

On the Action of Water upon Lead. By ROBERT CHRISTISON, M.D., F.R.S.E.,
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IN an experimental inquiry into the action of water on lead,* published by me in 1829, in continuation of some previous researches by GUYTON-MORVEAU, it was stated as the general result, that all very pure waters, such as distilled water, rain, and melted snow, act upon lead,—dissolving a trace of it, and causing the formation of an insoluble carbonate of lead in large quantity. It was likewise shewn, that this action is prevented by the existence of neutral salts in solution; so that most terrestrial waters, as they contain saline matter, act feebly and only in circumstances favourable in other respects. Farther, it appeared to flow from comparative experiments, that this preventive power depends upon the acids of the salts, and not upon their bases;—and that their energy as preventives, that is, the minuteness of the proportion required to annihilate the action, is in the ratio of the insolubility of the compounds which the acids of the salts are capable of forming with oxide of lead.

Since the time when the investigations now referred to were first made public, my attention has been repeatedly recalled to the subject by divers interesting facts connected with the economic use of lead, which have illustrated practically the conclusions drawn from experiments conducted in the laboratory. Two of these facts, which relate to the employment of lead as the material for water-pipes, are so remarkable in their circumstances, that I am induced to lay them before the Society. On the one hand, they shew that the action of water on lead, notwithstanding its serious consequences, and all that has been written respecting it, does not seem to have attracted the attention among such professional men as engineers, architects, and others, which it unquestionably deserves. And on the other hand, when taken along with the general principles formerly established by me, they point out the risk of the action of water on lead-pipes being unexpectedly developed, where due care is not taken, but at the same time fix the conditions in which the action may be foreseen, and likewise provide a simple and efficacious remedy.

As an appendix to this communication, I propose also to take notice of a topic of more purely scientific interest,—namely, a question which has arisen

* *Treatise on Poisons, first edition, 1829, p. 384.*

since I first wrote on this subject, as to the exact nature of the substance formed by the action of water upon lead.

The first fact to be mentioned has been already briefly alluded to by me in a former publication in 1836.* But its circumstances appear to merit a more detailed statement.

A few years ago, the water of a spring was introduced into the mansion of Dalswinton in Dumfriesshire, by a lead-pipe, from a distance of three-quarters of a mile. While on a visit there in the autumn of 1834, only a few days after operations were finished, and the water was flowing into the great cistern for supplying the house, my attention was called one morning by one of the guests to the water-bottle on his dressing-table, and a tumbler of water which had been poured from it. The bottle was lined with a thin white incrustation of a pearly lustre; and the water, which had stood some time exposed to the air, presented a thin film of the same appearance over its whole surface. The cause being at once suspected, we proceeded with our host, Mr LENY, to examine the great cistern into which the water was discharged directly from the pipe. Here we found the water entirely covered with a similar film, and the bottom and sides of the cistern lined with a loose pearly white incrustation, in such quantity as to appear as if painted with white paint. It was also remarked, that water fresh drawn from the pipe was perfectly transparent at first, but, on exposure to the air, quickly presented the white film seen in the tumbler. It needs scarcely be stated, that the appearances now mentioned were recognised as the result of the action of the water on the lead of the pipe. And it may be added, that the white substance was afterwards ascertained to be a carbonate of lead.

I confess that the observations thus made surprised me not a little. For being told, the previous autumn, that it was proposed to bring into the house in lead-pipes the water of this spring, which had long enjoyed a high character in the neighbourhood for purity, I made an experiment for the purpose of discovering whether it could be safely conveyed in lead; and finding that several pieces of fresh-cut lead retained their lustre almost untarnished when immersed for fourteen days in a tumbler of the water, I concluded that it contained salts enough to prevent corrosion of the lead. I did not at the time advert to the difference between an experiment in which some ounces of water were left at rest on a few square inches of lead, and one in which a column of water only three-quarters of an inch in diameter flowed constantly over a surface of nearly 800 square feet.

