and allowed to stand in a closed vessel over night. On distilling, it was found that carbonic acid continued to be given off in perceptible but gradually decreasing quantities until the end.

Fifth Experiment.—For this and the three following experiments a solution containing 12.3 grammes crystallized sulphate of magnesia (in a litre?) was used. Carbonic acid was passed through some of this solution for about 10 minutes, and the liquid allowed to stand in a closed vessel over night. On distillation there passed during the second fraction very little, during the third and fourth fractions decidedly more, during the fifth again much less, and afterwards, to the end, slight but perceptible traces of carbonic acid.

Sixth Experiment.—The solution was heated to nearly boiling, and CO_2 passed into it until it was cold, the whole being allowed to stand over night. During the passage of the second, third, fourth, and fifth fractions, the amount of gas was about constant and small. It increased greatly during the sixth, falling away again during the seventh.

Seventh Experiment.—The conditions were exactly the same as those of the fifth experiment; and the results in the two cases agreed well with each other, the amount of gas coming off increasing slightly about the middle of the operation. In order to see if the rise of temperature consequent on concentration had any thing to do with the phenomena under consideration, a thermometer was immersed in the boiling liquid. It read at the end of the second, third, fourth, and fifth fractions $102^\circ.5$, $102^\circ.9$, 103° , and $103^\circ.2$ respectively.

Eighth Experiment.—The conditions were the same as in the last, only that the solution stood two days before distillation. In the results there was this peculiarity, that in the fourth fraction the carbonic acid disappeared altogether, reappearing, however, again in the fifth.

* It is unnecessary in the cases where no means were taken to free the solution from simply dissolved carbonic acid to repeat in each one that the first fraction contained abundance.

Ninth Experiment.—Sea-water from the Firth of Forth was distilled. Here, as in the case of the sulphate of magnesia, the amount coming off increased about the middle, falling away again in the fifth fraction. In the sixth, however, it experienced a slight increase, falling off again towards the end of the operation.

From these experiments we may conclude that, alone and in the degree of concentration in which they occur in the sea, the two most abundant salts, namely chloride of magnesium and chloride of sodium, exercise no retarding influence on the liberation of carbonic acid on boiling. When mixed, however, as in the fourth experiment, they appear to have this effect. Whether, if sufficiently diluted to represent sea-water, they would continue to do so I was unable to ascertain, as the investigation of the sulphates occupied all the time at my disposal. It is further evident that, in the sulphate-of-magnesia solution experimented on, we have a solution which behaves towards carbonic acid in the same way as sea-water.

Let us pass now to the second set of the analytical series—namely, the estimation of the amount of carbonic acid retained in consequence of the presence of the salts in question. The apparatus used was the same as that in the last set, baryta-water being contained both in the receiver and in the V-tube.

Experiments were made on solutions of sulphate of magnesia, of sulphate of magnesia and chloride of sodium, and of sulphate of lime, to which were added some on sea-water itself. In every experiment the quantity of solution operated on was 300 c. c. The carbonic acid coming off was retained by baryta-water of known strength, the remaining free baryta being afterwards determined by means of oxalic acid. Rosolic acid was used to determine the point of neutralization. The oxalic acid was rather stronger than tenth-normal; it contained 6·478 grms. $C_2H_2O_4 + 2H_2O$ in the litre, which is equivalent to 2·259 grms. carbonic acid. 1000 c. c. baryta-water required 3235 c. c. oxalic acid for neutralization.

The method of conducting the operation was as follows:—Carbonic acid was passed through the solution until it could be assumed to be saturated. Six to seven litres of air were then drawn through it cold, after which it was heated to boiling, and allowed to boil for from two to three minutes in a current of air. The receiver with the baryta-solution was then attached, and the distillation continued in a stream of air, until the contents of the flask were nearly dry. The baryta-water then remaining unneutralized was titrated, and from it the amount of carbonic acid ascertained.

