

**On the absorption of carbonic acid gas by liquids / by W.B. Rogers and R.E. Rogers.**

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ON THE

ABSORPTION

OF

CARBONIC ACID GAS BY LIQUIDS.

BY

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AND

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SINCE the experiments of Dalton and Henry of Manchester, and the more elaborate researches of Saussure on the absorption of carbonic acid and other gases by various liquids and solids, this branch of enquiry seems to have been regarded by chemists as in a great degree exhausted, and unlike most of the researches of that earlier day, has failed to command any extensive re-investigation.

The experiments forming the subject of the present paper, extend over a part only of the ground occupied by those of Saussure, but although confined to the absorption of carbonic acid, they embrace many liquids not referred to in his enquiries, or in the similar but less varied observations of Dr. Henry. We believe that they furnish much more accurate results than the simple but rather rude methods used by these experimenters could be expected to afford. Besides a great number of results obtained with different liquids and solutions at  $60^{\circ}$ , they include in the case of water a series of determinations at *various stages of temperature*, from  $32^{\circ}$  to  $100^{\circ}$ .

Apart from the general value which in a scientific sense must always attach to the determination of exact numerical constants in subjects of this kind, there are points of the present enquiry which claim attention from their bearing upon certain other branches of research. It will be seen, for example, in the sequel, that the absorption of carbonic acid gas by sulphuric acid at ordinary temperatures, is far greater than chemists have hitherto suspected, and that the processes in which this gas, before being estimated, is made to pass through or over a considerable volume of sulphuric acid, may lead to errors which although hitherto unnoticed, are too important to be overlooked.

In a paper, *on the analysis of the carbonates*, published in the American Journal of Science in 1844, we called attention to the fact, that in using sulphuric or hydrochloric acid for decomposing the carbonates, the resulting solution or mixture always retains an amount of carbonic acid too great to be neglected in accurate research, and that this gas cannot be expelled without the use of *a continued boiling heat*. Some experiments undertaken in the hope of ascertaining precisely the absorbent power of these acids and solutions, led us into the more extensive field of enquiry, of which we propose now to embody the results.

Availing ourselves, at first, of the simple methods employed by Dalton, Henry and Saussure, we found that with all care in the manipulation and in applying the proper corrections, we were unable to attain consistent and reliable results.

In operating with a graduated tube over mercury, as was practised by Dalton, and by Saussure for the more absorbent liquids,



the great slowness of the absorption in many cases, rendered it impossible to determine, even after some days, whether the action was still in progress or had ceased, and the form of the apparatus made it unsafe and almost impracticable to apply that *brisk and continued agitation*, which is the only means of greatly expediting the absorption. With some liquids, such as sulphuric acid, the penetration of the gas is so extremely slow, that without this mechanical aid, weeks of exposure would probably be necessary to complete the absorption. Yet by continued and thorough shaking for thirty minutes, this result is attained so perfectly, that no prolonged exposure afterwards indicates a continuance of the absorption. The importance of attending to this point in constructing an apparatus for experiments in absorption, is evident from the fact that while by our observation, which occupied generally less than thirty minutes, sulphuric acid of common density was found to absorb 98 per cent. of its volume of the gas, Saussure's experiments, which continued for one or more days, make the absorption only 45 per cent.

The difficulty and uncertainty of the method above mentioned, is moreover increased by the necessity of restoring the instrument to the standard temperature before measuring the absorption, and of taking account of the change of barometric pressure in the interval. To these objections must be added the errors of measurement due to the weight of the column of liquid above the mercury, as well as the large diameter of the tube in which it was necessary to operate, and lastly, the consideration that this method is inadmissible where we are operating with liquids, which like nitric acid and many saline solutions react with mercury.

Results as little satisfactory attended our trials with the other process of Saussure. In this mode of operating, which he adopted in cases where the absorption was small, the liquid and gas are brought together in a well stopped bottle, and after continued agitation for some time, the absorption is measured by removing the stopper in an immersed position. But here, besides the difficulty of making the absorption in a precise manner, we encounter a more serious objection in the fact, that the rarefaction of the remaining gas causes the absorption to cease before reaching the full amount proper to an undiminished pressure. This evil may, it is true, be rendered insignificant in cases where the absorption is slight, by using as Saussure did, a volume of gas many times greater than that of the liquid; but with carbonic acid, such a procedure would in most cases call for so large a volume of gas as greatly to increase the errors arising from a slight variation of temperature during the experiment, while it would augment the difficulty of securing the coincidence of temperature required.