The means of clearing up the cause of the action, by analyzing the water, were not within my reach. It was presumed, however, from the general principles established by previous inquiries, that the reputation of the spring for extra-

* *Treatise on Poisons, third edition, p. 489.*

ordinary purity was not without foundation. Accordingly, it afterwards appeared from analysis to be very unusually pure. Oxalate of ammonia occasioned a white haze, and slowly a very scanty white precipitate, shewing a trace of lime. Phosphate of ammonia had no effect at first, on being added to the water after removal of the lime; but in the course of some hours, a few microscopic shining crystals formed on the glass, thus indicating a trace of magnesia. Nitrate of baryta, however, did not affect the water in the slightest degree, proving the extreme scantiness of sulphates. And nitrate of silver caused only a faint opalescent whiteness; so that even the muriates were present in unusually small quantity. On concentrating the water it was found that the salts existing in it were hydrochlorates, sulphates, and carbonates of lime, magnesia, and soda, and that the hydrochlorates greatly predominated. A minute estimate of the several ingredients was not attempted, because unnecessary. But their total amount proved to be only 0.554 of a grain in 11,860 grains, or $\frac{1}{21400}$ th.* Water taken direct from the pipe, and kept for some days well corked in a bottle, was quite transparent when first poured out; but, on being slightly concentrated by boiling, a few white shining crystals of great delicacy were formed. These, when detached and washed with distilled water, disappeared in water acidulated with nitric acid; and on this solution being evaporated to dryness, there was obtained a trace of crystalline powder, which, when re-dissolved, gave a fine yellow precipitate with bichromate of potash, and a black one with sulphuretted hydrogen,—clearly proving the presence of lead dissolved in the water.

On referring to what has been stated in my account of my first experiments respecting the action of water on lead, it will readily appear why this water should have oxidated and dissolved the metal of the pipe. The spring is not only one of very great purity, but the protective salts contained in the water likewise consist chiefly of those whose preventive power is the feeblest of all the natural ingredients of springs. For in my experiments on the small scale, it did not appear that the hydrochlorates effectually prevented the action of distilled water, unless present in the proportion of a 2000th at least.

It remains to take notice of the remedy applied in this case. When a similar instance happened at Tunbridge, in 1814,—with the additional circumstance that its nature was not discovered till lead-colic began to appear among the inmates of the houses supplied with the water,—the only satisfactory remedy which could be thought of, was the expensive one of removing the pipes and replacing them

* On again lately analyzing the water, I found the solid residuum to be exactly one grain in 17,500. Nitrate of baryta, after twenty-four hours' rest, occasioned an exceedingly scanty deposite of sulphate; and the residuum left, on evaporating 17,000 grains, effervesced very slightly with diluted nitric acid. The sulphates and carbonates were thus again proved to exist in very minute proportion. In this water a stick of polished lead became tarnished in an hour; and in four days a little white powder formed on the bottom of the vessel under the lead.

with others of cast-iron; and this was accordingly done. Reflecting, however, upon what I had observed in many experiments with weak solutions of neutral salts, and remembering that in general, after the action had gone on slowly for some weeks, it gradually became less and less, while, at the same time, a firmly-adhering film formed on the lead, consisting of carbonate mingled with a salt of oxide of lead in union with the acid of the salt in solution, and that, when lead so lined was transferred even into distilled water, no action seemed to take place,—I conceived that an effectual remedy might be provided by producing, in like manner, an incrustation of the same kind on the inside of the pipe. For this end, it was proposed to leave the pipe for some months filled with a weak solution of phosphate of soda, in the proportion of a 25,000th part, which is somewhat stronger than what had seemed sufficient to prevent the action of distilled water on the small scale. It was hoped that a fine film of mixed carbonate and phosphate of lead would thus be formed while the water was at rest, which would adhere so firmly as not to be swept away when the water was allowed to flow, and which would serve as a lining to prevent the contact of the running water with the metal. Circumstances prevented this plan being tried at once; and in the mean time it was judged right to try the effect of forming a lining of carbonate of lead, by leaving the water at complete repose in the pipe, so as to allow the carbonate to crystallize slowly and firmly on its interior. This experiment was attended with complete success. The pipe was kept full of the spring-water, and without water being drawn from it, for four months. The water was then found to flow without any impregnation of lead, and has done so ever since.

The other incident I propose to describe occurred last year at Buchan-ness Lodge, a cottage-residence of the EARL of ABERDEEN. It resembles the former singularly in all its leading circumstances.