Experiments on sulphate-of-magnesia solution containing 12·3 grammes crystallized salt per litre.—As all were conducted in precisely the same way, it will be sufficient to give the results in a tabular form. The first

three experiments were made with portions of one and the same solution; for the last two a fresh solution (prepared, to all appearance, in exactly the same way as the previous one) was used. The difference in the results obtained show the precarious nature of the combination:—

Volume of solution used.	Volume of baryta-water.	Volume of oxalic acid.	Grammes carbonic acid in 300 c. c.	Grammes carbonic acid in 1 litre.
300 c. c.	25 c. c.	78.96 c. c.	0.0043	0.0143
300 „	10 „	30.0 „	0.0053	0.0165
300 „	10 „	30.9 „	0.0033	0.0110
300 „	15 „	47.5 „	0.0023	0.0077
300 „	10 „	31.32 „	0.0023	0.0077

Two experiments were made with a solution prepared as follows:—The quantity of sulphuric acid necessary for the formation of 12.3 grammes crystallized sulphate of magnesia was diluted to a litre, and pulverized carbonate of magnesia suspended in it. Although the mixture was allowed to stand over night, shut off from the influence of the atmosphere, the solution was still exceedingly acid. It is well known that carbonate of magnesia is difficultly soluble in cold dilute acids. To have heated the solution would have frustrated the object of the experiment, which was, by bringing nascent sulphate of magnesia together with nascent carbonic acid at ordinary temperatures, to give them the best opportunity of combining.

Two experiments were made with a similarly prepared solution of sulphate of lime. In this case sulphuric acid was added to the water in quantity sufficient to form, with lime, more salt than was necessary for the production of a saturated solution of gypsum. Here neutralization took place without difficulty, and, as might have been expected, the amount of carbonic acid formed was considerably greater than in the case of the magnesia salt.

Two experiments were made with an ordinary sulphate-of-magnesia solution containing 2.05 grammes crystallized salt per litre.

Two further experiments were made with a solution containing 2.05 grammes sulphate of magnesia and 20 grammes chloride of sodium per litre. All were conducted in the way described above, and the results are given in the following Table. The experiments with the carbonates of magnesia and lime were made at a considerably later date than the others; the value of 10 c. c. baryta-water had in consequence become equivalent to 32 c. c. instead of 32.34 c. c. oxalic acid.

Nature of solution.	Volume of solution used.	Volume of baryta-water.	Volume of oxalic acid.	Grammes carbonic acid in 300 c. c.	Grammes carbonic acid in 1 litre.
Mg CO ₃ + H ₂ SO ₄ {	300 c. c.	10 c. c.	30·6 c. c.	0·0032	0·0107
	300 "	10 "	30·9 "	0·0025	0·0083
Ca CO ₃ + H ₂ SO ₄ {	300 "	10 "	27·5 "	0·1014	0·3380
	300 "	10 "	27·5 "	0·1014	0·3380
2·05 grms. Mg SO ₄ + 7H ₂ O { per litre.	300 "	10 "	31·2 "	0·0026	0·0087
	300 "	10 "	31·3 "	0·0023	0·0077
Mg SO ₄ + 7H ₂ O + Na Cl {	300 "	10 "	31·6 "	0·0016	0·0053
	300 "	10 "	31·4 "	0·0021	0·0070

Five experiments were made with sea-water taken at the end of Portobello Pier, on the Firth of Forth. In the first three it was submitted immediately to the same treatment as the saline solutions; in the last two carbonic acid was first passed through it for some time. As the results given in the following Table are identical, it is evident that, in its natural state, the water in question was saturated with carbonic acid in this peculiar state of combination.

Experiments on Sea-water.

Volume of water used.	Volume of baryta-water.	Volume of oxalic acid.	Grammes carbonic acid in 300 c. c.	Grammes carbonic acid in 1 litre.
300 c. c.	15 c. c.	39·75 c. c.	0·0198	0·0660
300 "	10 "	23·0 "	0·0211	0·0703
300 "	10 "	23·15 "	0·0208	0·0693
300 "	10 "	23·34 "	0·0203	0·0677
300 "	10 "	23·34 "	0·0203	0·0677

Subsequent experiments made at sea, on water from mid-ocean and from various depths, have shown me that the above quantities are very much in excess of the quantities usually contained in ocean-water. From the large quantity of organic matter poured into the Forth, not far from Portobello, there must be an abundant production of carbonic acid in the water itself, and we have seen above the effect of bringing sulphate of lime and carbonic together in the nascent state. Sea-water contains, on an average, about 8 parts sulphate of lime in 10,000. A saturated solution of the same salt in distilled water contains at 15° C. 24 parts in 10,000.

