

SECTION III.

CHEMISTRY, METEOROLOGY, AND GEOLOGY.

ADDRESS,

BY THOMAS STEVENSON, M.D., F.R.C.P.,
(MEMBER).

PRESIDENT OF THE SECTION.

DURING the last ten years, perhaps no subject has received greater attention from chemists, biologists, and sanitarians, than that of what was formerly termed the self-purification of water, the manner in which, and the natural agencies by which, this process of purification is effected. Gradually during the last twelve or fifteen years the views of most of us have undergone a great change; and many of those who formerly held the view that a river once polluted with sewage is incapable of self-purification, and that even when filtered the water is still unpotable, now hold that by sedimentation and filtration such a water is effectually purified and freed from all noxious constituents. Happily, those who administer the municipal affairs of the great city in which we meet took, before the revolution in views which I have indicated, the wise and proper course of securing a water supply from unpolluted sources, and obtained a water presumptively free from all danger to public health by organic pollution.

As might be expected, experimental researches carried out on new lines, and aided by the light afforded by many scientific fields, have led to novel discoveries; and all along the line our knowledge of the agencies at work in water supplies has increased; benefit has undoubtedly accrued to public health, and still greater benefits may be expected to be reaped in the near future.

The time must be within the memory of almost the youngest here present when a great, prolonged, heated, and for a long time quite indecisive controversy raged among chemists as to whether or not a water once contaminated could by prolonged exposure to the atmosphere ever recover its original organic

purity, or even whether it could do so by any process short of distillation and reprecipitation, either artificially carried out, or naturally by means of vaporisation by the sun's heat and subsequent condensation into rain-water. It was further held by some that soil-filtration, except where percolation took place through great depths of soil, was inadequate to purify a polluted water so as to render it safe and potable. On the other hand, there were those who did not accept this pessimistic view, but without bringing forward conclusive scientific evidence of their more optimistic views. Facts were adduced by the holders of these discordant opinions in support of their respective contentions. On the one hand, the obvious disappearance of the grosser forms of sewage matter when turned into a stream, and within a comparatively short distance of their inflow, was a fact patent to every observer. A stream black, befouled, and repulsive to the senses of sight and smell, within a few miles—and often within a far shorter distance—was known to lose all evidence to sight and smell of its antecedent pollution. To all appearance every trace of contamination has disappeared. As against this were opposed the facts that a water purposely contaminated with sewage may be exposed in the laboratory to air, and may be agitated therewith, and yet persistently retain nitrogenous organic matter, refuse to nitrify, and at a certain stage refuse with the greatest pertinacity, to part with more organic matter. Even sea-water has been found to contain organic matter of a highly nitrogenous character; and sea-water is river-water, in many cases antecedently polluted, which has undergone a maximum of exposure to aerial influences. Organic matter in water was taken to be presumptive evidence of the unsafeness of this for drinking purposes; and water which contained an excess of organic matter, or which by its abundant yield of nitrates, showed evidence of previous sewage contamination, as it was called were, illogically perhaps, but for the most part with manifest advantage to the public health, was unhesitatingly condemned as a drinking supply.

It was admitted that the free oxygen in a water would, up to a certain point, effect the oxidation of organic material; but the process was admittedly a slow one. A further destruction of organic matter was known to be effected by the ravages of aquatic animals; but how far these themselves, by their living and excretory processes, contribute to undo what they had otherwise done as feeders on filth, is unknown. Again, it was supposed by some that aquatic plants served to effect purification, though the living actions of green plants involve processes of reduction rather than oxidation of organic matters. The

effects of sedimentation are here excluded from consideration, as it was then as now considered to be a step only towards effective purification.