In the syphon formed apparatus used by Dr. Henry, the flexible tube beneath, facilitates the experiment by enabling the operator to apply agitation to the wider limb containing the gas and liquid, but the results are exposed to error from the dilation of the flexible connection and from the effects of concussive compression caused by shaking a large mass of mercury with the gas and absorbent liquid. Of course, this method is inapplicable where the liquid reacts upon the mercury.

From what has now been stated, it will be apparent that the modes of experimenting on this subject, used by the distinguished chemists referred to, were not adapted to an accurate determination of the absorbent power of liquids. To be capable of precise results, the absorbing apparatus must fulfill the following conditions:—

*First.* It must provide means for maintaining the temperature uniform throughout the experiment.

*Second.* It must maintain the tension of the gas unaltered.

*Third.* It must afford means for rapid and continuous agitation of the liquid with the gas.

*Fourth.* The tube in which the absorption is measured by the mercurial column, must be apart from the vessel in which the absorption occurs, and the mercury must not be introduced into that vessel.

In view of these requisites we were led, after many unsatisfactory trials with other arrangements, to the form of apparatus represented in the accompanying diagram, (see next page,) which, besides greatly expediting the experiments, affords uniform and consistent results seldom varying in successive trials, to the extent of one per cent., and which is equally applicable to all liquids.

*Absorption Apparatus.*—This consists of a gasometer A, plunged in a large wooden reservoir B, containing water to the level indicated in the figure, adjoining which is a smaller but taller reservoir C, of glass, also containing water. In the latter is immersed, in a fixed vertical position from the strong frame above, a syphon-shaped measuring tube with a finely graduated scale between the limbs. A horizontal arm of thick barometer tube extending from the top of this, is united by a short gum-elastic joint, with a similar tube which bends down over the edge of the frame and is inserted below into the actual opening of the absorption flask D. Cylinder thermometers graduated to tenths of a degree are placed in the gasometer, large and small reservoir, and flask. [Figure 2 is a larger view of the flask.]

The main reservoir, charged as indicated in the figure, contains five thousand six hundred cubic inches of water, the smaller one, of glass, six hundred cubic inches, and the gasometer three hundred cubic inches. The large volume of water in the reservoirs,



Fig. 2.

