II. "The Removal of Micro-organisms from Water." By Percy F. Frankland, Ph.D., B.Sc., F.C.S., Assoc. R. Sch. Mines, Demonstrator of Chemistry in the Normal School of Science, South Kensington Museum. Communicated by E. Frankland, F.R.S. Received May 18, 1885.

The overwhelming evidence which has been now accumulated of the fact that some at least of the diseases called "zymotic" are propagated by means of living organisms, renders it interesting to discover in what manner such organisms may be removed from the media—air and water—through which they are in general distributed. In the following pages I have the honour to bring before the Royal Society the results of some experiments upon which I have been recently engaged, with a view to discover whether and to what extent micro-organisms may be removed from water by submitting this medium to some of the various processes of treatment which are in vogue for its purification. For although the chemical efficiency of numerous methods of water-purification has been largely studied, little has been done in the matter of determining their value as agents for the removal of micro-organisms.

The method of investigation which I have adopted was to take water in which the number of organisms was approximately known, submit this to treatment in such a manner as not to introduce extraneous organisms during the experiment, and then determine the number of organisms which remained in a given volume of the water after treatment. Since we are doubtless at present only acquainted with a few of the micro-organisms which are capable of producing disease, it appeared to me to be, in the first instance, desirable to study the question irrespectively of the nature of the organisms, and only to take into consideration their aggregate number before and after treatment. Moreover the employment of specific organisms would in all cases have greatly enhanced the difficulty of the experiments, and would in some cases have actually rendered them impossible.

The organisms generally used in these experiments were those which develope in diluted urine after exposure to the air. The solution was further diluted more or less with water so as to obtain a liquid containing a convenient number of organisms in a given volume.

The method of determining the number of organisms present in the waters, both before and after treatment, was, with a few modifications, that devised by Koch, in which a definite volume of water is mixed with sterilised nutritive gelatine and then poured out upon a

glass plate, when, after the lapse of a few days, the colonies derived from the individual centres of life can be counted by means of a lens, and from this the number present in a cubic centimetre or any other volume of water can be calculated. The following is a description of the exact mode of procedure adopted :—

Determination of the Number of Micro-organisms in Water.

The nutritive gelatine was prepared thus:—1 lb. of lean meat is finely minced and then infused with $\frac{1}{2}$ litre of water for 1—2 hours, the solid part being then strained off through linen. 100 grams of white French gelatine is allowed to soak in another $\frac{1}{2}$ litre of water, and to this the extract of meat obtained above is added. The whole is now boiled for a few minutes to complete the solution; 10 grams of peptone and 1 gram of common salt are then added and dissolved. The mixture so obtained gives an acid reaction, which is carefully neutralised with carbonate of soda. The liquid is now clarified by beating in the contents of two or three eggs along with the broken shells, the whole being briskly boiled for a few minutes. The coagulated albumen rises to the surface and carries with it the other solid particles in the liquid. On then straining through linen, an almost clear liquid is obtained, which is finally clarified by passing through filter-paper kept hot by means of a water-jacket. On cooling this liquid, it sets to a yellowish-brown transparent jelly. Whilst still liquid it is poured into clean test-tubes, so that each of these contains 2 or 3 c.c. The test-tubes are tightly plugged with cotton-wool, and then sterilised by steaming them for half an hour, on three consecutive days. Tubes thus prepared were found to keep for an indefinite period of time. The glass plates destined to receive the film of gelatine were well washed, and then placed in a copper box provided with a tightly fitting lid, the whole being sterilised by heating for at least three hours to 150° C.

The glass dishes in which the gelatine plates are placed during the development of the organisms were always well washed, and then rinsed with a 2 per cent. solution of mercuric chloride immediately before use. Some of the same solution of mercuric chloride was poured into the bottom dish, so as to preserve the internal atmosphere saturated with moisture, and the two dishes were always placed in a porcelain tray containing a solution of mercuric chloride, so that the interior of the dishes was disconnected from the outside air by means of a mercuric chloride seal, whereby all ingress of organisms from the atmosphere was prevented during incubation. The dishes also contained a small glass tripod, bearing a glass plate, the surface of which was carefully levelled by placing the dishes on a table provided with three screws. When the apparatus is thus prepared, the sterilised plate is rapidly transferred to the levelled plate, the gelatine is carefully melted in