But this vain and unprofitable warfare was not to continue. Some dozen years ago light began to dawn on the minds of those who had habitually to consider these questions, and it was seen that the problem must be attacked on new lines if it were ever to be settled; and this new attitude of mind towards the question was guardedly referred to in 1884 in the Final Report of the Royal Commission on Metropolitan Sewage Discharge, of which Commission I was a member, where it was said:—"But the *rationale* of these processes (precipitation processes) has apparently been but little recognised, and, indeed, it is only within the last few years that scientific knowledge has sufficiently advanced to enable us to understand the matter. There are two chief methods by which effete organic materials, such as excreta, are got rid of, namely, by fermentation and by oxidation. Nature, in this climate at all events, utilises both these processes, and in the above order. The organic molecules of effete matters are first split up by fermentation (and putrefaction is one kind of fermentation) into less complex substances, often of an offensive character, and these are subsequently oxidised into inodorous inorganic substances. The agents by which these fermentations are brought about are those microscopic organisms known as *bacteria*, which either themselves set up fermentation or excrete substances which act as ferments. Bacteria, or their spores, are present everywhere, and, gaining access to sewage, set up fermentation."

It must be remembered that this was written ten years ago; but, nevertheless, it represents a great advance on the opinions held ten years antecedently, although it is only a foreshadowing of what could or would be written now under similar circumstances.

If these statements are compared with those put before the late Royal Commission on Metropolitan Water Supply, the advance in knowledge during the intervening nine years is well seen. During the last nine years advances in our knowledge have been very great, and although there is a great conflict of evidence between bacteriologists, and the science of bacteriology is still in its infancy, we now know much more of the life-history, the functions, and the effects of bacteria, and the chemical processes associated with them, than we then did. The fact is accepted by all, that bacteria are among the main agents in effecting the purification of water, as well as in inducing infectious diseases, such as typhoid fever and cholera. And, indeed, although the bacteria which produce summer diarrhoea and

many other diseases, have not with certainty been isolated and recognised that such diseases are induced through the agency of micro-organisms is a part of the current creed of scientists.

We have to look upon micro-organisms in water as of at least two kinds, (1) the pathogenic or disease producing organisms, (2) the beneficent or purifying organisms; to which may perhaps be added a third kind, the inert organisms—inert, as neither producing definite disease, nor, perhaps, acting as purifying agents. Whether we recognise a two-fold or a three-fold division, the importance of discriminating between pathogenic and non-pathogenic organisms in water is all important to the physician, and, happily, new appliances and new methods have done much in this respect, and knowledge is advancing with rapid strides.

Pathogenic bacteria appear, as a rule, to produce their specific effects through the agency of the products of their living processes or excreta. But though ptomaines, toxins—alkaloidal or other products—act as poisons, such chemical entities as I have referred to have as yet almost never been demonstrated in the drinking water of rivers. It may be that in some cases the introduction of the bacteria into the human body alone directly induces the mischief, or it may be that the excretory products introduced with them act as poisons. We cannot as yet dogmatise as to this.

In the human organism, provided the conditions are favourable, the bacteria grow, multiply, and generate those poisonous chemical products of their activities which produce disease. A few germs introduced into the body quickly become incredibly multitudinous, the toxins proportionally increase in amount, and circulating in the blood, toxic effects are manifested. Hence the importance of preserving our water-courses from specific contamination, and the equal importance of securing their purification, when polluted, by placing them under such conditions that the pathogenic bacteria may be starved, killed, or destroyed and consumed by beneficent micro-organisms.

We are almost entirely in the dark as to how far and what kinds of pathogenic bacteria are destroyed by the non-pathogenic. One assumption by the Royal Commission on Metropolitan Water Supply is supported by slender evidence. It may be true, as stated by the Commissioners, that it is the generally accepted doctrine of bacteriologists, that the pathogenic organisms and the ordinary river bacteria to which the decomposition of organic matter is due are naturally antagonistic; but antagonism has rarely been proved to exist between such organisms. Such antagonism has been proved to exist only

between a very few organisms, and never between ordinary river bacteria and the typhoid bacillus. Although experimenters for the most part agree that the bacilli of typhoid can be found at a much later date in sterilised than in unsterilised water, this is not conclusive as to the antagonism of the pathogenic and non-pathogenic organisms.

