SECTION III.

CHEMISTRY, METEOROLOGY, AND GEOLOGY.

ADDRESS

BY AUGUST DUPRÉ, Ph.D., F.C.S., F.R.S.

PRESIDENT OF THE SECTION.

IN this jubilee year there is a very general tendency in those occupying a position such as I now occupy before you, to review the progress made during the fifty years just elapsed in the various sciences to which our attention will be directed. The accomplishment of such a task would, however, involve too great a claim on your time and patience, even if it were in my power to do justice to the theme.

On the general subject I will therefore content myself in stating that, as far at any rate as modern times are concerned, sanitary science is, practically, a product of the last fifty years, and surely no other advance in art, science, or industry made during Her Majesty's reign has contributed more to the welfare and happiness of the nation.

In the following remarks I shall restrict myself to two questions, regarding which I may claim some special acquaintance, namely, the questions of water analysis and the treatment of sewage. Both subjects, I am afraid, have been frequently treated of at former sanitary congresses, and we are promised several papers on the subject to-day; but as they are, perhaps, the two most important questions on which the chemist can assist the sanitarian, I hope you will bear with me for a short time while I endeavour to bring some of the more salient features before you. In doing this I shall have to point out defects in our present methods, and shall venture to point out directions in which, in my opinion, further advance should be sought; for I believe that the function of a Congress such as this is not only the taking note of any progress made, but also to stimulate research and facilitate further progress. And now let us, in the first instance, turn to the question of water. Here, strictly speaking, all the chemist has to do is to find out the various substances contained in a given sample of water, and leave it to the medical man and sanitary engineer to draw their own conclusions, and apply their own remedies. Such a division of labour would be, ideally, the most perfect; and it is, I think, frequently carried out, as between the sanitary engineer and the chemist. The provinces of the medical man and the chemist are not however, as a rule, kept so strictly separate; nor are they, perhaps, so readily separable. The chemist thus frequently usurps the functions of the medical man, and the medical man those of the chemist; the result is not always such as would be most desirable or beneficial. As a chemist I trust I may be pardoned in saying that, in my opinion, the fault is more often on the side of the medical man than on that of the chemist. Questions, strictly medical, that arise in relation to our ordinary domestic water supply are, after all, but few; whereas, on the other hand, water analysis becomes every year more and more complicated and specialized, and requires a greater and greater amount of skill and knowledge for its successful prosecution, so much so that the time seems almost to have come for the setting up of a special class of chemists devoting themselves entirely to the examination of water.

Thirty or so years ago water analysis, I speak of it of course merely in relation to its sanitary aspect, was, comparatively speaking, a very simple matter. It consisted mainly, and I well remember the time, in the estimation of the total dry solid residue left by the water on evaporation, of the loss suffered by this residue on ignition, a loss usually put down as organic matter, and perhaps, a more or less rough examination of the nature of the mineral matters present. Gradually however, as the influence on health, exerted by the quality of the water consumed, became more and more recognised, the necessity for a more complete knowledge of the matters present in a water required for domestic use became increasingly pressing. New methods of analysis were devised and perfected until at the present day we are in possession of analytical processes which, so far as the detection and estimation of dead matters are concerned, leave but little to be desired. Without going minutely through these various processes, I may be permitted to glance shortly at some of them, mainly however in regard to the various constituents which it was, or is, desired to estimate.

The various substances found in a water, as far as they are of interest to the sanitarian, may be roughly divided into three classes. *Firstly*, mineral matters derived solely from the soil or rock through which the water has percolated; *secondly*, mineral matters derived either directly from organic matter, such as nitric acid and ammonia, or which, as being frequently found associated with certain kinds of organic matters, indicate by their presence the probable or possible pollution of the water by these organic matters, such as chlorine and phosphoric acid, always associated with the urine of men and animals; and *thirdly*, organic matters. Living organisms I leave out of consideration for the present.

In regard to matters falling into the first class, little or nothing need be said here, for unless they are present in excessive proportions they need not, as a rule, trouble the sanitarian. I of course exclude from this general statement all distinctly poisonous mineral matters occasionally found in potable waters, and also, for the present, such mineral matters as may exert an injurious action on the materials with which the water, in the course of domestic use, is brought into contact.

The next class, namely, those mineral matters directly derived from organic matters, or those the presence of which indicates the probable presence of organic matters, offers however far greater difficulties; not so much in regard to the analytical processes to be employed as in the interpretation to be put on the results obtained. This latter point, though by no means the only, is by far the main difficulty we have to deal with, and very serious differences regarding it exist among analysts. The matters falling into this category are mainly *nitric acid*, *ammonia*, *chlorine* and *phosphoric* acid, and, in a minor degree, sulphuric acid and the alkali metals, sodium and potassium.

Nitric acid.—This was early recognized as a most important feature in a sanitary analysis of water, and there is probably no single point connected with water analysis regarding which so many analytical processes have been elaborated, or which has raised more discussion in relation to the significance of the indications furnished. As regards the processes used for its quantitative estimation I need not trouble you here, they may be found fully described in many books and papers, and it must suffice to say that the analyst has a choice of a number which fulfil all requirements as regards accuracy and ease of execution. The choice of any particular process is greatly a question of training and convenience. As far as I myself am concerned, the process I chiefly employ is the indigo process, which, when carefully conducted, is accurate enough for all practical purposes. When however we come to the interpretation of the analytical data obtained, difficulties begin to crowd upon us. In the first place very few, if any, unpolluted waters are found free from nitric acid, and the mere presence of this acid cannot be taken as of any significance, and quantity has to be taken into account. The question thus presents itself, how does this nitric acid get

into the water? Now, in the first place, rain-water, which is the source of all our wells, spring or river water, always contains traces of nitric acid, and this nitric acid is probably produced mainly by purely physical agencies. The nitric acid from this source is, however, as far as we know at present, the only nitric acid thus produced, and its amount is, fortunately, extremely small, not more than a few hundredths of a grain per gallon on an average. The presence of this nitric acid clearly cannot be taken as indicating organic pollution. The main quantity of the nitric acid, however, is derived, there can I think be no doubt, from nitrogenous organic matters, chiefly of animal origin, which have been decomposed or destroyed by the vital action of certain micro-organisms. It would thus appear that whenever we find more than a mere trace of nitric acid in a water, we should be justified in concluding that the water under consideration had, at some previous stage of its history, been polluted by nitrogenised organic matters, mainly of animal origin, or, as in the case of water, these matters are, practically, mainly derived from sewage or surface drainage, that the water had been polluted by sewage or drainage from manured land or some similar source.

It was this consideration, I suppose, which led Prof. Frankland to use the expression, "previous sewage contamination," for which he has been so severely criticised by many.

Now in great measure I agree with Prof. Frankland in the notion this term was intended to express, although in its practical application it requires some modification and caution. This modification is required because we are acquainted with certain waters which contain appreciable quantities of nitric acid in excess of that derivable from rain-water, and which, nevertheless, from their position, depth, &c., cannot possibly have been subjected to any recent pollution by sewage or drainage from manured land, &c., and, therefore, as applied to such waters, the term is somewhat, not to say entirely, misleading. Not but that I believe that even in these cases the nitric acid is derived from nitrogenised animal matter by the intervention of micro-organisms; but this animal matter is not of recent origin, and may have been deposited contemporaneously with the chalk itself; it certainly is not derived from any recent sewage.

We are thus reduced to this position: the presence of nitric acid by itself, even when in appreciable quantity, cannot be taken as indicating sewage pollution (when I speak of sewage pollution I do not mean merely the liquid flowing in our sewers, but any organic matters derived from a similar source). What then is the amount of this acid, which, when found, must be taken as proving such pollution? I shall try to answer the question, as far as I can, later on.

Ammonia.—There is such a concensus of opinion regarding ammonia that I will pass it over, and merely indicate an exception to the general rule which I know sometimes misleads analysts.

In some cases waters contain considerable proportions of ammonia derived from nitric acid, probably due to the reduction of the latter by micro-organisms, sometimes by the metal pipes conveying the water. In such cases, the presence of ammonia therefore does not indicate more than the nitric acid would have done; this is the case, for example, with some of the London chalk water.

Chlorine.—This is one of the most important of the purely mineral constituents to take into consideration, in judging the quality of a water; chlorine, as before stated, being a constant constituent of urine, and one which, unlike some other mineral matters, when once it has found its way into the water, remains there and can be traced with certainty. In our endeavours, however, to draw conclusions, the same difficulties confront us as we found in the case of nitric acid. Chlorine is present in waters, its amount varies greatly even in unpolluted waters, according to the character of the soils or geological formations from which the water is derived, or even according to its geographical positions. Thus water from wells or springs in the neighbourhood of the sea, or of tidal rivers, even though considerably above high water, but within the influence of spray carried by winds, frequently shows an amount of chlorine greatly in excess of what it would be if removed from these influences.

Phosphoric acid.—This, like chlorine, is a characteristic constituent of urine, and, like the substances just considered, is also found in every natural water, but, unlike these, it is, according to my experience, rarely or never found in any notable quantity in a pure unpolluted water. The presence therefore of phosphoric acid in anything beyond minute traces, is in my opinion, perhaps the strongest evidence we can obtain, from mineral matters alone, that the water under consideration is polluted by sewage. In the long series of analyses which I made some years ago in conjunction with Dr. Cory, for the Medical Department of the Local Government Board, I could not unfrequently pick out the polluted samples by the fact of their containing a greater proportion of phosphoric acid than the unpolluted water, even when all other analytical methods failed to bring out any clear distinction. But although the presence of phosphoric acid in any notable quantity may be

taken as one of the strongest proofs of pollution, its absence must not be taken as proving the absence of pollution, for there are many natural causes at work tending to the removal of phosphoric acid.

The Alkali Metals.—In relation to these I will merely state that whereas sodium is the greatly predominating alkali in the urine of men, the urine of horses and cattle contains a considerable proportion of potassium, and hence a careful estimation of these two alkali metals in a polluted water may sometimes enable us to find out the particular source of its pollution. In some cases this may be of importance from a sanitary point of view.

The presence, or absence, of the various mineral matters so far considered is, however, of interest mainly as throwing light on the previous history of the water. In themselves they are not injurious, and undoubtedly a water may be perfectly wholesome in spite of its containing considerable quantities of these various matters. So much so is this the case that, as is well known, one of our foremost water analysts, in judging of the suitability of a water for drinking, practically ignores the presence of most of them, notably that of nitric acid. This is bad enough in the hands of a master, but in the hands of his followers it leads to serious mistakes. For, although these animal matters throw light mainly on the past, they also enable us, to a great extent, to read the future. A water containing these matters in certain proportions must, at some previous period of its flow, have been contaminated by animal matters, or what comes to the same thing, must have passed through soil thus contaminated. In its passage through soil or rock the organic matters are removed or changed into mineral matters, some of which remain in the water and testify to the prior presence of the organic matter. The mineral matters with which the organic matter was associated also remain in greater or less proportion in the water. Now it is well known that this destruction of the organic matters depends upon a variety of circumstances, such as the amount of pollution, temperature, aëration of the soil, &c., &c. These conditions vary during the seasons of the year, and also from year to year, and hence a water which at one time contains these mineral matters only may, at another time, contain the organic matters from which these were derived, or with which they were associated. These mineral matters therefore indicate the possibility, in some cases the absolute certainty, that the water in which they are found will, at some other period, be charged with organic matter. It is this consideration that gives importance to these mineral matters in water analysis.

It is, however, the proportions of actual organic matter present in judging of the fitness or otherwise of a sample of water which, for domestic use, has been, and still is, our chief guide. Various processes have been devised to enable the analyst to form some approximate estimate of the amount of organic matter present in a water, but no process as yet known enables him to determine its absolute quantity. The old process, namely, of heating the dry residue to a red heat and finding the loss it sustained thereby, has now, I suppose, been universally discarded as useless for the purpose. Nevertheless, for all those at least who do not employ the organic carbon and nitrogen process, the simple ignition of the dry residue often yields valuable results. A pure water residue is white and does not change colour on heating. A residue from a water containing organic matter is usually more or less yellow or brown; it darkens or blackens on heating, but becomes white on continued application of heat, the carbon gradually burning off. Carbon derived from vegetable sources generally burns off readily, whereas the carbon derived from animal sources usually burns off with difficulty. For myself I never omit this simple process.

The next process in point of time, and which is still in use, is what is known as the permanganate process, the object of the process being the estimation of the amount of oxygen which the organic matter present is capable of abstracting from a solution of permanganate; and from this forming some sort of estimate as to the amount or nature of the organic matter present. Many chemists have worked at this process, but the modification which in my opinion gives the best results consists in acting on the water with the permanganate and acid, in a stoppered bottle and at a given temperature. The advantages gained by this are: 1st, all influence which the atmosphere of the laboratory may have on the permanganate solution is excluded, and no correction for it is necessary; 2nd, the presence of even considerable proportions of chlorides does not prevent the application of this test, even sea water may be tested;* and 3rd, uniformity of temperature insures uniformity of results—and strictly comparative results. A modification of this process employed by some, namely, boiling the acidulated water in a flask with permanganate solution for ten minutes, is, as a rule, quite inadmissible,

* The hydrochloric acid liberated from the chlorides by the sulphuric acid decomposes permanganate, and chlorine is produced. When the process is carried on in an open vessel much of this chlorine escapes into the air, and is lost; if however a closed bottle is employed the chlorine is retained, and when at the end iodide of potassium is added for the purpose of estimating the amount of permanganate remaining, this chlorine liberates as much iodine as the permanganate would have done which was destroyed in its production, and is thus estimated in terms of permanganate.

for chlorides, under the conditions of the experiment, decompose permanganate, and the chlorine thereby produced is expelled by the boiling, and appears in the final result as organic matter. This permanganate process does not give us the actual amount of organic matter contained in the water examined, nor will it give us even the relative proportions of organic matter contained in different waters, unless the nature of the organic matter is the same, for different kinds of organic matter absorb widely different proportions of oxygen from permanganate. If, however, the nature of the organic matter is the same this process gives us relative quantitative results. Moreover, as I hope I shall be able to show, it is not so much the absolute proportion of organic matter as the relative proportion of oxygen absorbed, that is of value as a guide.

The next process in point of time is, I believe, the so-called albuminoid ammonia process proposed by Wanklyn, Chapman and Smith. This process has for many years enjoyed, and still enjoys, a very wide popularity in this country, in spite of the frequent attacks to which it has been subjected. This popularity is owing in the first place, I have no hesitation in saying, to the intrinsic merits of the process, but in the second place undoubtedly to the comparative ease with which it can be applied; and let us not be too ready to sneer at those making use of a process because it is easy to carry out. Ease of manipulation often means accuracy of results, or at least uniformity of results, which in most analytical processes is the great desideratum. The albuminoid ammonia process gives us, as most of you will know, in the first place the amount of free ammonia present in the water, and in the second place a certain, or perhaps I should say an uncertain proportion of the organic nitrogen, also in the form of ammonia, and this latter is known as albuminoid ammonia. The proportion of the total nitrogen yielded in this form by various kinds of organic matter undoubtedly varies within very wide limits, and it would be easy to make up two samples of water of which the one containing the least amount of organic matter would yield by far the greater proportion of albuminoid ammonia. In practice however this objection loses much of its force. The organic matters found in natural waters, although no doubt they differ from each other, do not range through the whole series of organic compounds and, as a rule, show a considerable degree of similarity, particularly when waters from similar sources are compared with each other, and the experienced analyst will not easily be misled by such variation. Moreover, let me emphasize once again, that our estimate of the quality of a water depends, in great measure, on a comparison between similar waters.

The last process, as applied to non-living organic matter contained in water, I propose to glance at, is the so-called organic carbon and nitrogen process devised by Professors Frankland and Armstrong. The process, when carried out skilfully, gives very good results as far as organic carbon is concerned; the results are less satisfactory in regard to organic nitrogen, particularly in the presence of much nitric acid. The process does not, as little as those previously considered, give us the actual amount of organic matter contained in the water analysed, inasmuch as it takes account of only two of the elements, but those, certainly the most characteristic, and leaves the rest out of consideration. It gives us, however, with a considerable degree of accuracy, the *actual* amount of one of the two elements, namely, the carbon, and that of the second, the nitrogen, with a more or less close approximation to the truth. In this respect the process has certainly the advantage over those previously considered. This advantage is, however, at present, to a great extent neutralized by the fact that the material at our disposal which can serve as a guide is incomparably smaller than that available in regard to the other two processes; and also by the far greater trouble and difficulty involved in its application. The former disadvantage will probably gradually diminish; the latter, however, will remain, and will act as a bar against its general adoption, as long at least as its superiority over the other process alluded to as a method of practical water analysis, is not definitely established, which can hardly be said to be the case at present.

Not improbably the estimation of organic carbon and of organic nitrogen will in future be carried out in two operations. Both estimations will thereby gain in accuracy, and the two processes can be carried out more readily in ordinary analytical laboratories than can the original process. Detmar's process for organic carbon and nitrogen; Dupré and Hake's organic carbon process; Kjeldahl's organic nitrogen process.

Thus far the analytical processes shortly passed in review deal with mineral and non-living organic matter merely, and on the whole they fulfil the object for which they were devised in a very satisfactory manner. When once, however, it was recognised that the injurious effects produced by the drinking of impure water were due not so much to the dead organic matter it contained as to the presence in it of living organisms, the importance to be attached to the dead organic matter naturally diminished.

This dead organic matter hence has occupied a position practically similar to that previously occupied by nitric acid, chlorine, &c., that is, the presence of the dead organic matter might in most cases be taken as an indication of the presence, or possible presence, of living organisms also. It was then that doubts began to be expressed as to the value of water analysis; some, I believe, going so far as to deny its value altogether. This doubt is, I think, best expressed by Dr. Buchanan in his report to the Local Government Board for 1881. In this he states, "The chemist can, in brief, tell us of impurity and hazard, but not of purity and safety. For information about these we must go, by the aid of what the chemist has been able to teach us, in search of the conditions surrounding water courses and affecting water services."

Now taken in the abstract there can, I think, be no doubt that Dr. Buchanan is right; but in practice this principle should not be applied too rigidly. There can of course be no doubt that an artificially polluted water may be prepared which, while containing an amount of infectious material which would render the water dangerous to those drinking it, would yet be passed as pure by the analyst. In practice, however, such cases very rarely occur, and ought never to occur. As a general rule the proportion of infectious matter that finds its way into a well or water-course is extremely small compared with the amount of non-infectious matter that finds its way into the same; and hence whilst the analyst might be unable to discover the presence of the infectious matter, if it alone were present, he will as a rule have no difficulty in detecting the presence of organic matter, or of products of its decomposition or those accompanying it, due to the far larger proportion of non-infectious material which has entered the well or water-course, &c. Such cases as that of the well at Caterham are, it is to be hoped, extremely rare. They are of the utmost value as showing how small a proportion of infectious matter may prove dangerous, but they must not be taken as proving that chemical analysis by itself is valueless. They should however teach this lesson to the analyst: whenever his analysis shows him undoubted indications of present or past pollution he should condemn the water, or rather, I should say, he should condemn the well or spring, &c., from which the water came, bearing in mind that the non-infectious matter, the presence of which can be proved, indicates the possibility of the presence of infectious matter, the presence or absence of which he cannot at present demonstrate.