its test-tube, and before removing the cotton-wool plug the latter is burnt outside, so as to destroy any organisms that may be adhering to the exterior. A given number of drops of the water or other liquid under examination are now introduced into the open test-tube by means of a pipette, which has been previously sterilised by heating it nearly to redness in a Bunsen flame. The water and liquid gelatine are mixed by agitation, and then quickly poured out on to the sterilised plate, the glass cover being immediately replaced. The whole operation is so managed that the time of exposure to the air is reduced to a minimum. A solution of mercuric chloride is then poured into the porcelain tray as already described, and when the gelatine has set, which generally takes place in about ten minutes, the dishes are placed in a cupboard, and maintained at a temperature of 20—25° C.

After a period of incubation, varying from 3—6 days, the organisms make their appearance in isolated colonies, which may be readily counted with the assistance of a lens. The operation of counting is greatly facilitated by placing the plate on a black ground, ruled in squares.

That when due precautions are taken in the execution of this process little or no appreciable error is introduced by the unavoidable but momentary contact of the gelatine with the air, was proved by making blank experiments, in which all the abovementioned operations, excepting the addition of water, were performed, and in these cases no organisms were found. Additional proof of this is also furnished by the fact that on several occasions no organisms were found in the course of the experiments to be described below.

The experiments were in nearly all cases made in duplicate, the concordance in the results of parallel experiments being, on the whole, very satisfactory ; occasionally, however, wide discrepancies did occur, but these could in most cases be accounted for through the water under examination not having been rendered sufficiently homogeneous by agitation.

Experiments on the Filtering Power of Different Substances.

The substances selected for experiment were natural greensand, silver sand, powdered glass, brickdust, coke, animal charcoal, and spongy iron.

These substances were all obtained in a fine state of division by powdering them in a mortar, and then passing them through a sieve (40 meshes to the inch). The filters were constructed of pieces of glass tubing (1 inch diameter), drawn off at one extremity to a small aperture ; the latter was plugged with a small quantity of asbestos, and upon this was placed a column 6 inches in height of the closely packed filtering material, the surface of which was again protected by

a thin layer of asbestos. Before use, the filter thus prepared was sterilised by heating it to a temperature above 150° C. for at least three hours. After sterilisation the filter was at once put in operation by supplying the infected water at the wide end of the tube, the filtered water being collected when required in a vessel sterilised in the same way beneath the lower extremity of the tube. In those experiments in which the filtration was carried on for many days, or even weeks, the infected water was constantly supplied to the filter by means of an inverted flask fitted with a delivery-tube, the latter dipping into the water above the filtering material. The following results were obtained with the various materials :—

Greensand.—The urinous water passed through this filter, on starting, at the rate of 2·07 inches per hour. The sand was highly ferruginous, and the filtered water contained a noticeable proportion of iron.

On examining the unfiltered water, it was found to contain 64 centres of life in one, and 97 centres per c.c. in a duplicate experiment; these consisted almost wholly of organisms causing liquefaction of gelatine, a few fungi, and the remainder small spherical colonies. In the filtered water, on the other hand, there were no organisms of any description discoverable. *The filtration had thus completely sterilised the water.*

In order to ascertain whether the greensand would continue to exercise this influence, the arrangement for continuous filtration, as already described, was put in operation, and after being in action for thirteen days, during which time 7·1 litres of water passed through, the efficiency of the filter was again tested. The *unfiltered* urine-water was found to contain 8193 centres per c.c. The *filtered* water was found to contain 1071 centres per c.c. These experiments show that although the original power of the greensand was broken down, the filter was still arresting a considerable proportion of the organisms present in the water passing through it.

The efficiency of the filter was again determined after the continuous filtration had proceeded for one month, when 20 litres of water had passed through. The following results were obtained :—

The *unfiltered* water contained ..	1281 centres per c.c.
The *filtered* ,, ,, ..	779 ,, ,,

On the whole, therefore, even after the lapse of an entire month, a notable proportion of the organisms was still being removed by the greensand filter.