In considering the degree of safety conferred upon a water polluted with sewage by the natural processes going on in streams, we have to weigh the results brought about by sedimentation, disintegration, solution, oxygenation, dilution, light, and by the living processes of vegetable and animal organisms contained in the water. A few only of these agencies can now be reviewed; but the question may be considered, how far do those agencies, separately and in combination, bring about the destruction of noxious matter? This is the point of chief interest to us as sanitarians and to the public. In what I am about to say I feel that there are wide lacunæ in our scientific knowledge, how dimly we grope at precision where no precision is at present attainable, and what a vast field lies open to future research.

Sedimentation is a very important factor in the purification of river water. The amount of suspended and even dissolved organic material carried down by the deposition of finely divided clay and other aluminous and calcareous matter, either accidentally present or artificially introduced into a water, is relatively enormous. In the deposition of sediment countless bacteria are entangled, carried down, and doubtless perish in the end, by the action of light, the suspension of their activities, and the withdrawal of the conditions necessary for their growth and multiplication. Assuredly, sedimentation is one of the great beneficent agents increasingly at work in purifying our water supplies. Its value cannot be over-rated; but it must be admitted that it is not altogether effective.

The experiments of Professors Percy Frankland and Ray Lankester show that by sedimentation it is possible to remove all the bacteria from a water. This can, however, occur only under exceptionally favourable conditions, and it is agreed that the process cannot be exclusively relied upon, and that it needs to be supplemented by other means of purification.

When bacteria are separated from a water by deposition in the mud, we cannot be sure that they may not be capable of revivification and multiplication, when the mud is disturbed as in times of flood. But it is not likely that they are capable of retaining their potentiality for evil for an indefinite period; yet the fifteen days assigned as the limit of activity for the typhoid bacillus rests on no sufficiently assured basis.

How far simple oxygenation of a water is capable of destroying organic matter and living organisms is undetermined. As we all know, water is capable of taking up from the atmosphere nearly two cubic inches, or about half a grain of oxygen, per gallon of water; and when this gas is withdrawn or consumed in the oxidation of organic matter present in the water, a further supply of oxygen is quickly absorbed from the air. Hence the degree of aëration of a water was proposed and used to ascertain the purity of river waters. If aëration was found to be fairly complete, it was assumed that organic matters were fairly well oxidised, and presumptively rendered inert; whilst on the other hand, a deficiency of free oxygen in a water, indicated that processes of oxidation were still going on and hence that decomposable organic matter was still present. Setting aside the difficulty of ascertaining by analysis the amount of free oxygen actually present at any given moment in a river, the test is an inadequate one. It is probable that it is not chiefly the inert ordinary free oxygen that is the active agent in effecting oxidation of organic matter. Rather, the evidence tends to show that it is the more active form of oxygen, ozone, and still more the hydrogen dioxide formed during many chemical changes going on around us, that are the effective oxygenants. Yet all agencies which tend to aërate a water, tend also to introduce ozone, hydrogen dioxide, or whatever be the efficient oxidiser, into the water.

Agitation and free exposure of as large a surface of the water as possible to the atmosphere are most effective in bringing about water purification.

Among the other agents of purification is disintegration, which is doubtless an important factor, dead and torpid organisms undergoing in sediment a slow or rapid disintegration and destruction. But the effects of disturbance, as by floods, must not be lost sight of, for by disturbance bacteria may again be set afloat in a stream, and meeting with the necessary conditions and the pabulum for their growth, may grow and multiply afresh.

Disintegration leads to solution, and solution to dilution, and as it is undeniable that the dose of a poison may be so far reduced as to render it inactive or non-toxic, the products of bacterial life, and the products of bacterial decay, may be so far diluted as to render them practically inert.