The question yet remains to be answered: when, if ever, are we justified, from the results of chemical analysis, in pronouncing a water free from pollution and safe, and when must we pronounce it polluted and unsafe? This lies at the root of the matter, and is by far the most difficult question that comes before the analyst. The mere working out of an analysis is, comparatively speaking, a simple matter: it is the true interpretation of the results obtained that tasks the knowledge and experience of the analyst.

This difficulty was felt very early in the progress of water analysis, and many attempts have been made to overcome it by laying down certain general standards to judge by, and waters were divided into good, bad and indifferent.

Against the setting up of such general standards I have already repeatedly raised my voice, and wish to do so again before this Section. All such standards are fallacious: they serve only as crutches, so to speak, for the ignorant to lean on; the chemist who thoroughly knows his work does not require them, and those who do require them are not fit to undertake water analysis at all. It is the existence of these general standards that so frequently leads to mistakes. One sample of water is condemned because it contains a little more organic carbon, or yields a little more albuminoid ammonia, or absorbs a little more oxygen from permanganate than has been laid down as a standard, while another water is cheerfully passed because in these particulars it falls within the standard; and yet the first water may be perfectly wholesome and unpolluted in the proper sense of the term, while the second may be entirely unfit for use. As long as we are dealing with definite compounds or with non-living organic matters, however injurious they may be, it is always possible to state a quantity below which, if taken, they will not prove injurious; and general standards may have been of use. The moment however that we are dealing with living organisms capable of self-multiplication, this ceases to be the case, for what may be an infinitesimal quantity in the water may become a dangerous quantity in the body of the consumer. As long however as we cannot by analysis detect the infectious living matter, we must have some guide for drawing correct conclusions from the results of our analysis; and even should we gain this power, chemical analysis and the necessity of its true interpretation will not lose their value; and in fact the analyst who bases his conclusions solely on the presence or absence of dangerous organisms, commits the same mistake as he who only regards organic matter and neglects mineral matter derived from organic matter. For at the time of examination a water may not contain any infectious matter but may nevertheless show signs of general pollution, and thereby show that infectious matter may find its way into the water. What guide then do I recommend? For some kind of guide we must have. This guide was first, I believe, strongly insisted on by my friend Mr. Hehner and myself, in a paper read before the Society of Public Analysts in February, 1883.

It is the conformity of the water to, or its divergence from, the general character of the waters of the district from which it comes, or of the geological formations from which it springs, which from their position and surroundings may fairly be taken as unpolluted. In other words, district standards instead of general standards should be used.* This of course implies a knowledge of district standards, and these are not always easy to obtain, and the obtaining of them frequently necessitates the co-operation of the Sanitary Engineer to select the unpolluted samples; such co-operation is in every respect desirable, and should always be had recourse to in important cases. I freely confess that I have repeatedly been saved from error by such co-operations. District standards might also be obtained if analysts in all parts of the country would freely communicate their analytical results to their professional brethren. In the paper previously referred to we appealed for co-operation in the establishment of such standards to the members of our Society; professional jealousy, however, stands in the way. Perhaps this Society might give effective aid towards the accomplishment of so desirable an object by collecting and publishing standard analyses from all parts of the country from which they are obtainable. By the aid of such district standards, the analyst has, as a rule, no difficulty in giving an opinion regarding the purity or impurity of any water submitted to him, although he may not be able to prove the presence or absence of infectious matter. In the before mentioned paper several series of analyses are given of water collected along the Undercliff, I.W., which clearly demonstrate the polluted character of waters which, on the strength of any conceivable general standard, would have been pronounced as perfectly pure.

I cannot leave this subject without recording my high appreciation of the value in this respect of the sixth Report of the Royal Commission on Rivers Pollution.

Biological Methods.

I have already several times had occasion to allude to the fact that the injurious effect of polluted water is, in all probability, not to say certainty, due to the presence in it of living

* It is of course desirable, when possible, to collect the waters to be used as standards simultaneously with the suspected sample; but this is not absolutely necessary. It is one of the characteristic features of unpolluted waters, particularly in the case of deep wells, to remain practically uniform in composition through considerable periods of time, and a carefully chosen district standard will therefore remain available for some length of time.

organisms. Attempts have accordingly been made to detect these organisms, and a considerable degree of success has been achieved in this direction. Most careful water analysts have for many years been accustomed to the use of the microscope in the examination of water, and very often valuable results were thereby obtained. The first, however, who, so to speak, aided the microscope by adding a cultivating material to the water was, I believe, Mr. Charles Heisch. Mr. Heisch added some pure cane sugar to the water and examined the fungus found growing in sewage polluted water, in consequence of this addition, microscopically. The process has quite recently been again taken up with promising results. The best known biological method is, however, that brought forward by Professor Koch, of Berlin, which consists in adding a small but known quantity of the water under examination to a gelatinizing cultivating material. This mixture is spread on glass slides and examined after a time. If the water is free from organisms no growths make their appearance in the cultivating material, whereas, if the water contained any living organisms, or the germs of such organisms, these will grow and multiply, and thus become visible, each centre of growth corresponding to at least one germ or mature organism, and the number of such germs or organisms in a given bulk of water very approximately ascertained, and special organisms may even be identified. This method has been taken up warmly in this country by Dr. Percy Frankland, who has already published a number of valuable papers on the subject, and who, I am happy to see, is here and will favour us with a paper, and also by Dr. Bischoff and others, and we may look forward with confidence to valuable results from their hands. In theory nothing could well be better than this method; in practice, however, serious difficulties will have to be overcome before this method can be pronounced thoroughly reliable. Thus, some of these organisms grow best in the dark, others require light; some grow only at a moderately low, others only at a moderately high temperature; some like one, some another cultivating material. Hence the number of centres which one and the same water will yield may vary with all these conditions, and some kinds of organisms may not appear at all under one set of conditions, which appear in abundance under a different set of conditions. All these points, as well as others not mentioned, will have to be studied and cleared up before the method will become generally available.

A second biological method which I should like shortly to bring before you is one of my own, but for the working out of which, as far as I have gone, I am strongly indebted to aid afforded me

by Dr. Buchanan. As a chemist it has always been my endeavour to use chemical means in my researches, in preference to any other, whenever possible. Accordingly when the question of these micro-organisms came forward I sought for chemical means for their detection, and I believe I have to some extent succeeded. The method adopted still requires a great deal of work to be expended on it, and I bring it forward here in the hope of inducing some of those present to take it up. The subject is too large for one worker, who moreover is otherwise busily engaged, to work it out in any reasonable time. The process will be found fully described in the reports of the Medical Officer of the Local Government Board for the years 1885 and 1886. Shortly stated it is as follows. If a pure, thoroughly aërated water be kept out of contact with air for say ten days, it will be found to have remained fully aërated. The same will be found to be the case even with an impure water, provided the water contained no living organisms. Sewage polluted water when sterilized by heating remains fully aërated. If however the water contains living organisms, the state of aëration will alter, and in the majority of cases will diminish; and the degree of diminution will give some measure of the number of organisms present. The experiment may be varied by adding some sterilized cultivating material to the water previous to bottling, by keeping the water at various temperatures or varying the amount of light to which the bottle is exposed during keeping, &c. Again, some kinds of organisms are killed in all their stages of development when heated to a comparatively speaking, low temperature; others, particularly in certain stages of development, are capable of withstanding a comparatively high temperature without losing their vitality. By thus varying the conditions of the experiment it becomes possible not only to distinguish, by chemical means, between dead and living organic matter, but even different kinds of organisms may be distinguished from each other.

There is one other question connected with water I should wish to allude to, as it has scarcely received the amount of attention from chemists that it deserves, namely, the action exerted by some waters on metals, notably on lead and on iron, these being the principal metals used in connection with water supplies, &c.

Action on Lead.—Up to within the last few years it was generally supposed that the action exerted by some waters on lead was due, mainly, to their softness, that is, chiefly to the insufficient proportion of lime salts they contained. In addition to this, the main cause, it was ascribed to the presence of nitrates, nitrites, organic matter, &c. Within the last few years, however, an elaborate research has been undertaken by Drs. Tidy, Odling and Crookes, by which they were led to the conclusion that the real protective agent, that is, the agent which prevented the action of water on lead, was silica. According to this explanation, waters will act on lead if they do not contain a sufficient proportion of silica. They will not act on lead if a sufficient proportion of silica be present, not less than half a grain per gallon, whatever, speaking broadly, the rest of the constituents might be. Drs. Tidy, Odling and Crookes have brought forward many facts tending to bear out their contention; and although they have not, in my opinion, quite proved their case, they have at any rate made out a strong case for investigation, and in future analysts will do well to direct their attention to this point. The question is one beset with difficulties, inasmuch as so many factors have to be taken into consideration before a definite conclusion can be arrived at. The chief points to be kept in view are, in my opinion: The reaction of the water, whether acid, neutral, or alkaline, the most delicate reagents to be used for detecting the same; if the reaction is acid, the amount of this acidity, and if possible its nature; the amount of free carbonic acid; the total dry residue; the proportion of lime and magnesia salts in this; the proportion of chlorine; the proportion of nitric acid; organic matter; and lastly, the amount of silica. It is only by taking all these points into consideration that a satisfactory final result will be arrived at.

Action on Iron.—This has not received anything like the attention which has been bestowed on the preceding question; mainly I suppose because iron not being a poisonous metal, a slight degree of action may be, and generally is, overlooked. In not a few cases, however, the action is so powerful as to constitute a serious nuisance, leading sometimes to considerable expense. This action is observed mainly in connection with a hot water supply, and is, in my experience, due chiefly to the presence of an excess of magnesium salt, particularly of chloride of magnesium. The action may be prevented, or at any rate greatly reduced, by submitting the water to Clark's process. Of course pipes other than iron may be employed. The selection of the kind of pipe to be taken is, however, of some difficulty, particularly in cases in which expense is an object, and the thorough treatment of the question well merits the attention of the sanitary engineer and the chemist.

While I am on this question I may mention another frequent cause of the corrosion of water pipes. This is the setting up of galvanic action whenever two kinds of metal are brought into contact. As far as possible the use of different metal in water conduits should be avoided, and where it cannot be avoided the two metals should be kept from metallic contact by the interposition of a non-conducting material.

Sewage.

I have often thought, and have given public expression to the thought, that, from a sanitary point of view, the production of sewage, ordinarily so-called, that is the water carriage of our house refuse, was a mistake. However, for good or for evil, the plan has been adopted, and we must do the best we can for its satisfactory disposal. The question is a very large and important one, and I cannot treat it in any but a very fragmentary manner here.

The first point I would mention is, that all authorities who have to deal with the disposal of sewage should clearly understand that sewage is a nuisance to be got rid of, and not a thing to make a profit out of.

The next is, that if sewage is to be disposed of to the greatest advantage of the community, the sewage of every place will have to be dealt with on its own merits; no general scheme will do equally well for all.

Many schemes—good, bad and indifferent—have been elaborated for the proper disposal of sewage, but I cannot deal with them here; perhaps we shall hear something about them at this meeting. But with your permission I will throw out some suggestions on the general aspect of the question.

In the first place, I am decidedly of opinion that whatever scheme may be adopted (except destruction of the sewage material by fire), the agents to which the ultimate destruction of sewage is due are living organisms (not necessarily micro-organisms), either vegetable or animal. If this be so, our treatment should be such as to avoid the killing of these organisms or even hampering them in their actions, but rather to do everything to favour them in their beneficial work. Now in order to avoid this danger, and at the same time reduce to a minimum the nuisance due to the existence of sewage, we must begin our treatment in the sewers themselves, a step further back than it is usually begun. Of course I am aware that sewers are laid out with a view of bringing the sewage in the shortest possible time from the sources of production to the general outfall; but even in towns of moderate size the time elapsing in the passage of the sewage between these two points is sufficient to render the sewage offensive, at least in summer time, while in large towns the sewage has time to become very highly offensive. No doubt the great bulk of the sewage as a rule reaches the outfall in a short time, but the time which has to elapse before the whole of the sewage contained in the sewers at a given time is discharged is far longer than is generally supposed. This offence ought to be avoided; how can it be done? It should not be done in a manner to destroy our beneficial organisms, or even seriously to check their action; in other words, the use of disinfectants or of powerful antiseptics should be avoided. I have the less hesitation in saying this, because, on the score of expense, it is practically impossible to really disinfect infectious matter when once it has found its way into the sewers. All that is usually done in this direction is really a deception—no doubt a self-deception—on the part of those employing such means. All we can therefore really do is to deodorise the sewage, and this can be done without in the least interfering with the immediate or subsequent action of the organisms on which we depend for the final destruction of the sewage. The best material for this purpose is, in my opinion, a solution of permanganate of potassium, prepared on the spot from crude manganate by the addition of acids or suitable salts to the same. Sanitarians are, I think, greatly indebted to Mr. Dibdin, of the Metropolitan Board of Works, for bringing, by his energy and courage, the manganates, and consequently also the permanganates, within the reach of practical sanitation. And let it not be supposed that all we effect is simply deodorization of the sewage; but we also in great measure check putrefaction, and thus do away with what seems to be the chief agent in carrying disease germs into our streets and houses, namely, the rising and bursting of gas bubbles from the sewage.

Sewage thus treated will arrive at the outfalls in a practically inodorous condition, or nearly so, according to the amount of manganate used, and is fit for any kind of treatment we wish to adopt, such as:

Sewage farming with untreated sewage.

Sewage farming with sewage clarified by subsidence.

Sewage farming with sewage clarified by precipitation.

Precipitation and filtration.

Precipitation and discharge, if necessary previously deodorised, into a river of sufficient volume to prevent the production of a nuisance. According to the exigencies of each particular locality.

As regards processes of precipitation, I will merely remark that inasmuch as no proportion of chemicals which can practically be employed will do much more than clarify the sewage, the proportion of chemicals employed should be kept as low as is consistent with the object to be obtained, namely, clarification, and that, more particularly, the use of large quantities of lime should be avoided.

To sum up: let natural agencies have their way, assist and direct them into proper channels as far as you can, but interfere with them as little as possible.

Mr. Rogers Field, M.Inst.C.E. (London), moved a vote of thanks to Dr. Dupré for his admirable address. As bearing on the subject matter of that address he might say he had known of more than one case in which water had been analysed by a local chemist and pronounced to be good, when he himself had been nearly certain from the surroundings that it had been polluted with sewage. The discrepancy had been cleared up for him by Dr. Dupré. The opinion that the water was unpolluted was given simply on the general grounds that water which contained only such and such ingredients was unpolluted. But directly a sample of unpolluted water of the district was obtained and compared with the water in question it was found that the water was clearly polluted.

Mr. J. B. Gass (Bolton) seconded the vote of thanks to Dr. Dupré for his admirable address, and remarked on the vital importance of correct and high standards for the purity of water for domestic purposes, as a question, the application of which directly affected the health of the whole population.

Dr. A. Dupré, F.R.S. (London), expressed his thanks for the compliment, and then called on Mr. Frankland and Dr. Parkes to read their papers, saying it would be better to discuss them both together.

On "*The Application of Bacteriology to questions relating to Water Supply*," by Percy F. Frankland, Ph.D., B.Sc. Lond., F.C.S., F.I.C., Associate of the Royal School of Mines.

Although the modern development of the study of bacteria and other allied micro-organisms has now attracted the attention of the public for a number of years, and has excited such general interest that references to "bacteria," "germs," "microbes," and the like are frequently to be found in the daily papers and other prints freely circulated amongst all classes of the population, yet it is often only too palpable from these very allusions that but little sound knowledge concerning these micro-organisms has penetrated beyond a comparatively limited circle.

I am, therefore, of opinion that on the present occasion it will not be out of place to point out briefly some of the more important applications of bacteriology to the subject of water supply.

In the first place it may be stated generally that bacteriological science has so far been applied to the investigation of the sanitary aspects of water supply in three different ways:—

1. In the actual detection of disease-producing or pathogenic micro-organisms in potable water.
2. In determining the influence which filtration and other methods of water purification (both natural and artificial) have on micro-organisms in general.
3. In ascertaining the fate of disease-producing or pathogenic microbes when introduced into different kinds of water.

We will deal with these three applications of bacteriology in order:

1. *The detection of pathogenic micro-organisms in drinking water.*

It is frequently and very generally supposed that the all-important task of bacteriology in connection with drinking water is to ascertain whether or not a given sample of water contains micro-organisms capable of producing disease. Now, even assuming that we were fully acquainted with all the micro-organisms capable of producing disease, which we certainly are not, even then the examination of water for hurtful microbes would be a comparatively unimportant application of bacteriology, one possessed of only limited and local interest, and if relied upon alone, capable of leading to most erroneous and dangerous deductions. For instance, of what value would it be to ascertain that a sample of some particular water supply was free from the infectious principle of typhoid fever or cholera on some particular occasion? Information of this kind has obviously next to no interest whatever, for the absence of these infectious principles on one occasion affords no indication that they may not be present at a future time. Imagine the absurdity of examining all the potable waters of England for the specific poison of typhoid fever, and assuming that the poison, if present, could be detected with unerring certainty, how many of the most dangerous waters would escape condemnation because at any particular moment the chance of their containing the poison is infinitesimally small!

It cannot be sufficiently emphasized that the mere detection of zymotic poisons in water is a matter of complete unimportance from a general point of view, and the fact that the detection of

even the few known zymotic poisons is at present a matter of the greatest difficulty, and in consequence of the almost invariable and enormous preponderance of harmless organisms, is really of but little consequence, as the important bearings of bacteriology on water supply lie in an altogether different direction.

It should, however, be mentioned here that the organism which is widely credited with being the producer of cholera was by Koch found during an epidemic in the tank-water used for drinking in India, and quite recently the organism, which is believed to be the *contagium virum* of typhoid fever, is alleged to have been found in a well-water which had been used by persons suffering from this disease.

It is obvious that this first application of bacteriology to water-sanitation is of far more interest in throwing light upon the manner in which particular diseases may be disseminated than in forming our opinion as to the fitness of water for domestic use. It is in fact of interest rather to the student of disease than to the student of water-sanitation.

2. *Determination of the Influence which Filtration and other methods of water-purification (both natural and artificial) have on micro-organisms in general.*

Inasmuch as a large proportion of all the water available for domestic use has at some period of its history been exposed to the risk of contamination with infectious matters, it obviously becomes a matter of primary importance to ascertain with what degree of probability these infectious matters, should they have gained access to the water, would be removed in the subsequent natural or artificial treatment which the water has undergone.

Now the infectious matters which the systematic investigation of zymotic disease has revealed are in every case micro-organisms, and thus the study of the removal of infectious matters from water becomes synonymous with the study of the removal of micro-organisms from water. But as we are acquainted with only a few of these infective micro-organisms, it is necessary to study the influence of methods of water-purification on micro-organisms in general, irrespective of their hurtful or harmless character. On this subject, bacteriology in its present stage of development is capable of throwing the most important light.