In the beginning of June last, Mr JOHNSTON of Peterhead was requested to visit professionally the housekeeper of the Lodge, who was affected with indigestion and constipation;—from which, however, under his directions, she speedily recovered on this occasion. Six weeks afterwards he was requested to visit her again, and found her then affected with vomiting, constipation, severe spasmodic pain at the pit of the stomach, retraction of the umbilicus towards the spine, great weakness of the limbs, and other symptoms of less note, which it is scarcely necessary to particularize in this communication, but which are proper to the severe form of colic occasioned by slow poisoning with lead. After treating the case judiciously for three days, Mr JOHNSTON was surprised to find, that, notwithstanding frequent temporary benefit, no permanent amelioration had taken place. At last, on the third day, while considering the circumstances of his patient's illness, his attention was drawn to the water-bottle on her dressing-table. It was lined with a

white shining incrustation, and the surface of the water was covered with a film of similar appearance. On inquiry, he learned that the water always presented this appearance after being exposed for some time, but that it was quite transparent when first drawn; and he afterwards personally verified these facts.

Being well aware of the action of water on lead, and of the consequences of the insidious introduction of the compounds of that metal into the human body, Mr JOHNSTON, with much discernment, although he had never seen a case of lead-colic before, was strongly inclined to believe that he had to deal with that disease. He suspended his ultimate decision, however, until he had an opportunity of examining chemically the substance deposited by the water. This he found to be soluble in weak acetic acid; and the solution gave a white precipitate with sulphuric acid, a white one with carbonate of potash, a yellow one with iodide of potassium, and a black one with sulphuretted hydrogen. The last test, an extremely delicate one, likewise made the water itself brown. As these results left no doubt whatever of the presence of lead in the water, he could as little entertain any doubt of the nature of the housekeeper's illness. She was treated accordingly, recovered slowly but steadily, and in October was quite well. She had resided in the house, and constantly used the water for eight months before her final severe illness; but for some months previous to that attack, she had been often annoyed with stomach-complaints and constipation. Her niece, a girl of twelve, who had been residing with her for a few weeks only, was also attacked with these premonitory symptoms of lead-colic; but she soon recovered under Mr JOHNSTON'S care. No other person had resided for any length of time at the Lodge during the period in question. LORD ABERDEEN had been there with some friends for a few days only.

Mr JOHNSTON, with whose approbation, as well as the sanction of LORD ABERDEEN, the facts of this incident are made public, consulted me respecting it about the middle of September, and afterwards communicated much additional information,—partly, indeed, in reply to suggestions made by me. The following is a short narrative of the whole particulars. The water was first introduced into the house in the summer of 1840, by a lead-pipe from a spring at the distance of rather more than half a mile. The spring was purchased for the purpose, as it had been represented to be of fine quality; and an analysis, by a chemist in the neighbourhood, appeared to shew that it was of unusual purity, and contained very little saline matter. This will presently be seen to be by no means the case.

The pipe had been in use for several months before the housekeeper went to reside at the Lodge. When Mr JOHNSTON first examined the water, it had been in constant use for twelve months. And yet it continued to impregnate itself with lead to the last: In the water, when fresh drawn, he could detect lead by sulphuretted-hydrogen even without concentrating it.

The architect, under whose directions the water had been introduced into the house, was slow to believe that the housekeeper really suffered from the effects of lead, or that the water was impregnated with this metal. Even the condition of the principal cistern, which was found in precisely the same state as at Dalswinton, did not open his eyes altogether to the truth, and indeed rather impressed him with the notion that negligence in cleaning the cistern was the source of any mischief that might actually have arisen. This was not surprising. For it was plausibly argued, that such accidents had not been observed in other places, and more especially at Aberdeen, where lead is prevalently used for conducting water; and the architect was probably unacquainted with the scientific details of the subject, as they have been hitherto little dwelt upon except in works on Toxicology.

It has been just stated, that the spring was purchased as one of great purity, represented from actual analysis to "contain but a very small quantity of solids." I therefore inferred, that, like the water of Dalswinton, it was too pure for the preventive power of the usual neutral salts of springs to be efficaciously exerted. Being anxious, however, to fix positively the circumstances connected with so remarkable an instance of the action of a natural water on lead, I obtained some of the water for examination. It was transmitted by Mr JOHNSTON with all due care to ensure its purity. The result is, that, although by no means the sort of water it was alleged to be, the circumstances of the case come precisely under the general principles established by me in 1829.