Animal Charcoal.—Perfectly similar experiments were made with this well-known filtering material. On examining the initial efficiency of the filter, it was found that whereas the *unfiltered* water contained so many organisms that the gelatine on the plates had become entirely

liquefied, the *filtered* water did not contain in either of two experiments any organism whatever. The filter had thus completely sterilised the water passing through it.

The rate of filtration was considerably less rapid than in the case of the greensand, being only 0·82 inch per hour. Continuous filtration was then carried on for twelve days, during which time 4·2 litres of water passed through, after which the unfiltered and filtered waters were again examined.

The *unfiltered* water contained ..	2792 centres per c.c.
The *filtered* ,, ,, ..	No organisms of any kind.

Thus the efficacy of the filter remained unimpaired after twelve days' continuous action.

After acting for one month, 14·6 litres of water having passed through, the waters were again examined.

The *unfiltered* water contained..	1281 centres per c.c.
The *filtered* ,, ,, ..	6958 ,, ,,

Thus at the end of one month the filter was actually delivering water more highly impregnated with organic life than that with which it was supplied.

Spongy Iron.—The filtering power of this material was also examined by means of a similar series of experiments. The rate of filtration at the commencement was 1·84 inches per hour, and the following results were obtained :—

Unfiltered water contained....	80 centres per c.c.
Filtered ,, ,, ...	No organisms whatever.

After twelve days' continuous filtration, 3·6 litres of water having passed through, the following results were obtained :—

Unfiltered water contained..	2792 centres per c.c.
Filtered ,, ,, ..	No organisms whatever.

Again, at the close of one month's continuous filtration, 9 litres of water having passed through, the examination was repeated :—

Unfiltered water contained..	1281 centres per c.c.
Filtered ,, ,, ..	2 ,, ,,

The column of spongy iron, 6 inches in depth, was thus able to remove all the organisms from the water for upwards of twelve days, and even at the end of the month, the water after filtration was almost destitute of organic life. The rate of filtration was, however, greatly diminished in the course of the month during which the filter was in operation. It is worthy of notice that the organisms found in the filtered water were all of the same kind, and caused no lique-

faction of the gelatine, whilst a number of those in the unfiltered water produced liquefaction of this medium.

Brickdust.—The following results were obtained with a filter constructed similarly to the above, and charged with pulverised red brick, the powder being passed through the before-mentioned sieve.

Initial efficiency.

Unfiltered water contained..	3112 centres per c.c.	
Filtered ,, ,, ..	732 ,, ,,	

After being in action for five weeks, during which time 12·75 litres of water passed through the filter—

Unfiltered water contained..	5937 centres per c.c.
Filtered ,, ,, ..	406 ,, ,,

This material, therefore, does not wholly remove the organisms, even when fresh, but it continues, even after five weeks, to remove a considerable proportion of them.

Coke.—With this material, which was also used in the same state of division, the following results were obtained:—

Initial efficiency.

Unfiltered water contained..	3112 centres per c.c.
Filtered ,, ,, ..	No organisms whatever.

After being in action for five weeks, when 13·25 litres of water had passed through—

Unfiltered water contained..	5932 centres per c.c.
Filtered ,, ,, ..	86 ,, ,,

This substance, therefore, possesses filtering powers which are second only to those of spongy iron; at the outset the result is equally perfect with both, and even at the close of five weeks' continuous work the coke removes a large proportion of the micro-organisms present in the unfiltered water. Moreover, the rate of filtration through coke was considerably greater. In the case of the coke, as in that of the spongy iron, the organisms found in the filtered water were almost exclusively of one kind, only one colony causing liquefaction, forming an exception.

Silver Sand.—Owing to the highly ferruginous character of the greensand employed in the previous experiments, and bearing in mind the well-known antiseptic properties of salts of iron, it was deemed advisable to investigate the filtering power of sand free from iron. The silver sand employed for this purpose was digested for some days with hydrochloric acid, the latter then carefully washed out, and the filter sterilised as already described. The following results were obtained with this material:—

The rate of filtration was exceedingly rapid, viz., 1 inch in less than two minutes, or more than 30 inches per hour. The number of organisms found in the unfiltered and filtered waters respectively were—

Unfiltered water......	11,232 centres per c.c.		
Filtered ,, ...	1,012	,,	,,

Thus already at the outset the silver sand filter fails to arrest all the organisms in the water, although it very considerably diminishes their number, even when the rate of filtration is exceedingly rapid.