In a paper which I had the honour of bringing before the last meeting of the Sanitary Congress at York, I had occasion to point out some of the results which I had obtained in the application of bacteriological methods to the examination of the London water supply. I there showed how the process of sand-filtration, which is employed by seven out of the eight companies supplying the metropolis, is in reality an operation of the greatest sanitary importance, and not a mere useless formality, as had been generally supposed before.

As every fresh confirmation of these results is necessarily of importance in establishing the truth of this new departure in our views, I venture to bring before you on this occasion the fresh material which I have accumulated in carrying on these investigations for the Local Government Board up to the close of the past year.

In the following table I have recorded the number of micro-organisms, as determined by gelatine-plate cultivation, in the unfiltered waters of the Thames and Lea, as well as in the filtered waters supplied by each of the seven companies drawing from these sources:—

1886.

Total Number of Colonies obtained by Cultivation of one Cubic Centimetre of Water.

Description of Water.	Jan.	Feb.	March.	April.	May.	June.
THAMES.						
Thames unfiltered	45,400	15,800	11,415	12,250	4,800	8,300
Chelsea	159	305	299	94	59	60
West Middlesex	180	80	175	47	19	145
Southwark	2,270	284	1,562	77	29	94
Grand Junction	4,894	208	379	115	51	17
Lambeth	2,587	265	287	209	136	129
LEA.						
Lea unfiltered	39,300	20,600	9,025	7,300	2,950	4,700
New River	363	74	95	60	22	53
East London	224	252	533	269	143	445

Total Number of Colonies—continued.

Description of Water.	July.	August.	Sept.	Oct.	Nov.	Dec.	Average.
THAMES.							
Thames unfiltered	3,000	6,100	8,400	8,600	56,000	63,000	20,255
Chelsea	59	303	87	34	65	222	146
West Middlesex	45	25	27	22	47	2,000	234
Southwark	380	60	49	61	321	1,100	524
Grand Junction	14	12	17	77	80	1,700	630
Lambeth	155	1,415	59	45	108	305	475
LEA.							
Lea unfiltered	5,400	4,300	3,700	6,400	12,700	121,000	19,781
New River	46	55	17	10	32	400	102
East London	134	243	165	97	248	280	253

In connection with this table it should be pointed out that the figures obtained for the New River Company are not really comparable with those of the East London Company, inasmuch as the New River Company draws from the river Lea at a point many miles above the intake of the East London Company, and its river supply is to a considerable extent diluted with water obtained from deep wells.

If it be assumed that the samples of unfiltered water represent the average composition of the river waters gaining access to the various companies' reservoirs, it is obvious that we can represent the diminution in the number of micro-organisms which has taken place before delivery by percentage figures representing roughly the efficiency of the treatment which the water has received at the hands of the several companies. In the following table this percentage reduction is recorded for each of the companies, excepting the New River, which for the reasons mentioned above is not comparable with the others:—

1886.

Percentage Reduction in the Number of Developable Micro-organisms present in the River Waters before delivery by the Companies.

Description of Water.	Jan.	Feb.	March.	April.	May.	June.
THAMES.						
Chelsea	99·7	98·1	97·4	99·2	98·8	99·3
West Middlesex	99·6	99·5	98·5	99·6	99·6	98·3
Southwark	95·0	98·2	86·3	99·4	99·4	98·9
Grand Junction	89·2	98·7	96·7	99·1	98·9	99·8
Lambeth	94·3	98·3	97·5	98·3	97·2	98·5
LEA.						
East London	94·4	98·8	94·1	96·3	95·2	90·5

Percentage Reduction—continued.

Description of Water.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Average.
THAMES.							
Chelsea	98·0	95·0	99·0	99·6	99·9	99·7	98·6
West Middlesex	98·5	99·6	99·7	99·7	99·9	96·8	99·1
Southwark	87·3	99·0	99·4	99·3	99·4	98·3	96·7
Grand Junction	99·5	99·8	99·8	99·1	99·9	97·3	98·2
Lambeth	94·8	76·8	99·3	99·5	99·8	99·5	96·2
LEA.							
East London	97·5	94·3	95·5	98·5	98·0	99·8	96·5

These results are confirmed by the experience obtained in other places. Thus I have had an opportunity of examining the effect of similar treatment on the water supply of a large town in the north of England. In this case the results obtained were as follows:—

Unfiltered Water.	31,200	micro-organisms found in one cubic centimetre.
Filtered Water.	122	ditto.
Percentage Reduction.	98·0 per cent.	

Results entirely in harmony with these have been obtained in the similar systematic investigation which has for some time past been made of the water supply of Berlin, and the amount of material which has thus been accumulated, both here and in Germany, is now so overwhelming as to place the facts which I have brought before you altogether beyond doubt.

It is, however, of the greatest importance that further investigations of a more detailed nature should be carried out, in order to render the process of filtration less empirical in character and to do away with the occasional irregularities in the efficiency which are apparent in the above tables.

The natural purification of water by filtration through porous strata of the earth may be similarly ascertained provided it is obtained in a continuous stream from the water-bearing stratum without having undergone storage. I may cite as instances of this kind of filtration, which I have had occasion to examine the efficiency of—

1. The underground water of the Grand Junction and Southwark Companies.
2. The deep well water of the Kent Company.

The underground water of the Grand Junction and Southwark Companies, is obtained from the extensive gravel beds which are found in the immediate vicinity of the Thames at Hampton, in fact the water of the Thames is artifically introduced into these beds and then abstracted again after it has traversed them for a horizontal distance of about 100 ft. When I examined these waters bacteriologically some time ago, I obtained the following results:—

Underground Water.	Number of micro-organisms found in one cubic centimetre.
Grand Junction Company	208
Southwark Company	58

Now as the unfiltered Thames water would doubtless contain about 10,000 organisms in the cubic centimetre, it is obvious that the percolation through the gravel beds had in each case effected a very large reduction.

In the case of the deep well water of the Kent Company, which I have under constant observation, the number of micro-organisms in the water as it is pumped from their deep wells in the chalk is generally very small indeed, as seen from the following record for the year 1886:—

Number of Micro-organisms found in one cubic centimetre of Water.

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average.
Kent Company's deep well water	...	5	41	7	8	4	12	9	5	82	12	11	18

The occasion when the number amounted to 82 per cubic centimetre was after the well had been under repair, and consequently the regular course of working had become disturbed.

Of course, in the case of natural filtration of this kind it is impossible to say what may have been the original condition of the water, and, consequently, the efficiency of the process cannot be expressed by means of any percentage figure, as was adopted above in the case of artificial sand-filtration.

It is clear, however, that the small numbers obtained in the case of this deep well water really amount, practically, to complete removal of all originally present micro-organisms, since the well, pumps, pipes, &c., used in raising the water cannot be rendered sterile, as would be done in the case of a laboratory experiment, and a small number of organisms must, therefore, be expected in the pumped water, even if the water actually issuing from the strata was absolutely sterile.

3. *Determination of the fate of disease-producing or pathogenic microbes when introduced into different kinds of water.*

As already pointed out, it has only in most exceptional cases been possible to discover the presence of organisms known to be pathogenic in water, it was only natural, therefore, to ascertain experimentally what becomes of such pathogenic micro-organisms when they are purposely introduced into water of different kinds. I have made a number of experiments in this direction, the principal pathogenic organisms which I have employed for the purpose being the *bacillus anthracis*, *Koch's comma spirillum*, and the *streptococcus of erysipelas*. It would be beyond the scope of the present paper to detail the nature of these experiments, which I have fully described in communications to the Royal Society and the Society of Chemical Industry, but I may briefly summarize the results as follows:—

1. The "comma" spirilla were found to flourish and multiply

abundantly in London sewage, whilst in deep well and filtered Thames water, although they were still demonstrable after nine days, they were only present in very diminished numbers. In the sewage the "comma" spirilla were still found to have retained their vitality after eleven months.

2. The bacillus anthracis containing spores retains its vitality, even when introduced into distilled water, for a practically indefinite time, and when introduced into London sewage it undergoes extensive multiplication.

3. The streptococcus of erysipelas was found to possess but little vitality either in potable water or sewage; it was, however, still discoverable in filtered Thames water after five days.

These experiments, therefore, show that, whilst ordinary drinking water does not form a suitable medium for the extensive growth and multiplication of the pathogenic micro-organisms, and that in some cases these forms may undergo more rapid destruction than was formerly supposed, yet, that in the condition of spores, they are extremely permanent in any kind of water, however pure; and that even those of which no spores are known may often be preserved for days, or even weeks. We have thus no difficulty in understanding both how zymotic poisons can be carried by water, as well as how in some cases water known to be infected may fail to communicate zymotic disease. In fact, these experiments prove most conclusively that no reliance can be placed on the spontaneous destruction of pathogenic organisms gaining access to potable water.

It is obvious that the experimental field in this third department of the subject is a very extensive one, and that an almost unlimited amount of work remains to be done both with those pathogenic organisms which are already known, as well as with those which may be discovered in the future.

Finally, I should like to point out a fourth possible, although perhaps not probable, development of the application of bacteriology to questions of water supply, and that is the future discovery of micro-organisms absolutely characteristic of sewage pollution generally. It is obvious that the identification of such distinctive forms would be of the utmost value, as it would enable us to fix upon waters which had received sewage contamination, and had not subsequently undergone such purification as to remove all the organisms which were present in the sewage. Such a test would be of an altogether different order from that referred to in Section 1, for we should condemn water which had undergone sewage contamination, irrespectively of whether the sewage was harmless or infectious; whilst the test referred to in Section 1, and which is frequently supposed to be the ultimate aim of the bacteriological examination of water, would

lead us only to condemn waters which had been contaminated with infective sewage. But if a water is contaminated with harmless sewage to-day, it may be fouled with infective sewage to-morrow; and thus the utter worthlessness of the idea that the aim of bacteriology applied to water consists in discovering pathogenic organisms is apparent.

[*For discussion on this paper see page* 388.]

On "*Water Analysis*," *by* LOUIS PARKES, M.D., Public Health Cert. Lond., Assistant to the Professor of Hygiene and Demonstrator in the Hygienic Laboratory, Univ. Coll., London.

THE practice of submitting to an analyst samples of water used, or intended to be used, for drinking purposes, is one undoubtedly much in favour amongst the public. The householder who has read of the dangerous pollutions to which water in wells or cisterns is liable, wishes to know as regards his own domestic arrangements whether the water he drinks is pure and free from suspicion of contamination. He collects some of the water in a bottle and sends it to an analytical chemist for his opinion on the matter. In the course of time a report is received, couched in language and figures unintelligible for the most part to the lay comprehension, but with a few sentences at its termination approving or condemning the water on the results of the analysis; and on this opinion the householder proceeds to act. His faith in the purity of the water is either restored or it is shattered, with the result of his making extensive alterations in the water arrangements of the house, or else seeking a new source of supply. The question therefore of the extent to which chemists and sanitary experts are justified in forming definite conclusions as to the safe or dangerous characters of waters submitted to them for examination is one of considerable interest to the public generally.

Broadly speaking, there may be said to be three methods of examining water, as regards its fitness for domestic use:

1. *Physical Examination*, by which such qualities as its appearance (colour, clearness, lustre), its taste and its smell are determined. No one thinks of relying solely on the colour or smell of a water when he wishes to form an opinion about its

fitness for drinking; so that although this examination, being easily and rapidly made, is always included in every scheme of water analysis, the indications it gives are necessarily only confirmatory of the other results that may be obtained. The microscopical examination of the sediment deposited by a turbid water should also be included in the physical examination; but of this we shall have to speak further on.

2. *The Quantitative Examination of dissolved solids in the water by chemical analysis*, is the second method; and

3. The *Biological Examination*, which is concerned with the quantitative estimation in the water of living micro-organisms belonging to the Bacteria and allied species is the third method.

It will be necessary, owing to the limited time at our disposal, to confine our attention to that aspect of the subject which is connected with the determination of the possible organic pollutions of a water; and, indeed, it is only on this question that any misconception exists. No one denies that the presence of inorganic salts in a water—salts which may render it, from their excessive amount or poisonous natures, unfit for drinking—can be determined accurately by the chemist. The chemist can and does rightly condemn the water which is brackish from infiltration of sea salts, or that which contains excess of lime and magnesian salts, causing an undesirable or positively injurious amount of hardness, or the water which in its passage through various strata may have taken up traces of lead, copper, or arsenic. In such cases as these there is no room for controversy, but it is in those cases where an opinion is desired on the nature and extent of the organic pollutions that a water has been subjected to, that the scientific mind has been so deeply stirred. The question is not yet settled, nor is it likely to be, until our knowledge is more extensive and more accurate; but in the meantime a review of the matter in its larger aspects may not be out of place.

Firstly, it will be well to consider what it is the analyst wishes to determine when he is dealing with the possible organic pollutions of a sample of water submitted to him. He wishes to determine (*a*) the amount of organic matter present in a measured volume of water, and (*b*) the nature of this organic matter, *i.e.*, its source or origin, and its potentialities for evil. Does chemical analysis enable these two apparently simple points to be correctly determined? First, as regards (*a*) the amount of organic matter present. No one who has looked into the subject at all needs to be told that no simple method of estimating organic matter has yet been devised. There is no reagent which can be used as a quantitative test for organic matter, for the simple reason that there is such a numberless

variety of substances all conveniently included under the generic term "organic," that no single chemical reagent could possibly have the same affinities for all of them, and consequently whilst it might give correct indications of the amount and presence of one or more of them, it could not possibly do so for all. No doubt the Potassium Permanganate solution can—as the test is now carried out—be trusted to estimate approximately the amount of *oxidisable* organic matters present in the water. But those matters which are oxidisable by Permanganate of Potassium solution are not the only matters of organic origin which may be present; we do not know what proportion they form to the total organic matters, nor do we know whether their deleterious properties are greater or less than those of the non-oxidisable matters.

Failing in our efforts to identify organic matters *as such* in a water, two methods have been devised for their estimation from the amounts of some of their constituents—processes involving in the one case the breaking up of the complex organic molecule into the simple compound ammonia, by means of destructive distillation with a strongly alkaline solution of permanganate of potassium; and in the other the resolution of the organic matter into its primitive elements carbon (or more accurately carbonic acid) and nitrogen, by means of heat applied to the dry residue obtained from a measured volume of water by evaporation. The first process—the joint invention of Wanklyn, Chapman, and Smith—is known as the "albuminoid ammonia process," because albumen is one of the principal substances which yield ammonia on distillation with an alkaline solution of permanganate of potash. The second, or combustion process, is due to the inventive genius of Frankland and Armstrong. There can be no doubt that theoretically, and considered from a philosophical standpoint, Frankland's process should give better results than Wanklyn's. In the former, all the organic matter present is acted upon—none can escape. In the latter, the whole of the nitrogen contained in the nitrogenised organic matters is not converted into ammonia, for whilst permanganate of potash acts powerfully on some kinds of organic matter, it has little or no effect upon others, and the non-nitrogenised organic matters are left out of account altogether. Thus the results obtained have not an absolute significance as they have in Frankland's process, but only a relative. Is this a drawback in actual practice when Wanklyn's process is in use? From Dr. Cory's experiments* it would appear that it is, for he found that the results of different analyses were not comparable with each other except

* Report of the Medical Officer of the Local Government Board, 1881.

under certain conditions, as when the polluting material was of the same nature in all; but on the other side plenty of evidence is to hand showing that under the conditions met with in actual practice the process is to be relied on, especially in estimating those very minute quantities of organic matter which alone are usually found in natural waters. I would more particularly refer to the experiments of Mr. Cassal and Dr. Whitelegge* on the quantitative estimation of egg—albumen in water by Wanklyn's process—experiments which throw some doubt on the conclusions arrived at by Dr. Cory from his own experiments. When the polluting ingredients are relatively very large in amount, there can be no doubt that considerable increases or decreases in the amounts of organic matter are not shown in an exactly proportional increase or decrease of albuminoid ammonia. But this is not a matter of practical importance, for if it is right to condemn a water which shows more albuminoid ammonia than the minimum taken as a standard by Wanklyn from his own experience, then it cannot much matter whether the albuminoid ammonia exceeds by 50 times or only by 20 times the allotted amount. Wanklyn's process is easily learnt and easily worked, whilst Frankland's is most difficult: except in the hands of the most expert it may give an error of experiment greater than the total quantity to be measured.

But after all it is not the amount of organic matter in a water which renders it harmful, but its kind; and hence the folly of setting up a minimum standard, as Wanklyn has done, for every adversary to tilt at. Our food consists very largely of organic matters, and we ought not to object to taking food and water together, were it not that experience has shown that the organic matter in water is often derived from food materials which have already once passed through the human body, acquiring thereby a potentiality for mischief not to be lightly risked.

We have seen then that chemical processes enable us, in one way or another, to estimate the amount of organic matters in a water—more or less roughly it may be, but still sufficiently for the purpose. Do they give us any information as to the kind of organic matter present? To a certain extent they do; for by their means we can in most cases discriminate the origin of the organic matter, that is to say, its derivation from the animal or vegetable kingdom. When the pollution is of vegetable origin, chlorides and free ammonia are usually present to

* Remarks on the analysis of water for sanitary purposes. Transactions of the Society of Medical Officers of Health, 1884.

only a slight extent. By Frankland's method under such circumstances it is found that the ratio of organic carbon to organic nitrogen is high, whilst by Wanklyn's the proportion of albuminoid ammonia to free or saline ammonia is relatively large. When the pollution is derived from an animal source, and more especially when it is derived from sewage infiltration, owing to the large amount of common salt and ammonia from decomposed urea found in urine, chlorides and free ammonia are present in excess, the free ammonia that is distilled over greatly exceeds the albuminoid ammonia, and the ratio of organic carbon to organic nitrogen is low. Microscopic examination of the sediment greatly aids in this determination. In the one case fragments of decaying vegetable structure and the minute forms of aquatic life which find a habitat in such materials may be found; whilst in the other, objects such as fibres of linen and cotton, hairs, epidermic scales, &c., which are characteristic of excretal and waste refuse, may be discerned. It is possible then in most cases to distinguish by chemical processes, with the aid of the microscope, between pollutions of animal and vegetable origin; and this distinction is an important one, for there can be no doubt that pollutions caused by sewage infiltration, by soakage from graveyards, or by decomposing animal bodies, are infinitely more dangerous than the pollutions arising from decaying plants and the organisms that thrive amongst them. But these latter must not be thought of as harmless. Ague, intermittent fevers, and dysentery are propagated by drinking vegetably-polluted waters, and we cannot tell whether the specific virus of one of these disorders may not be lurking amongst the more innocent matter.