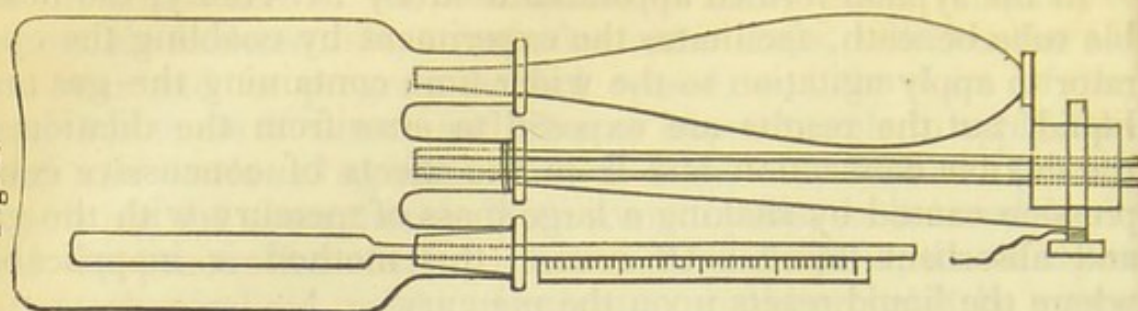
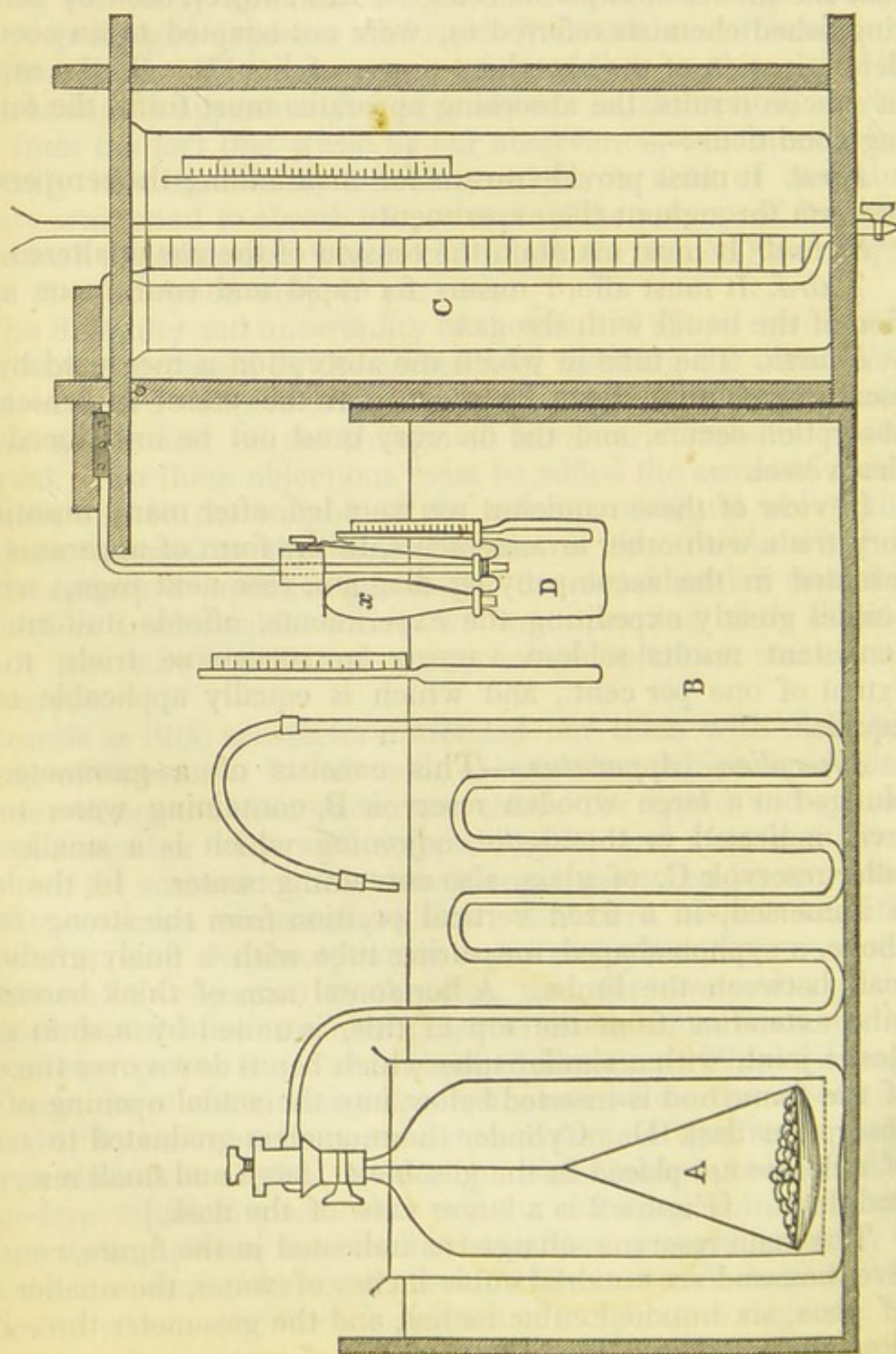


Fig. 1.





serves to maintain an almost absolute uniformity of temperature in the flask and measuring tube during the experiment. The capacity of the flask usually employed by us, is 6.2 cubic inches. The measuring tube is read to  $\frac{1}{200}$ th of a cubic inch.

A long winding leaden tube serves to conduct the gas from the gasometer to the flask in the process of charging the latter, and being plunged in the water of the large reservoir, secures us against any variation of temperature in the gas, which might arise from the reaction of the materials in the gasometer. The gas will thus in all cases have the temperature of the main reservoir, when conveyed into the flask. The end of this tube is mounted with a close cork and smaller glass tube, to be placed in the near opening of the flask when the gas is to be passed into the latter and the measuring tube.

Connected with the flask is a movable vessel *x*, adapted by accurate grinding to the mouth of the former, and designed to contain the liquid whose absorbent power is to be determined. This *unit bottle* as we will call it, has its opening below contracted to about *one-eighth of an inch*, so that when filled with the liquid and connected in an inverted position with the flask, as in the diagram, *the liquid is in no danger of flowing out*. When thus inserted in its proper position, it is confined in place by the strong pressure of a steel spring, attached to the central tube of the flask, and which by a revolving motion is then brought to press by a leather cushion upon its upper end. This secures the juncture at the stopper perfectly air-tight during the active agitation of the flask.

The central tube is in like manner ground to an air-tight joint at its insertion into the flask, and the connection is forcibly secured by a strong cord wrapped around the neck and then passed around a screw peg inserted in a wooden block which is firmly cemented to the tube above. To avoid all chance of leakage at this and the junction of the unit bottle with the flask, a very delicate coating of tenacious cement made of beeswax, rosin and talow, is applied to the upper part of the ground surface. This from its very minute amount, and its removal from the gas in the interior, is incapable of exercising any appreciable absorbent effect. Indeed we have found that even with a large mass of this cement placed in the flask, the effect is quite insignificant.