The water is clear, colourless, and without taste. Polished lead immersed in it becomes tarnished in a few hours, but undergoes no farther change in fourteen days. Twenty thousand grains evaporated to dryness left a residuum, which, after exposure to a low red heat, weighed 4.482 grains, indicating a 4460th of solids. Hence the water is far from being a pure spring-water: It is not more so than that of many streams in the Scottish Lowlands. It contains, in fact, so large a proportion of salts, that, if these were of the ordinary kind, lead would scarcely be acted on by it at all. But its ingredients are chiefly the least energetic in preventive power of all the salts usually found in terrestrial waters. Oxalate of ammonia has at first no effect, but slowly causes a slight haziness; which in some hours gives place to a scanty white precipitate, indicating the presence of a mere trace of lime. Phosphate of ammonia has no effect even after twenty-four hours; but when the water is much concentrated, this test occasions a crystalline precipitate, proving the existence of a minute trace of magnesia. Nitrate of baryta produces slowly a very scanty precipitate. As neither this precipitate, nor the saline residuum obtained by evaporating the water to dryness, presents any effervescence with diluted nitric acid, the water does not contain any carbonate. The barytic precipitate from 4375 grains of water weighed 0.218 of a grain, and therefore corresponded with the small proportion of only a 32,000th of some sulphate, either sulphate of soda or probably sulphate of lime. Nitrate of silver, however,

occasions at once a dense milkiness and white precipitate, shewing the presence of a large quantity of muriates. Lime and magnesia being present only in the most minute proportion, it is evident that the chief base in union with the muriatic acid is soda; which farther appears from the cubical tendency of the crystals obtained by evaporation. It therefore follows, that this water contains about a 4500th of its weight of muriate of soda, the merest traces of sulphates and muriates of lime and magnesia, and no carbonates of any kind. Since carbonates and sulphates are the most energetic of the preventive salts usually met with in terrestrial waters, and the muriates, the only salts here present in any material quantity, do not act as preventives effectually unless in at least double the proportion observed in my analysis, it is easy to understand why the lead was so readily attacked in this instance.

When the fact of the water being poisoned with lead was clearly ascertained, it was at first proposed at once to substitute iron pipes for those of lead. But Mr JOHNSTON suggested that a trial should be made of a weak solution of phosphate of soda, as explained above, and recommended in 1836 in my "Treatise on Poisons." The experiment was accordingly tried by keeping the pipes constantly full of a solution containing a 27,000th of phosphate of soda. For three weeks no improvement took place; but it was found that owing to a leakage in the pipe, the solution required to be constantly renewed, and was therefore never completely at rest. As it appeared essential to secure this last condition, the leak was found out, though not without difficulty, and was properly stopped. Fourteen days afterwards the spring water was readmitted, and a manifest improvement was ascertained to have taken place, although lead was still contained in the water. The solution being replaced, another trial was made in the course of six weeks more; and sulphuretted-hydrogen then barely tinted the water. A third examination was made fourteen days later; and after the water had been running for some time, sulphuretted-hydrogen did not in the slightest degree affect it. The last report I have from Mr JOHNSTON, dated the 27th of January, states that the solution had been withdrawn for a month previously,—that the water had been kept running constantly for several days before it was subjected to examination,—and that no trace of lead could be detected in it by careful analysis.

From the facts now detailed, together with the results of my former inquiries, the following conclusions may be drawn as to the employment of lead-pipes for conducting water.

1. Lead-pipes ought not to be used for the purpose, at least where the distance is considerable, without a careful chemical examination of the water to be transmitted.

2. The risk of a dangerous impregnation with lead is greatest in the instance of the purest waters.

3. Water, which tarnishes polished lead when left at rest upon it in a glass vessel for a few hours, cannot be safely transmitted through lead-pipes without certain precautions.*

4. Water which contains less than about an 8000th of salts in solution cannot be safely conducted in lead-pipes, without certain precautions.

5. Even this proportion will prove insufficient to prevent corrosion, unless a considerable part of the saline matter consist of carbonates and sulphates, especially the former.

6. So large a proportion as a 4000th, probably even a considerably larger proportion, will be insufficient, if the salts in solution be in a great measure muriates.

7. It is, I conceive, right to add, that in all cases, even though the composition of the water seems to bring it within the conditions of safety now stated, an attentive examination should be made of the water, after it has been running for a few days through the pipes. For it is not improbable, that other circumstances, besides those hitherto ascertained, may regulate the preventive influence of the neutral salts.

8. When the water is judged to be of a kind which is likely to attack lead-pipes, or when it actually flows through them impregnated with lead, a remedy may be found, either in leaving the pipes full of the water and at rest for three or four months, or by substituting for the water a weak solution of phosphate of soda in the proportion of about a 25,000th part.