Supposing it to be allowable to pass as satisfactory a water contaminated to a slight extent with vegetable matter—on the ground that such waters can usually be drunk without the slightest fear of injury, and that therefore a minimum standard of pollution under such circumstances may be a very necessary thing,—it must be admitted that there can be no reason why a water which is reasonably believed to be polluted with sewage or other animal emanations should not be condemned at once, however small the pollution may be. It may be said that large numbers of people are continually in the habit of taking sewage into their systems along with their drinking water—the circular system of water-supply from cesspool to well, and again from well to cesspool through the human body being all too common,—but all scientific history proves that such people are walking on the brink of a precipice which may at any time crumble away and precipitate them into the depths below. The difficulty in water analysis is, in many cases, to distinguish between sewage pollutions and other conditions which are characteristic of pure natural waters. Unless the source of the water is known, a deep well water may easily be conceived to be a water polluted at some former period with sewage, and therefore liable to further contamination, and consequently dangerous.

Chemical analysis enables us to determine, by a quantitative estimation of the nitrates and nitrites, whether a water has been polluted with animal organic matters at a former period. By the action of nitrifying bacterial organisms, water in its passage through the soil is purified—the organic matter is converted into nitrates and nitrites of the alkaline earths. Many deep well waters of the purest kind organically are thus known to have been originally derived from polluted sources; but they have become purified by filtration through the immense thicknesses of soil and rocks that they have traversed in their passage from the surface of the earth. A "previous sewage contamination," as it has been termed by Frankland, is a matter of no practical importance, as regards the fitness of a water for potable purposes, so long as it occurred at a sufficiently remote period to leave the quality of the water at the present time unaffected by it, and provided that it does not occur again. On this latter point of course chemistry can tell us nothing.

Chemical analysis can detect and estimate very minute traces of organic matter in water; but can it help us in those cases where, although the amount of pollution has been almost infinitesimal, it has been sufficient to cause widespread outbreaks of disease? Such cases have occurred at Caterham, where, according to Dr. Thorne Thorne,* more than one and a half million gallons of water were in a fortnight rendered capable of propagating typhoid fever by the infected discharges of one man. Again at Plymouth, in Pennsylvania, the excrement of one typhoid fever patient which had been thrown upon the snow near a stream which supplied the town reservoir, was sufficient to cause a widespread epidemic amongst the consumers of the water. This water, we are told, was chemically the purest of the three sources of supply for that town.† It does not appear that the Caterham water was analysed at the time of the outbreak; but supposing the facts to be as recorded, the pollution is evidently so infinitesimal—much less than one grain of polluting material to the gallon—that there must have been a failure to identify it as a dangerous pollution by chemical analysis. We can only conclude then that such cases, when they occur, are beyond the reach of chemistry. They are very

* Report of the Medical Officer, Local Government Board, 1879.
† Sixth Annual Report of the State Board of Health of New York.

similar in character to those where artificially manipulated waters have been submitted to a chemist for his opinion, and he has failed to detect the pollution. But these infinitesimal pollutions are very rare in practice; in ninety-nine cases out of a hundred, specific pollution of a water occurs along with such gross pollution by other organic filth, either recent or at a former period, that the chemist cannot fail to detect it. We may conclude, then, that there are cases where a chemist may pass a dangerous or actually disease-productive water as pure, but that such cases in actual practice are very rare; and that it is not right to condemn a method altogether because it fails under a very rare combination of circumstances. The failure really lies in the inability to distinguish between the different kinds of organic matter, between the dead and living, the noxious and the innocuous. The chemist can tell us none of this; we must remain satisfied with the information he can give as to the amount of polluting material and its probable derivation from the animal or vegetable kingdom. As Dr. Buchanan has said, "the chemist can tell us of impurity and hazard, but not of purity and safety."

The biological examination of a water by what is known as Koch's gelatine-peptone test has been thought by many to be capable of supplying that information as to the number and nature of the living micro-organisms in a sample of water which we have seen that chemical analysis is unable to furnish us with. It is desirable to consider a few points in connection with this new method, upon which so many hopes have been founded. In the ordinary microscopic examination of water little can be learnt unless there is enough sediment deposited to form a distinct object in the field of the microscopic lens. In this field various microscopic animalculæ may be seen, and where putrefactive changes are in progress the different forms of bacterial life always associated therewith may be observed under a high power. The cultivation test is not concerned directly with any of these larger microscopic objects, but aims at developing on the cultivating medium the germs or spores of the fungi or bacteria present in the water (but not to be detected in the ordinary way by the microscope) into isolated colonies, which after a certain period of growth are quite visible to the naked eye, and present more or less characteristic microscopic appearances. A pure cultivation of any one of these colonies may subsequently be made on a sliced potato, or in a test-tube containing sterilised broth or peptonised gelatine, and the mode of growth in these media determined; or the colony may be submitted directly to examination under a high power of the microscope.

There can be no doubt that the dangerous properties of polluted water are due not to the dead organic matter it contains, but to the living micro-organisms always found in association with dead matters. The proof of this is known to everybody. When a suspicious or dangerous water is boiled for a few minutes it is rendered harmless. The organic matter is not destroyed—it is still there, and can be detected, as before, by chemical analysis—but the living organisms are killed. Koch's cultivation-test enables us to estimate approximately, in any sample of water, the number of germs which, when cultivated on peptonised gelatine under ordinary conditions of light, moisture, and temperature, are capable of forming well-defined colonies. In so far then as this test gives information as to the amount of organic life in a sample of water, it tells us what chemistry cannot. But it must be remembered that there are many micro-organisms—and amongst these many pathogenic micro-organisms, whose presence or absence in a water we are most particularly concerned about—which cannot grow in peptonised gelatine; they must be cultivated in broth or blood serum, or some other medium. There are others which do not grow at ordinary temperatures, or which only grow in darkness, or which can only be cultivated under a variety of conditions not to be found in the ordinary method of employing the test. The conclusion to be arrived at, therefore, is that the gelatine-peptone test can only afford partial information as to the number of microphytes in a water: the results of one examination may be and no doubt are directly comparable with those of another conducted under like conditions, just as albuminoid-ammonia results are comparable with one another—but this is all that can be said.

Is there any relation between the amount of organic life—the number of "centres" or "colonies," as determined by the gelatine-peptone test—and the amount of organic matter as determined by chemical analysis? According to Professor Bischof* there is, when the samples are examined without any delay. In a chemically-polluted water the number of colonies is enormously in excess of those found in a chemically pure water. But should the examination be delayed, the influences of storage and temperature come into play. Under suitable temperatures (20° C. to 40° C.) an enormous development in the number of microphytes takes place, even in a water so chemically pure as the New River Company's supply to London, when stored for a few days. This is the more remarkable, as it might be supposed that so pure a water did not contain sufficient nourishment to enable an enormous multiplication of living micro-organisms to take place. An analogous circumstance, which is capable of explanation as above, is well known to those who practice Wanklyn's method. When a somewhat polluted water is analysed a second time, after keeping a few days, it is found that the free or saline ammonia has considerably diminished, whilst the albuminoid ammonia has increased. The ammonia has served to nourish the microphytes, and enabled them to undergo enormous development—a fact made known to the analyst by the increase of albuminoid and corresponding decrease of free ammonia.

* Transactions of the Society of Medical Officers of Health, 1885-86.

The next question which suggests itself is—has the number of colonies as determined by Koch's test any relation to the possible dangerous properties of a water? The answer must be no: no more, but probably less, than the amount of organic matter has. In the first place, the greater number of micro-organisms known to us belong to harmless species; secondly, experience shows that water when properly stored in houses or on board ship does not acquire any harmful properties thereby, although the number of its contained microphytes may have increased a hundred or even a thousand-fold; thirdly, there is good reason to believe that microphytes, like the higher animal species, have to fight amongst themselves for the nourishment they require for their continued existence. Hence an enormous multiplication of colonies may mean that the harmless species, always in excess, have entirely exterminated their pathogenic *confrères*. May this not be the explanation of the very remarkable fact that although the specific poisons of enteric and other fevers are constantly passing into the Thames but a few miles above the water companies' intakes,* yet no evidence has ever been forthcoming of disease traced to the quality of the water supplied by any of the Thames companies from Thames Ditton or Moulsey? Evidently the specific poisons do not multiply in Thames water; probably they are forced out of existence in the struggle for life with the countless species of innocuous bacteria which abound in the Thames, aided by the purifying influences of dilution and oxidation.

Failing to extract any satisfaction from the number of colonies, we may next inquire if Koch's test gives any information as to the nature of the colonies, and if it enables us to distinguish pathogenic from non-pathogenic forms. In examining a cultivation plate it is possible at once to distinguish

* The sewage of Staines passes untreated into the Thames 10 miles above Moulsey, (West Middlesex, Grand Junction, Vauxhall, Lambeth and Chelsea).

certain moulds and fungus-growths, and also to discriminate between the liquefying and non-liquefying centres—those, namely, which in the course of their growth liquefy the gelatine and those which do not. It has been assumed that where the number of liquefying colonies is large in proportion to the whole number, it is a sign of possible danger. The assumption is groundless if we are to believe, as Bischof and Klein tell us, that liquefying centres are due to the growth of motile bacilli—bacilli which are always found in excess where oxygen is abundant, and which are consequently more numerous in the top strata of water, which are exposed to the air, than in the deeper layers. The motility of a bacillus is not necessarily evidence of disease-producing properties. Many of the colonies in a plate cultivation may be identified at once or by subsequent processes as belonging to more or less common harmless species; but the number of pathogenic species could not be ascertained, even if they were all capable of growing in gelatine, because we do not know yet as regards the diseases most often spread through water, viz., cholera, typhoid fever, diarrhœa, dysentery, ague, &c., how to identify the organisms which play the rôle of specific virus, or carriers of specific virus, in these affections. It is perhaps allowable to except cholera from this category, as the mode of growth and other characteristics of Koch's comma bacillus are now well known, and Koch himself has isolated the bacillus from a water-tank in India. But cholera happily is very rarely prevalent in this country; we may indeed almost hope that cholera visitations are not likely to occur again on an extensive scale, so minute are the precautions taken to stamp out the disease as soon as imported. The fact then remains that as regards the diseases most commonly spread through the agency of drinking water—and in this list might also be included the common zymotic fevers in which a mode of propagation by water has not yet been disproved—the specific organisms, which are believed to stand in relation to them as cause and effect, cannot be identified by any method of biological cultivation as yet known. With the advance of knowledge such identification may become possible, but the labour of investigation in any case must be enormous. Every colony not recognised at once by its naked-eye characters, must be prepared afresh as a pure cultivation in test tubes of gelatine, in blood serum, or on potatoes, until a place has been found for it amongst one of the numberless species known to the micro-biologist; and, failing this identification, inoculation into the lower animals must be practised, to determine if possible its effect on the animal body. Even inoculation experiments on the lower animals are misleading, for many specific diseases to

which man is liable are not represented by any corresponding affection in the lower animals, and *vice versa* many specific febrile disorders of the lower animals are not transmissible to man. The difficulties in the way of the proper development of the biological cultivation tests for water are immense; they are certainly not insuperable, for it must be remembered that we are at present only on the threshold of this particular branch of knowledge. In the meantime whilst the pursuit of such methods should be persisted in for the sake of the advancement of knowledge, it must be acknowledged that they afford very little help to the water-analyst in enabling him to form a sound judgment on the wholesomeness or otherwise of a water submitted to him for examination.

There is one other method of examination that should always be practised whenever it is possible. This may be called the "sanitary survey of the source of the water." It is not sufficient for the analyst to be told that the sample of water submitted to him was taken from a deep or shallow well, from a cistern, or from a water pipe. He should make careful observations, in the case of a well, as to its depth, mode of steining, the nature of the soil in which it is sunk, the distance from the well of possible sources of pollution (cesspools, drains, and sewers); and in the case of a shallow well he should try to determine the direction of the flow of the underground water, whether from possible sources of contamination to the well, or in the opposite direction. If he is not satisfied as to the freedom of the well from all suspicion of contamination at every period of the year, he should insist on further analyses being made during or after periods of heavy rainfall, or at such other times as he thinks it likely pollution may occur. A physical examination of the source of the water, conducted as above, will materially help the analyst to put a right interpretation on the results of his analysis; and he will not then be liable to commit the serious error of passing as wholesome a sample of water which is taken from a source, pure perhaps at the time the sample was taken, but threatened with a dangerous pollution, not to be foreseen except by actual inspection of all the surroundings.

When a sample of water is taken from a house cistern, an inspection of the place and manner in which the water is stored is most urgent. If the overflow pipe of the cistern is connected directly with the soil drains, it is possible to imagine that the water thus stored, whilst not giving sufficient evidence of sewage contamination to warrant its condemnation by the chemist, may yet be most potent for mischief, for it may be specifically contaminated with sewer or drain air infected by the discharges and the bowel excretions of an enteric fever patient.

To sum up the conclusions to be derived from the arguments adduced: Chemical analysis, aided by microscopic examination, is sufficient in the great majority of cases to determine the amount of organic pollution of a water, and whether it is of recent date. In many cases the source of the pollution, whether from sewage or vegetable matters chiefly, can also be determined; but there is no possibility of ascertaining whether the water thus polluted is actually potent for evil or whether it may not be entirely harmless. Chemical analysis is powerless to deal with those cases of infinitesimal pollution of a pure water with infective material from the human body. Cultivation tests are equally powerless to cope with such cases. The only possible way of ascertaining the probable effects on the human system of drinking such water, is for the operator to perform the experiment on his own person—a course not likely to be pursued. The cultivation tests, as now practised, add very little to the results obtainable by chemical analysis. Micro-biology must undergo further development before germ cultivation methods can be expected to throw much light on water-pollutions. Lastly, the sanitary survey of the source of the water, or its mode of storage, should always be carried out whenever any doubt exists as to the freedom of the water from all possible sources of contamination.

[*This discussion applies to the two preceding papers by* Dr. PERCY F. FRANKLAND *and* Dr. LOUIS PARKES.]

Dr. ALFRED CARPENTER, (Croydon), who opened the discussion, said it would be very presumptuous on his part to criticise any of the observations which had fallen from the expert chemists who had addressed them. He wished them therefore to look upon him simply as an enquirer endeavouring to elicit some further information. He had heard with a great deal of satisfaction the expressions of Professor Dupré, with regard to the chemical analysis of water supply. He believed more confidently in chemical analysis than did many chemists themselves; for he had yet to learn that any water supply for a considerable district which had been pronounced to be pure and fit to drink by chemists, had ever given rise to an epidemic of typhoid fever. The district of Caterham was alluded to as giving some kind of support to the idea that the water might be pronounced chemically pure, and yet contain the organisms which might spread typhoid fever. He saw a good deal of that epidemic, and he had an impression that if that water had been analysed

by Professor Dupré, for instance, on the day on which it was distributed, he would not have hesitated to pronounce it unfit for distribution. There were circumstances which were not detailed, and which did not come to the knowledge of the enquirers who reported upon the case, and as after it was examined by a local medical man, he did not hesitate to say, "this water has something wrong with it, it could not be truthfully argued, as it was constantly, that the Caterham case was an instance in which the chemist could not detect the presence of disease germs. It was true that by putting half a pint of secretion coming from a patient into a million gallons of water, it was possible that a chemist might not detect it; but he had an idea that if that was done, and it was well mixed up with the water, the condition of that water was such as to draw the tooth of the poisonous matter and render it perfectly harmless, that the germs would abort and would not fructify, even if they retained vitality. He believed that in the waters which Providence provided us with, which were safe, there were measures by which those minute dilutions were deprived of their disease-giving properties. That led him to appear to be the critic of Dr. Frankland. That essayist was speaking of micro-organisms as being themselves poisons, which were the causes of the mischief. He (the speaker) suspected that Dr. Frankland hardly meant what his terms implied; he himself did not consider that micro-organisms were themselves the poisons which had produced the mischief, but they acted upon the organic matter which was in the polluted water; and out of that organic matter they produced the poison which aggregated in the constitution in which the organism was lodged, until it might ultimately be sufficient to destroy life; that was his idea of how the micro-organisms acted as poisons. Just as Simon said five and twenty years ago, they were the tests by which the presence of a poison was made manifest, and he (Dr. Carpenter) had an idea, that when micro-organisms came into contact with water which was comparatively pure, they would abort, and even get completely destroyed; or if they did grow into colonies, such as was shown by the gelatine test, in time they lost their infectious character and did not set up diseases, which at other times they might produce. That might explain some difficulties which had arisen in regard to the *comma* or cholera *bacillus*. Looking at the question from this point of view, it was possible that they might have a *comma-bacillus*, at one time infective, and at another non-infective. He thought that was proved by Dr. Saunderson's experiments, in reference to peritonial inflammations; in the one case the same material was harmless, and in another, by cultivation it became a most virulent poison; whilst apparently it was the same thing. Those were matters regarding which they could not at present draw any dogmatic conclusions, because they were *sub judice*, and had to be followed out much more seriously than they had hitherto been. He thought they might congratulate the Metropolis on the presence of those filtration areas which belonged to the Water Companies, and which were of some service in depriving disease germs of their infective character. The fact that there was at this moment poured into the Thames the excreta of thousands, and tens of thousands of people; some of whom were labouring under typhoid and other fevers, and that this water was pumped up and supplied to the Metropolis without serious extension of those fevers and other evils consequent upon impure water, was certainly to his mind, due to the filtration so carefully performed by the Water Companies. But he had a sort of idea that whilst the Water Companies by their filtration were arresting the micro-organisms which existed, as active, living, moving micro-organisms, and whilst they were taking out a large portion of the organic matter upon which those micro-organisms lived and propagated their kind, they were still allowing some of those resting spores to which Dr. Frankland had alluded, and which corresponded to the resting spores of the allied tribe of Fungi, pass through the meshes of their filters, and that one of these days when we do get a length of hot weather during the months of July or August, when the water in the mains supplied by the companies rises in temperature above a certain point and remains for a certain length of time above that point, say of 65 F., we should have these resting spores developing into living, moving, growing micro-organisms, capable of feeding on the organic matter which had not been arrested by the filter, and that there would be one of those seasons a rapid and extensive growth of typhoid fever or other fevers in the districts supplied by the Metropolitan companies; and it was a question therefore of the utmost importance, so far as London was concerned, whether those towns above should be compelled to take their sewage out of the river Thames altogether. What he had described would arise one of these times and might possibly lead to panic, and whenever panic did come, it was quite certain to lead to legislation or action on the part of Local Authorities, which would be precipitate, and probably in the wrong direction, whilst its pecuniary effect would be very serious to the ratepayer. Those micro-organisms to which Dr. Frankland made such a startling reference, and which were undoubtedly of the greatest importance, might he thought be altered in their character by the presence or absence of an excess of carbonic acid in the water in which they lived. They might undoubtedly alter in their character according to the fact, as to whether that water were neutral, whether it were acid, or whether it were alkaline. These three conditions would alter micro-organisms in a very important degree, and then the fourth one of temperature came in, and was of the highest importance. Those points required to be sifted out: they wanted information as to the temperature at which the examination was made; they wanted information as to the chemical character of the water; as to the presence or absence of carbonic acid in excess; as to the presence or absence of oxygen; as to the presence or absence of nitrogen; and as to the acidity or alkalinity of the water itself. Until those points were worked out, he did not think they had all the information with regard to the action of micro-organisms upon the water supply, that they would be able to obtain when those points were followed out in the same careful way, as the quantities of the micro-organisms had been studied by Dr. Frankland.

