CHAPTER II.

WATER AND THE FOREIGN MATTER USUALLY ASSOCIATED WITH IT.

Chemical Composition and Physical Characteristics of Water—Phenomena of Freezing and Boiling—Latent Heat of Water and Steam—Solvent Power of Water—Sources of Water: Rain; Impurities of Rain Water—Lakes, Streams, and Rivers: Soft River Water from Impervious Districts; Effect of Soft Waters on Iron Pipes; River Waters from Districts where Carbonate of Lime prevails; River Pollution—Organic Impurities, and the Capability of Chemical Analysis to estimate the same—Action of Atmospheric Oxygen in rendering the Impurities innocuous—Nitrates and Nitrites—Albumenoid Matter—Germs—Microscopical Examination of Water—Spring and Well Water: Impurities of the Water from Shallow or Surface Wells; Quality of Deep Well Water from the Chalk and the New Red Sandstone—Action of Water on Lead—Dr. Clarke's Soap Test—Temporary and Permanent Hardness—Hard Water *versus* Soft, viewed with Regard to Health, and Domestic and Manufacturing Economy—Clarke's Softening Process—Analysis of the Softened Water from the Canterbury Works.

WATER, when pure, is an inodorous and tasteless liquid, composed of two gases, oxygen and hydrogen, in chemical combination, and is in small quantities colourless and transparent. It is a bad conductor of electricity. It is slightly elastic: with a pressure of about 200 atmospheres, it is reduced in bulk about one-thirteenth. It is about 770 times heavier than atmospheric air at 69° Fahr., an imperial gallon weighing 10lbs. avoirdupois. It is the standard to which the specific weight of all solids and liquids are referred, and on this account its specific gravity is taken as 1, or 100. Water on cooling becomes denser until it reaches the temperature of 39·2° Fahr. (4° C.); after this it again expands, if the temperature be still lowered, until it reaches 32° Fahr. (0° C.), when it solidifies into ice. Water is therefore denser at 39·2° Fahr. (4° C.) than at any other temperature. This peculiar property prevents large masses of it from becoming completely frozen.

In the act of freezing water expands considerably, and with such force as frequently to cause the fracture of strong iron pipes, rocks, &c.; this is the cause of the bursting of the water-pipes in houses, although the latter is most generally attributed to the thaw. The pipes are burst by the expansion of the water in becoming ice, but it is obvious that until the ice again melts, it cannot run through the openings in the pipes. The specific gravity of ice is 0·916; being therefore lighter than water, it floats on the surface.

Hail and snow are frozen water in different states, the rapidity with which solidification takes place being much greater in hail than in snow; for the latter is found to be formed of beautifully shaped crystals, belonging to the form of six-sided prisms, with various stellate variations.

Although water freezes at 32° Fahr. (0° C.), it may be cooled many degrees below this, if it be kept perfectly still; but if vibration be caused in it by any means, it immediately becomes solid, which solidification is accompanied by a considerable rise of temperature,—up to 32° Fahr. If ice be placed in a vessel supplied with a thermometer, and heat be applied, the portions first melted remain at 32° Fahr. until all the ice has become melted. The heat thus consumed has supplied the place of that given out when the ice was formed, and has become heat of liquefaction, and imperceptible to the thermometer, or latent.

The latent heat of water is 142·5° (61·1° C.). It may be shown in this way: if 1 lb. of water at 142·5° Fahr. be mixed with 1 lb. of ice at 32° Fahr., the ice will be melted, but the whole of the water (2 lbs.) will only have a temperature of 32° Fahr.; the ice will, in fact, require as much heat to enable it to become water as will raise an equal weight of water from 32° Fahr. (0° C.) to 142·5° Fahr. (61·1° C.).

When water is heated in metallic vessels to 212° Fahr. (100° C.), it enters into a state of ebullition, if the barometer stands at 30 inches. The boiling-point of water varies with the barometric pressure, being higher as the pressure is greater; on this account, water will boil at a lower temperature at the top of a high mountain than it will at the level of the sea—about 550 feet difference of level will make a difference in the boiling-point of about 1° Fahr. The cause of this is plain enough: ebullition is merely the rapid and violent escape of water in the shape of steam, and of course this cannot take place until the elastic force of the steam is sufficient to overcome the pressure of the atmosphere; the higher we ascend, the less the weight of the atmosphere above us, and the steam requires less elastic power to overcome the weight. Water may, on the other hand, and from the same cause, be heated much above 212° Fahr. (100° C.) without entering into ebullition, if the pressure be increased; for instance, the water in a locomotive boiler worked at a pressure of 120 lbs. will have a temperature of 310° Fahr. (172° C.).

In the following table will be found values given by Arago and Dulong, of the boiling-point of water under different pressures.

Pressure in Atmospheres	Temperature (Centigrade)	Pressure in Atmospheres	Temperature (Centigrade)
1	100°	12	190°
1·5	112·2°	14	197·2°
2	121·4°	16	203·6°
3	135·1°	18	209·4°
4	145·4°	20	214·7°
5	153·1°	25	226·3°
6	160·2°	30	236·2°
7	166·5°	35	244·8°
8	172·1°	40	252·5°
10	181·6°	45	265·9°

If instead of metallic vessels glass ones are used, the water will be found not to boil until rather above 212° Fahr. (100° C.); this is caused by the attraction of the sides of the glass vessel for the water preventing the steam from escaping until it has acquired a greater elastic force. It often happens when water is boiled in glass vessels, that after a time the water will not boil steadily, but remains still for some time, and then suddenly bursts into ebullition, which is often violent enough to eject a portion of the water from the vessel. In this case the water becomes heated above its boiling-point, and the excess of steam suddenly generated, when ebullition sets in, endeavours to escape all at once; after the ebullition, the temperature falls to the ordinary boiling-point.

If, instead of by ascending to a great height, the pressure be removed from the surface of the water by any other means, we thereby lower the temperature at which the water will boil. This is just the effect of evaporating *in vacuo*, for then water will boil at 67° Fahr. (19·4° C.). Liquids which are liable to be injured by evaporation at the ordinary temperature above 212° Fahr. (100° C.) are therefore evaporated *in vacuo*, as is the case with the juice of the sugar cane.

At the ordinary atmospheric pressure a cubic inch of water occupies in the shape of steam about a cubic foot.

When not in contact with water, steam behaves in a manner exactly similar to permanent gases, on the application of heat; the rate of expansion and increase of elastic force are the same. In the presence of water, this is no longer the case. As ice in becoming water absorbs a large quantity of heat, which becomes latent (heat of liquefaction), so water, in becoming steam, absorbs a large quantity of heat, which also becomes latent (heat of vaporisation).

