

normal position, and the gas jets at their minimum. When this rate changes, we have acceleration in the one or other sense, and this is indicated by the flaring up of the corresponding gas jet.

The model illustrates merely one-third of the complete apparatus, as it shows the results of acceleration about one axis only, and in both senses about that axis.

Perhaps, in making such a model, it would be better to work the stop-cocks by means of cranks from the wheels, and so diminish the friction of the axles on their bearings. However, in the model shown, this friction is so small that very moderate acceleration is well indicated.

The apparatus was made, from Professor Crum Brown's instructions, by Mr Alexander Frazer, 7 Lothian Street, Edinburgh.

2. On the Temperature and Currents in the Lochs of the West of Scotland, as affected by Winds. By John Murray, Esq.

3. Note on the Influence of Pressure on the Solubility of Carbonate of Lime in Sea Water containing Free Carbonic Acid. By W. G. Reid. *Communicated by* JOHN MURRAY, Esq.

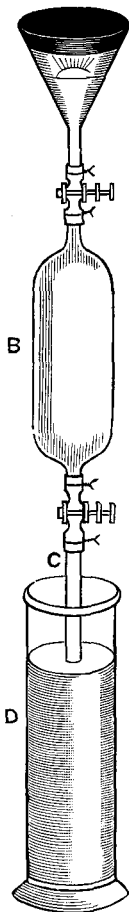
Analysis of the dredgings brought to the surface during the Voyage of H.M.S. "Challenger," has shown, that in deeper water as the depth increased, the quantity of carbonate of lime shells decreased,* and as the pressure is in direct proportion to the depth under water, it was surmised that some connection existed between the pressure and the disappearance of lime shells. To ascertain if there was any truth in this surmise, Mr Murray suggested the following experiments. The results are unfortunately incomplete; nevertheless, Mr Murray thinks it advisable to publish them.

During this investigation, I had the honour of working with Mr H. N. Dickson, who, with his hands full of more important work,

* Murray, "On Coral Reefs," *Proc. Roy. Soc. Edin.*, 1880, p. 509; and *Narrative of the Cruise of the Challenger*, p. 923.

superintended the physical part of these experiments with characteristic patience and kindness.

This subject does not seem to have been previously investigated. Th. Schloesing and others have demonstrated that the solubility of carbonate of lime, &c., in water containing carbonic acid, increases as the pressure of carbonic acid increases, and that according to a definite law; but nothing is said about the effect on the solubility, when, the quantity of carbonic acid in solution remaining the same, the pressure is increased. The latter was the object aimed at in these experiments, and as they had special reference to the conditions existing in the ocean, sea water was taken and charged with a definite quantity of carbonic acid, that the effect might be exaggerated, and therefore more easily studied.



For the experiments done under pressure the following *modus operandi* was adopted:— A (see sketch) is a Bohemian glass funnel, having a glass cover ground to fit; a flat india-rubber band of the same circumference as the cover is put between it and the funnel. A rubber capsule is now stretched over the top, and for greater security the neck of the funnel is passed through a slit in a strong rubber band, which is then stretched over the capsule. The funnel contains a filter paper, and a cambric bag, within which is a weighed quantity of shells. To the funnel the bulb B is attached, and this is connected by the glass tube C to a vessel containing mercury D. The whole is tied to a suitable support, and is ready for immersion in the water, contained

in the pressure apparatus, *i.e.*, the celebrated “gun” belonging to the “Challenger” Commission. The bulb B, which has been accurately measured, contains sea water charged in the following manner with a definite quantity of carbon dioxide. B is first filled with sea