It may be mentioned, that the most convenient way to detect lead in water is, *first*, to examine what separates on exposure to the air by dissolving it in warm acetic acid, and testing the solution with sulphuretted-hydrogen, iodide of potassium, and bichromate of potash,—*then*, if this process fail, to concentrate the water to an eighth part, and again test any insoluble matter which separates,—and *lastly*, failing this procedure also, to evaporate the water to dryness, subject the residue along with charcoal to a red-heat, act on what remains with warm diluted nitric acid, and test the solution when filtered and neutralized with an alkali. It may admit of question, whether, in the event of lead being indicated in the last way only, the very minute quantity which may then be present can prove detrimental. But this is a topic which it is foreign to my present object to enter into.

* Conversely, it is probable, though not yet proved, that, if polished lead remain untarnished or nearly so for twenty-four hours in a glass of water, the water may be safely conducted through lead-pipes.

As connected closely with the subject of the preceding observations, I beg to append a few remarks on the nature of the compound of lead which is formed in the course of the action of water on the metal.

Where salts are present, whose acids are capable of forming insoluble compounds with oxide of lead, the deposit which gradually forms on the lead consists partly of these compounds. But where a substance is produced which floats loosely in the water, as in the action of distilled water ; or where the water, from being clear when fresh drawn from a pipe, deposits a white precipitate on exposure to the atmosphere—as in the instance of the two spring-waters mentioned above—a compound of a different kind is produced. That which is formed in distilled water is the only variety produced readily in sufficient quantity for examination.

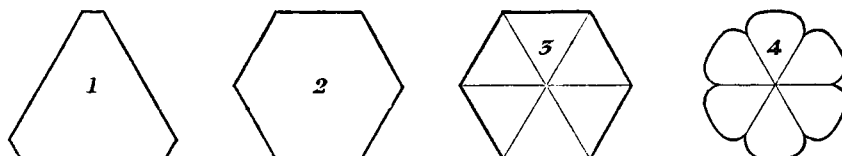
GUYTON MORVEAU thought this substance was the hydrated oxide of lead. From my experiments, published in 1829, I was led to infer that it is carbonate of lead, for it effervesces strongly while dissolving in diluted acids ; and it appeared to me to be the neutral carbonate ($\text{PbO} + \text{CO}_2$), partly because no other carbonate of lead was known at that time to chemists, and partly because, when deprived of hygrometric water by a temperature of 212° , its loss of weight, on being subsequently heated to redness, corresponded closely with the theory of its elements being united in the proportion of a single equivalent of acid and oxide. In 1834, however, Captain YORKE, who made some interesting experiments on this subject, —without being, for some time, aware of those previously conducted by me,—thought, in the first instance, that the substance formed in distilled water was the hydrated oxide: but he afterwards found reason for considering that it contained both carbonate and hydrated oxide of lead, although in proportions variable and not definite.

It appears improbable, that a substance which puts on invariably and entirely a crystalliform appearance, as this compound does when formed in distilled water, should be a mere mixture, of indefinite composition. Accordingly, I find that it is for the most part, and under certain conditions invariably, a regular definite compound of the carbonate and hydrate of the oxide of lead.

If lead be immersed in distilled water deprived of its gases by ebullition, and exposed to atmospheric air which has been freed of carbonic acid by solution of potash, the water soon becomes turbid and the lead tarnished, and there is slowly formed on the lead a crust of transparent microscopic crystals, presenting triangular and quadrangular facettes, and on the bottom of the vessel a whitish powder with a shade of leaden blue, and not crystalline. Both the crystals and powder are soluble, without effervescence, in nitric acid, and convertible into a yellow powder, with disengagement of much moisture, when they are heated to redness

after having been dried at 212° . This is evidently a hydrated oxide of lead. The powder becomes carbonated when left exposed to the air, even in the dry state.

When the action of the water takes place in the air, the product is more abundant, and seems to consist entirely of a mass of white, pearly, microscopic crystals. These acquire a pale gray tint, when removed from the water and allowed to dry spontaneously. When examined in water with a powerful compound microscope, they present the appearance of a congeries of thin tables. The primitive form of the table is probably the equilateral triangle, the crystals being therefore thin sections of a regular tetrahedre. Some crystals present the triangular form (1.), but with the angles always slightly truncated; others, by excessive truncation, have become hexagons (2); others present slender radiating lines, dividing the hexagon into six constituent equilateral triangles (3); and others of the latter construction assume the appearance of rosettes, probably by erosion of the angles of the hexagon (4).



When 28.62 grains had been dried at 180° , they lost only 0.01, on being heated to 250° ; and no further change took place till the temperature rose to 350° , at which point moisture began to be slowly discharged. A low red heat expelled much carbonic acid and a considerable quantity of water.