The latent heat of steam is, according to Regnault, about 996·4° Fahr. (535·77° C.), but it diminishes as the temperature of the steam rises, so that equal weights of steam will have nearly the same heating power, whatever their temperature. This also appears to take place below the boiling-point, so that the same quantity of heat is required to evaporate water at whatever temperature the evaporation be conducted.

The solvent power of water is very great—in fact, there are very few things it does not dissolve to some extent; but the quantity of the several substances which a given portion of water is capable of dissolving varies considerably. Its solvent powers are for the most part increased by rise of temperature, but there are a few exceptions to this: chloride of sodium (common salt) is dissolved in it to nearly the same extent, whatever the temperature; sulphate of lime is less soluble in hot than in cold water. Water also dissolves gases in variable quantities; ammonia and hydrochloric acid gas in very large quantities; but the gases of the atmosphere, oxygen, nitrogen, and carbonic acid, only in small quantities.

Water generally dissolves more gas the lower the temperature and the greater the pressure, and, upon boiling, the gases are expelled entirely, unless they be very soluble. Carbonic acid is soluble in water, at the ordinary atmospheric pressure, to the extent of about an equal volume.

The liquefaction of solid bodies by solution in water obeys the same laws as liquefaction by the direct application of heat. When a substance which does not act chemically on water is dissolved in it, the solution is attended by diminution of temperature, the heat lost to the thermometer having become heat of liquefaction for the substance dissolved. On this depends the formation of freezing mixtures; and generally the more rapid the solution, the lower the temperature obtained.

Since the greater number of substances are more soluble at a high temperature than a low one, a solution saturated at comparatively a high temperature will deposit a portion of the substance, if the temperature be reduced. It is in this manner crystals of different substances are obtained by the manufacturer. A saturated solution may, however, be cooled down considerably without the separation of any portion of the substance, if the solution be kept perfectly still; but, as in the case of water cooled below 32° Fahr. (0° C.), the least vibration in the solution causes instant solidification with a rise of temperature.

In treating of the various sources from which potable waters are obtained, it will be advisable to divide them into rain; lakes, streams, and rivers; and wells.

Rain.—Rain as it leaves the clouds is doubtless pure water, but in its passage through the air it absorbs certain gases, and carries with it, mechanically, particles of matter which are floating about in the air. This is the case more especially with rain that falls after a long drought, that which falls after a continuance of rain being comparatively free from them. The substances thus absorbed by the rain in its passage to the earth are the gases oxygen, nitrogen, carbonic acid, a little ammonia, and nitric acid, this latter more especially during a thunderstorm, it being formed by the action of the electric spark on the ammonia and vapour of water contained in the air. The particles floating in the air, which are carried down by the rain, are for the most part organic. The above would be the principal if not the only impurities found in rain water, if it were collected before it reached the earth in the open country. In or near large manufacturing towns, the case is different; several other substances would then be found in it, as sulphurous acid, &c., varying with the kind of manufactures carried on near the spot. Again, if rain be collected after it has fallen on the roofs of houses, it will be further contaminated with substances with which it has come in contact, more especially where lead pipes or gutters are used. (See p. 27.) Dr. Hassall, however, says that, of the rain water in two butts submitted to him for examination, the quantity of organic matter bore no comparison to that present in river water, being at least a hundredfold less.*

Lakes, Streams, and Rivers.—The water found in rivers, streams, and lakes, is either that which has been immediately drained into them from the surface of the land; or, having been previously absorbed by porous strata, has fed them in the shape of springs; or, thirdly, that which has been drained into them by artificial means. In any case, however, the nature of the foreign matter contained in river water will depend upon the nature of the strata through which it has percolated, and over which it has flowed: the effect of the introduction into rivers of the sewage of towns is a subject open to grave discussion, and deserves here a separate consideration.

Where the rain falls on impervious strata, such as granite, it runs off the surface without encountering any substances which it can dissolve to any great extent; it therefore remains comparatively free from foreign matters. The water from rivers and lakes in such districts approaches more nearly the nature of rain than any other natural water. It is the softest of river water, and its solvent powers are therefore comparatively high. Such are the waters supplied to Plymouth and Devonport from the granite hills of Dartmoor; the water of Loch Katrine, supplied to Glasgow; the water supplied to Manchester from the river Etherow; that obtained from the Tay for Perth, and that from the Dee for Aberdeen.

The following are analyses of these several waters:—

FOREIGN MATTER PER GALLON.

	Plymouth	Devonport	Glasgow	Aberdeen	Perth	Manchester
	Grains	Grains	Grains	Grains	Grains	Grains
Inorganic Matter.	2·38	2·59	1·284	2·184	3·787	3·24
Organic or Volatile Matter. . . .	0·57	1·46	0·960	1·816	1·240	1·10
Total Solid Matter	2·95	4·05	2·244	4·000	5·027	4·34
Chloride of Sodium	1·25	1·20	0·59	0·67	0·955	1·29
Ammonia . . .	0·0045	0·004	—	—	—	0·0042
Nitrates	None	None	—	—	—	—
Hardness before Boiling . . .	0·61°	0·90°	0·8°	1·2°	2·4°	2·59°
	Cubic inches	Cubic inches	Cubic inches	Cubic inches	Cubic inches	Cubic inches
Carbonic Acid . .	Not determined		·080	0·38	1·0	Not determined
Oxygen			2·420	2·19	2·0	
Nitrogen . . .			4·277	4·63	5·0	
Total Quantity of Gases	—	—	6·777	7·20	8·0	—

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* Minutes of Evidence, Royal Commission on Water-Supply, 1869, p. 260.

The districts from which these waters are obtained generally contain peat, and the waters are therefore frequently coloured more or less by the peat.

These waters act rapidly on unprotected iron pipes, converting the iron into oxide of iron, thereby reducing to a considerable extent the internal diameter of the pipe. A coating of asphalte or pitch, however, will prevent the contact of the iron and the water, and consequently the oxidation of the iron. Cast iron and steel are less affected than wrought iron, and in the order given.

When water acts on iron pipes, rusting their interior, it is always found, when the water runs red from rust of iron, that a large quantity of the dissolved organic matter previously contained in the water has been removed.

The following is an analysis of a deposit taken from the inside of iron pipes through which a soft water had been passed for some time.

COMPOSITION IN 100 PARTS.