Then the most important and exhaustive paper, so far as it went, of Dr. Parkes, would commend itself to all young men; for he was quite sure they would find in that paper a very large amount of information which should be committed to their memory, and should be studied so that they would be able to see the directions analysis might take in their own districts. In conclusion, he said he had much greater confidence in chemists than they had themselves, and than some persons who were endeavouring to cast suspicion upon chemical analysis. He trusted chemical analysis, and he thought all Corporations should have their water supplies analysed frequently during the year. They should have a local analysis of the water such as Professor Dupré had referred to, and any departure from that habitual state should be carefully enquired into by the Medical Officer of Health and the analysing chemist. Every Water Company ought to have attached to its staff an analysing chemist who should be supplied at irregular intervals with the water ordinarily distributed to the people. This arrangement would afford a great protection to all dependent upon a company or a Corporation for their water supply.

Mr. C. E. De Rance (London) said that the instances where deep well waters had been found to be polluted, were due to want of care on the part of the engineers, who, in constructing the wells, had not jointed the cylinders or lining tubes, or made up the space in the back with concrete, allowing pollution to run down to the water at its source of supply. Special care is requisite in sinking wells in formations which are fissured and jointed, allowing the water to pass through underground channels, whether vertical, or horizontal, without filtering through the rock.

Mr. Pendlebury thought that the method of water analysis which had the greatest future before it, was that of the estimation of the æration of the water. He did not know what method Dr. Dupré recommended. One he had had experience in, was that of the addition of a diluted quantity of known value of sulphuric acid together with a small quantity of sulphate of manganese, which had the remarkable property of bringing about the union of the oxygen dissolved in the water with the sulphurous acid to produce sulphuric acid. After the liquid had been allowed to stand for a time, the residual sulphuric acid was determined with iodine. The pure water from the same district furnished the standard. As to mineral poisons in the water, he did not know whether they knew that Dr. Odex had recently conducted some experiments at Sheffield in regard to the water supply there, some cases of lead poisoning having taken place. He found that although in some instances soft water seemed to have dissolved lead and thus produced lead poisoning, in other apparently similar cases, lead poisoning had not been produced. This latter effect he found to be due to a small quantity of Silica dissolved in the water, and he recommended this course (the solution of Silica in water) to be always adopted with regard to every soft water.

Mr. L. L. Macassey (Belfast) observed that in times past the prevailing opinion had been, that filtration of water through sand made the water brighter in appearance, but without taking out micro-organisms which might be present in the unfiltered water. Water-works engineers had been told by the chemist that their sand filters were practically useless, and this view had been repeated over and over again in the scientific papers of the day. Dr. Frankland had thrown a most important light upon the subject by his recent experiments in Bacteriology. His first paper read last year before the Institution of Civil Engineers, had attracted a good deal of attention, and the present communication supplemented the information thus given in a most important manner. Engineers might now fairly assume that sand filtration was really beneficial in reducing the number of micro-organisms in drinking water. He had himself in certain cases experimented with finely crushed cinders, in part substitution for sand, and had got very good results. A layer of crushed cinders placed between two layers of sand made a most efficient water filter.

Mr. Charles E. Cassal, F.C.S. (London), was glad to hear Dr. Frankland point out the mistake made by people, in supposing that bacteriologists would be able to tell what waters would produce typhoid; what would produce diphtheria; what diarrhœa, and so on. The joy that was felt by a number of people who had no love for chemists as sanatarians, when bacteriology attained its more recent development, knew no bounds. Indeed it was thought by some, that chemists were to be done away with entirely; that water analysis by chemical means was a thing of the past; and that fees might go at last to those who had not had to undergo a severe chemical training. It had, however, been found that the bacteriological results simply furnished an additional "test," and a test quite as uncertain as any chemical test, if not more so. He gathered from Dr. Frankland that the only value of bacteriological methods in regard to water supply, was approval or non-approval of a water according to the number of colonies which he could obtain from it. The paper of Dr. Parkes threw out, as he thought in a very satisfactory way, the view which ought to be taken as to the value of water analysis for sanitary purposes. He had, however, not taken notice of the importance of drawing conclusions from a number of results; there was a tendency to draw conclusions from single results. Some people rode one hobby to death, and it appeared to be a great difficulty to the minds of others to deal with more than one figure at once. Some time ago an analyst proposed the creation of a sort of scale of "marks" to be given to water according to the results yielded by various processes: appearance and colour, chlorides and nitrates, and so on, were to have numerical values assigned to them, put down, added up, and the conclusion drawn from magnitude of sum total at the end. That proposition was extremely unscientific, and his contention was that if analysts would cultivate the habit of drawing conclusions from a number of results, they would never go far wrong. He held it to be most unlikely that a chemist who knew and did his duty, would pass a water as fit for consumption which was not fit, and he also held that no case in which this had been done could be pointed out. As to the Caterham case, he might point out that he had previously drawn attention to the fact in dealing with the report on that case, that no analyses were made of the water supply at the time of the outbreak.

Professor A. Dupré, F.R.S. (London), said he had been greatly interested in the two papers. He could confirm many of Dr. Frankland's results by experiments of his own made by a different method, the aeration method. Pure aerated water remained aerated when kept out of contact with air even for some time; but water containing any living organisms decreased in its degree of aeration during keeping. Now unfiltered Thames water greatly decreased in its degree of aeration during keeping, whereas the filtered Thames water as supplied to London remained almost completely aerated. Still there were great differences in some cases. When Dr. Frankland applied his test to the Kent water he found a very small number of organisms; but when he (the speaker) applied his test, he found that it diminished greatly in its degree of aeration. He was of opinion that further research on the point was necessary, for though they now knew a great deal more than they did formerly, more still remained to be known.

Dr. Louis Parkes (London) thought it would be very difficult to set up local standards of purity for water supply, because they knew that the quality of underground water would vary a good deal according to the season of the year; and they might have a standard which would vary according to the season, and according to the kind of season. Then it would vary according to the geology of different parts of a given district; they might have one half of a village standing on one kind of a geological formation, and the other on an entirely different one. The idea of a local standard of purity was of course an important one, but it required a great deal of working out. With regard to Dr. Frankland's paper, he differed from that gentleman as to the importance of determining the pathogenic micro-organisms in water. It would be a most important thing if they were to be able to point out in the future organisms which they believed were the cause of disease—if they could say "Here is a water which contains a specific disease organism, therefore it is impure." It did not matter very much whether that organism might be present on a future occasion, they had it then and that was sufficient for them. Water was brought to them which was supposed to have caused an epidemic. If they were able to say at once, "We know it has done so because we find the organism in it, which is the cause of that disease;" if they could get to that, it would really solve the whole question. With regard to Thames water, it seemed to him that London depended to a very great degree upon the efficiency of sand filtration. According to Dr. Frankland's researches, if the filtration was carried out properly they obtained a proportionate reduction of the micro-organisms; but supposing an epidemic of cholera or typhoid were to affect the towns on the upper reaches of the Thames, and supposing that in any case the filtration should fail in any degree, it was possible that the disease germs might pass into the mains of the London companies and so cause disease. That seemed to him the great danger of trusting to an artificial system of filtration.

PERCY FRANKLAND, Ph.D., F.C.S. (London), reiterated what he had said about the value of detecting specific germs. He could not admit the great importance of knowing whether this or that water contained disease organisms. What they wanted to know was whether any given water might, under ordinary circumstances, become contaminated with sewage, quite irrespectively of whether the sewage was dangerous or not at any particular time, for it might be dangerous at one time and not at another. It was quite conceivable that water which had occasioned an epidemic might be found not to contain any dangerous organisms in it, for it was obvious that the organisms might have disappeared since the epidemic was occasioned. With regard to filtration, he was not there as an advocate of the methods adopted by the London Water Companies; he was simply there to say what the results of his experiments had been, and he told them that the reduction in the number of organisms was very much greater than might have been expected. Still it was perfectly obvious that it did not prevent the possibility of organisms passing through those filters, although they did not pass through in anything like the number that people would probably have imagined. As to what Professor Dupré had said about the Kent Company's water, the results of his experiments shewed that the water issuing from the water-bearing stratum was exceedingly pure as regarded micro-organisms; but after it had been stored for a few days the number increased with far greater rapidity than anything he had noticed in unfiltered river water. When the Kent water had been kept for some length of time, although multiplication had taken place, they could distinguish between such a sample and a sample of unfiltered river water, by the fact that the number of different varieties of microbes in the unfiltered water was very much greater than was the case in stored deep well water. In the latter case they found they had an almost pure cultivation of one, two, or three organisms, whilst in the case of river water they had not only a large absolute number, but a large variety of organisms. It appeared to him that this phenomenon was explained by the fact that in the river water those different varieties acted as a check one upon the other and so impeded multiplication; whilst in the case of the deep well water, each variety had a freer field. He did not wish the impression to be carried away that any opinion could be formed of the purity of the water from the number of micro-organisms found in it. He had never himself undertaken to determine the number of micro-organisms in water brought in an indiscriminate way. Such a determination he held to be absolutely valueless, because when the water was collected indiscriminately the result would bear no sort of relationship with the result

which would have been obtained if the water had been taken direct from the water-bearing stratum. He wished to add that as regarded purification by filtration, it seemed to him that this biological test was of far greater importance than any chemical test, because everyone would admit that what they desired to remove in filtration were the micro-organisms of various kinds, and by relying solely on chemical analysis very erroneous conclusions had been arrived at as to the value of certain filters. There were filters which produced a remarkable change chemically and yet had little or no effect in removing bacteria, whilst there were other filters which produced absolutely no effect chemically, and yet biologically were so efficient that they removed all micro-organisms from any liquid passed through them. As to the use of cinders, he had no doubt they made a very efficient mechanical filter. Powdered coke was also a valuable filter, as he had previously pointed out.

On "*The Air of Buildings and Sewers*," by J. S. HALDANE.

THE subject of my communication is apparently such a wide one, that I fear you may consider that any discussion of it here within reasonable limits cannot fail to be unprofitable. My intention, however, is not to attempt to treat the subject with anything approaching to fulness, but mainly to bring under your notice the results of some experimental researches on vitiated air, recently conducted by Professor Carnelley, of Dundee, and myself,* and to initiate a discussion by the members of the Congress on the conclusions to be drawn from these experiments.

The first series of observations refers to the air of buildings. The fact that an enormously increased mortality prevails amongst persons who spend much of their time crowded together in ill-ventilated rooms is universally admitted. It is therefore unnecessary that I should recapitulate here any of the evidence we possess on this subject, or of that which more directly connects an increased mortality with vitiated air.

* The details of most of the experiments referred to here, will be found in a paper by Prof. Carnelley, Dr. Anderson, and myself, in the Philosophical Transactions of the Royal Society, Vol. 178 (1887), B, and in a further paper by Prof. Carnelley and myself, which appeared in the Proceedings of the Royal Society for June 12th, 1887. The results of the experiments in the Bristol sewers are communicated here for the first time.

One of the first requisites for success in the endeavour to procure pure air is a knowledge of the nature and amount of the various impurities present in vitiated air, and the sources from which they arise. Hitherto our knowledge of the amounts of these impurites has related almost entirely to the carbonic acid and moisture. Carbonic acid is easy to estimate in air, and its amount is rightly assumed to be a pretty good index of the impurities directly communicated to air by respiration. It is, however, highly improbable that carbonic acid itself has any appreciable influence on health in the proportions in which it is ordinarily present in vitiated air. And on the other hand it is a mere assumption, and as we shall see an unjustified assumption, that the carbonic acid is anything like a certain measure of the impurities which are directly or indirectly communicated by human beings to air in other ways than by respiration.

Of the other impurities of vitiated air perhaps most interest attaches in view of recent advances in pathology to the micro-organisms, and especially to the bacteria. It has lately become possible to estimate the latter with relative ease and accuracy, thanks to methods of research introduced by Professor Koch and Dr. Hesse. There are still other impurities, some of which we can detect by the sense of smell. We know little as to their chemical composition, and if possible less as to their hygienic significance. They may be roughly set down as "organic matter." They indicate their presence by several chemical reactions, one of these being the bleaching of solutions of permanganate of potash. For the purposes of our research Dr. Carnelley introduced a process dependent on this reaction, by which the relative amounts of the bleaching action in different specimens of air could be rapidly estimated. (Carnelley and Mackie, Proc. Roy. Soc., Vol. 41, page 238).

Our observations on the air of buildings, relate chiefly to dwellings and schools in Dundee. The main part of our work consisted in making a large number of simultaneous estimations of carbonic acid, "organic matter," and micro-organisms; but we endeavoured in addition to throw what light we could on the sources of each constituent.

THE AIR OF DWELLINGS.

The analyses of the air of dwellings were made during the night, between the hours of one and five in the morning, as we considered that at this time the air would contain about an average amount of the impurities existing in the air during the presence of the inhabitants. We examined the air in sleeping rooms of 18 of the better class of houses in Dundee, in 13 two-

roomed, and in 29 one-roomed dwellings. The results were as follows:—

	One-roomed houses.				Two-roomed houses.				Houses of four rooms & upwards.			
	No. of Cases.	Lowest.	Highest.	Average.	No. of Cases.	Lowest.	Highest.	Average.	No. of Cases.	Lowest.	Highest.	Average.
Persons per house (per room in last class)	29	2	10	6·6	13	4	10	6·8	18	1	3	1·3
Space per person	29	104	528	212	13	148	395	249	18	391	4206	1833
Temperature (°F.)	21	43	61	55	9	50	59	53·5	13	42	63	54·5
Carbonic acid......	29	6·3	32·1	11·2	12	7·1	13·2	9·9	18	4·5	11·7	7·7
Organic matter...	29	7·8	38·1	15·7	11	5·0	30·2	10·1	18	1·1	12·0	4·5
Total micro-organisms:—	28	6·0	240·0	60·0	13	8·0	128·0	46·0	18	0·5	22·0	9·0
Bacteria	19	6·0	120·0	58·0	11	6·0	118·0	43·0	16	0·5	16·0	8·5
Moulds	19	0	5·0	1·2	11	0	10·0	2·2	16	0	1·0	0·4

On each night similar analyses of outside air in the streets were also made for purposes of comparison. If we subtract the amounts found in the air outside from the above quantities, and take the corrected averages for the air of the better class of dwellings as unity, we obtain the following table:—

	Houses of four rooms and upwards.	Two-roomed houses.	One-roomed houses.
Cubic space per person	1	0·13	0·11
Carbonic acid	1	1·5	2·0
Organic matter	1	1·6	4·4
Micro-organisms (total)	1	5·1	6·7
Bacteria	1	5·1	6·9
Moulds	1	5·5	3·0

These tables show clearly the enormous differences in the purity of the air of different classes of dwellings.

Dr. Anderson, Medical Officer of Health for Dundee, with whom we were associated in our work, and who originally suggested it, obtained by special arrangements with the registrars materials which made it possible to construct a table of the mortality statistics of Dundee for 1884, arranged in a similar manner.

		No. of Cases.	Per 1,000 living. Whole Population	Houses. 4-roomed and upwards.	3-roomed.	2-roomed.	1-roomed.	1 & 2-roomed, including Infirmary and Poorhouses.
Death-rate.	General death-rate	3119	20·7	12·3	17·2	18·8	21·4	23·3
	Death-rate of children under 5 years of age	1347	9·0	3·3	5·8	9·8	12·3	10·8
	Ditto of all above 5 years of age	1772	11·7	9·0	11·4	9·0	9·1	12·5
	Ditto of all above 20 „	1419	9·4	8·2	8·9	7·3	8·5	9·8
	Ditto of all above 70 „	293	1·9	2·4	2·1	1·4	1·3	1·4
	Ditto of all above 80 „	75	0·5	0·65	0·77	0·39	0·20	0·41
Mean age at death.	Of all who died	3119	24·5	40·0	30·6	21·3	20·9	23·9
	Of all who died above 70 years	293	76·3	76·9	77·2	76·9	74·6	76·0
	Of all who died above 20 „	1419	53·6	57·7	54·4	51·6	54·8	52·1
	Of all who died below 20 „	1619	2·5	4·5	4·4	2·2	1·8	2·3
	Of all who died above 5 „	1732	45·2	51·7	45·5	43·0	48·2	44·1
	Of all who died below 5 „	1306	1·1	1·4	1·2	1·1	0·9	1·0
	Of all who died between 5 and 20 years	313	9·2	11·7	12·2	8·3	7·0	8·3

Diseases causing more than 50 deaths.	Deaths from under-mentioned causes:—		Per 10,000 living.					
A	Diarrhœa	253	16·9	6·1	11·3	17·4	26·4	20·2
A	Measles	94	6·3	1·3	3·6	7·0	9·1	7·9
A	Convulsions	78	5·2	1·7	2·3	6·5	6·7	6·6
A	Accidents (including over-laying)	93	6·2	1·7	1·8	3·4	14·6	8·3
A	Premature birth and debility during first days of life	177	11·8	3·0	6·3	13·4	17·0	14·8
A	Acute bronchitis & broncho-pneumonia	224	14·9	7·8	9·5	13·4	26·7	17·6
B	Chronic bronchitis	159	10·6	6·3	9·5	8·1	16·5	11·8
B	Croupous pneumonia	155	10·3	3·5	6·6	12·7	9·5	12·5
B	Meningitis	122	8·1	5·7	6·8	8·9	6·7	8·9
B	Hooping-cough	99	6·5	0·9	6·8	8·3	6·3	7·8
B	Tumours	73	4·2	2·2	3·6	4·1	3·1	5·7
B	Heart (valvular) disease	159	10·6	9·1	9·5	8·4	9·4	11·1
C	Phthisis	369	24·6	13·0	27·6	24·4	14·6	26·4
C	Apoplexy, thrombosis, & embolism of vessels of brain	160	10·7	17·4	5·9	6·9	7·9	10·2
C	Diphtheria and croup	93	6·2	7·0	4·1	6·9	3·1	6·5
C	"Old age"	150	10·0	8·7	12·7	5·5	7·5	9·7

I have not time to say anything further here with regard to this table, but I think it has many points of interest of its own quite apart from our experimental results. It shows that not only is the mean age at death on the whole about twice as long

in the best as in the worst houses, but that at all periods of life up to old age those who live in the better houses have the advantage.

The fact that the increase in death-rate runs parallel with the increase in air-pollution does not prove that the former is the cause of the latter. But we may argue from other evidence, such as that so ably presented by Dr. Ransome in his lecture last night, that the pollution of the air is one very potent cause, and probably the chief cause, of the increased mortality.

The Air of Schools.