Under the most favourable circumstances, then, one would expect sea-water to bind about one third of the quantity retained by an equal volume of sulphate-of-lime solution. We have seen that a litre of this solution is capable of retaining 0.338 grm. CO_2 , while the same volume of sea-water contained only 0.07 grm., or considerably less than the third of that held by the sulphate of lime. In ocean-water I have never yet found more than 0.064 grm. CO_2 per litre, including both the *simply dissolved* and the *half bound*. We have, then, in the sulphate of lime alone, an agent capable of retaining much more carbonic acid than is usually found to exist in sea-water. Besides this there is also, at least, the sulphate of magnesia possessing this property. How much it would be capable of absorbing if the carbonic acid were presented in a nascent state in a neutral solution we do not know; it would be interesting to determine the amount of carbonic acid retained by a sulphate-of-magnesia solution in which organic matter had been allowed to decay.

The practical conclusion to be drawn from the preceding experiments is that, as the carbonic acid is retained by the presence of certain sulphates, the gas will be more easily boiled out if we get quit of these sulphates. For this purpose I always add to the sample of sea-water, in which the CO_2 is to be determined, a sufficient quantity of a saturated chloride-of-barium solution to precipitate all the sulphuric acid present. The effect has answered my expectations. After the first fifth of distillate has passed, there is rarely a perceptible turbidity in fresh baryta-water. In practice, however, and as it costs but little trouble, I always distil off from three quarters to seven eighths, and often quite nine tenths of the solution.

The determination of the carbonic acid in sea-water is carried on on board the 'Challenger' by means of an apparatus, a very slightly modified form of the one described by Dr. Jacobsen in the 'Annalen der Chemie und Pharmacie,' a drawing and description of which he was good enough to give me when the 'Challenger' was fitting out.

A flask with a capacity of about 500 c. c. receives the sea-water to be operated on, usually from 200 c. c. to 250 c. c. It is closed by an india-rubber cork, through which pass two tubes; one, reaching to the bottom, communicates with the condenser, a cylindrical copper vessel, 10 in. high by $5\frac{1}{2}$ in. diameter, with a block-tin worm. The lower end of the worm is attached to the receiver by a bent glass tube with a flexible joint, from which a glass tube leads to the bottom of the receiver. The flexibility thus obtained is, in practice, of the greatest use, enabling the operator, by shaking, to expose constantly fresh surfaces of baryta-water to the passing gases. The receiver is connected by an india-rubber tube with two bulbed V-tubes. An aspirator enables a stream of air to be drawn through the apparatus, a soda-lime safety-tube being interposed between it and the V-tubes. The water running from the aspirator is conducted outside the port by a tube which passes

through a hole in the sash. The flask containing the sea-water is supported on a ring, by a clasp holding its neck. Both of these, along with the spirit-lamp underneath the flask, are attached in the usual way to an iron rod, which is attached to the projecting side of the ship by an eye-bolt, in which it has a play of rather more than an inch in the direction of its length. The lower end of the rod sits securely in a hole, let into the top of the working-table. When the apparatus is dismantled the rod is pushed up, till its lower end has freed itself from the hole and laid flat along the roof, being supported at one end by an eye-bolt, at the other by a hook. The aspirator and the condenser are retained in their places by wooden blocks, which fit in between them and the ship's side or the battens on the bench.

The water in which the carbonic acid is to be determined is introduced into the flask by means of a tube reaching to the bottom. When the carbonic acid is to be determined in a specimen of water, the apparatus is first put together and a current of air, free from carbonic acid, drawn through, care having been taken to see that it is thoroughly dry in all its parts. The corks in the receiver and V-tubes are then eased, and from 15 c. c. to 20 c. c. baryta-water, usually of about $\frac{1}{10}$ normal strength, run into them. The water to be examined is introduced into the flask through a tube reaching to the bottom; 10 c. c. of a nearly saturated solution of chloride of barium are then added, the apparatus closed and heat applied. When the liquid begins to boil, care must be taken to lower the flame to avoid frothing over. A gentle current of air is now conducted through the boiling liquid, and the receiver constantly agitated. After half an hour's boiling, about 100 c. c. water have distilled over, and at the same time *all* the carbonic acid. That the latter is the case, I ascertained by changing the baryta-water at this point, and continuing the distillation, when no turbidity was produced. That, at any rate, no appreciable amount of carbonic acid passes after even the first 50 c. c. water have been distilled over, may be very easily seen by the liquid in the receiver passing from a turbid, somewhat frothy solution, to a clear one, in which a well-defined precipitate is suspended, and whose amount does not visibly alter as the distillation proceeds. Although such is the case, I have usually, as it costs but little more time and trouble, carried on the distillation until seven eighths have passed, and indeed, in many cases, until crystallization has commenced. When proper attention is paid to the agitation of the receiver during the first part of the distillation, the amount of carbonic acid reaching the first V-tube is quite insignificant, and the baryta-water in the second remains perfectly clear. When this operation is finished, the contents of the V-tubes are washed into the receiver with boiled water, and the remaining alkalinity determined with hydrochloric acid of known and convenient strength. The point of neutralization is indicated by rosolic acid.