water, noting the temperature, and the pieces of india-rubber tubing at each end securely clamped. The tube C is attached and secured with wire, then filled with mercury, and another bulb, also accurately measured, and filled with carbon dioxide at a known temperature and pressure, is attached in the same way as B, to the other end of the tube. The clamps are now unscrewed, and the carbon dioxide is allowed to come in contact with the water, and as it is absorbed the vacancy so caused is filled up by allowing mercury to be sucked in. When the carbon dioxide is all dissolved, the mercury is allowed to flow to the smaller bulb (always that which contained the carbon dioxide), which may be detached after clamping the rubber tube at the bottom of tube C. Where pressure is applied, the mercury is forced up into the bulb, and the water into the funnel, the air in which at the pressure employed (4 tons per square inch, or nearly 600 atmospheres) contracts to a very small bubble, and thus allows the water to come into contact with the shells. In these experiments the pressure was kept at its maximum for 30 minutes, then released, and again applied and kept up for 60 minutes. When the pressure is let off, the air expands and drives the water out of the funnel; the effect therefore of the break in the application of the pressure is to cause a slight agitation, and to bring a fresh portion of the liquid into contact with the shells. After each experiment the alkalinity of the water was carefully determined, and the original alkalinity deducted therefrom: the quantity of carbonate of lime dissolved was thus ascertained.

Each of the experiments made under pressure was repeated, at the ordinary pressure, under as nearly as possible the same conditions. The funnel taken in this case was larger, and a scratch on it indicated the capacity of the funnel used for the corresponding pressure experiment. A glass cover protected the contents of the funnel from dust. The lower end of the bulb B was attached to a tube which passed through an india-rubber stopper in one neck of a small Woolff's bottle, through the other neck a funnel tube about 20 inches long was passed. Both tubes dipped under the surface of mercury contained by the Woolff's bottle, and by pouring mercury into the funnel tube, the water was forced into the funnel until it reached the scratch aforementioned.

Table showing Influence of Pressure on the Solubility of Carbonate of Lime in Sea Water containing Carbonic Acid.