But it is to the bacteria, not to speak of the other and higher organisms in water, that is to be attributed the chief effect in the purification process. Beneficent and pathogenic bacteria live and have their being in impure water, break up and appropriate the nutritive material contained therein, and carry on

their life-processes either amicably side by side, or are mutually destructive of one another. Doubtless, too, they secrete material, which, at all events, in the case of the pathogenic bacteria, is noxious. How far noxious, we know not. The excretory products of bacteria are generally destructive to other species.

And here I may parenthetically remark that we do not know the amount and kind of animal excreta contributed to our water supplies by the animal life inhabiting them. Excretory matter there must be, *e.g.*, that of fishes; but Sir William Roberts informs me that we are entirely ignorant of the composition of the liquid excreta of fishes. Their excreta in the normal condition are probably fairly inert when present in water; but the kind and nature of the organic matters present in river water must in some degree be dependent on the animal life present in the stream.

To return to what I was saying about bacteria. The danger of pathogenic bacteria in water depends, I believe, on the liability of the organisms themselves to be ingested by the human being, and not to any material extent upon the ingestion of toxins or other chemical substances, the products of bacterial action, in the water. Hence the importance of depriving a water as far as possible of all bacteria, whether pathogenic or non-pathogenic, before utilization for drinking purposes. Bacteriological examination is sometimes inconclusive, and we can only judge of the safety of a water by its obvious freedom from bacteria of all and every kind. At present bacteriologists have gone a little and not much further, except in some special cases, than the counting of bacteria, or of colonies of these; but we may hope that at no distant date something more will be done, and that with improved and easier modes of recognition, pathogenic will be readily distinguished from non-pathogenic forms in a water, to the great advantage of the public health.

Not the least interesting of the processes going on in running water is that brought about by light, an agent very potent in destroying or benumbing the activities of pathogenic bacteria. As Professor Percy Frankland has pointed out, in his work on micro-organisms in water, to Downes and Blunt belongs the credit of having, seventeen years ago, not only first demonstrated the bactericidal effects of light, but in having at once so perfectly indicated almost all the factors connected with this action, that the further investigations which have been carried out on this subject during the intervening years, have been little more than confirmations or additions of detail to their work. Undoubtedly bright sunlight acts deleteriously on bacteria, especially in the vegetative forms as distinguished from their spores, and this independently of the direct rise of

temperature due to exposure to the sun's rays; air and moisture being important adjuncts to light. The formation of hydrogen dioxide during insolation may be contributory to the bactericidal effects, and must aid oxidation. But unfortunately, notwithstanding the researches of Marshall Ward, we know too little of the effects of the dim and diffused light which alone can penetrate through considerable depths of water. Further experimental observation is needed with various pathogenic bacteria as to the effects of dim light as a bactericidal agent, and also as an attenuator of the activities of bacteria without destroying them. I myself am inclined to think that some able experimenters are too sanguine as to the speedy destructive effects of light on micro-organisms; nor would I venture to do what one distinguished bacteriologist no long time ago expressed to me his willingness to do—viz., to drink without fear water known to be infected with typhoid bacteria, provided that after infection, and before drinking it, the water had been freely exposed to light in an uncovered cistern for three or four hours.

Filtration is the last and most important resort which must be had recourse to for the purification of our water-supplies. The mechanism, if I may use the term, and the results of sand-filtration have received within the last few years the greatest attention at the hands of scientific observers and sanitarians. We now know—dimly and imperfectly, it is true—how filter-beds act; and the results once attributed to mechanical effects or to chemical action are now known to involve a biological factor. Briefly, a filter-bed, when effective, has become covered with a gelatinous, colloidal mass of bacteria, and this living area has the power of arresting 97·5 per cent., or more, of the bacteria in the filtering water. It is not that the micro-organisms, are not small enough to penetrate the interstices of the filtering area; but somehow, be they large or be they small, micro-organisms are for the most part arrested, dissolved, disintegrated, consumed, or, it may be, poisoned by the excretions of the zoogloea mass of which the filtering area is composed. At all events, whatever be the exact nature of their action, a water teeming with bacteria, like the unfiltered water of the Thames, issues on the lower surface of the filter-bed containing on an average only 29 organisms per cubic centimetre. Indeed, so great is the diminution in the number of micro-organisms brought about by ordinary sand filtration that some persons are, as I believe rashly, disposed to think that sedimentation in reservoirs, supplemented by sand filtration, is all that is necessary to render our polluted water supplies safe and potable. But when we reflect that the two, three or four per cent. of escaping bacteria