Synthetical Experiments.—In order to check the above experiments, it appeared to me to be of importance to determine the absorption-coefficients of one or more of the solutions for carbonic acid. Before knowing any thing of the retention of carbonic acid by sea-water, I had determined, if possible before the sailing of the 'Challenger,' to investigate the solutions of some of the salts occurring in sea-water, with reference to their power of absorbing the atmospheric gases. It was well known that sea-water, in common with most other salt-solutions, absorbed a smaller quantity of air than distilled water would do under the same circumstances; but it had never, to my knowledge, been attempted to find out whether this diminution of absorptive power was distributed equally over the three gases, or was exhibited more strongly in the case of one gas than in that of another. From a preliminary experiment in which a 2 per cent. solution of Na Cl in distilled water was saturated with air and the air then expelled and analyzed, it appeared that the oxygen was present in slightly greater quantity relatively to the nitrogen than would have been the case if the liquid had been distilled water. Of course, this being the result of only one experiment, no conclusion can be drawn from it; but it shows the necessity of the investigations which I had proposed to myself. Unfortunately, the time at my disposal was too short to allow of any thing being done, except a few experiments with carbonic acid and solutions of sulphate of magnesia and of sulphate of lime.

For this purpose I made use of a Bunsen's absorptiometer, and followed his method, with the modifications rendered necessary by having to do, not with a simple liquid, but with a saline solution. The carbonic acid was introduced into the absorption-tube and measured, not in the mercurial trough, but in the absorptiometer itself, the lid being left open. This is a much more expeditious way, inasmuch as the gas quickly assumes the temperature of the water of the absorptiometer; and as the readings after absorption are all done in this way, there can be no object in reading the gas alone in another way. After absorption, the instrument is always read with the lid shut, so that what corresponds to the height of mercury in the trough is given by the height of it in the outside graduated leg of the absorptiometer. In all of the determinations this height is given, not in the reading on the leg itself, but in the corresponding reading on the absorption-tube, which can be directly observed with sufficient accuracy with the ordinary telescope used in gas-analysis. As after shaking the instrument and opening the stopcock connecting the leg with the body of the instrument some of the water frequently passed into the former, we have generally a reading marked "water in outer leg," which forms a factor in estimating the tension of the gas.

The solutions experimented on were, one containing 1.23 per cent. crystallized sulphate of magnesia and one containing 0.205 per cent. gypsum. It was necessary that these solutions, before being introduced

into the absorption-tube, should be deprived of air without affecting their state of concentration. This was effected in the following way. A flask was filled up to a mark in the neck with the solution, half of it was then emptied into another flask and the two boiled, while distilled water was kept boiling in a third. When the boiling had been kept up for about half an hour, the contents of the second flask were emptied into the first and washed out with the hot distilled water, the volume of the solution being brought in this way up to the mark, and so far above it as was equivalent to the expansion of the solution for the difference of temperatures. A glass syringe of convenient size was now filled with the boiling liquid and passed hot into the absorption-tube. This method may be objected to on two grounds: first, that there is some uncertainty about the exact concentration of the solution when introduced into the absorption-tube; and, second, that some air may have been absorbed by the liquid in its passage through the syringe to the tube. As to the first objection, when the operation is carried out in the way I have described, the possible difference between the actual and assumed concentration is so small that it would be extremely unlikely to have any influence on the coefficient of absorption of the liquid. As to the second, if the manipulations be expeditiously carried out, there is but little fear that the liquid at so high a temperature, and exposed to the small quantity of air of diminished tension in the syringe, should be contaminated in an appreciable way. However much or little importance one may attach to these possible sources of error, they probably explain why the whole subject has been left almost entirely untouched.

Our object in these experiments is, not to determine the absorption-coefficient for a standard pressure such as 760 millims., but to determine it for various pressures, the temperature being kept as uniform as circumstances will permit, and to compare the results obtained with those calculated for distilled water.