Powdered Glass.—This material also was employed, with a view to determining the value of non-ferruginous siliceous matter. The rate of filtration in this case was also very great, viz., 1 inch in less than eight minutes.

The following results were obtained :—

Unfiltered water	11,232 centres per c.c.		
Filtered ,, ...	792	,,	,,

The results obtained with the powdered glass very closely resemble those obtained from the silver sand; but as neither were efficient filters, even at the outset of their action, no further experiments were made with them.

Removal of Micro-organisms by Agitation with Finely Divided Solid Matter.

The above experiments show that micro-organisms may be more or less completely removed by mere contact with solid particles, some of which are incapable of exerting any chemical action upon them; it therefore appeared of interest to ascertain whether these organisms may be removed by agitating the water with the same substances, and then allowing them to subside. The experiments undertaken with this object were conducted in the following manner :—

50 c.c. of urine-water, in which the number of organisms was determined, were placed in a small accurately stoppered bottle, previously sterilised by being heated to 150° C., for at least three hours. A given weight of the substance was placed in a small test-tube, plugged with cotton-wool, and then sterilised in the same way. The sterilised substance was then transferred to the water in the stoppered bottle, and the latter violently shaken for a definite length of time, after which it was allowed to stand at rest until complete subsidence had taken place. Some of the clear supernatant liquid was then taken out with a pipette, and examined for organisms by means of gelatine cultivation in the manner already described. The substances were in all cases employed in the same state of division as in the filtration experiments.

Spongy Iron.—5 grams of this substance were shaken up with 50 c.c. of urine-water in one case for one minute, and in another for fifteen minutes; in both cases the waters were subsequently allowed to subside for half an hour before examination. The following results were obtained:—

Untreated water		609 centres per c.c.
Treated ,,	shaken for 1 minute.	28 ,, ,,
,, ,,	,, ,, 15 minutes	63 ,, ,,

Thus the reduction in the number of organisms by agitation is exceedingly marked, and curiously the most favourable result was obtained when the agitation was only continued for a single minute. A pure cultivation was not obtained in the treated water, some colonies producing liquefaction of gelatine, and others not, thus presenting a contrast to the results obtained by filtration through this material.

Chalk.—1 gram of water was shaken up with 50 c.c. of urine-water for fifteen minutes, and then allowed to subside for five hours. The following results were obtained:—

Untreated water	8325 centres per c.c.
Water after 15 *minutes' agitation with chalk*	274 ,, ,,

A very large reduction indeed in the number of organisms was thus obtained.

Animal Charcoal.—1 gram of animal charcoal was shaken up with 50 c.c. urine-water for fifteen minutes, and then allowed to subside for nearly five hours. The following results were obtained:—

Untreated water	8325 centres per c.c.
Water after 15 *minutes' agitation with animal charcoal*	60 ,, ,,

The efficiency of the animal charcoal in this respect is thus very markedly greater than that of chalk.

Coke.—1 gram of coke was shaken up with 50 c.c. of urine-water, and then allowed to subside for forty-eight hours, as the water did not clear before. The following results were obtained:—

Untreated water	Too numerous to be counted.
Water after 15 *minutes' agitation with coke*	No organisms whatever.

It thus appears that simple agitation with coke for fifteen minutes is sufficient to entirely remove all organisms.

China Clay.—1 gram of this was shaken for fifteen minutes with 50 c.c. of urine-water; subsidence was not complete for five days. On examining the clear water it was found to yield a very large number of organisms indeed, thus showing that prolonged subsidence with

finely divided matter like clay is not conducive to the separation of micro-organisms.

A similar result was obtained with brickdust, which, however, did not take quite so long to subside.

Effect of Subsidence on Micro-organisms in Water.

As in the above agitation experiments the water for examination was always taken from the clear upper layers, it became of interest to know whether the micro-organisms would not, by subsidence alone, separate out from the upper layers without the influence of solid particles. In order to ascertain this, three sterilised Winchester bottles were filled up to the shoulder with urine-water, and plugged with sterilised cotton-wool. The bottles were placed in a room (temperature about 10° C.) and left at perfect rest; the number of organisms in the urine-water was ascertained at the outset of the experiment, again at the end of six hours the number was determined in one of the bottles, at the end of twenty-four hours in the second bottle, and lastly, at the end of forty-eight hours in the third bottle. The numbers found were as follows:—

Hours of subsidence.	No. of centres found per c.c. of water.
0	1,073
6	6,028
24	7,262
48	48,100

These experiments show that far from there being any tendency for the upper layers of water to become deprived of organisms by subsidence, the tendency is for the number to increase very rapidly indeed.