Oxide of Iron	69·54
Insoluble Residue	11·32
Lime	0·40
Magnesia	0·54
Moisture (liberated at 130° C.)	9·00
Organic Matter	8·90
Lead	a trace
	99·70

Of the action of these waters upon lead, notice will be taken hereafter.

The next waters are the rivers which have passed over or through districts containing carbonate of lime in some form or other. They vary but little in the nature of their inorganic constituents (consisting principally of carbonate of lime, sulphate of lime, carbonate of magnesia, and chloride of sodium), but vary very considerably in the total quantities of these substances, and the proportions of them one to the other in the several waters.

Coming next in softness to the water last described will be such water as that of the river Exe, above its junction with the river Culm, in Devonshire, of which the following is an analysis.

FOREIGN MATTER PER GALLON.

		Grains.
Inorganic Matter		6·63
Organic and Volatile Matter		1·00
Total Solid Matter		7·63
Chloride of Sodium		1·75
Ammonia		0·006
Nitrates		a trace.
Hardness before boiling	4·57°	
Hardness after boiling	2·72°	

The inorganic constituents were carbonate and sulphate of lime, carbonate of magnesia, and chloride of sodium.

Next in order may be taken waters like that of the Thames at Kingston, such as is drawn for the London supply by some of the water companies. Their composition is about as follows, the nature of the foreign matter in them being exactly the same as in the last-mentioned water (Exe), but in larger quantities.

FOREIGN MATTER PER GALLON.

		Grains.
Inorganic Matter		18·34
Organic and Volatile Matter		0·98
Total Solid Matter		19·32
Chloride of Sodium		1·63
Ammonia		0·001
Nitrates		1·25
Hardness before boiling	13·6°	
Hardness after boiling	4·6°	

This sample was taken in December 1869, after much rain. In the summer months, the total solid matter would be less.

The foregoing examples will give a fair idea of the nature of ordinary river waters—the principal ingredient being carbonate of lime. This substance is soluble in water, free from carbonic acid, only to the extent of about two grains per gallon; the quantity beyond this contained in any water is held in solution as bicarbonate of lime by the excess of carbonic acid. On this account therefore, if the excess of carbonic acid is removed by any means, as by boiling the water for some time, the quantity of carbonate of lime beyond the two grains per gallon is removed from the water as an insoluble sediment; and this carbonate of lime, together with some of the sulphate of lime and organic matter, composes the sediment found in kettles, boilers &c. where these waters are used. It is the removal of the free carbonic acid by the continued application of heat which renders the water softer after boiling. These waters have but slight action upon iron, and comparatively little or none on lead. (See p. 27.)

The general question of river pollution is one which may be viewed in many aspects. The evidence of direct chemical analysis will always suffice for guidance, as far as inorganic matters are concerned; but with regard to organic impurities, the case is very different. When a river receives in its course the sewage of towns and the drainage of cultivated lands, the important question arises, How far will such rivers be available as a source of wholesome supply? And it is unfortunate that hitherto chemical science has not in this case offered that satisfactory assistance which has been found so valuable in other questions. The Royal Commission on Water-Supply (1869) obtained on this important subject evidence of the highest scientific authorities, and the following are extracts from their very able Report. Referring to the river Thames, which, above the point where the supply for the metropolis is abstracted, is contaminated by the excrements of more than 200,000 human beings, the Report says: 'If the waters of the Thames had no impurities beyond the solid mineral contents, the question as to their wholesomeness and general suitability for the supply of the metropolis would be easily disposed of.

'But attention has been called strongly to the *organic impurities* contained in Thames water, which, though more indistinct in their form, and less appreciable in their quantity, are said to be more deleterious in their nature, and to render the water, if not dangerous and unwholesome, at least liable to suspicion.' These noxious elements 'would be sufficient to do great mischief, were it not for a most beneficial provision of nature for effecting spontaneously the purification of the streams. Some of the noxious matter is removed by fish and other animal life, and a further quantity is absorbed by the growth of aquatic vegetation; but, in addition to these abstractions, important changes are effected by chemical action. The organic compounds dissolved in the water appear to be of very instable constitution, and to be very easily decomposed, the great agent in this decomposition being oxygen, and the process being considerably hastened by the motion of the water. Now, as such waters contain naturally much air dissolved in them, the decomposing agent is ready at hand to exert its influence the moment the matter is received into the water, in addition to which the motion causes a further action by exposure to the atmosphere; and when (as in the Thames) the water falls frequently over weirs, passes through locks, &c., causing further agitation and aëration, the process must go on more speedily and more effectually.

'The effect of the action of oxygen on these organic matters, when complete, is to break them up, to destroy all their peculiar organic constitution, and to rearrange their elements into permanent inorganic forms, innocuous and free from any deleterious quality.

'The question now naturally arises, Can we not by careful analysis of the Thames water discover what quantity of organic matter it contains, what is the nature and character of such matter, and how far they are deleterious or otherwise? We have endeavoured to arrive at a solution of this question, but unfortunately without much success. The enquiry seems beset with difficulty. The organic matter is present only in very small quantities, and in shapes and conditions which are very difficult to identify and to reduce to actual measure. The treatment of them is still a problem in chemical science only now beginning to be effectually studied; the most eminent chemists are yet by no means agreed either as to the processes most proper to be followed in the analysis, or as to the value and bearing of the results obtained.

'It does not follow that all organic matter in water is prejudicial; great mistakes have arisen on this point, as it is often given out that the very suspicion of organic contents of any kind in a drinking water should disqualify it for use. But almost all our drinks other than water owe their distinctive qualities to the varieties of their organic contents, and hence it is clear that the presence of organic matter *per se* is not necessarily prejudicial. It is however necessary, in potable waters which contain organic matter, carefully to distinguish between such combinations as are innocent and such as are noxious, and here lies one of the greatest difficulties.

'It is well known that decomposing organic matter is constantly giving rise to alkaline nitrites and nitrates. Dr. Frankland refers them, not simply to organic matter taken generally, but to sewage or manure matter especially; and the quantity of these salts is made the measure of the estimated previous sewage contamination of the different waters, for which a separate column is given.* This seems to be an inference which can hardly be accepted. It would be perfectly correct if all the nitrogenised matter supplied to the Thames or other waters was, after conversion into nitrates or nitrites, retained in the water, and if also all these salts could be referred to sewage and manure matter solely. But such is not the case. All the analyses show how variable the quantity of these salts is in different parts of the rivers' course, and that the quantity present at any place is not so much dependent upon the sewage received as upon the removal which has been effected by vegetation and other causes, by the interference of tributaries, and by the addition from springs, so that, even supposing them to originate solely from animal origin, the residue affords no comparative results as to the amount of original contamination. The interfering causes are too numerous to allow us to assign any value to the remainder.