Let V = volume of gas (at 0° and 760 millims.) before introduction of solution,

V_1 = volume (reduced to 0°) of gas after absorption,

P_1 = pressure of this gas,

then the volume of gas absorbed will be

$$V_2 = V - \frac{V_1 P_1}{760} \quad \dots \dots \dots (1)$$

And if h be the volume of the solution, we have for the coefficient of absorption at pressure P_1 and the temperature of observation,

$$a_1 = \frac{1}{h_1} \left(V - \frac{V_1 P_1}{760} \right) \quad \dots \dots \dots (2)$$

Two series of experiments were made on solution of sulphate of magnesia containing 1.23 per cent. crystallized salt, and one series on sulphate-of-lime solution containing 0.205 per cent. of $\text{CaSO}_4 + 2\text{H}_2\text{O}$.

The detailed results are given in four Tables. In the first are given the original volumes of the carbonic acid used in each series, with the data for finding the same. In columns 1 and 2 are found the volumes used in series I. and II. respectively for sulphate of magnesia; in column 3 is the volume for the sulphate-of-lime experiments.

TABLE I.

Table giving the original volumes of carbonic acid used in the three series of experiments I., II., and III.

		1.	2.	3.
Barometer	δ	741.5	741.5	736.5
Lower mercury-level in trough	a_1	594	581	586
Upper mercury-level in tube	b_1	323	322	331
Mercury column in tube (δ_1)	$a_1 - b_1$	271	259	255
Height of water column in outer cylinder...	w_1	552	544	558
Equivalent mercury column	q	40.7	40.15	41.18
Temperature of water in cylinder	t	10.8	9.8	10.8
Vapour-tension for t°	T	9.665	9.045	9.665
Reacting pressure ($\delta - \delta_1 + q - T$)	P	501.5	513.6	513
Volume in c. c. of δ_1 from calibration Table	v	73.267	73.039	75.09
Volume (v) reduced to 0° and 760 millims.	V	46.509	47.650	48.759

In series III. (Table IV.) with sulphate of lime, and in series I. (Table II.) with sulphate of magnesia, the readings were made without loss of time, the pressure being successively increased for each experiment. In series II. (Table III.) particular attention was paid to the length of time this gas and solution were in contact at the different pressures, and for each experiment the pressure was successively diminished. They were left in contact for nine days at the highest pressure (column 1) before reading; No. 2 was read twenty-two hours later, No. 3 forty-one hours later than No. 2, No. 4 twenty-five hours later than No. 3, and No. 5 after the lapse of some days.

TABLE II.

Determinations of the absorption-coefficient of a 1.23 per cent. solution of crystallized sulphate of magnesia for carbonic acid at the temperatures and pressures indicated. $V = 46.509$ c. c.

		1.	2.	3.	4.
Barometer	δ	741.5	739.5	741.5	738.0
Thermometer	t	12.0	11.5	11.9	11.9
Outer level of mercury	a_1	568.7	293.0	397.5	182.5
Inner level in absorption-tube	b_1	314.2	224.0	255.5	199.0
Upper level of solution in absorption-tube	c_1	162.0	69.0	102.0	39.5
Upper level of water in outer leg	f_1	568.7	242.0	352.0	123.0
Resultant water column $\{a_1 - f_1 - b_1 + c_1\}$	W	-152.2	-104.0	-108.0	-100.0

TABLE II. (*continued.*)

		1.	2.	3.	4.
Equivalent mercury column	q	— 11·2	— 7·68	— 7·97	— 7·38
Vapour-tension for t°	T	10·457	10·120	10·389	10·389
Resultant pressure on gas $\{\delta - \delta_1^* - T + q\}$	P_1	476·54	652·7	581·14	736·73
Volume in c. c. of c_1 from calibration Table	v	36·943	16·19	23·481	9·648
Volume v reduced to 0° and 760 millims.....	V_1	22·190	13·343	17·206	8·962
Volume in c. c. of b_1	v_1	71·218	50·875	57·968	45·254
Volume of solution $(v_1 - v)$..	h_1	34·275	34·685	34·487	35·606
Coefficient of absorption for temperature t and pres- sure P_1 millims. $\frac{V - V_1}{h_1}$...	α_1	0·7095	0·9562	0·8496	1·0545
Absorption-coefficient of dis- tilled water for same tem- perature and pressure ...	β_1	0·6909	0·9631	0·8455	1·0718

TABLE III.

Determinations of the absorption-coefficient of a 1·23 per cent. solution of crystallized sulphate of magnesia for the temperatures and pressures indicated, the duration of the reaction being taken into account.
 $V = 47·650$ c. c.