Effect of Clark's Process on Micro-organisms in Water.

Owing to the encouraging results obtained by agitating water with finely divided chalk, it appeared probable that still more striking effects would be obtained if the chalk were present in a more finely divided state, such as is the case when water is softened by means of lime (Clark's process). In order to ascertain the effect of Clark's process in this respect, three stoppered Winchester bottles were taken, and to each were added 2 litres of ordinary Thames water, to which some urine-water had been added, so as to impart a convenient number of organisms. To two of these bottles 100 c.c. of clear lime-water (1 c.c. = 0·0013 gram CaO) were added, calculated to remove 11·6 parts of carbonate of lime per 100,000 parts of the water. Each of these bottles was violently shaken, and then allowed to subside for eighteen hours. The third bottle, to which no lime-water was added,

was first tested for the number of organisms contained in the water used in the experiment. After eighteen hours the two bottles to which lime-water had been added were tested without disturbing the precipitate, and also the third bottle containing the untreated water which had been left at rest in the same place as the other two. The following results were obtained:—

Untreated water	85	centres	per c.c.
,, ,, *after* 18 *hours' rest*	1,922	,,	,,
Water after Clark's process and 18 *hours' subsidence*	42	,,	,,

In order to appreciate the real effect of the treatment by Clark's process, it is necessary that the treated waters should be compared, not with the original water, but with the latter after eighteen hours' rest, for this shows what the condition of the water would have been at the time of testing if no lime-water had been added. It is evident that after the subsidence of the carbonate of lime precipitate has taken place, there is every probability of the organisms becoming again distributed throughout the upper layers of the water, and with a view of determining whether this actually takes place or not, the same waters which had remained well stoppered and at rest were again tested after the lapse of ten days. It was then found that the untreated as well as the softened waters contained immense numbers of organisms in their upper layers.

As the effect of Clark's process in removing organisms from water appeared to be of great practical importance, the above experiments were repeated, the conditions being essentially the same as before. The following results were obtained:—

Untreated water...............	37	centres	per c.c.
,, ,, *after* 21 *hours' rest*	42	,,	,,
,, ,, *after* 48 *hours' rest*	298	,,	,,
Water after Clark's process and 21 *hours' subsidence*	22	,,	,,
Water after Clark's process and 48 *hours' subsidence*	166	,,	,,

Owing to the number of organisms in the original water having been very much smaller, the results are not so pronounced as in the former case, the main facts are, however, fully substantiated.

It appeared also to be of interest to ascertain what results are obtainable on the large scale. For this purpose the process of softening as practised at the Colne Valley Waterworks at Bushey, near Watford, was investigated, as well as the new modification of Clark's process devised by Messrs. Gaillet and Huet, which is now in operation at Mr. Duncan's, Clyde Wharf, Victoria Dock. I am indebted

to Mr. Verini, of the Colne Valley Waterworks, as well as to Mr. Duncan and Mr. Newlands, for their kindness in permitting me to carry out these experiments.

At the Colne Valley Waterworks, the hard water obtained from a deep well in the chalk is mixed with the requisite proportion of clear lime-water, and then allowed to settle in open tanks. The subsidence is so rapid that under favourable circumstances the upper layers of water are, after three hours' time, fit for distribution. On the occasion of my visit, however, boring operations were being carried on, and the water was in consequence milky, and the necessary subsidence after softening had to be increased to two days. I was unfortunately unable to obtain a perfectly representative sample of the water before softening, and the number of organisms found in the untreated water is probably in excess of that which was actually present in the unsoftened water itself. The following results were obtained :—

Unsoftened water..............	322 centres per c.c.
Water after softening and 2 days' subsidence (from main)	4 „ „

The almost complete absence of organisms in the softened water shows how perfect a result is obtained even on the large scale.