'We cannot help concluding,' continues the Report, 'that considerable sewage contamination may take place without indication of its presence by nitrites and nitrates, whilst in other cases these salts may be derived from vegetable matter, and from springs which cannot be suspected of having been contaminated with true sewage matter.† Their presence in moderate quantity does not indicate with certainty the presence of old sewage matter, nor does their absence prove freedom from such matter. At the same time, where an excess of these salts occurs, as in some wells, they should be regarded with suspicion, and form cause for immediate enquiry, for that they are generated largely by town sewage is indisputable.

'Nor can we agree with some eminent authorities in looking at river water in a solely chemical point of view, and speaking of the presence of the 10 to 20 grains of mineral matter in the gallon as *impurities*. So, chemically speaking, they are; but as this seems to be almost a normal condition of river waters, we should not be disposed to consider this term an appropriate one to be applied to substances so constantly present in natural springs and streams.

'Where a minute quantity only of organic matter escapes destruction, it would seem that chemistry is not yet sufficiently advanced to pronounce authoritatively as to its exact quality and value; and with microscopic living organisms, especially, chemistry is incompetent to deal, and other modes of examination are needed.

'Where the organic matter is present in quantities sufficient to diminish the free oxygen in the water, or to tend to putrefactive decomposition, danger is to be apprehended; and considering the nature and scale of the experiment now about to be made with respect to the disposal of the sewage of towns, too much care and watchfulness cannot be exercised in face of the risk which any mistake or oversight might give rise to.'

It would appear from the foregoing that the Commission rely on the fact of sewage becoming innocuous after having undergone a natural process of river purification; but in justice to the very able reasoning on the other side of the question by eminent authorities (amongst whom Dr. Frankland takes the lead), it is only fair to notice, although necessarily briefly, a few of the arguments adduced in support of the opposite theory.

It is asserted that water contaminated with sewage contains that which is noxious to human health, and that there is no process practicable on a large scale by which it can be removed to render the water suitable for domestic use.

As regards the water supplied to the city of London, it is found that there is present the following quantities of material which may be regarded as the skeleton of the sewage which has been previously poured into the water: namely, of nitrogen in the form of nitrates and nitrites, a mean quantity of ·192 in 100,000 parts of water—that is, in the Thames water. It is also stated that this inorganic skeleton of sewage will find its way through considerable thickness of filtering strata, such as sand, gravel, and even chalk. Although it is admitted that the presence of these nitrates and nitrites does not prove that there is anything in themselves injurious to health, yet they reveal the fact that these waters have been previously contaminated with sewage; and there is no guarantee that other portions of that sewage may not have escaped the purifying processes of oxidation and filtration in the passage of the water along the course of the river or through the sand and chalk, and may not be present in that water, those substances being in quantities too minute to be capable of detection by chemical analysis.

The noxious part of sewage is that which is held in mechanical suspension, and these globules are beyond the reach of the chemist, and, to a great extent, of the microscopist. There are only two processes by which it can be effectually removed: the one is by boiling for a long time, and the other is by distillation, both impracticable on a large scale.

No process of filtration that has yet been devised will remove choleraic dejections from water; and as it is

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* In the Reports by the Registrar-General.

† Mr. Charles Bain, in a paper read before the Chemical Society, January 19, 1870, 'On the origin of Nitrates in Potable Water,' said that finding nitric acid in the water of a spring that was very remote from any agency capable of imparting decaying animal matter, he was led to a closer examination, which resulted in the discovery that the water in question had passed through a *fossiliferous deposit*.

generally believed that the noxious matter of sewage exists there in the form of minute germs, which are probably smaller than blood globules, a filtration through even a considerable stratum of chalk cannot be relied upon (as some maintain) to free the water perfectly from such germs.

It is very difficult to get rid of sewage matter by running water; that portion of it which remains undecomposed after its passage through the sewers oxydises with extreme slowness.

About four-fifths of the nitrogenous matter contained in fresh sewage, which has just been produced as it enters the sewer, is decomposed before the sewage, after a run of two or three miles, emerges into the river; but the remainder is decomposed with extreme slowness afterwards—indeed, when once sewage finds its way into the river, it is very difficult to say where it will end.

The foregoing is principally founded on the evidence given by Dr. Frankland before the Royal Commission on Water-Supply, and it will suffice here to refer to the Report of the Commissioners on this point.

There is a method of water analysis, known amongst chemists as the method of Wanklyn and Chapman, by which an estimate can be formed of the quantity of albumenoid matter present in the sample;* this albumenoid matter is converted into ammonia, by boiling with alkaline permanganate, and separately estimated, the 'albumenoid ammonia' thus becoming a measure of the 'possible amount of germ.' The process is a very valuable one, and yields highly interesting results. The following are some of the results of the application of this method to waters supplied to different places. † Under 'free ammonia' includes the ammonia present in the water as such, and that evolved by carbonate of soda from the *urea* in the water.

PARTS IN 1,000,000 (MILLIGRAMMES IN A LITRE).

		Free Ammonia	Albumenoid Ammonia
1867	LONDON		
July	West Middlesex Company	·01	·064
„	Grand Junction Company	·01	·07
„	Chelsea Company	·01	·07
„	Ditto	·01	·10
„ 6	Southwark and Vauxhall Company	·03	·16
„ 18	Ditto ditto	·015	·12
„ 18	Ditto ditto	·01	·15
	New River Company:—		
June 21	Cab rank, Moorgate Street.	·015	·084
July 12	London Institution	·010	·05
„ 20	Supply-pipe in house, Kingsland Road	·015	·05
Aug. 21	Cab rank, Moorgate Street.	·002	·064
1868			
Jan. 25	London Institution	·02	·09
1867	East London Company	·03	·089
Aug. 19	MANCHESTER	·006	·06
		·014	·07
	EDINBURGH		
Sept. 25	Swanston water	·03	·10
„	Crawley „	·006	·08
„	Colinton „	·14	·08
„	Comiston „	·004	·034
	GLASGOW		
Oct. 3	Loch Katrine	·004	·08
	MISCELLANEOUS		
July	Bala Lake	·01	·25
June	Pump in Bishopsgate Street, London	7·50	·255
„	Pump in Drapers' Hall, London	6·00	·315
„	Thames at London Bridge:—		
	High Tide	1·02	·50–·59
	Two hours' flood (filtered through filter-paper) . . .	1·76	·35
	Water from well in a village east of London, after heavy rain .	40·00	3·00

It may be observed from the foregoing, that the Comiston water, forming part of the Edinburgh supply, ranks by far as the purest sample in point of nitrogenous organic matter. (See also p. 31.)