		1.	2.	3.	4.	5.
Barometer	δ	736·5	737·0	747·0	742·0	734·0
Thermometer	t	11·1	11·0	10·45	11·1	11·1
Outer level of mercury	a_1	63·0	257·0	446·5	506·0	553·5
Inner level in absorption- tube	b_1	174·5	230·5	265·6	277·0	303·0
Upper level of solution in absorption-tube	c_1	40·6	95·8	131·4	143·0	169·0
Upper level of water column in outer leg	f_1	3·0	195·0	382·0	440·0	488·0
Resultant water column $\{a_1 - f_1 - b_1 + c_1\}$	W	— 73·9	— 72·7	— 69·7	— 68·0	— 68·5
Equivalent mercury column	q	— 5·46	— 5·37	— 5·15	— 5·02	— 5·05
Vapour-tension for t°	T	9·857	9·792	9·443	9·857	9·857
Resultant pressure on gas $\{\delta - \delta_1^* - T + q\}$	P_1	8·327	695·3	551·5	498·1	468·6
Volume in c. c. of c_1 from calibration Table.....	v	9·905	22·106	30·07	32·67	38·52
Volume v reduced to 0° and 760 millims.....	V_1	10·429	19·441	21·016	20·576	22·824
Volume in c. c. of b_1	v_1	39·761	52·337	60·256	62·841	68·72
Volume of solution $(v_1 - v)$...	h_1	29·856	30·231	30·186	30·171	30·200
Coefficient of absorption for temperature t° and pres- sure P_1 millims. $\frac{V - V_1}{h_1}$...	α_1	1·2467	0·9331	0·8823	0·8974	0·8221
Absorption-coefficient of dis- tilled water for same tem- perature and pressure.....	β_1	1·3052	1·0445	0·8461	0·7456	0·7014

* $\delta_1 = \alpha_1 - b_1$.

TABLE IV.

Determinations of the absorption-coefficient of a 0.205 per cent. solution of gypsum for carbonic acid at the temperatures and pressures indicated. $V=48.759$ c. c.

		1.	2.	3.	4.	5.	6.
Barometer	δ	737	738	738	743	743	743.5
Thermometer	t	10.1	12.9	13.3	11.1	11.1	11.65
Outer level of mercury	a_1	439.5	268	165	149	108	31
Inner level in absorption-tube	b_1	274.5	231.5	210	192.5	185.6	172.5
Upper level of solution in absorption-tube	c_1	153.5	111	85.5	65.5	57.6	43
Upper level of water in outer leg	f_1	426.0	238	126	101.5	54.5	-27.5
Resultant water column							
$\{a_1 - f_1 - b_1 + c_1\} \dots$	W	-107.5	-90.5	-85.5	-79.5	-74.5	-71
Equivalent mercury-column	g	- 7.9	- 6.64	- 6.3	- 5.86	- 5.5	-52.4
Vapour-tension for t°	T	9.227	11.09	11.383	9.857	9.857	10.22
Resultant pressure on gas							
$\{\delta - \delta_1 * - T + g\} \dots$	P_1	554.87	683.77	765.3	770.8	805.2	869.5
Volume in c. c. of c_1 from calibration Table	v	35.02	25.5	19.83	15.42	13.67	10.43
Volume reduced to 0° and 760 millims. ...	V_1	24.656	21.908	19.042	15.029	13.918	11.320
Volume in c. c. of b_1	v_1	62.27	52.56	47.73	43.80	42.25	39.31
Volume of solution ($v_1 - v$)	h_1	27.25	27.06	27.90	28.38	28.58	28.88
Absorption-coefficient for temperature t and pressure P_1 . .							
$\frac{V - V_1}{h_1} \dots$	a_1	0.8845	0.9923	1.0651	1.1885	1.2191	1.2964
Absorption-coefficient of distilled water for same temperature and pressure...	β_1	0.8617	0.9618	1.0624	1.1534	1.2048	1.2757

Comparison of the results of series I. and II. shows the effect which these sulphates have in altering the power of absorption of water for carbonic acid, when they are allowed sufficient time for the reaction. The subject of the absorption-power of saline solutions is one of much importance, and affords an almost inexhaustible field for research, when the effect of varying the nature of the salt, the strength of the solution, the temperature, the pressure, and the duration of the action of the solution on the gas are taken into account. I hope, at some future time, to be able to resume this interesting inquiry.

H.M.S. 'Challenger,' Simon's Bay, Nov. 4, 1873.

$$* \delta_1 = a_1 - b_1.$$