In the process of softening, due to Messrs. Gaillet and Huet as practised at Mr. Duncan's, the water from an artesian well is mixed with a suitable proportion of lime-water and caustic soda, the mixture being then made to pass upwards through a tower provided with diaphragms, which accelerate the precipitation of the carbonate of lime. The passage through this tower occupies a period of about two hours. Samples of water before and after treatment were examined with the following results :—

Well water	182 centres per c.c. (38 caused liquefaction of gelatine.)
„ *after softening*	4 centres per c.c. (None of the centres caused liquefaction of gelatine.)

These experiments, as well as those made in the laboratory, show that the softening of water by Clark's process is attended with a great reduction in the number of organisms, the best results being obtained when the clear liquid is separated from the precipitated carbonate of lime as speedily as possible.

Pasteur's Filter.—Through the kindness of Colonel Sir Francis Bolton, R.E., I have had the opportunity of examining one of the above filters, in which the water is made to pass through a cylinder of biscuit-porcelain. The one with which my experiments were made

consisted of ten such cylinders, and the water (ordinary Thames water) was forced through under a pressure of between 30 and 40 feet of water. Under these circumstances the filter commenced by yielding 1 litre in 40 minutes, or 36 litres per 24 hours, but already at the end of a fortnight's continuous action it was only delivering 1 litre in 1 hour 14 minutes, or rather less than 20 litres per 24 hours; and after $2\frac{1}{2}$ months the rate of filtration was 1 litre in 1 hour 22 minutes, or $17\frac{1}{2}$ litres in 24 hours.

The water both before and after filtration was examined for micro-organisms with the following results:—

Thames water..............	54 centres per c.c.
,, *after filtration*..	0

The water before and after filtration was also submitted to chemical analysis with the following result:—

Results of Analysis expressed in Parts per 100,000.

	Thames water. Before filtration.		Thames water. After filtration.
Total solid matters............	33·70	....	30·04
Organic carbon	·282	....	·284
,, nitrogen	·028	....	·027
Ammonia	0	....	0
Nitrogen as nitrates and nitrites	·288	....	·289
Total combined nitrogen	·316	....	·316
Chlorine	1·9	....	1·9
Temporary hardness	15·7	....	14·4
Permanent ,, ...	4·9	....	5·3
Total ,, ...	20·6	....	19·7

Both samples were clear and palatable.

It thus appears that although this filter, when new, effects the complete removal of the micro-organisms in the water, it has but a very trifling influence upon the chemical composition of the water, the only change in this respect being a slight diminution in the amount of mineral matter present.

Micro-organisms in Potable Water.

I have also submitted numerous samples of natural waters of different origin to examination for the number of micro-organisms which they contain. My investigation in this direction is, however, still far from complete, but I append the results which I have obtained from a monthly examination of the various waters supplied to the Metropolis during the present year. When the history of the water is accurately

known, and due precautions in collecting samples have been taken, there can be no doubt that in many cases it is capable of throwing considerable light upon the quality of water and in assisting to interpret the results of chemical analysis.

The method of collecting samples which has been employed by me is the following:—

Small (about 3 oz.) bottles, accurately stoppered, and sterilised by being heated to 150° C. for at least three hours, are kept tightly stoppered until they are to be used. In taking the sample, the outside of the bottle is well washed in a stream of the water to be examined, the stopper is then removed, the bottle nearly filled with water, and the stopper replaced as rapidly as possible. The examination of the water should follow as soon as possible after collection.

The following results were obtained with samples taken as above from the mains of the various companies supplying London:—

	No. of centres per c.c. of water.		
	January.	February.	March.
Chelsea	8 (0 liq.)*	23 (2 liq.)	10 (0 liq.)
West Middlesex	2 (0 liq.)	16 (2 liq.)	7 (0 liq.)
Southwark	13 (0 liq.)	26 (2 liq.)	246 (1 liq.)
Grand Junction	382 (4 liq.)	57 (23 liq.)	28 (12 liq.)
Lambeth	10 (2 liq.)	5 (0 liq.)	69 (1 liq.)
New River	7 (4 liq.)	7 (0 liq.)	95 (1 liq.)
East London	25 (0 liq.)	39 (0 liq.)	17 (0 liq.)
Kent	10 (0 liq.)	41 (0 liq.)	9 (1 liq.)