The flask suspended by the horizontal part of the tube just described, hangs, when in its natural vertical position, at such depth as to immerse about half the length of the unit bottle. The agitation is given by a hooked rod which embracing the central neck, is moved to and fro longitudinally, and causes the flask to swing as rapidly as the operator pleases, the axis of motion being the part of the horizontal tube which is external to the flexible joint, and lies upon the wooden frame near its end. The rest of the



horizontal tube is connected with the measuring tube, and firmly attached, along with the latter, to the horizontal bar of the frame. This slides up and down upon the vertical supports, and can be adjusted to a proper position by the movable pins seen in the figure, immediately beneath it, or can be lifted off, carrying the measuring tube and flask. To secure the axis tube from lateral motion during the shaking, a wooden block descends by a hinge over the flexible joint and this tube, and embracing them in a longitudinal groove retains them in place.

The stop-cock at the bottom of the measuring tube is used for adjusting the level of the mercury in the two limbs at the beginning of each experiment, and for removing the mercury which is poured in through the funnel above, to maintain the columns at the same height during the progress of the absorption.

It will be seen from the figure, that while the flask and measuring tube are both constantly immersed as the experiment is going on, and are thus kept at an invariable temperature, the connecting tube, between the two levels of water, is necessarily out of the liquid, and must be influenced by the temperature of the ambient air. The capacity of this exposed part of the tube was found to be very nearly  $\frac{2}{10}$ ths of a cubic inch, the expansion of which for  $1^{\circ}$  is equal to  $\frac{1}{2000}$  cubic inch. As the temperature of the apartment seldom differed from that of the apparatus by more than some four or five degrees during our experiments, the entire error would be within  $\frac{1}{500}$ th of an inch, while as before mentioned, the smallest reliable reading of the measuring scale is  $\frac{1}{200}$ th cubic inch. It has therefore been thought useless to attempt any correction for the temperature of this part of the enclosed gas.

*Mode of Manipulating.*—From the description just given of the several parts of the apparatus, the general method of operating with it will be readily inferred, and but few words need be added on this head.

Bringing the entire apparatus to the required temperature, ( $60^{\circ}$  in most of our experiments,) the unit bottle, charged with the liquid to be used, is hung in the large reservoir, to attain exactly the same temperature. The back of the gasometer pipe is inserted in the flask air-tight, and a brisk stream of carbonic acid is suffered to flow through the apparatus for five minutes. Some mercury is now poured by a long funnel into the measuring tube to arrest the current. The flask being raised so as to lay bare the mouth, the cork is withdrawn, and at the same moment, while the stream of gas is pouring out and overflowing from the flask, the unit bottle is secured in the opening and fastened by the spring above. After swinging the flask down to its vertical position, the level of the mercury in the measuring tube is carefully adjusted, and the agitation is now commenced. The liquid



at first descends only by drops, but soon begins to flow more rapidly. The vibratory movement of the flask is of that sudden kind which effectually brings the gas and liquid into intricate contact—and the absorption rapidly proceeds. Two operators are necessary in conducting the experiment, one to keep up the shaking, and the other to supply the outer limb of the measuring tube with mercury as the column on the other side ascends.

With water, we have found the absorption to be completed in about five minutes. The oils, dense saline solutions and sulphuric acid, require a longer time, but even with the last named substance which is one of the most sluggish in its action, the absorption reaches its limit in less than thirty minutes.

*Purity of the Carbonic Acid.*—The gas used in our experiments was supplied by the reaction of dilute hydrochloric acid and fragments of calc spar, contained in the self-regulating apparatus figured in the preceding diagram. For sometime, after charging the vessel with water and acid, the gas evolved contains a marked proportion of atmospheric air, derived from the air originally present in the water, and which is slowly disengaged as the carbonic acid is absorbed by the liquid. This admixture with air was found to continue until the solution became well charged with the gas, and this result, in the ordinary use of the apparatus, was very slowly attained. To hasten the saturation, and thus bring the materials into a condition to furnish unmixed gas, the action of the acid liquid on the carbonate was renewed at short intervals, by opening the stop-cock of the reservoir, and in this way in a few hours the gas evolved was almost absolutely exempt from atmospheric air.