This method of Wanklyn and Chapman, valuable as it no doubt is, does not profess to be more than a measure of the '*possible* amount of germ.' What we require to know is, how far the water which is to pass into our systems is likely to contain particles possessed of actual vitality. The quantity of organic or even of

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* 'Water Analysis: Determination of the Nitrogenous Organic Matter.' By J. Alfred Wanklyn, E. T. Chapman, and Miles H. Smith. Journal of the Chemical Society of London, vol. xx. See also 'Note on Frankland and Armstrong's Memoir on the Analysis of Potable Waters.' By the same authors. Ibid. vol. xxi.

† A Practical Treatise on the Examination of Potable Water. By Wanklyn and Chapman. 2nd edit. 1870.

albumenoid matter is, to this, of secondary importance. The following extract from a paper,* by Mr. Charles Heisch, deserves to be introduced here:—

'Water was procured from various sewers, and after standing a few days to settle, 6 drops of clear water were mixed with 10,000 grains of West Middlesex and New River water; to 6 oz. of this mixture, 10 grains of pure sugar were added, a like quantity being mixed with 6 oz. of the water without the sewage. All these samples were placed in stoppered bottles in a window where plenty of light could reach them. The water and sugar remained clear and sweet. The water with this trace of sewage did the same. The water, sewage, and sugar became turbid in times varying from twenty-four to sixty hours, and exhibited [under the microscope] the cells and strings before spoken of [small spherical cells, with, in most cases, a bright nucleus]; and ultimately the odour of butyric acid was always perceptible. One drop of fresh urine in 10,000 grains of water, a mixture which may be kept for weeks without showing any sign of turbidity, produced in twenty-four hours abundance of cells, and in forty-eight hours branched strings. No other substances which I have tried produce the same result. Urea, albumen, nitrates, milk, and various other things have been tried, and though some have produced growths of some sort, none have resembled these peculiar and unmistakable cells and strings. A curious circumstance took place during the last outbreak of cholera in 1866. On some few days the water of one of the water companies, which is ordinarily perfectly without action on sugar, produced to a slight extent those same growths on being mixed with that body. . . . Filtering the water through the finest Swedish paper does not remove the germs, as on the addition of sugar they grow as fast as ever. Boiling for half an hour in no way destroys their vitality. Filtration through a good bed of animal charcoal is, as far as I can find at present, effectual in removing them; and if the charcoal be well aired from time to time, it retains its power for several months; but if the water be passed continually through it without this precaution, it soon loses it, and the filtered water is as bad as the unfiltered.'

It appears strange that the Commission on Water-Supply should not have encouraged evidence of microscopical examinations of the Thames and other waters. Although alluded to incidentally, this highly important and scientific subject does not appear in any distinct form. In the year 1852, Drs. Lankester and Redfern made separate Reports to the London (Watford) Spring Water Company, on 'The organic Contents found by the Microscope in Waters supplied from the Thames and other Sources,' and a glance at these alone would be sufficient to convince the most sceptical of the necessity for a searching investigation, the result of which, had it been conducted before the late Commission, would have perhaps modified the conclusion at which that body arrived, viz. 'That there is no evidence to lead us to believe that the water now supplied by the companies is not generally good and wholesome.'

Wells.—Spring and well water is that which has fallen upon the surface of the earth in the shape of rain, and has percolated through a porous stratum, either to appear again upon the surface at a lower level, as in the case of the former, or to be stored up in subterraneous reservoirs, approachable only by artificial means. The waters of 'shallow' wells, obtained from surface gravel or the like, near large towns, are invariably much contaminated with organic matter, ammonia, nitrates, and chlorides; the ammonia being obtained by the putrefaction, and the nitrates by the oxidation, of the organic matter. The water which falls on the surface in such districts percolates through the gravel, carrying all soluble matter with it, and when near churchyards, stables, cesspools, &c., organic matter of the worst kind is present in large quantities. These waters are totally unfit for domestic use, but as a general rule are liked for drinking; for, when fresh from the well, they are cool, sparkling, and pleasant to the taste, qualities brought about by the decomposition and oxidation of the filth obtained from the above-named sources; the excess of carbonic acid renders them sparkling, and the nitrates cool to the palate.

The following analysis gives a fair average of their composition:—

Foreign Matter per Gallon.		Grains.
Inorganic Matter		82·30
Organic and Volatile Matter		6·90
Total Solid Matter		89·20
Chloride of Sodium		14·70
Alkaline Nitrates		20·00
Hardness before boiling	43·0°	
Do. after do.	24·0°	

These waters act rapidly on lead, and often contain lead in solution when the parts of the pump in the water are made of lead.

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* Journal of the Chemical Society of London, vol. xxiii.

The waters of 'deep' wells will depend for their characteristics upon the nature of the strata through which they have percolated and the soluble matters contained therein; they are more free from organic matters than river waters, as they undergo a more or less complete natural filtration; the greater the depth of the well, or rather the longer the time which the process occupies, the more complete will be the oxidation of the organic matters.

The following analysis is of the water from a deep well in the chalk, at Deptford, where, by a geological fault, the chalk appears near the surface, not having above it the upper strata of the regular London basin:—

FOREIGN MATTER PER GALLON.

		Grains.
Inorganic Matter		24·313
Organic and Volatile Matter		2·100
Total Solid Matter		26·413
Chloride of Sodium		3·323
Nitrates		0·680
Hardness before boiling	18·5°	
Do. after do.	8·5°	

The inorganic matter consists chiefly of the carbonate and other salts of lime.

Mention must now be made of the water which is obtained from the chalk underlying the other tertiary strata, as in the London basin. This water, although being stored up in the chalk, is very soft, containing a considerable quantity of soda salts, instead of salts of lime. The only explanation for the presence of these salts is, that the hard water which exists in the bed of chalk at higher levels has percolated down until it has come into contact with alkaline silicates, which are known to exist in some of the sands just above the chalk. This would account for the presence of the carbonate and sulphate of sodium, and for part of the chloride of sodium; the remaining quantity of chloride perhaps comes from the sea, since the chalk crops out under the German Ocean.