No. of Experiment.	Capacity of Funnel.	Carbonate of Lime used.		Quantity of Sea Water taken.	Carbon Dioxide.				Pressure.		Temperature.	Resolving per Litre.	Res. Alk. (m) minus original Alkalinity.	(n) = CaCO ₃ Dissolved per Litre Sea Water.	(p) CaCO ₃ Dissolved per Grm. CO ₂ taken.
		Kind.	Quantity.		Taken.	Vol.	Weight.	Vol.	Weight.	Amount.					
I.	c.c. 65.5	Glob. I.	grms. 1.5092	c.c. 54.33	grms. 1.074	c.c. 509.4	grms. 1.0071	4 tons.	minutes. 30 to 60	12.0	91.5	39.9	grms. .0906	.0904	
II.	65.5	Do.	1.5867	62.39	1.233	530.8	1.0494	4 "	Do.	12.0	117.0	65.4	.1486	.1416	
III.	84.4	Do.	1.5897	117.53	1.237	532.3	1.0523	4 "	Do.	9.0	104.0	52.4	.1191	.1106	
IV.	65.5	Do.	1.5800	106.65	1.088	516.1	1.0203	4 "	Do.	9.0	99.1	47.5	.1080	.1060	
V.	65.5	Do.	1.5020	106.65	1.077	511.0	1.0102	Atmospheric.	Do.	12.2	76.6	25.0	.0568	.0562	
VI.	84.4	Do.	1.5620	117.54	1.263	543.4	1.0744	Do.	Do.	10.0	76.8	25.2	.0572	.0545	
VII.	91.1	Do.	1.5620	117.53	1.266	545.0	1.0777	2 tons.	Do.	8.3	95.6	44.0	.0999	.0927	
VIII.	65.5	Glob. II.	1.5030	106.65	1.096	519.7	1.0275	4 "	Do.	8.6	85.1	33.5	.0761	.0758	
IX.	84.4	Do.	1.5020	117.54	1.254	539.6	1.0668	4 "	Do.	8.8	95.5	43.9	.0997	.0935	
X.	65.5	Do.	1.5600	106.6	1.066	505.9	1.0001	Atmospheric.	Do.	15.0	61.9	10.4	.0236	.0236	
XI.	84.4	Do.	1.5600	117.5	1.180	507.8	1.0089	Do.	Do.	13.2	63.4	11.9	.0270	.0269	
XII.	91.1	Coral sand I.	1.5680	117.54	1.256	539.4	1.0664	4 tons.	Do.	8.8	113.1	61.5	.1398	.1311	
XIII.	65.5	Do.	1.5025	106.65	1.079	511.4	1.0115	4 "	Do.	8.8	96.0	44.4	.1011	.0999	
XIV.	91.1	Do.	1.5070	117.5	1.222	525.2	1.0402	Atmospheric.	Do.	11.6	71.4	18.9	.0429	.0413	
XV.	65.5	Do.	1.5020	106.6	1.073	509.3	1.0069	Do.	Do.	10.5	70.9	18.4	.0418	.0425	
XVI.	91.1	Do.	1.5580	117.5	1.135	488.9	.9666	4 tons.	Do.	12.2	69.42	17.92	.0407	.0421	
XVII.	91.1	Coral sand II.	1.5595	117.54	1.246	536.0	1.0596	4 tons.	Do.	9.1	105.3	53.7	.1220	.1152	
XVIII.	91.1	Do.	1.5600	117.53	1.261	543.9	1.0738	Atmospheric.	Do.	9.0	68.8	17.2	.0391	.0364	
XIX.	91.1	Pteropods.	.9850	117.54	1.267	545.2	1.0779	4 tons.	Do.	8.3	99.9	48.3	.1098	.1019	
XX.	91.1	Crystal.	8.0027	117.52	1.244	535.9	1.0557	Atmospheric.	Do.	11.0	74.3	22.7	.0516	.0490	
XXI.	91.1	Do.	...	117.52	1.211	521.4	1.0307	4 tons.	Do.	8.3	67.9	16.3	.0371	.0360	
XXII.	91.1	Do.	...	106.65	1.052	499.0	.9865	4 "	Do.	9.0	57.4	5.8	.0132	.0137	
XXIII.	91.1	Do.	...	106.65	1.050	498.0	.9845	Atmospheric.	Do.	10.0	56.1	4.5	.0102	.0104	
XXIV.	91.1	Do.	3.1387	117.48	1.165	526.5	1.0410	Do.	Do.	12.2	55.1	3.6	.0082	.0078	
XXV.	91.1	Do.	8.1379	117.53	1.235	531.7	1.0513	Do.	Do.	12.2	53.7	2.2	.0050	.0047	
XXVI.	91.1	Do.	8.1371	117.49	1.226	528.0	1.0440	Do.	Do.	13.1	53.0	1.5	.0034	.0032	
XXVII.	91.1	Do.	8.1355	117.55	1.238	532.7	1.0532	Do.	Do.	14.7	53.6	2.1	.0048	.0045	
XXVIII.	91.1	Do. ground.	2.9938	117.5	1.238	532.9	1.0532	Do.	Do.	12.6	65.7	14.2	.0322	.0306	

The accompanying table gives the results of the experiments. The columns of the table are explained by the headings, and Mr Murray adds the following notes with reference to the contractions used in column (c).

GLOBIGERINA Ooze.—Collected on the 21st March 1876, in the South Atlantic. Lat. $21^{\circ} 15' S.$; long. $14^{\circ} 2' W.$; depth, 1990 fathoms.

Specimen I., consists of the larger shells in this deposit, such as the shells of the Pelagic Globigermidæ, such as *Orbulina universa*, *Globigerina hustigernia*, *Spheroidina*, *Pullenia*, *Pulvinulina*. In addition to these there were the shells of a few bottom living Foraminifera, as *Biloculina*, and fragments of Echinoderms, Lamellibranchs, and otoliths of fish. The average size of the shells and particles in this specimen is about $\frac{1}{6}$ of a millimetre.

Specimen II., consists of the smallest shells in the same deposit, being almost wholly made up of young shells of the above mentioned Globigermidæ. The average diameter of the grains of this fine sand are less than $\frac{1}{10}$ of a millimetre.