We examined during winter at least two rooms in each of the Board schools and several denominational and private schools in Dundee, besides several lecture-rooms in University College. The rooms examined may be classified in the first place according to the means of ventilation, as this was found to make an enormous difference in the results. A certain proportion were ventilated by ordinary means, such as fires, open windows, and ventilators in the roof. The rest were ventilated mechanically by blowing air by means of fans over hot pipes, and thence into the several rooms by means of shafts. The following table gives the results obtained with the two kinds of ventilation:—

	Schools. Naturally ventilated. No. of cases.	Lowest.	Highest.	Average.	Mechanically ventilated. Average.	Lowest.	Highest.	No. of cases.
Per cent. of windows open	...	...	...	22	3	...	...	...
No. present, including staff	39	27	191	92	64	20	170	20
Space per person	39	56	427	168	164	119	228	20
Temperature (°Fahr.)	35	44	65	55·6	62	58	69	18
Carbonic acid	39	7·9	37·8	18·6	12·3	7·0	19·6	20
Organic matter	38	5·0	40·3	16·2	10·1	3·4	19·0	20
Total micro-organisms:—	35	8	600	152	16·58	0	58	18
Bacteria	28	8	600	151	16·0	0	56	18
Moulds	28	0	4	1·1	0·58	0	2	18
Or above outside air:—								
Temperature (°Fahr.)	25	3	34	16·8	24	22	26	3
Carbonic acid	39	4·4	34·3	15·1	8·9	3·5	16·1	20
Organic matter	38	0	31·4	7·8	1·1	0	5·3	20

Or, if we take as units the average cubic space, the average excess over outside air of temperature, of carbonic acid, of organic matter, and of micro-organisms, in mechanically ventilated schools, the comparative results for naturally ventilated schools may be expressed as in the following table:—

	Mechanically ventilated.	Naturally ventilated.
Cubic space per person	1	1·0
Temperature in excess of outside air	1	0·66
Carbonic acid " "	1	1·7
Organic matter " "	1	7·0
Micro-organisms " "	1	9·2
Bacteria " "	1	9·4
Moulds " "	1	2·0

We have not included in the above table the Dundee High School, nor the only private school we have examined, as in these two cases the cubic space per person was about three times as great as in the other schools. The results for these two schools were as follows.—It will be seen that practically they confirm the conclusions drawn from the results in other schools, though the effects of mechanical ventilation are not nearly so marked:—

	Private School (Girls) Naturally ventilated.				Dundee High School (Boys and Girls) Mechanically ventilated.			
	No. of rooms examined.	Lowest.	Highest.	Average.	Average.	Lowest.	Highest.	No. of rooms examined.
Numbers present	3	6	11	9	36	13	64	6
Space per person	3	320	528	457	538	320	1102	6
Temperature (°F.) ...	3	56	57	57	57	51·5	60·5	6
Carbonic acid..........	3	10·7	13·3	11·9	13·0	8·5	16·4	6
Organic matter	3	6·2	11·8	8·9	3·9	1·7	5·6	6
Total micro-organisms	3	4	15	9·3	3·6	1	11	7

We now come to some of the most unexpected and interesting of our results. Wishing to test more thoroughly the results of mechanical ventilation, we made a number of comparative experiments on different days in the same room. The circumstances were as nearly as possible the same, except that on some days the mechanical ventilation was in operation, and on other days not, open windows, &c., being used instead. We found, to our surprise, that whereas the carbonic acid present in the air was increased from 12·6 to 18·6 volumes with the mechanical ventilation not in operation, the average number of micro-organisms remained almost exactly the same. Even when the mechanical ventilation was kept off for a week this had no distinct effect in increasing the number of micro-organisms. These anomalous results did not lead us to doubt the effects of mechanical ventilation in diminishing the number of micro-organisms in air, as we found the number very small even in rooms where every other condition except the ventilation seemed to favour a large number. We were, therefore, forced to conclude that while the ventilation at the time is the decisive factor in influencing the amount of the gaseous impurities, it is, other things being equal, the habitual state of the ventilation which influences the micro-organisms. This led us to inquire into a number of points regarding the sources of the micro-organisms.

It had previously been proved by Tyndall and others, that physical disturbances of any kind, such as those caused by the presence of human beings, have a great effect in disseminating micro-organisms in air, and that air left perfectly still gradually deposits its micro-organisms. We naturally, at first, expected that varying amounts of physical disturbance would very much obscure other differences. It turned out, however, that this is not the case. Although the influence of difference in physical disturbance is well marked, under ordinary circumstances other influences have a much greater effect, as we shall see.

That the micro-organisms do not come from the breath, but are on the contrary filtered off by respiration, we showed by means of some experiments, the details of which need not be described here (see Phil. Trans., vol. 178, B, page 92). That they do not come in any large number directly from the clothes or skin of the persons present in a room was shown by a number of observations made in the two chemical lecture rooms. Even during a course of crowded popular lectures there was found to be an average of only four micro-organisms per litre, as compared with an average of about three when the room had remained empty. Nor did the number rise beyond six per litre when the room was left unventilated during the lecture, and the carbonic acid rose to nearly 40 volumes per 10,000. This observation alone shows strikingly, I think, that the carbonic acid is no measure of the number of micro-organisms in the air of a room.

The micro-organisms thus do not come to any large extent from the bodies of the persons present at the time. Nor do they come from the outside air, which is comparatively free from micro-organisms during winter, as shown both by our own experiments and by the more recent and systematic ones of Dr. Percy Frankland. We must therefore conclude that they come from the floor and other parts of the room itself. If this is really so, the state of a room as regards cleanliness ought to have an effect on the number of micro-organisms. This we found to be actually the case, as shown in the following classification of both schools and houses:—

		No. of cases.	Average space per person.	Average carbonic acid.	Average organic matter.	Average micro-organisms.
One-roomed houses	Clean	1	295	8·0	13·1	18
	Dirty	7	200	9·9	18·1	41
	Dirtier	13	221	10·7	13·5	49
	Very dirty	6	220	11·0	15·1	93
Two-roomed houses	Very clean	2	273	12·2	10·8	10
	Clean	4	261	9·3	7·7	22
	Dirty	7	233	9·4	11·2	69
Naturally ventilated Board schools	Cleaner	12	167	19·7	18·1	91
	Average cleanliness	12	166	14·2	16·2	125
	Dirtier	12	191	22·5	15·2	198
Mechanically ventilated schools and college	Cleanest	7	194	12·5	12·7	3
	Clean	11	155	12·8	8·3	16
	Less clean	4	152	10·8	9·8	30

We next classified the schools according to age, and obtained the following results:—

	No. of cases.	Micro-organisms per litre.
Opened before 1866	7	311
„ 1875—1880	20	150
„ 1884—1885	5	38

This was not at all what we expected to find. One would rather have anticipated that the micro-organisms, like the ordinary dust particles in a room, would very soon reach a maximum, depending on how often the room was cleaned. But the causes under the action of which a room becomes infested with micro-organisms are evidently no merely temporary ones, but have a gradually cumulative action. Further investigations on this point are now being carried out by Professor Carnelley at Dundee.

At the time when the results of our analysis led us to this important result, we were unaware of a very interesting research made recently by Dr. Emmerich of Leipzig; I think the results he obtained may throw a great deal of light on this cumulative infection of the air by micro-organisms. At any rate his research was such an important one, that I need not apologise for shortly referring to it.

He made a large number of analyses of the damping material used for filling up the space between the ceiling of one flat, and the floor of the flat above. He found an almost incredible pollution of this material. His analyses show that, to use his own words, "there exists nowhere in nature, not even in the neighbourhood of human dwellings, a soil so highly contaminated with nitrogenous organic substances and their decomposition products as the damping material under the floor of dwelling rooms." The amount of chloride of sodium found in this material was on an average seven times greater than that found in the ground under leaky cesspools, and twelve times greater than that in the soil round a dung hill, although this soil was visibly soaked with filth. When the coarse pieces of stone were separated from this material, it was found that the finer dust and sand which was left, contained even more nitrogenous matter than human excrement. "In the damping material of a single room, there was usually more excremental matter present than in a large cesspool." That all this filth is alive with micro-organisms, is shown by the amount of the products of decomposition which result from their activity. Thus under the floor of one single room Emmerich found that there were more than 6 cwt. of nitric acid in the form of nitrates. He also showed that the carbonic acid in the air of rooms left shut up and empty increased, although all other known sources of carbonic acid, such as sub-soil air, &c., were excluded. The chief cause of this contamination was undoubtedly the soaking of fluids and shaking of dust through the fissures and spaces between the boards in the floor. Often, however, the rubbish which was used as damping material was contaminated from the beginning, having been taken from old houses, or rubbish heaps, such apparently as many houses in this country are built upon.

Emmerich's paper is such a remarkable one, and contains so many points of interest, that one is surprised at not having heard something of it in this country. It is well worth the careful attention of everyone interested in questions of public health. There seems no reason to doubt that a very similar state of pollution exists in the damping material of English houses. A few days ago I obtained a specimen of this material from an old house in Edinburgh. One could see at a glance that it was highly polluted with organic matter, and the part which past through a coarse meshed wire sieve was found to lose about a third of its dry weight on ignition, giving off at the same time a most offensive smell. I am told by Mr. Krunear, of the Dundee Sanitary Department, that houses are sometimes made uninhabitable merely by the smell of this material, which in these cases has to be removed.

Emmerich followed up this research by another no less interesting one in connection with the same subject. In a prison at Amberg there had persistently occurred for years epidemics of croupous pneumonia. The last of these had attacked every seventh, and killed every twentieth prisoner. As is well known, the late Dr. Friedländer of Berlin discovered the presence in cases of croupous pneumonia of a species of bacterium, cultivations of which, when inhaled by, or inoculated into certain animals, produces a similar disease in them. There can thus be little doubt as to the causal connection between this organism and the disease, or at any rate certain forms of it. Emmerich examined the damping material from the infected rooms in the Amberg prison. He not only found this material full of organic matter as usual, but actually discovered Friedländer's bacterium in enormous numbers.

To return to our own researches, it seems very likely that the progressive contamination of the material in the floors, and perhaps elsewhere about the room, may be connected with the progressive contamination of the air with micro-organisms. Emmerich's researches throw a vivid light on the manner in which this progressive contamination may affect the health of the inhabitants. A glance at our table of statistics will show how the mortality from croupous pneumonia, for instance, increases from 3·5 per thousand in the better houses to 6·6 in the three-roomed, and 12·5 in the one and two-roomed. Probably the mortality would be even larger in the latter class were it not for the influence of hospital treatment, which is very frequently taken advantage of in cases of croupous pneumonia, and is of great benefit.

In what manner exactly mechanical ventilation reduces the number of micro-organisms in the air seems still rather obscure. The explanation may perhaps lie in the more efficient sweeping out with the air of the particles of suspended organic matter which would otherwise have formed a pabulum for the growth of micro-organisms. Or perhaps the growth of the latter may be prevented by the greater dryness of the rooms mechanically ventilated.

Let me refer to one or two further points before leaving the

subject of school ventilation. We classified the schools according to the cubic space per child at the time of our visit. It will be seen that increased cubic space up to 300 cubic feet brought with it no diminution in the pollution of the air. With mechanical ventilation, on the other hand, there was a diminution, at any rate in the number of micro-organisms, with increase of cubic space.

Cubic space per person.	Naturally ventilated.				Mechanically ventilated.			
	No. of Cases.	Carbonic Acid.	Organic matter.	Total micro-organisms.	No. of Cases.	Carbonic Acid.	Organic matter.	Total micro-organisms.
Cubic feet.								
50—100	6	21·5	16·2	119				
100—150	14	15·5	19·6	128	7	14·0	7·8	23
150—200	5	18·9	12·3	150	8	11·4	9·6	14
200—250	9	21·1	16·8	188	5	11·8	12·3	10
250—300	4	17·1	9·5	187				
300 and upwards.	4*	15·1	11·8	12	6	13·0	3·7	2

We also divided the naturally ventilated schools we examined into two classes, according as they were heated and ventilated by fires or by hot pipes respectively: and we obtained the following results. The data for mechanically-ventilated schools are added for comparison:—

Description of School.	No. of rooms examined.	Carbonic acid.	Organic matter.	Total micro-organisms.
Ventilated mechanically, and heated by hot air blown into the rooms ..	20	12·3	10·1	16·5
Heated by fires, and ventilated in the ordinary way	18	16·9	15·7	169·0
Heated by hot pipes in the room itself, and ventilated by windows, ventilators in the room, and in some cases by a few small Tobin's tubes ..	21	20·0	16·5	92·0

* Three of these were in a Private School.

The following table shows the result of a comparison of a number of pairs of rooms. The rooms in each pair were as similar as possible in every respect (such as age of children, &c.) except that one was occupied by girls and the other by boys:—

	Space per person.	Temperature. (° Fahr.)	Carbonic acid.	Organic matter.	Micro-organisms.
No. of rooms compared	30	20	20	16	30
Boys	275	60	15·0	7·9	92
Girls	382	58	12·3	6·7	65

The general result of our investigations has, I think, revealed a state of matters in schools urgently calling for improvement. The amount of loss of life and health resulting from the vitiated state of air is in all probability enormous. Captain Douglas Galton dealt with this subject in his admirable inaugural address at the Newcastle Congress of this Institute. Let me only recall one of the facts mentioned by him: that the mortality among teachers in elementary schools was found to be about 20 per 1000, as compared with 5 per 1000 in two classes where the average age was presumably about the same—the police and navy—and 3 per 1000 amongst prisoners.

We can afford to provide abundance of fresh air for criminals, and surely we might do as much for our children. It is not only abundance of ventilation that is required for keeping the air of rooms pure, but the room itself must be prevented from becoming contaminated with dirt. For this both personal cleanliness is required, and the means of keeping the room itself and everything underneath and about it absolutely clean. I do not doubt that engineers and architects can devise not only satisfactory and sufficient methods of ventilating and warming schools, but also floors which will be incapable of becoming polluted in the manner just referred to.

THE AIR OF SEWERS.

The analyses we have made of sewer air refer chiefly to sewers at Dundee and at Westminster Palace. We used exactly the same methods as had been used for houses. Altogether we examined thirty-two specimens of sewer air at different times and places. The average results obtained at Dundee and Westminster are shown in the following table:—

	TOTAL.				In excess of outside air at time.			
	Temp. F.	Vols. carbonic acid per 10,000 vols. of air.	Vols. oxygen to oxidize the organic matter in 1,000,000 vols. of air.	No. of micro-organisms per litre.	Temp. F.	Vols. carbonic acid per 10,000 vols. of air.	Vols. of oxygen to oxidize the organic matter in 1,000,000 vols. of air.	No. of micro-organisms per litre.
April 19th to May 19th, 1886.								
In sewers	51°	7·5	7·2	8·9	5·2°	3·8	4·9	—7
Outside air at same time	49	3·7	2·2	15·9	...	...	...	...

If we compare these results with those obtained in schools and dwellings, an astonishing difference appears in favour of the sewers. This is brought out more clearly in the following table, in which the average quantity in excess of outside air of each constituent in sewer air is taken as unity:—

	Carbonic acid.	Organic matter.	Micro-organisms.*
Sewers	1	1	1
Houses: one-roomed	1·7	1·3	$7x$
Houses: two-roomed	1·4	0·45	$5x$
Houses: four rooms & upwards	0·9	0·3	x
Schools: naturally ventilated .	4·0	1·6	$17x$
Schools: mechanically „ .	2·3	0·2	$2x$

Evidently in some respects sewer air is one of the most free from micro-organisms anywhere in a town. It is in this respect twice as pure as outside air, in summer at any rate. This result may perhaps come as a surprise to many people, but is in reality not in the least surprising. Professor Nägeli of Munich showed some years ago that micro-organisms, like other particulate matter, are not given off from moist surfaces. As everything inside a sewer is moist we should therefore not expect micro-

* In this case we have represented the relation of the number for sewer air to that for air in four-roomed houses by x, as the calculated number for sewer air is negative. The real value of x must be between $\frac{9}{7}$=1·3, and infinity.

organisms to be given off. That even the motion of water running as in a sewer does not give off anything particulate was also shown by some interesting experiments with lithia solution published by Professor Frankland in 1877.

We may contrast the obstacles which thus exist to micro-organisms being given off by sewers, with the absence of such obstacles in the case of accumulations of dirt about or underneath the floor of a room. The latter accumulations are more or less dry, and constantly being shaken, and the air of the floor is usually being sucked up into the room. There are thus all the conditions present for air contamination. How easily such contamination may arise is shown by the fact that a slight shake of the bottle containing the specimen of damping material referred to above, was sufficient to cause a distinct cloud of dust to rise.

What now are the sources of the few micro-organisms actually found to be present in sewer air? Professor Frankland showed that the bursting of bubbles disseminated particles of lithia solution, and therefore presumably micro-organisms. We made some laboratory experiments at Dundee, which showed directly how completely Professor Frankland's inference was justified. But in the sewers we visited there was no bursting of bubbles, as the current was far too fast for sufficient putrefaction to take place; it therefore seemed desirable to ascertain whether the micro-organisms had not simply come in by the ventilators from outside. It was not so easy as might have been supposed to get conclusive evidence on this point; but I think we can show that it is at least exceedingly probable that this was the source of almost all the micro-organisms.

In the first place if the micro-organisms came from any part of the sewer or its contents, we should expect that the longer the air remained in the sewer, the more would it become charged with micro-organisms. It is usually difficult to discover from direct observations how long in any particular case air has remained in the sewer, but we can judge roughly of this from the amount of carbonic acid present. If we classify the results in three equal divisions, according to the amount of carbonic acid found, we obtain the following table:—

Total:—	Temperature.	Carbonic acid.	Organic matter.	Micro-organisms.
4·9—6·2 vols. carbonic acid	55·8°	5·7	5·1	8·7
6·7—7·9 " " "	53·1	7·3	6·3	6·4
8·6—10·9 " " "	53·0	9·4	10·5	5·4

It will be seen that as the carbonic acid increases, the micro-organisms decrease in number. A similar result is obtained by classifying according to the strength of the draught:—

	Carbonic acid.	Organic matter.	Micro-organisms.	In excess of outside air.		
				Carbonic acid.	Organic matter.	Micro-organisms.
Strong draught	6·6	5·7	9·9	2·6	3·5	— 2·3
Moderate draught	7·5	8·8	8·9	3·9	6·6	— 9·2
Little or no draught ..	9·4	8·1	6·7	6·0	5·5	—14·3

Again, we analysed the air in the main Westminster Palace sewer, before and after certain improvements in the ventilation had been made. After the improvement there was a much stronger air current along the sewer. It will be seen that while the amounts of carbonic acid and organic matter were diminished by the improved ventilation, the micro-organisms increased in number.

	Carbonic Acid.	Organic matter.	Micro-organisms.
Average before improvement	7·8	11·0	7
Average after improvement	6·2	2·7	10·3

In order to investigate this point further, it was evidently desirable to examine air in a sewer as much as possible cut off from outside air. As is well known, the Bristol sewers are as completely as practicable shut off from outside air. I therefore applied a few weeks ago for permission to examine them. Dr. Davies, Medical Officer of Health, and Mr. Ashmead, C.E., kindly gave me every possible facility for my work.