At the commencement of each set of experiments, a specimen of the gas, two cubic inches, was passed into a tube over mercury and tested by a moist fragment of caustic potash. When the contents of the reservoir were in a proper condition, the residuum of unabsorbed gas in this experiment was a *mere globule*, rarely more than  $\frac{1}{20}$ th of an inch in diameter, and therefore indicating from  $\frac{1}{15000}$ th to  $\frac{1}{30000}$ th of gaseous impurity.

Thus assured of the almost total absence of atmospheric air in the gas supplied under these conditions, our next precaution was to determine the degree of purity it retained, when transferred, as in our experiments, by simple displacement into the flask and measuring tube. For this purpose a V shaped tube, eighteen inches in each leg, with a stop-cock at the bend, was attached temporarily to a flask like that of the absorbing apparatus, and was charged by allowing a stream of  $\text{CO}_2$  to pass through the vessel and tube steadily for five minutes. The stop-cock of the tube was then closed, the open end stopped with the finger, and the tube detached and inverted over mercury. The contents were now examined in the usual way with caustic potassa. In a



number of such trials, made at different stages of our investigation, we found the amount of residual gas to range from about  $\frac{1}{4000}$ th to  $\frac{1}{8000}$ th of the entire volume employed. In the absorption apparatus, the charge of gas is probably less, and certainly not more contaminated with atmospheric air than in the trials just mentioned, and can therefore involve no sensible error from this source.

It remains to ascertain how far the  $\text{CO}_2$ , escaping from the gasometer, might be mingled with *hydrochloric acid*. The presence of this impurity was deemed so probable, that in our first experiments, a small vessel containing nitrate of silver was interposed in the current of issuing gas. Finding no milkiness to arise in the time required for the experiment, we prolonged the trial to a period of several hours, during which a stream of gas from the gasometer was passed in bubbles through the nitrate. But no precipitate was formed. This result, many times repeated, sufficiently attests the absence of *hydrochloric acid from the gas*. It is important, however, to remark, that using a *much larger proportion* of hydrochloric acid with the water of the reservoir, distinct traces of this substance may be detected in the issuing gas, and to remove all chance of error, therefore, after each new charge of acid, the gas was carefully tested by transmission through the solution of nitrate of silver.

*Of the Hygrometric State of the Gas.*—Excepting in the experiments on sulphuric and some other acids, the gas was transmitted through the long submerged tube into the flask, *without desiccation*. This course was rendered necessary by the fact, that in repeated trials, with gas previously dried and saline solutions, there occurred an irregular expansion of the gaseous volume in the first stage of the action, which did not show itself when the undried gas was used. Such an enlargement, due evidently to the rise of aqueous vapor into the dry space in the first moments of the agitation, being of variable amount according to the solution used, would form a serious obstacle to the exact measurement of the absorption.

In the case of the sulphuric acid and other bodies referred to as exceptions, this would not take place. On the contrary, the *presence* of aqueous vapor in the gas would here involve other errors, due to the absorption of the vapor by the liquid, or to the heat disengaged by their reaction.

The drying of the gas being thus prohibited in a great majority of the experiments, it became important to ascertain whether the carbonic acid, coming from the gasometer, was *saturated* with vapor, as in this case, from the *observed absorption of the moist gas*, it would be easy to compute the *amount of dry gas* which had actually disappeared.



For this purpose, the acid solution in the gasometer was allowed to continue its action until it became *entirely neutral*. A measured volume of the gas was then passed *very slowly* through a long drying tube of chlorid of calcium, previously counterpoised. By preliminary trials with an additional smaller tube, similarly charged, it was ascertained that scarcely a trace of moisture escaped absorption in the long tube. Before the second weighing of the latter, it was freed from carbonic acid by aspiration, the smaller tube being attached to prevent the entrance of atmospheric moisture. In repeated experiments thus performed, the weight of vapor contained in the gas was found to correspond closely with that proper to the temperature and a state of saturation. In other words, *the vapor mingled with the gas was at its maximum tension*. As in its neutral state, the liquid of the gasometer contained most dissolved matter, it was to be inferred that the effect upon the tension of the vapor rising from it would then be most perceptible, and that therefore in the working condition of the apparatus, the saturation of the vapor could not be less, although it might be a small fraction more. Similar experiments with the gas under these conditions gave us, however, the same results. We concluded, therefore, that the dissolved matter in the gasometer, is not in sufficient quantity to produce a sensible modification of the tension of the aqueous vapor evolved, and that in all our experiments, *we may assume the gas to be saturated with vapor proper to the temperature at which we operate*.