CORAL SAND.—Collected off the Great Barrier Reef of Australia on the 31st August 1874. Lat. $11^{\circ} 35' 25'' S.$; long. $144^{\circ} 2' E.$; depth, 135 fathoms.

Sample I., consists chiefly of the coarser fragments of these deposits, and is made up of particles of broken Pteropods, Gasteropods, Lamellibranchs, Echinoderms, Polyzoa, Serpulæ tubes, and numerous Foraminifera. The average size of the fragments were from 2 to 3 millimetres in diameters.

Sample II. This was a sample from the same deposit, and made up of the same kind of fragments as Sample I., but these were considerably smaller in size.

PTEROPODS.—These consisted of the shells of *Cavolinia clio*, *Cuvierina*, *Limacina*, and shells of *Atlanta*. These were complete, or nearly complete shells, and apparently free from sand and mud, and were picked out from the coral sand above mentioned.

The last column in the table (column p) contains the results stated, so as to render all the experiments comparable. Taking these figures, we have the following average results:—

	Amount of CaCO ₃ dissolved per grm., CO ₂ taken.	Difference from Extremes.
<i>Globigerina Ooze, I.</i>		
At 4 tons pressure, . . .	·1121	± ·03
At 2 „ „ . . .	·1019	
At atmospheric pressure, .	·0553	± ·0009
<i>Globigerina Ooze, II.</i>		
At 4 tons pressure, . . .	·0846	± ·009
At atmospheric pressure, .	·0252	± ·0017
<i>Coral Sand, I.</i>		
At 4 tons pressure, . . .	·1155	± ·015
At atmospheric pressure, .	·0419	± ·0006
<i>Pteropods.</i>		
At 4 tons pressure, . . .	·1018	
<i>Crystal of Iceland Spar (XXIV.– XXVII.).</i>		
At atmospheric pressure, .	·0050	± ·0018
<i>Crystal, ground to coarse powder.</i>		
At atmospheric pressure, .	·0322	

The disparity between the various results obtained in the pressure experiments I am unable to account for satisfactorily. Nevertheless, the amount of carbonate of lime dissolved at a pressure of 4 tons per square inch, is so much greater than the amount dissolved at the ordinary pressure, that I think it justifies the conclusion that the effect of pressure is to increase the rate of solution; or, in other words, that the chemical activity of a solution of carbonic acid is increased by pressure.

It is to be noted, that although these results may indicate that the solution of carbonate of lime in carbonic acid water is more rapid under high pressures, it by no means follows that the solubility is *greater* than at the ordinary pressure (*ceteris paribus*). Schloesing and other investigators have shown, that in order to get

the maximum amount of carbonate of lime dissolved, the carbonic acid solution had to be left in contact, and agitated with the carbonate for five or six days. With the apparatus at our command we could not accomplish this, and had to rest contented with the results given.

In the experiments XX. to XXIII., a crystal of Iceland spar was taken. The results show a gradual falling off in the quantity dissolved. The reason for this I cannot explain, but that it is not due to the properties of Iceland spar is shown by the experiments XXIV. to XXVII. For these another crystal was taken, and after each experiment it was washed, dried, and weighed carefully. The amount of carbonate dissolved by 117.5 c.c. of sea water (the total quantity taken for each experiment) was as under. A is the amount obtained by titration (alkalinity), and W the loss as observed by weighing. Considering the smallness of the quantity to be measured, and the opportunities for observational error, the results agree fairly well with each other.

	A	W
XXIV. . .	·0009 grms.	·0008 grms.
XXV. . .	·0006 „	·0008 „
XXVI. . .	·0004 „	·0010 „
XXVII. . .	·0006 „	·0007 „

For the last experiment (XXVII.) the crystal, used in the preceding four, was ground to a powder, the grains of which varied from about 1 mm. square down to impalpability. This was done to try the effect of increasing the surface exposed. As was expected, the amount dissolved was much greater (six times).

My thanks are due to Mr T. Lindsay for kind assistance in some of these experiments.