The Bristol sewers can only be entered, without digging, at two places, each of these being close to the outlet of the sewer. At only one of these outlets (the one a short way below the Clifton Suspension Bridge) were the conditions favourable for the experiment. In this case there was a draught down the sewer towards the man-hole. This air must have come a long distance in the sewer, as there were no inlets anywhere near. It was found that the number of micro-organisms at this point was exceptionally small, the average of two analyses giving only two per litre. The result thus entirely confirmed our hypothesis. At the other outlet, the temperature in the sewer was so high that when we opened the trap-door there was a double draught in the man-hole, the hot air of the sewer rising, and cold air rushing down and along the sewer. Hence the sewer air became mixed to a certain extent with outside air. As was to be expected, therefore, the sewer air was not in this case so free from micro-organisms. A short way up this sewer there were found in each of two analyses 8·5 micro-organisms per litre, whereas the outside air at the mouth of the man-hole contained 13 per litre.

There was hardly any smell perceptible on entering or leaving the Bristol sewers. The carbonic acid near the Clifton outlet amounted to only 19·7 and 20·7 volumes per 10,000 in two analyses, while the amount was much less (14·1 and 9·1 volumes) near the other outlet. This amount is of course very small, less than what was found in many schools. If we consider that the subsoil air at the depth of the sewer probably contained more than ten times as much carbonic acid, the result is rather surprising. There was a rapid flow along these sewers, so that no time was given for putrefactive changes in the sewage.

An interesting point in the Bristol experiments was that the number of moulds in the sewer air was found on an average to equal that of the bacteria, whereas in the air of the streets in summer weather the bacteria found far exceed the moulds as a rule. Now it has been shown by Hesse that moulds, although their spores are much larger than bacteria, nevertheless remain suspended in the air much more readily. Hence we expressed in a previous paper the anticipation that on the hypothesis that the sewer micro-organisms come from the outside, the proportion of moulds would be found to increase in proportion to the decrease in the ventilation. The Bristol experiments thus bear out the hypothesis.

The point is well illustrated by the results of some experiments made with a long piece of wide tubing arranged to represent the sewer, and with a draught through it of about a foot per second. The micro-organisms were estimated simultaneously at the two ends of the tube. The air passed along the tube was very rich in micro-organisms. As the average of two experiments with this arrangement we found that while there were 225 bacteria to 57 moulds at the mouth of the tube, there were only 100 bacteria to 57 moulds at the other end. Thus the bacteria had diminished by half while passing along the tube, whereas the moulds had not diminished at all.

I think there is thus a strong case, from the sewer point of view, against outside air. It is evidently, as a rule, the outside air which contaminates the sewer air with micro-organisms, and not

the other way. Nevertheless, in one respect we obtained clear evidence of contamination by micro-organisms arising from the sewer itself. In two cases where there was splashing in a sewer from pipes entering in the roof, we found that the air close to the splashing contained 103 and 25 micro-organisms per litre; whereas the air a few feet away, and after the splashing had ceased, contained only 12 and 8 micro-organisms. Some experiments with the artificial sewer showed that large numbers may be disseminated in this way. Air, in a litre of which no micro-organisms were found before splashing caused by pouring a putrefying infusion from a height, was found to contain several hundreds per litre during the splashing. Splashing in a sewer should therefore be avoided if possible.

The results of these researches will perhaps tend to mitigate some of the terror with which we have come to regard sewer air. Sewer air has commonly been supposed to be "loaded" with micro-organisms, whereas, in reality, it turns out to be some of the freest air from micro-organisms that can be found. It may be answered that it is not a matter of quantity, but of quality. There may be very few germs, but they may be very deadly ones. Doubtless they may be, but until we have definite reasons for supposing that this is the case, the presumption is, that they are no more harmful than other germs which are floating about everywhere.

What is the supposed evidence for the causation of typhoid fever and other diseases by the inhalation of sewer air? We may dismiss at once as absolutely worthless by themselves collections of cases in which something has been found wrong with the drains in a house where a case of typhoid fever has occurred, or where the patient has been found to have sniffed at a sewer grating or ventilating pipe shortly before his illness. What one would require to know is whether the proportion of cases occurring among those most exposed to sewer emanations is greater than among those less exposed. Without evidence on this point, isolated cases prove absolutely nothing, considering how constantly most persons are exposed to a greater or less extent. Let me recall some of my own experiences in this respect during the last few months. I do not suppose there is anything exceptional in them. During the recent hot weather, I could seldom go along the streets of Oxford without being unpleasantly reminded of the sewers at very frequent intervals. During last autumn I worked all day for many weeks in a laboratory in Berlin, where one or other of the traps connected with the sinks was forced every few minutes, this sometimes causing an offensive smell; and I can recall various other ways in which I have been more or less constantly exposed to emanations from sewers or drains. I may add that we never felt the slightest ill effects from working in the sewers, although on some days we spent several hours in them.

But apart from individual cases of typhoid, there are various records of groups of cases having occurred in houses where something was wrong with the drains. Some of the most noteworthy are contained in Dr. Murchison's famous book on Continued Fevers. On looking through these records, one finds again and again that the reason why these outbreaks were traced to emanations from sewers and cesspools was simply that no other cause could be discovered at the time. When one considers that nothing is more common than for groups of people to be exposed in a similar way without typhoid fever occurring, it seems to me that, so far as the evidence goes, one might quite as well trace the fever to the influence of almost any other local cause. What is required to make such instances of the slightest value is satisfactory negative as well as positive evidence. Such apparent negative evidence as is offered is usually entirely illusory. The fact, for instance, that an epidemic stopped after some drainage defect was altered, proves nothing at all, because, judging from experience in other cases, the epidemic would have ceased at any rate. Nor does the fact that epidemics are sometimes localised in buildings round some source of drainage emanations prove anything without corresponding negative evidence. Systematic observations carried on for years in the Munich barracks, and reported by Dr. Port, showed that groups of cases often occurred at some particular part of the barracks. Sometimes these cases occurred close to the privies, but they showed no special tendency to occur in these parts of the buildings. As regards sewer air in particular, let me once again recall the fact shown by Buchanan for English towns, and abundantly confirmed by more recent German statistics, that the introduction of sewers to towns has been almost universally followed by a diminution in the amount of typhoid.

I cannot now enter further into this controversy. I have argued that the belief in the connection of sewer air with typhoid fever rests not on satisfactory evidence, but largely on *a priori* reasoning. Our observations on the impurities of sewer air would have no weight against any satisfactory evidence for the connection between sewer air and fevers; but I think they have very great weight against the *a priori* reasoning on which I have tried to show that the sewer air theory largely depends.

When I say this, I do not wish it to be supposed that I am arguing that emanations from drains are in every way harmless. It seems to me highly probable that a house, the air of which is contaminated in this way, is unhealthy, as well as, and perhaps simply because it is, unpleasant. The organic and other substances contained in such air may, from their unpleasant smell or otherwise, have a very serious effect on health. In any case I feel confident that the attention which has been given to the means of preventing such contamination is well worth the trouble. But in the present negative state of our knowledge on the subject we should cease to attribute blindly to sewage emanations cases of disease of which we do not know the cause, and patiently seek for convincing evidence as to the real causes; whether these lie in sewage emanations or floor-damping materials, or in the subsoil, or the water supply, or elsewhere.

August Dupré, Ph.D., F.C.S., F.R.S. (London), said the paper was a very valuable one and exhibited a vast amount of research, although it was rather startling in some of the conclusions drawn. Though the writer had seemed to be very cautious in what he said, he (Professor Dupré) could not help thinking he had rather exaggerated some parts of his case. Dr. Emmerich's conclusions were not by any means generally accepted in Germany by men of science.

Dr. Louis Parkes (London) thought the Sanitary Institute ought not to allow the paper to pass without a few words of caution to the public as to the character of the atmosphere in sewers. The method pursued in this case rather showed them what micro-organisms they could find than what were really present. There might be hundreds, thousands, aye, millions of organisms which could not grow in peptone gelatine at ordinary temperatures under ordinary conditions. From what they knew of the state of research in this country it followed that those experiments must be taken with great limitations; they told them what they could find out, but they told them nothing of the boundless organisms which were not capable of being recognised by that process. They all knew that micro-organisms were not given off by wet surfaces, they were found on dry surfaces, and yet they all preferred to live on a dry rather than on a damp soil. If they were to accept the teachings of Mr. Haldane's paper, they would have to put aside all the teachings of sanitary science and all past experience as to the spread of disease and fevers. The accumulated evidence on this point was now very strong, and the facts that had been brought forward in the paper did not really controvert any of the evidence as to the dangers of inhaling sewer gas. What had been said about micro-organisms might be just as stated; but that was no reason why they should cease to endeavour to keep sewer air from entering their houses. Let them not go away with the idea that sewer air was purer than the external atmosphere, and therefore better to breathe. If they did, the logical conclusion must be that they had better pass their lives in the sewers.

Mr. JOHNSON MARTIN (Bolton) suggested that the increased number of micro-organisms found when fresh air was admitted to the sewers might arise from the increased rapidity of the air current, which carried more of the organisms into a given space. He had met with many cases of fever himself where there was absolutely no other cause except sewage emanations to which the outbreak could be attributed, and it would be a most dangerous thing for it to get abroad that sewage emanations were not dangerous to health and ought not to be guarded against. The statement made by Mr. Haldane was simply one of theory.

Prof. CARNELLEY (Dundee) said that all they wished to emphasise was that the proofs which had been advanced in support of the supposition that sewer air produced typhoid and infectious diseases, were not conclusive. They did not say it was harmless, nor did they wish anyone to breathe sewer air; they simply wished to get at the facts of the case. It did not always follow that because a case of typhoid could be traced to no other source than sewer gas, that it was therefore true that sewer gas was the cause. The case mentioned by Mr. S. W. North in the sitting of the Congress the other day, was a case in point. Mr. North mentioned that they had 130 cases of typhoid in York, and that 120 of them were traced conclusively to the milk supply. But Mr. North had plainly stated, that had it not been for that fact being brought to light by notification, he should have set it down to some defect in the sewers. As to "damping" material, he did not think it was generally used in this part of the country, but it was extensively used in Scotch towns, in the space between the ceiling and the floor, and it was thus used so as to deaden the sound. There were cases where this space was entirely filled up by cinders, which appeared to have been ashpit refuse, and which might therefore be contaminated to a dangerous degree. So that when the floors were washed, and the rooms became warm in the natural order of things, there were all the conditions necessary to the gross multiplication of disease-producing organisms; and he had no doubt that many cases of disease which had been put down to the effect of sewer gas, had really been due to that "damping" material, which was especially harmful in rooms used as nurseries, where there were usually other conditions likely to contribute to the fermentation of the filth below. As to the effects of cleanliness, they had been making some experiments in schools in Dundee; they thought it must be very good if schools could be washed a great deal oftener than at present. At Dundee they were only washed two or three times in the course of a year. They therefore chose two schoolrooms which were as nearly as possible alike as regarded cubic space per child, and as to the condition of the children attending. The air of these two rooms was analysed every other day for a fortnight, one being washed at regular intervals, and the other left as before. The result was very curious; whilst the number of micro-organisms in the air of the unwashed room kept up to one average, those in the washed room first decreased after washing to 31, and then increased to 147, and finally settled down to 106; whereas the average before washing had been 112. The above results are difficult to explain; the experiments, however, are as yet far from complete, and no doubt the true solution of the problem will be forthcoming, when the conditions have been thoroughly investigated. In the meantime, there cannot be the slightest doubt, as other experiments have conclusively shown, that cleanliness has a very material effect in diminishing the number of micro-organisms present in the air of buildings.

AUGUST DUPRÉ, PH.D., F.C.S., F.R.S. (London), here said Mr. Chadwick had sent a letter to the sitting which was too long to read, but which stated that the statistics he had collected bore out the experiments related in the paper.

On "Notes on Lancashire Water Supply," by C. E. DE RANCE, Assoc.Inst.C.E., F.G.S., F.R.G.S. Secretary of the Underground Water Committee of the British Association.

AN ordinary geological map of the county of Lancaster, gives but little clue to the conditions which induced the early settlers in the county to locate themselves in the spots now covered by almost countless towns and villages. The site of original habitation is nearly invariably on a knoll or patch of sand and gravel, forming a portion of the Glacial Drift, which covers the plains of Lancashire, and sweeps far up into the deep valleys covering the older rocks like a mantle, so that they are only seen at intervals where the rivers have cut down deep, and the denuded edges of the strata are seen beneath the Drift. So much so is this the case, that no sections of the older rocks occur on the coast of Lancashire from the mouth of the Mersey at Liverpool, to Heysham Point in Morecambe Bay; and again northwards the Drift is still seen forming the cliffs at Hest Bank, and westward at Rampside, near Barrow. At Blackpool the cliffs of Boulder Clay and Sand rise to a height of more than 100 feet; and the valleys of the Ribble, at Preston, and the Irwell, at Manchester, are entirely excavated in a Glacial Drift of more than 150 feet of vertical thickness.

The average rainfall of western Lancashire is between 35 and 65 inches, steadily increasing eastward to the county boundary, which for the most part follows the Pennine watershed separating the rivers flowing into the Irish Sea, from those flowing eastward into the German Ocean. The Pennine Chain rises to an average height of 2,000 feet, and is composed of the Millstone Grit, which attains in Lancashire its maximum development in England.

The *Millstone Grit* is subdivided as follows:—

Rough rock, or First grit. Shale.
Haslingden flags, or Second grit. Shale.
Third grit. Shale.
Kinderscout grit, or Fourth grit. Shale.
Upper Pendle grit. Shale.
Lower Pendle grit.

The alternating character of permeable and impermeable material, and the deep ravines by which Millstone Grits are intersected, cause them to be extremely valuable for waterworks purposes; the rainfall sinking into the area of grit exposed at the surface, being supported and held up by the underlying and separating beds of shale: these cause the rainfall, that would otherwise have flowed away in devastating floods, to be stored up and delivered in springs, which maintain the dry-weather flow of the streams of upland Lancashire. A chain of waterworks may be followed from district to district in this formation, from Manchester waterworks at Longendale, to the Lancaster waterworks at the head of Wyresdale. In this chain of gravitation reservoirs, impounding the springs of the Millstone Grit, are those of the Preston, Blackburn, Padiham, Burnley, Todmorden, Wigan, Bury, Ashton, Oldham, and Bolton Corporations, those of the Rossendale and the Fylde waterworks, and also those of the Leeds and Liverpool canal. Nowhere can the Millstone Grit be better studied than in the picturesque district of supply of the Bolton Corporation waterworks around Belmont, on the eastern side of Rivington Pike; westward and northward of the ridge culminating in the Pike, are the Anglezark or Rivington reservoirs of the Liverpool Corporation waterworks, to which also belong the Roddlesworth reservoirs further north, the waters of which originally drained into the Darwen, and eventually into the Ribble. In nearly all the waterworks provision has been made for the wants of the mill owners, formerly supplied by these streams, by the construction of enormous compensation reservoirs, delivering in the case of Manchester fifteen million gallons a day. Mill owners have

been enormously benefited in having a regular daily supply sent down to them, instead of having to depend upon the capricious volume formerly coming to them, influenced by climatic changes of drought and floods. In many cases the provisions and engagements entered into by corporations with the mill owners appear to be so onerous, that, in exceptional years of drought, they ought to have Parliamentary relief from the penalty clauses of not being able to supply. Manchester at the time of writing has had to give clear spring water for mill purposes, the compensation water being exhausted, while a water-famine, as regards human consumption, stares the water-committee in the face.

I have long been of opinion, and have advocated in various papers, the great importance of constructing "dumb-wells" in areas of porous rocks, which, communicating with joints and fissures beneath, would receive the surplus rainfall, which is not sufficiently long on the surface of the rock to be absorbed, and therefore is either evaporated or passes off on to impermeable material and goes to increase the floods devastating the lowlands.

When sandstone or Millstone Grit is examined under the microscope, spaces are seen to exist between the grains of sand forming the rock. The size and extent of these spaces limit the capacity for water-storage of the rock, the water being stored between the interspaces, just in the same way that water is stored in a pail full of shingle into which water has been poured. In chalk and limestone the water is probably also held between infinitely small particles; but the chief water available for waterworks purposes in these cases is that present in cracks, fissures, and joints. In the latter rocks water is absorbed rapidly, but is parted with, with extreme slowness.

Rainfall falling on a surface of porous rock sinks until it reaches the plane of "permanent saturation," which varies within certain limits, being governed by the amount of annual rainfall. The higher this plane is situated in the rock, the stronger the flow of the springs issuing from its outcrop, and the longer will their efficiency be maintained. It is seldom that the full saturation level reaches to the top beds of a porous rock near its outcrop, but by a judicious selection of sites for "dumb" or "drainage wells," the saturation plane could be artificially kept up, the flow of the springs increased, and the consequent "dry-weather flow" of the streams during drought maintained. Recent examples have shown that heavy thunder showers are of no avail in replenishing the springs of rocks directly exposed to the surface; the ground being so hard that the rain does not percolate, and is caught up by the hot air and evaporated.

Ordinary wells can be sunk with great advantage in the Millstone Grit, yielding good supplies of soft water, free even from the small amount of organic impurity, due to a vegetable source, generally present in the gravitation waters of the millstone grit. As examples, I may mention three wells originated by myself in this formation. The well at Walton summit-level, for the Walton-le-Dale waterworks, in the third grit; the well of the Star Paper-works, Fenniscowles, near Blackburn, where the water overflows the surface, rising at artesian pressure from the first grit; and the well of the Leyland Local Board waterworks at Clayton Green, which gives a very plentiful supply of most excellent water. At the Eagley Mills, near Bolton, I advised the piercing of the beds, beneath the shales below the Rough Rock or first grit, with excellent results; and I believe if my report to the Bolton Corporation, as to sinking wells for the Corporation supply, had been carried out, it would have had equally successful results.

The *Middle Coal-measures* of the Lancashire coalfield consist chiefly of shales, with a few bands of rock, ironstone and coal-seams; there are no rocks of any value for waterworks purposes, corresponding to the sandstone of the Yorkshire coalfield, except possibly the rock associated with the Pemberton coal at Bryn, near Wigan. Not only are the sandstones thin, but are seldom at the surface, and are overlaid by impermeable shales and impermeable boulder clay, and their ends truncated by faults are not exposed to surface percolation. Beneath are the *Lower Coal-measures* or "gannister series," which contain the massive sugary quartz-like gannister rock, forming the eminence at Billinge Beacon; these in their turn are too hard and compact to be of any value for the sinking of wells.

The *Permian rocks* do not occupy a large area in Lancashire; the most important is the district lying between Preston and Garstang, near which town several domestic wells have been carried into them, but the supply is probably limited owing to the thick covering of boulder clay of impermeable character. At Clayton Vale, east of Manchester, a boring in search of coal proved a plentiful supply of water in the Permian sandstone, which has not yet been utilised; the supply being derived from water that has filtered through 1,000 feet of red sandstone should be of great value.