*Of the Correction for Moisture.*—This being deduced from the pressure of the atmosphere and the vaporous tension jointly, requires a record of the barometer for each experiment. By the equal adjustment of the columns in the measuring tube, the entire tension of vapor and gas together, is the same at the close as at the beginning of the experiment, and is measured by the height of the barometer. The tension of the vapor remains unchanged, because it is vapor of saturation, and is condensed into water in proportion as the gaseous space contracts in the progress of the absorption. If therefore  $V$  represent the *apparent absorption*, or the volume which has disappeared, and  $v$  the volume of dry gas in  $V$ , estimated under the full atmospheric pressure; and if  $p$  denote that pressure, in other words, the height of the barometer, and  $f$  the tension of the vapor proper to the temperature, we have  $v = V \cdot \frac{p-f}{p}$ .

It is important to remark, that the tension of the gas under which this absorption takes place, is  $p-f$ , and not  $p$ , and that in tabulating the results, the corrected absorption should refer to *the actual pressure of the gaseous atmosphere* in the flask, and not to the entire atmospheric pressure.



From experiments upon the absorption of carbonic acid gas at *various pressures* by water, Dr. Henry, as is well known, was led to infer that equal volumes are absorbed at all pressures, or what is the same thing, that the quantities of gas absorbed are exactly proportioned to the pressures. This very simple law, if true, would render the correction for moisture superfluous. For in that case, the volume absorbed at the pressure  $p - f$ , would equal the volume absorbed at  $p$ . Thus  $V$ , the *apparent absorption*, that is, the volume disappearing at the pressure  $p$ , consisting partly of gas and partly of vapor, would be precisely the same as the volume of dry gas alone which would disappear at the same pressure. But further experiments are, we think, needed, to determine with precision the law of absorption as dependent on pressure, and in the mean time, the law of Henry can only be looked upon as approximately true. From observations on this subject in which we have lately been engaged, and which we hope to continue, we have been led to infer that, in comparing widely variant pressures, there is a marked departure from this law.

Although therefore, from the small difference of gaseous pressure (that between  $p$  and  $p - f$ ) in our experiments, we believe that no sensible error could be introduced by applying the law of Dr. Henry to the results, we have thought it proper in reporting them, to state the volume of dry gas absorbed and the reduced pressure, as well as the apparent absorption and entire barometric pressure.

Having now presented all the details of our mode of operating, and of the precautions and corrections we have used, we proceed to give an account of the results, treating of them in the following order :

I. Of the absorption by water.

II. Of that by sulphuric and other acids, and by other unmixed liquids.

III. Of that by various saline aqueous solutions.

I. *Absorption of Carbonic Acid by Water*.—The water used in these experiments, as well as in making the solutions employed in others to be described hereafter, was prepared by careful distillation in a copper vessel. Its purity was such, that several cubic inches evaporated in a platinum capsule, gave no indication of alkaline matter to the most delicate test paper, and when entirely volatilized, left scarcely a trace of residuum. Before being used, it was briskly boiled for half an hour, quickly transferred to a well stopped bottle, and when sufficiently cooled, exposed to the exhausting action of a good air-pump. The bottle was then suspended in the large reservoir, to bring it to the proper temperature, before the charge was introduced into the flask.

The absorption was seen to begin as soon as the first drop descended from the flask, and with brisk agitation, the process was



completed in about five minutes after the liquid was brought in contact with the gas. To satisfy ourselves that no further absorption would occur, we repeatedly prolonged the agitation to fifteen or twenty minutes, allowed the apparatus to rest, and again resumed the shaking, but without producing any appreciable change in the column of the measuring tube.

Although, from the purity of the gas used, the closeness of the apparatus, and the care with which it was charged with gas, we had no reason to apprehend *any dilution* of the  $\text{CO}_2$ , yet as such a change would cause the absorption to terminate short of the saturation of the liquid proper to an unmixed atmosphere of the gas, experiments were made to determine if any further absorption was caused by a renewal of the charge. This was done by removing the flask, driving a stream of  $\text{CO}_2$  into the bottle, closing the orifice by an air-tight stopper, readjusting the levels, and submitting the liquid to further agitation. Repeated trials at  $60^\circ$ , gave no indications of additional absorption. We would therefore regard our results as furnishing a nearly accurate measure of the absorption of carbonic acid by pure water.

These results, together with the conditions under which the observations were made, are comprised in the following table.