The following analysis of water taken from a well in Grosvenor Road, Pimlico, will show about their average composition:—

FOREIGN MATTER PER GALLON.

		Grains.
Carbonate of Soda		15·884
Sulphate of Soda		15·034
Chloride of Sodium		15·058
Carbonate of Lime		4·280
Carbonate of Magnesia		2·283
Silica		0·121
Phosphoric Acid and Oxide of Iron		0·101
Organic Matter		0·530
		53·291
Hardness before boiling	6·25°	

The new red sandstone is inferior only to the chalk as a source of supply; the water, however, is perhaps liable to greater variation in quality.

The following are analyses of the water from wells in this formation.

Nos. 1 to 4 are from the Liverpool district, and the analyses were conducted by Mr. Richard Phillips, for the Liverpool Corporation. No. 5 is from a well of the Water Works Company at Aston, near Birmingham; the hardness before boiling of this sample was 5·9°, after boiling 1·5°; it may be taken as an average of the waters around Birmingham. The analysis was conducted by Dr. Hill, F.C.S., Analyst to the Borough of Birmingham. At Manchester, Dr. Angus Smith, F.C.S., has found that the water drawn from the deep wells of the permian and bunter sandstone yields on an average 8 grains of sulphate of lime and 6 grains of carbonate per gallon, besides other ingredients. No. 6 is of a sample from the south side of the city. There were also in addition to the compounds tabulated, traces of phosphoric acid, potass, and lithia, the last observed by the spectroscope. As an instance of very pure water from the new red sandstone, that from the well at Whitmore Station, Cheshire, is remarkable. The supply here is plentiful, and from the analysis of Dr. Zeidler it appears that there are only 6·10 grains of solid matter per gallon. Nearly equally pure is the water from a well at Parkside, near Warrington (No. 7), which, from the analysis of Mr. Dugald Campbell, F.C.S., is found to contain only 11·12 grains per gallon; the hardness before boiling is 5·8°, and after 4·1°.

Analyses of Well Water from the New Red Sandstone.

Foreign Matter	1 Grains	2 Grains	3 Grains	4 Grains	5 Grains	6 Grains	7 Grains
Sulphate of Lime . .	3·31	5·44	0·49	0·00	—	—	1·63
Sulphate of Magnesia . .	—	—	—	—	—	—	1·46
Sulphate of Soda . .	—	—	—	—	0·70	7·33	—
Carbonate of Soda . .	—	—	—	—	1·62	7·35	—
Carbonate of Lime . .	7·10	2·94	8·70	5·26	4·40	9·77	1·07
Carbonate of Magnesia .	6·93	8·81	7·43	2·66	2·70	5·29	0·70
Chloride of Sodium . .	3·37	4·47	3·42	2·23	1·08	4·88	1·76
Chloride of Magnesium .	—	—	—	—	—	—	0·71
Silica	0·48	1·12	1·20	0·63	0·62	—	0·80
Potassium	—	—	—	—	—	—	0·11
Organic Volatilized Matter .	2·81	2·02	1·94	2·81	1·70	—	2·64
	24·00	24·80	23·18	13·59	12·82	34·62	10·88

Action of Water on Lead.—From extensive experiments made some time since with regard to the action of the water of Loch Katrine and rivers Dee and Tay on lead, it was found that the action was most powerful in the case of the Loch Katrine waters, less in the water from the Dee, and least in that of the Tay. It was observed also, that while the amount of oxygen was greatest in the Loch Katrine water, and least in that of the Tay, the amount of carbonic acid, on the other hand, was greatest in that of the Tay, and least in that of Loch Katrine. From this it will be inferred that the action of these waters on lead depended on the quantity of oxygen and carbonic acid present in them. When there is a large quantity of oxygen, the lead is rapidly oxidised, and the oxide thus formed is to a certain extent soluble in pure water; but if the water contain a sufficient quantity of carbonic acid to convert the oxide into carbonate of lead, the water will be so far safe from any dangerous contamination with lead, for carbonate of lead is soluble in water only to the extent of about 1 part in 7,000.

It would appear, moreover, that the peaty matters which are generally to be found in soft water form, in a few weeks or so, a kind of paint upon the surface of the lead, thus protecting it from further action; and perhaps this fact is of greater weight than the insolubility of carbonate of lead just mentioned, for the latter substance is of a poisonous nature, and would therefore bring about serious results were it but to pass into the human system. As has been previously stated, water that has been for some time in contact with unprotected iron pipes is deprived of most or all of its free oxygen: such water is therefore less liable to action on lead than before.

The formation of this protecting surface occurs also with hard waters, the deposit being mostly sulphate of lime. On the whole, hard waters are considered to be less liable to contamination by lead, than soft waters, although, of the various earthy salts which constitute hardness, it is difficult to say which are the most efficacious in preventing this action. Where an excess of carbonic acid is present, it is possible that the carbonate of lead may be held in solution by it, as in the analogous case of carbonate of lime. In all cases, however, it is found that the more new and bright are the pipes, the more rapid and certain is the action of the water upon them.

The time of contact between the lead and the water—of whatever kind the latter may be—is undoubtedly an element in the consideration. Dr. Edwin Lankester, F.R.S., has said, that even where the pipes have been laid and in use for upwards of two years, he can still find traces of lead in water of the Grand Junction Companies when it has been standing in the pipes for about twelve hours. With regard to the question of what quantity of lead in water is capable of acting injuriously on the human system, it is very generally believed that so small a quantity as one-ninth and one-eleventh of a grain per gallon may produce ultimately poisonous effects. Of course some constitutions will withstand much larger doses than others; but in all cases lead poison is accumulative, and small portions repeated at intervals will bring about disastrous results in the end.

It has been found by experiment that water softened by Dr. Clarke's process (to be hereafter referred to) has less action upon lead than even the hard waters from the chalk. A certain preventive, however, against any possible contamination of water by leaden pipes may be found in using for distributing purposes the 'lead-encased tin pipe' (see Chap. XIV.), for it has been found that the tin lining is proof against distilled water, Thames water, water from the chalk wells, and water highly charged with organic matter. It is only just to note, moreover, that searching chemical experiments conducted upon a portion of this pipe, which had been bent into a sharp curve, proved that the protective action of the tin lining was in no way disturbed by the pipe having been so bent.