The *New Red Sandstone* of Lancashire consists of the following subdivisions:—

Keuper	Waterstones	100 ft.
	Building stones	350 „
Bunter	Upper mottled sandstones	350 „
	Pebble beds	1200 „

In the neighbourhood of Orrel and Waterloo private wells obtain good supplies from the Keuper sandstone, which is giving off springs in the Orrel railway cutting between Waterloo and Aintree. But the most important wells are in the Bunter division. The Southport Waterworks Company have their pumping station in the Upper Bunter at Springfield, near Ormskirk, and in the same neighbourhood the Upper Mottled Sandstone affords a good supply to Ormskirk; several million gallons a day could be obtained, if required, in this district. Further south are the new wells of the St. Helen's Corporation, at Knowley, yielding more than a million gallons from the Pebble Beds, the sites of which were chosen by myself; south of the St. Helen's coalfield are the old wells of that Corporation at Eccleston Hill, and Whiston. At Eccleston Hill the pumping has caused a considerable "cone of exhaustion;" consequently the water plane has been so depressed that springs which formerly issued at the foot of the hill have now ceased to flow. It is remarkable that so little is still understood of sanitary science, that an adjacent local board recently proposed to place a sewage farm over the site of those vanished springs, which flowed direct from the rock without any cover but a little sand! Eastward of the Eccleston well are numerous wells drawing on the underground stores of water of a triangular patch of New Red Sandstone, enclosed on either side by Coal-measures; the quantity so drawn amounts to a daily extraction equalling an absorption of ten inches of annual rainfall. on each square mile of surface exposed. Amongst these wells may be mentioned those of the Rainhill Gas and Water Company, and the Ravenhead Plate Glass Company. Further south are a group of wells belonging to the Widnes Local Board; they are placed in an area of former artesian overflow, but the level of the water is now pumped down.

Eastward are several wells sunk for the London and North-Western Railway, and the Cheshire Lines Railway, which prove the New Red to have thinned considerably, and the Coal-measures to be present beneath. At Winwick they are however at their normal thickness, and yield a magnificent supply to the Warrington Waterworks Company. At Warrington itself the underground water is salt, a boring at Dallan Lane Forge giving no less than 4,500 grains to the gallon. Westward, at Widnes, are numerous wells through thick post-glacial and glacial drift into the rock, giving large supplies.

At Liverpool four public wells yield an average of 6½ million gallons a day of excellent water, the deepest boring being 1,200 feet; they are separated from each other by a fault, but the water passes freely through it, whichever well is pumped, when the next is standing unworked, getting an increased supply of water; the pumping of one of these wells affects the water in Oakfield quarry, 2¼ miles away. Several public wells and numerous private wells in the western portion of the City have had to be abandoned through excessive pollution and the percolation of salt water; the whole of these wells are west of the great fault, ranging through Liverpool and Bootle, which is evidently a water-tight barrier. That this is so is proved by the fact that the waters of Messrs. Preston's well at Bankfield, on the western side of the fault, are heavily polluted, while the Corporation waterworks well at Bootle, only a few yards east of the fault, yields a pure supply identical with that yielded in 1851.

The sands and gravels of the *Glacial Drift* formed an important source of water supply to the early inhabitants of the county, and probably led to the choice of site of Preston, Lancaster, Chorley, Euxton, Leyland, Prestwich, Bury, and scores of other towns; but as populations increased, the water so derived became dangerously polluted, and a specimen of the former supply to Leyland, derived from a well near the churchyard, collected by Dr. Frankland, is placed as an example of a thoroughly bad water in the Food Museum of the Science and Art Department in London. But in some cases valuable water for trade purposes can still be obtained from this source, a recent example of which is a well for the Lancashire and Yorkshire Railway at Preston Junction, suggested by myself, in co-operation with Mr. Muir, C.E., of Manchester. A superficial edition, showing the Drift deposits, is now published by the Geological Survey of England and Wales; Lancashire is completed, and Cheshire in progress.

The population of Lancashire is about 3½ millions; this at 20 gallons of water a head means a daily requirement of 70 million gallons; with so large a demand and so crowded a population, it is no matter of surprise that both the Corporations of the cities of Liverpool and Manchester have gone beyond their own county for their future requirements; the former impounding the head-waters of the Severn and conveying them across the low watershed of the Dee to the Mersey basin; the latter abstracting the waters of Thirlmere Lake, and by artificially raising the level of that lake, rendering available for Manchester water that would otherwise have gone off in floods to the Solway Firth.

In my work on "The Water Supply of England and Wales," published in 1882, I made an attempt to show what was the probable supply of water available in all the river basins of England and Wales, and what was the amount required to satisfy the demands upon that supply; with the result that it appears to be amply demonstrated that the rainfall this country receives is more than sufficient to meet all the requirements of human consumption, manufacturing processes, and the purposes of canalization; and yet, with these resources, large districts still suffer from all the ills of polluted water supply, whilst other areas are devastated by floods, representing unproductive rainfall passing to the sea. In no county would this unproductive rainfall be more valuable than in that of Lancaster, where water is not only wanted for human consumption, but for the varied processes of the trade of the district, and nowhere could it be more largely increased by dumb-wells, in the manner suggested.

Prof. A. Dupré, F.R.S. (London), said it would be a very admirable thing if some of the water which now came down the rivers during the winter months could be impounded for use during the summer; or if some of the rainfall could be stored and similarly used, they would then rarely hear any complaints about the fouling of streams.

Mr. A. E. Eccles (Chorley) said that if trees were planted on the moors they might have the effect which Mr. De Rance suggested, as water followed the roots of trees in rainy weather, and the presence of trees in any district ensured a greater amount of water in the earth.

Prof. A. Dupré, F.R.S. (London) said if he understood Mr. De Rance correctly, the wells were not to be used for storing water in the well itself, which would be an insignificant amount, but they were to give the rain-water falling on the surface access to the water-bearing strata below. In connexion with this he might mention that old artesian wells are used in various parts of France for getting rid of large quantities of waste water, proving that dumb wells might be used for the purpose suggested.

Mr. Nimrod Simmons (Bristol) asked whether it were intended to line the sides of the wells or have them porous.

Mr. H. T. Crook (Eccles) said he had some difficulty in clearly understanding the object of the paper, whether it was intended to advocate sinking for water in opposition to impounding, or whether it was to urge the adoption of "dumb" wells for regulating the supply to reservoirs. The prosperity of Lancashire was mainly due to her many streams and copious rains; to these she owed her position as one of the chief seats of industry. Any proposals dealing with her water supply should be most jealously scrutinized, and no novel scheme undertaken without the most careful researches into the possible effects. This was the more necessary with regard to underground water because it was so exceedingly difficult to eradicate the popular notion that the rocks held a supply which was inexhaustible. Whenever there was a "scare" of a water-famine they always heard a great deal about this source of supply. It could not be too clearly driven into the public mind that whatever water was abstracted from the rocks below was so much taken from the discharge of the streams. Prof. Boyd Dawkins and even Mr. De Rance had sometimes he thought in their writings used language not sufficiently clear on this point. To show how little water might be available in the Millstone Grit they had the experience of works all along the Pennine chain, where something like 80 per cent. of the rainfall had been impounded: of the balance not more than 4 or 5 inches could possibly be available, and therefore to give to Manchester a supply equal to that now obtained from Longdendale, an area of some 236 square miles of country would have to be laid under contribution. With regard to compensation water he thought that Parliament might fairly be asked to consider whether some alteration might not be made in the amount to be given in seasons of exceptional drought such as they had experienced in the present year. The "dumb" well system advocated by Mr. De Rance he thought was surrounded with difficulties. The amount of water which each well would pass to the underlying strata would be very small, consequently a very large number of such wells would be required. To intercept the surface flow they must be placed on the lines of streams, and nearly every stream being utilized already very awkward questions of compensation would arise. The proposed system was merely impounding in a new form without the great advantage of the present surface system of knowing exactly what the effect of the operations will be.

Mr. C. E. De Rance, F.G.S. (London), in reply, said he felt it hard that after having written paper after paper during the last fifteen years, showing all water supply to be due to rainfall, he should have the last speaker apparently thinking he (Mr. De Rance) thought there was an inexhaustible underground supply. Mr. Bateman's figures just given, really included the underground water because the rainfall percolating, was returned to the surface as springs within the same drainage area. The dumb-wells would only absorb overflow or flood waters, and would therefore help to prevent floods. As to water rights, the position of the riparian owner would be improved, because the water which went into the wells would go to increase the springs, and to maintain the dry weather flow of the streams, the water absorbed during periods of excessive rains, being run off during drought.

On "River Pollution in Lancashire, and How to Prevent it," by John Collins, F.C.S., F.G.S., F.I.C.

No apology appears to the writer to be necessary in the presentation of this paper to the Congress.

The subject of river pollution, not only in Lancashire but throughout the Kingdom, is one of daily growing importance, and this importance has been making itself felt in particularly inconvenient fashion of late years. For it must be observed that while the growth of population and the increase of trade processes and manufactories have been going steadily on, the needful amount of forethought and of prudent prevision has been wanting in the collection and in the conservation of water for domestic and for trade purposes.

There are probably few of the elder members who are in attendance at this Congress but who fondly remember how in their youth they were wont to go fishing and bathing in the limpid waters of the brook or river, which now they are regretfully constrained to stigmatize as a foul and offensive sewer.

The steadily increased burden thrown on our rivers by the increase of dense populations collected together in large centres, the corresponding increase in extent and variety of pollutants resulting from the trade occupations of these centres, as well as the accumulations of effete and excrementitious matters from these populations, all share in the cry for some attention at the hands of those in authority.

It would be superfluous to point to the effects on the health of the people who, from the nature of the case, are bound to live on the banks of these rivers, or as near thereto as may be.

These rivers are our "Wealth," and deserve our highest care.

Water, it must be remembered, absolutely pure, exists nowhere in nature. Even at the moment of condensation from invisible vapour to cloud, water always absorbs various gases which are present in the atmosphere. And when it falls as rain to the earth it sinks through the subjacent strata, or it flows over various surfaces, from which it takes up various matters in solution and to varying amounts. Hence it is that when we speak of polluting matters we refer to elements and compounds which are of a nature other than those aforementioned.

When used as a prime mover of machinery it is of the greatest value, and especially so where fuel is scarce or expensive in use for steam purposes. But this mode of use of water in no way pollutes it, for it flows over, under, or through the "wheel" without material contamination.

And when the water coming from the hill side as a bountiful spring, clear and sparkling, is impounded for the supply of some town population, a certain amount is sent down daily by the water course as "compensation" water.

This comes to the first town or works on the stream in good condition, or, as we are in the habit of saying, "unpolluted."

The all important trades of the bleacher, printer, dyer, and paper maker are absolutely dependent on a plentiful supply of good water as an essential condition of a prosperous and a profitable trade.

And hence the water so required must be that which comes directly from the spring or other source, or it must be previously treated and cleansed to a degree to fit it for such use. Everywhere we find works after works occupying all available sites on the streams up to the nearest possible point to the source itself.

And so it comes to pass that the whole stream, which is, it must be remembered, the natural drainage outlet of the whole area or district through which it passes, is absorbed in or is applied to potable and to manufacturing purposes. And the extent of this evil—the magnitude of the interests, or the attainable margin of profits, is set up as a justification for such a monstrous use of one of God's best gifts.

If we proceed down stream from its source we find the various pollutions characteristic of and flowing from bleachers, dyers, printers, paper makers, and others, in most cases unfiltered, untreated, and without the slightest attempt at interception of noxious or polluting matters. In fact, we find a supreme indifference. And so we are not long in arriving at a point where the waters of the stream are worthless and useless for the ordinary trade purposes of the district, save for power.

Then we have this stream joined by others of a like character, and bearing similar burdens, and the pollution is intensified until it becomes unbearable.

Next we have the first sanitary authority we encounter complaining of this pollution by refuse from manufacturing processes, as well as by the sewage and drainage always found therewith.

All complain, even those who, while suffering from the inconvenience and annoyance which such a state of things entails, themselves add to the nuisance by following the general bad example.

The evils attendant on this state of things are not confined to the dwellers in towns, for all riparian land owners or residents within miles suffer in many ways. The stream which flows through the pasture cannot be drunk by the cattle. The old house of the resident on the river bank is rendered uninhabitable by reason of intolerable stenches. People are subject to perpetual annoyance or even ill health, the money value of the property is diminished, houses are rendered tenantless and unsaleable, and "life on the waters" is rendered impossible.

We have hitherto spoken mainly of manufacturing refuse as the pollutant. This is surely a grave enough evil, but its remedy is much more readily applied than that from sewage.

The bleacher contributes nothing which may be properly considered a very serious pollutant.

The paper maker can, and in some cases does, apply certain arrangements to his mill effluent, which renders it practically innocuous.

The printer and dyer have a more difficult problem before them; but with settlement and precipitation, careful filtration, and other well-known means, they may also escape much outcry.

Sewage, however, is most serious, as it constitutes the greatest bulk of polluting foulness to our rivers.

It is a very variable but always complex liquid.

It includes excrementitious matters from privies and water closets, urinary matters from gullies, slop waters from the kitchen and washhouse, with its animal, soapy, and other refuse, and drainage from the stable, shippon, and slaughter-house.

Sewage is water polluted with an almost infinite variety of matters, some of which are in suspension, while others are in solution; but both are in such condition and quantity as to render the liquid foul and dangerous to deal with easily or successfully.

As the town sewer is the common receptacle for all sorts of domestic waste and effete matter, so it is also of manufacturing refuse, when such manufactures are seated in towns.

And thus the nearest river or stream is almost universally considered the natural and proper receptacle for all foulnesses. We may assume that the pollution increases as the river flows along in its course, and the appended tables show this, among other things, most markedly.

Organic animal matter found in polluted waters is most offensive of all, and it is most dangerous to health. The organic matters from print and dye works come next in order, and last, such pollutions as are contributed by certain chemical (trade) processes.

The writer does not propose to deal with the remedies for the state of things which exist, save so far as to suggest that comparatively simple and inexpensive arrangements will, and do, effect much and immediate improvement; and he is the less disposed to do this on learning that other papers on the subject are to be submitted to the Congress.

It is obvious that filtration will do much to rid water of matters in suspension. But filtration can in no sensible degree affect pollutants which are in solution, and which are frequently most damaging and present in a large quantity. Filtration too must be carefully practised, or a mortifying failure is the certain result. The filter must be of a nature which is open enough to permit rapid oxidation of such matters as are intercepted by it, while not allowing the passage through it of such matters as it is the object of filtration to arrest. In other words, the more effective the filter is the more it is liable to choke rapidly, and the more care and attention it requires. It is always best to "settle" in properly constructed tanks or reservoirs before filtering, and in most cases it is here and at this point where the application of an agent to assist in or promote precipitation is easiest and most economical.

Where settlement, precipitation, and filtration do not effect the desired degree of clarification and of purification, other and special means to meet the case must be adopted; but it may be taken for granted that no pollution exists for which there is no remedy, and it is equally clear that this remedy should be applied by the person or authority which initiates the nuisance, and that before passing it on to his neighbour.

In support of this view it is worthy of note that most, if not all, the various pollutions with which our rivers are dosed are most readily removed if attacked at once, and before other reactions and compounds result.

It should be clearly understood that we must "prevent" the pollution of our rivers, and not attempt to "doctor" them after having drenched them with poisons. From the head of the stream to the mouth of the river we must be armed with legal powers to "prevent" the disposal of any waste, noxious or foreign matters, in such streams or rivers.

All we say is this: Take whatever you want, or at least, whatever you are entitled to, of the waters of the stream and use it for your own purposes, but return it to the stream in as fair a condition as you find it. Means are at hand to enable you to do this; but such is the immobility of public bodies, and of others who are interested in maintaining the present condition of things, that nothing short of a stern enforcement of the law which exists for our protection will ensure their adoption.

I have to express my thanks to my assistant, Mr. W. Hepworth-Collins, F.C.S., for his assistance in preparing the appended table results of analyses; and I am also indebted to him for several analyses made specially for this table.

Results of Analyses, tabulated for purposes of comparison. Grains per Imp. gal.

Description of Sample.	Solids. In Suspension.	Solids. In Solution.	Solids. Total.	Chlorine.	Ammonia.
1. R. Irwell, above Bacup	0·32	4·62	4·94	0·8	0·003
2. " below Bury, before confluence with R. Roach	11·13	17·11	28·24	2·6	0·331
3. R. Roach, above Rochdale	1·62	5·15	6·77	0·7	0·005
4. " below " before confluence with R. Irwell	16·21	21·03	37·24	3·2	0·301
5. R. Croal, before confluence with R. Tonge	0·93	5·10	6·03	0·6	0·003
6. R. Eagley, before affluent of R. Croal, before use	1·22	4·24	5·46	0·4	0·005
6*a*. " at confluence with Astley Brook	11·08	21·16	32·24	2·1	0·164
7. R. Bradshaw, before use, affluent of R. Croal	1·06	6·21	7·27	0·6	0·003
7*a*. " at confluence with R. Croal	9·57	22·17	31·74	1·7	0·626
8. R. Croal, at junction of R. Irwell	8·66	46·76	55·42	7·1	0·714
9. R. Irwell, below Radcliffe	10·22	43·09	53·31	5·9	0·621
10. " after confluence with R. Croal	4·72	47·97	52·69	5·9	0·626
11. R. Irk, above Royton	0·62	4·55	5·17	0·3	0·003
11*a*. " at Hunt's Bank, Manchester	22·03	50·21	72·24	6·2	0·702
12. R. Medlock, above Lees	0·63	6·01	6·64	0·5	0·003
12*a*. " at Bradford, Manchester	11·72	46·25	57·97	4·9	0·397
13. R. Irwell, at Albert Bridge	19·31	45·11	64·42	6·2	0·802
13*a*. " at Throstle Crest	12·90	47·74	60·64	7·9	0·816
14. R. Mersey, above Bredbury	2·15	5·92	8·07	6·8	0·005
14*a*. " at Carrington	6·63	45·53	52·16	6·2	0·611
14*b*. " after confluence with R. Irwell	17·15	40·02	57·17	6·4	0·621
15. R. Douglas, above Withnell	1·22	5·57	6·79	0·7	0·004
15*a*. " at Wigan	13·91	36·20	50·11	5·5	0·506
16. R. Darwen, above Darwen, "Jack's Key"	1·06	6·73	7·79	0·9	0·006
16*a*. " " Blackburn	24·11	36·09	60·20	4·2	0·342
16*b*. " at its confluence with R. Ribble	19·50	39·92	59·42	4·6	0·372
17. R. Ribble, above Cambeck	0·42	4·73	5·15	0·5	0·003
17*a*. Pendleton Brook, falling into R. Ribble at Clitheroe	35·83	32·44	68·27	2·1	0·292
17*b*. Barrow " " " Mytton	24·10	36·11	60·21	2·7	0·303
18. R. Calder, at Whalley, affluent of R. Ribble	19·23	39·21	58·44	6·1	0·721
19. R. Hodder, at Hodderfoot	1·27	6·55	7·82	0·8	0·007
20. R. Ribble, immediately above Preston	17·44	37·72	55·16	3·1	0·414

Analytical Laboratory,
Bradford Chambers, Bolton-le-Moors.

JOHN COLLINS, F.C.S., F.G.S., F.I.C., M.S.A.
WALTER HEPWORTH-COLLINS, F.C.S., &c.