* Liq. denotes that the organisms caused liquefaction of the gelatine.

It would be premature to draw any conclusions from these results, and I purpose to continue these observations over a longer period of time.

The waters were also at the same time submitted to chemical analysis, so that their biological and chemical characters might be compared; the results are given below.

General Conclusions.—(1.) Of the substances experimented with, only greensand, coke, animal charcoal, and spongy iron were found to wholly remove the micro-organisms from water filtering through them, and this power was in every case lost after the filters had been in operation for one month. With the exception of the animal charcoal, however, all these substances, even after being in action for one month, continued to remove a very considerable proportion of the organisms present in the unfiltered water, and in this respect spongy iron and coke occupy the first place.

Results of Analysis expressed in Parts per 100,000.

London Waters.	Temperature in Centigrade degrees.			Total solid matter.			Organic carbon.			Organic nitrogen.			Ammonia.	Nitrogen as nitrates and nitrites.		
	Jan.	Feb.	Mar.	Jan.	Feb.	Mar.	Jan.	Feb.	Mar.	Jan.	Feb.	Mar.	Jan., Feb., and Mar.	Jan.	Feb.	Mar.
Thames.																
Chelsea	3°·8	5°·9	6°·2	30·78	31·04	30·24	·166	·188	·192	·017	·017	·033	0	·251	·272	·242
West Middlesex.	4·0	6·8	7·5	30·50	30·40	30·60	·171	·210	·218	·028	·021	·031	0	·267	·275	·253
Southwark	4·4	6·8	7·5	31·16	29·74	30·04	·221	·286	·181	·053	·025	·030	0	·291	·283	·241
Grand Junction.	2·8	6·0	6·8	27·90	30·14	30·46	·255	·314	·150	·043	·033	·023	0	·181	·278	·251
Lambeth	3·7	6·4	6·9	25·50	27·26	30·50	·181	·179	·174	·046	·019	·021	0	·181	·219	·256
Lea.																
New River	3·4	5·9	6·8	31·80	31·32	28·14	·085	·080	·100	·015	·012	·019	0	·326	·361	·272
East London ...	3·8	6·0	7·2	35·54	36·70	34·90	·192	·200	·200	·043	·019	·034	0	·341	·402	·327
Deep Wells.																
Kent	12·0	12·0	12·6	41·36	35·40	37·12	·039	·024	·033	·010	·006	·006	0	·463	·416	·423

(2.) The results obtained by agitating water with various solid materials show that a very great reduction in the number of suspended organisms may be accomplished by this mode of treatment, and the complete removal of all organisms by agitation with coke is especially worthy of notice.

(3.) Again, the results obtained with Clark's process show that we possess in this simple and useful mode of treating water a means of greatly reducing the number of suspended organisms.

(4.) Thus, although the production in large quantity of sterilised potable water is a matter of great difficulty, involving the continual renewal of filtering materials, there are numerous methods of treatment which secure a large reduction in the number of organisms present.

Moreover, in judging of the value of filtering materials from examinations of this kind, it is only reasonable that a preference should be given to those materials with which a practically pure cultivation is obtained in the filtrate over those materials which appear to exercise no selective action upon micro-organisms.

In conclusion, I would point out that it is very desirable that experiments of this kind should be greatly multiplied and repeated under varying conditions, and it is my intention to continue and extend this examination.

III. "A Memoir introductory to a General Theory of Mathematical Form." By A. B. KEMPE, M.A., F.R.S. Received May 18, 1885.

(Abstract.)

The memoir is divided into 426 short sections which are arranged under 42 heads. Each head is given in the abstract, with a brief reference to the nature of the sections it comprises, except in the case of the second head, viz., "Fundamental Principles," the sections under which are given almost in full.

§§ 1—2. *Scope of the Memoir.*

The object of the memoir is the treatment of the "necessary matter" of exact or mathematical thought as a connected whole; the separation of its essential elements from the accidental clothing—algebraical, geometrical, logical, &c.—in which they are usually presented for consideration; and the indication of that to which the infinite variety which those elements exhibit is due.

The memoir is introductory only, comprising the statement of fundamental principles, and the vindication of their truth by a sufficient variety of applications.