Dr. Clarke's Soap Test.—The scale of hardness now universally employed in the chemical description of waters is that devised by the late Professor Clarke, viz. each degree of hardness is that which would be produced by one grain of chalk dissolved in a gallon of water, by whatever means it may be dissolved. If any other salt of lime, such as gypsum, is the cause of the hardness, the measure is still by grains of chalk. Clarke's soap test consists in the employment of a solution of soap of known strength, the quantity of which required to form a lather of a certain duration is a measure of the hardness. 'For the purpose of this test, in the first place, 16 grains of neutral chloride of calcium (prepared by solution of carbonate of lime in muriatic acid, and repeated evaporation to dryness, and re-solution and evaporation in an air-bath, until all the excess of acid is driven off) are dissolved in a gallon of distilled water, which is then said to be of the sixteenth degree of hardness; and a soap solution is formed by dissolving 120 grains of Hawes' white curd soap in a pint of proof spirit. The former of these liquids is used to graduate the latter. A graduated glass vessel, similar to an alkalimeter, is employed, each of the 100 measures being equal to 10 grains of distilled water. One hundred measures of the solution are put into a stoppered bottle capable of holding twice the quantity of water. The soap solution is carefully added, and the bottle with the stopper is agitated from time to time, and the soap solution added until the lather which is formed remains for five minutes on the surface of the liquid. This process is carried on until it is ascertained, by adding more soap or more spirit to the soap solution, that 32 measures of it will neutralise 100 measures of water of 16° of hardness.

'In testing the water, it is first violently agitated to get rid of any carbonic acid it may contain, and the air disengaged is sucked out; and this is done until it is supposed to be free of carbonic acid. The soap solution is then added to 100 measures of it in a stoppered bottle, and the mixture treated as above described, and the hardness estimated from the number of measures of soap solution required to cause a permanent lather to be formed, according to the subjoined table:—

Degrees of Hardness	Measures of Test Solution	Difference	Degrees of Hardness	Measures of Test Solution	Difference	Degrees of Hardness	Measures of Test Solution	Difference	Degrees of Hardness	Measures of Test Solution	Difference
1	3·2	2·2	5	11·6	2·0	9	19·4	1·9	13	26·7	1·8
2	5·4	2·2	6	13·6	2·0	10	21·3	1·8	14	28·5	1·8
3	7·6	2·0	7	15·6	1·9	11	23·1	1·8	15	30·3	1·8
4	9·6	2·0	8	17·5	1·9	12	24·9	1·8	16	32·0	1·7

'When the water is so hard that it will not yield a permanent lather with 32 measures of the soap solution, it must be diluted with an equal bulk of distilled water, and the solution of soap applied as before; and the process must be carried on till 60 measures of the soap solution have been used. If no result be still obtained, other 100 measures of water must be added, and the soap solution added till 90 measures of it have been used; then the number of soap measures used must be divided by the number of 100 measures in the mixture, and the quotient placed opposite the number of degrees in the table. Finally, this must be multiplied by the same division for the same number of degrees of hardness. The number of degrees of hardness nearly corresponds to the quantity of carbonate of lime, reckoned in grains, *equivalent* to the lime, magnesia, alumina, and iron in the gallon of water, reckoning the hardness by grains corresponding to the degrees.'*

When the actual measure of the soap test determined by the experiment is not given in the table, the number of degrees of hardness will correspond to the next lower number of degrees, and a fraction whose numerator is the difference between the actual number of measures required and the next lower number of measures in the table, and the denominator is the "difference" taken from the column of "differences;" thus 25·8 actual measures of the solution will correspond to $12\frac{25{\cdot}8-24{\cdot}9}{1{\cdot}8}=12{\cdot}5$ degrees of hardness.

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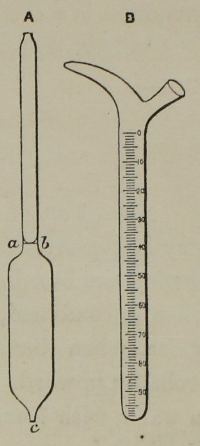
* Manual of Chemistry. Dr. R. M. Glover, F.R.S.E.

A and B, fig. 1, represent a standard pipette and a graduated burette, respectively, as manufactured by Messrs. Griffin & Sons specially for Clarke's test ; the latter is for measuring the quantity of soap-test solution, and is graduated into test measures, each equal to 10 grains of water, and every test measure (degree) divided into fifths. The pipette holds below *a b* 100 test measures of water (= 1,000 grains).

Fig. 1.



When the pipette is emptied, the drop of water at the beak *c* must be *drained* out, as it belongs to the measured quantity. It should not be blown out, for by this means the carbonic acid exhaled would affect the quality of the water.

Water at and below 6° of hardness is considered 'soft;' above this, water is considered 'hard,' as the hardness then first becomes perceptible in washing.

The degree of hardness is influenced in some cases by different causes. In spring water it is sometimes reduced one or even two degrees by passing it through a fresh filter ; but this change only occurs to the first portion of the water that passes through. The cause of this decrease of hardness proceeds from the free carbonic acid that usually exists in fresh-drawn water, but which is abstracted from it and secreted in the interstices of the filtering material in its passage through. To guard against the mistakes which arise from the presence of this acid in ascertaining hardness Professor Clarke directed that the bottle should be well shaken.

The hardness of water is of two kinds, temporary and permanent. The former is so called because it is capable of being reduced by boiling. Permanent hardness usually arises from the presence in the water of lime and magnesia in combination with sulphuric acid, whilst temporary hardness arises from the same earths in combination with an excess of carbonic acid. No amount of boiling will soften 'permanently' hard water, indeed the hardness is considerably increased by the operation.

Hard Water versus Soft.—The question of hard water *versus* soft may be viewed with regard to health, and domestic and manufacturing economy. On the first point, a favourite ground for argument has been the characterestic differences in health, *physique*, mortality, &c., of the populations of hard and soft-water districts respectively. A commission appointed by the French Government concluded from the evidence given before them, that the men were finer grown, and that less conscripts were refused on the ground of insufficient stature, or something of that kind, in the hard-water districts than in the soft-water districts. Similar evidence was also given before a commission appointed by the Austrian Government, and it was also reported that the men are better formed, that the bones are stronger and better formed, and that there is better health in moderately-hard-water districts. In exceptional cases, however, fine races of men are found in soft-water districts; an example of which is met with in the Highlanders of Scotland—a proverbially stalwart race. It is supposed that four-fifths of the globe yield hard water. Dr. Letheby, in his evidence before the Royal Commission on Water-Supply, stated that, in his opinion, water of between 10° and 15° of hardness is, on the whole, the most proper water for the supply of a city. The question, however, is, like many others connected with water-supply, open to much discussion, and various opinions on both sides have been expressed by good authorities. Soft water would seem to have a secondary rather than a direct influence upon health, through the medium of personal cleanliness, more of course among the poorer classes of the population.