*Table of the Absorption of Carbonic Acid by Water, from  $32^\circ$  to  $212^\circ$ .*

No. of Ex.	Temp. of $\text{CO}_2$ & $\text{H}_2\text{O}$ .	External thermom-eter.	Barom. = $p$ .	App. abs. by 100.... $\text{H}_2\text{O}$ .	Mean of app. abs. = $V$ .	Mean abs. of dry $\text{CO}_2$ = $v$ .	Tension of gas = $p-f$ .	Abs. V reduced to $60^\circ$ .
1	$32^\circ$	$54^\circ$	29.48	166.				
2	32	54	29.48	166.5	166.25	165.08	29.28	175.72
3	40	55	29.46	142.5				
4	40	55	29.46	142.	142.25	140.8	29.21	147.94
5	50	55.5	29.46	119.5				
6	50	55.5	29.46	120.5	120.	118.44	29.1	122.27
7	60	64.5	29.42	100.5				
8	60	64.5	29.42	100.2				
9	60	64.5	29.42	100.5	100.4			
10	60	65	29.25	100.5				
11	60	65	29.25	100.8		98.5	28.82	100.5
12	60	65	29.25	100.5				
13	60	65	29.25	100.5	100.6			
14	70	72	29.21	85.5				
15	70	72	29.21	85.5	85.5	83.36	28.48	83.86
16	80	75	29.51	71.				
17	80	75	29.51	71.5	71.25	68.75	28.5	68.60
18	90	80.5	29.54	60.5				
19	90	80.5	29.54	61.2	60.85	57.78	28.18	57.50
20	100	80.5	29.54	54.5				
21	100	80.5	29.54	54.	54.25	49.83	27.68	50.39

On comparing the second and third columns in the above table, it will be seen that, in the observations from  $50^\circ$  to  $80^\circ$  inclusive, the temperature of the contiguous air in no case differed from that of the apparatus by more than  $5^\circ.5$ . Hence during the few minutes occupied in each experiment, the temperature even of the smaller reservoir experienced only a very slight and quite un-



important change, amounting in none of the experiments to as much as *one-tenth* of a degree. In the experiments at  $40^{\circ}$ , it was found easy to maintain a uniform temperature by a few fragments of floating ice, and in those at  $32^{\circ}$ , the use of a large amount of ice in both vessels, preserved the temperature entirely unchanged. The observations at  $90^{\circ}$  and  $100^{\circ}$ , were attended with a slight cooling in the small reservoir, which however, in no case exceeded one degree, an amount too small to produce any measurable change in the mercurial column.

The above table presents we believe the first systematic series of observations on the comparative absorption of  $\text{CO}_2$ , by water at different temperatures, yet made known. The experiments of Dalton, Henry, Manchester and Saussure, were made almost exclusively at  $60^{\circ}$ . The only results, referring to other temperatures, which we have seen numerically noted, are one by Cavendish at  $55^{\circ}$  and one by Henry at  $85^{\circ}$ . According to Cavendish the absorption by one hundred volumes of water at  $55^{\circ}$  is one hundred and sixteen. In Henry's experiment the same volume of water at  $85^{\circ}$ , is said to have absorbed eighty-four volumes of the gas. The latter result departs very widely from the mean of our experiments at  $80^{\circ}$  and  $90^{\circ}$ , which is about sixty-six volumes instead of eighty-four. The experiment seems to have been made with little care and merely to test the effect of a higher temperature upon the amount of absorption. The number obtained by Cavendish in his observation at  $55^{\circ}$ , corresponds more nearly with our results, which, taking the mean of the experiments at  $60^{\circ}$  and  $50^{\circ}$ , would be about one hundred and ten, instead of one hundred and sixteen, the number which he has given.

In the more numerous and important experiments at  $60^{\circ}$ , the observed absorption as given by Saussure, is one hundred and six, by Henry, one hundred and eight, and by Dalton, one hundred. The two former present a marked excess over our result, the latter agrees with it very closely. The larger absorption obtained by Saussure and Henry, is we think explained by their mode of conducting the experiment. We have found that when a column of mercury is shaken briskly in a tube containing water and carbonic acid, the water is made to absorb a larger volume of the gas than is proper to the normal pressure. The concussive movement, violently compresses the gas at each vibration, and the additional quantity which in these circumstances is promptly taken up by the water, is very slow in separating after the quiescent pressure has been restored.

Referring to the arrangement of the preceding table, it will be seen that the numbers in the 7th column express the absorption, reduced to volumes of dry gas and to the density corresponding to  $p$  in the 4th column. The obvious formula for this has already been explained. The numbers in the 8th column, represent the



actual tension of the gas under which the absorption took place. These two columns give the direct experimental relation of the absorption of dry gas with the tension of the same. But assuming Henry's law to be correct, and in the present case it can involve no sensible error, this relation would be equally expressed by the corresponding numbers in columns 4 and 6. Thus while it is clearly proved, from the observations at  $50^{\circ}$ , that under the pressure  $29.1 = p - f$ , 118.4 volumes of dry gas are absorbed, it would also be true that under the pressure  $29.46 = p$ , 120 volumes of dry gas would be absorbed, for  $p : V = p - f : v$ .