An apparatus was constructed for transmitting the disengaged gas through fragments of chloride of calcium to absorb the moisture, as well as for collecting the dry gas over mercury. When the whole gas and water had been expelled by heat, air, previously deprived of carbonic acid gas and moisture by means of caustic potash, was passed through the tubes composing the apparatus, for the purpose of driving into the gas-jar the carbonic acid left in the tubes. The volume of carbonic acid was then ascertained by absorption with solution of potash, and properly corrected to the temperature of 60° and the barometric pressure of 30 inches. The results obtained with 24.20 grains of the substance formed in large quantity by the continuous action of distilled water for twenty months, were—

Oxide of lead,	.	.	.	.	21.035 grains.
Carbonic acid (5.588 cubic in.),	.	.	.	.	2.641 ...
Water,	.	.	.	.	0.535 ...
					<hr/> 24.211 grains.

These numbers correspond nearly with the theory, $3 \text{ PbO} + 2 \text{ CO}^2 + \text{Aq}$; that is, a compound of three equivalents of oxide of lead, two of carbonic acid, and one of water,—or rather, a compound of two equivalents of carbonate of lead in union

with one equivalent of hydrated oxide of lead. The exact numbers by calculation, supposing the oxide correct, are 21.035 oxide, 2.656 acid, and 0.540 water. The slight deviation in my numerical results for the carbonic acid from the exact atomic numbers, probably depends on some of the protoxide of lead having absorbed oxygen from the atmospheric air passed through the tubes at the close, while heat was applied to the oxide, so that some of it became red oxide of lead.

This experiment was repeated with 27.965 grains, and the products were—

Oxide of lead,	.	.	.	.	.	24.275
Carbonic acid (6.33 cubic in.),	.	.	.	.	.	2.992
Water,	.	.	.	.	.	0.650
						<hr/> 27.917

These numbers, like the last, approach closely to the theory $3\text{PbO} + 2\text{CO}^2 + \text{Aq}$, —the exact numbers, by calculation from the oxide, being 3.06 of carbonic, and 0.62 of water.

In a third trial with 23.935 grains, the results were—

Oxide of lead,	.	.	.	.	.	20.870
Carbonic acid (5.285 cubic in.),	.	.	.	.	.	2.497
Water,	.	.	.	.	.	0.547
						<hr/> 23.914

Theory applies here exactly so far as regards the water, but the acid is somewhat deficient, the correct numbers, by calculation from the oxide, being 2.635 acid, and 0.540 water.

I have also examined the proportion of carbonic acid in other differently prepared specimens, by wrapping the powder in filtering paper, and introducing this into a jar filled with mercury and a little strong muriatic acid previously charged with carbonic acid gas. The results have been conformable with those stated above. When the water was freely exposed to the atmosphere, I have never found that the proportions differed more than a small fraction from the theoretical numbers just assigned.

The substance in question is therefore a definite compound of two lead salts. Other analogous examples have been for some time known to exist among the oxides and salts of this metal. Though of a brilliant whiteness while in water, it is rather gray when dry. It is permanent in the air; for a specimen exposed for many months gave the usual proportion of carbonic acid, when decomposed with muriatic acid. When suspended in water and treated with a stream of carbonic acid, the water of the hydrated oxide is displaced, and a neutral carbonate is formed, which is more dense, and of a pure white colour when dry.

On first ascertaining the nature of this substance, I imagined it was a new

body, not previously recognised by chemists. I have since found that MULDER conceives the common carbonate of lead, the white lead of commerce, to be of the same nature. He has recently discovered it to consist sometimes of two, and sometimes of three, equivalents of neutral carbonate, united with one of hydrated oxide; and he states that the whitest and finest varieties contain most carbonic acid. I find the white lead of this city, which is usually of fine quality, to be a compound of four equivalents of carbonate and one equivalent of hydrate. MULDER adds, that he could not succeed in displacing the whole water by means of carbonic acid. This may be so; but the compound formed by the action of distilled water on lead is not similarly constituted. When agitated for two hours in water with a brisk stream of carbonic acid gas, 27.93 grains of the dry product gave, by analysis,—

Oxide of lead,	23.44 grains.
Carbonic acid (9.27 cubic in.),	4.38 ...
Water,	0.15 ...
	<hr/>
	27.97 grains.

The carbonic acid obtained is only 0.06 of a grain short of what is required to neutralize the oxide.