The consumption of soap is amongst the most important items of domestic economy, and it has been estimated that for each degree of hardness 2½ ounces of soap are uselessly consumed in every hundred gallons of water. From the manner in which the ordinary processes of washing are conducted, it would seem to be the hardness after boiling, rather than that before boiling, which would have to be taken into consideration in determining the total loss of soap for any given quantity of water used. For domestic use generally, baths, culinary purposes, &c., soft water is decidedly superior, on account of its great solvent powers; while for manufacturing purposes, dyeing &c., the softer water has an undoubted advantage over the harde[illegible] For brewing bright ales, a hard water is required; but for stout and porter, soft water renders necessary a smaller quantity of malt and hops. Rain water, which is of all natural waters the softest, may be used with great advantage and economy in domestic and other operations, where the small quantity of acid and carbonaceous impurities it contains, and the somewhat disagreeable flavour it possesses, may be considered unobjectionable.

Where water has to be stored or to remain exposed, as in reservoirs, for any length of time, there is, on the one hand, the greater liability of soft water to absorb noxious gases, and, on the other, the tendency with hard water to foster vegetation of various kinds. Waters from the new red sandstone are worse even than the chalk waters in this latter respect. Water softened by Clarke's process is comparatively free from this objectionable tendency.

For drinking in its natural state a hard water is almost universally considered the more pleasant, partly from its greater aëration, and partly on account of the saline ingredients rendering it palatable. As far as the effects of these ingredients are concerned, it has been ably remarked that the human laboratory is quite capable of separating from the water that which it does not require, and of passing it off by the excretory organs.

Clarke's Softening Process.—'In order to explain how this invention operates, it will be necessary to glance at the chemical composition and some of the chemical properties of chalk; for while chalk makes up the great bulk of the matter to be separated, chalk also contains the ingredient that brings about the separation. The invention is a chemical one for expelling chalk by chalk.

'Chalk then consists, for every 1 lb. of 16 oz. of—

Lime	9 oz.
Carbonic Acid	7 oz.

'The 9 oz. of lime may be obtained apart by burning the chalk, as in a lime-kiln. The 9 oz. of burnt lime may be dissolved in any quantity of water not less than 40 gallons. The solution would be called lime water. During the burning of the chalk to convert it into lime, the 7 oz. of carbonic acid are driven off. This acid, when uncombined, is naturally volatile and mild; it is the same substance that forms what has been called soda water, when dissolved in water under pressure. So very sparingly soluble in water is chalk by itself, that probably upwards of 5,000 gallons would be necessary to dissolve 1 lb. of 16 oz.; but by combining 1 lb of chalk in water with 7 oz. additional of carbonic acid (that is to say, as much more carbonic acid as the chalk contains), the chalk becomes readily soluble in water, and when so dissolved is called bicarbonate of lime. If the quantity of water containing the 1 lb. of chalk, with 7 oz. additional of carbonic acid, were 400 gallons, the solution would be a water of the same hardness as well water from the chalk strata, and not sensibly different in other respects.

'Thus it appears that 1 lb. of chalk, scarcely soluble at all in water, may be rendered soluble in it by either of two distinct chemical changes: soluble by being deprived of its carbonic acid when it was capable of changing water into lime water, and soluble by combining with a second dose of carbonic acid, making up bicarbonate of lime.

'If a solution of the 9 oz. of burnt lime, forming lime water, and another solution of the 1 lb. of chalk and the 7 ozs. of carbonic acid, forming bicarbonate of lime, be mixed together, they will so act upon each other as to restore the 2 lbs. of chalk, which will, after the mixture, subside, leaving a bright water above. This water will be free from bicarbonate of lime, free from burnt lime, and free from chalk, except a very little, which we keep out of account at present for the sake of simplicity in this explanation.

'The following table will show what occurs when this mutual action takes place:—

Agents.			
Bicarbonate of lime in 400 gallons	chalk	16 oz.	=2 lbs.
	with carbonic acid	7 oz.	
Burnt lime in 40 gallons of lime water		9 oz.	

'But instead of the whole chalk being separable by the process from the water, only ten-elevenths would be separated, so that with regard to the chalk the accurate result would be expressed if we suppose 440 gallons of similar water to be operated upon containing 17½ oz. of chalk. There would be separated 16 oz., there would remain in solution 1½ oz. Or, to express the result with reference to a single gallon, such gallon would contain of chalk, if unsoftened 17½ grains, if softened 1½ grains, and would deposit 16 grains.

'Thus our supposed water would be 17½ degrees of hardness before softening, 1½ degrees after softening. And this would be the real result, supposing there were in the water no other hardening matter than chalk; but in the best quality of chalk water from springs or wells in the chalk strata around the metropolis, there is actually present a small proportion of other hardening matter, such as to prevent the water from being softened lower than 2½ degrees. A gallon of such water, after being evaporated, was found to have held in solution of solid matter—

	Grains.
Before softening	23
After do.	7
The difference	16

was due to chalk removed by the softening process. These explanations will make it easy to comprehend the successive parts of the softening process.'

The following is an analysis by Mr. Dugald Campbell, F.C.S., of a sample of the water supplied from the new works at Canterbury, and submitted to Clarke's process:—

FOREIGN MATTER PER GALLON.

	Before. Grains.	After. Grains.
Carbonate of Lime	15·96	1·39
Sulphate of Lime	0·08	0·07
Nitrate of Lime	2·06	2·04
Magnesia (probably as silicate)	0·29	0·27
Chlorides of Sodium and of Potassium	3·45	3·41
Silica	0·96	0·40
Oxide of Iron	0·16	none
Volatile Matter	0·96	0·80
Total	23·92	8·38
Hardness	14·9°	3·8°
	Cubic inches.	Cubic inches.
Oxygen	2·21	2·09
Nitrogen	5·90	5·90
Total	8·11	7·99

From the above it will be seen that the softening process has practically no effect upon the aëration of the water, there being a loss of only ·12 out of a total of 8·11 cubic inches.

Professor Tyndall has recently applied the electric light to the comparison of different waters supplied to various towns; and the result is, that such apparently clear waters as those of Loch Katrine seem, under this searching test, to be water of a muddy pool compared with the unyielding transparency of the Canterbury water, which is brought about mainly by the effective precipitation of foreign matters with the carbonate of lime in the softening process.