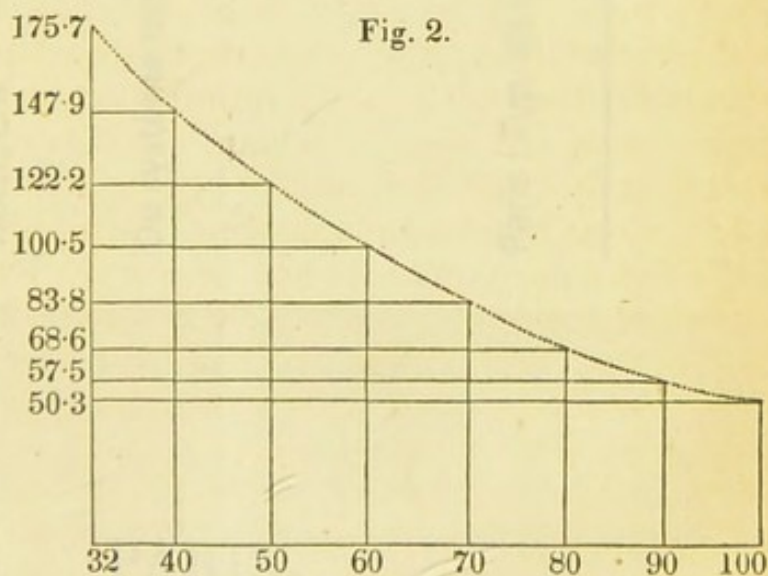
It is further evident that admitting this law, all the numbers ( $p$ ) in the column of barometric heights may be reduced to one standard number, as for example 30 inches, without at all changing the volume of  $V$ . Thus at  $50^{\circ}$  while one hundred and twenty volumes are absorbed under a pressure of 29.46 inches, one hundred and twenty volumes will also be absorbed at a pressure of 30 inches, the latter volumes being denser than the former in the proportion of 30 to 29.46.

The last column of the table represents the values of  $V$ , contained in column 6, after they have been *reduced to the common temperature*  $60^{\circ}$ . These numbers therefore indicate the relative quantities or weights of carbonic acid absorbed at the temperatures recorded.

The relation of the absorption to the temperature is simply pictured in the accompanying diagram, where the temperatures are measured in the horizontal, and the corresponding absorptions in the vertical direction.

It will be remarked that this curve approaches the horizontal axis less rapidly, as the temperature rises, so that, for example, the absorption is greatly more diminished in passing from  $40^{\circ}$  to  $60^{\circ}$ , than in passing from  $60^{\circ}$  to  $80^{\circ}$ , and still more than in passing from  $80^{\circ}$  to  $100^{\circ}$ . This would lead to the inference that at temperatures much above  $100^{\circ}$ , we should find the absorption still quite considerable.

To satisfy ourselves on this point, we made repeated experiments at  $150^{\circ}$  and  $212^{\circ}$ , by passing a stream of gas from the pipe of the gasometer through a measured quantity of water, maintained by a peculiar lamp arrangement, at the proposed temperature. The pipe being withdrawn while the temperature was con-





tinued, any floating carbonic acid was removed from the surface of the liquid by a blast of air, and a solution of baryta was then added. In the water at  $150^{\circ}$ , a very copious precipitate was formed. This was separated by filtration under a vessel kept full of hydrogen gas to prevent the absorption of atmospheric carbonic acid by the precipitant, and the weight of the carbonate determined by the method of double filters.

By this procedure, 14.5 cubic inches of water at  $150^{\circ}$ , gave 3.51 grs. of carbonate of baryta, which corresponds to 11.4 volumes of carbonic acid gas for one hundred volumes of liquid.

In the water at  $212^{\circ}$ , a precipitate was also formed, but the amount although sufficient to produce a very obvious cloudiness, was too small to be readily estimated. We propose however to determine its quantity accurately hereafter. In this experiment the liquid was in active ebullition, while the stream of gas was passing, and continued to boil for a few seconds after the removal of the gas pipe.

*It is thus clearly proved that water is capable of absorbing carbonic acid, in sensible quantity, while it is actually boiling under ordinary pressure.*