still form a huge number in the aggregate (29 per cubic centimetre represents 4120 bacteria per half pint of water—an ordinary glassful), and these may quickly multiply, our assurance of the safety of such water can only be relative. The fact that typhoid bacilli have never been detected in filtered Thames water is not conclusive as to these being altogether stopped by the filters, for these bacteria have never perhaps been detected in ordinary unfiltered Thames water. And seeing that on an average one typhoid stool in the Thames is diluted, according to the Commissioners, with 294 million gallons of river water, and further that on an average 97 per cent. of the bacteria are removed by filtration—not to speak of other agencies—the probability of the detection of typhoid bacilli in the filtered water is very remote. All that we can say is this that they can be but few in number.

The test of the strength of a chain lies in its weakest link. When we look at filters from a practical point of view, we see how many feeble links there are: cracking of the gelatinous surface of the filters: the formation of chinks and runlets in them, as is the case with all colloidal filtering masses; the over-taxing of the filters; all these are elements of danger. Speaking from daily personal observation of the filtered water supplies of two of the London Companies, I can testify that in the autumn and winter months these filtered waters are frequently slightly turbid, coloured, and uninviting in aspect when viewed in large masses. How far they are injurious to those who drink them it is difficult to say. Indeed no very obvious results ensue from the drinking of them, though one might perhaps anticipate results were the Thames at any time to receive a large access of cholera stools.

What, then, are the conclusions to be drawn from recent advances in our knowledge of river pollution and river purification? What practical inferences are to be drawn? What suggestions are to be made as to lines of future action?

The notion that organic matter in a water is *per se* to be regarded as injurious must be laid aside. The potable quality of a water must not be judged by the mere quantity of organic matter therein. Organic matter, and especially nitrogenous organic matter, must, however, be regarded with suspicion, and the presence of an unusual amount of it ought invariably to call for the rejection of such water as a source of drinking supply and the results of chemical analysis must in no case be set aside as altogether illusory.

Next, the necessity of guarding our rivers from all unavoidable pollution and especially excremental pollution, is rather emphasized than diminished, although practically we have been

unable to distinctly connect disease in the metropolis with Thames water-drinking, there is no small likelihood of there being an undiscovered connection between the two. The statistical evidence is vague, incomplete, and inconclusive, and does not enable us to say yea or nay to the proposition. With the evidence of the Tees Valley outbreak of typhoid fever before us, and the break down of all attempts to discredit the connection between the Tees Valley supply and that epidemic, we must hesitate to adopt the proposition that typhoid bacteria have but a very limited term of existence outside the body, that they speedily die or become incapable of resuming their pathogenic properties, and that they are unable to survive exposure to a limited amount of light and air, or even that they necessarily speedily become the prey of other bacterial organisms.

We must admit that light, air, agitation, precipitation, subsidence, and, above all, filtration, can do much in the way of purification; and that under favourable conditions these purifying agencies can and often do render a polluted water safely potable. But there is a danger in trusting too much to these in leading us to neglect the urgent necessity which everywhere exists of protecting our water supplies from pollution. Surely the need to protect our rivers from pollution was never greater than at the present time. The wisdom of large communities, such as those of Liverpool, Manchester, and many others, in securing water from unpolluted sources cannot be questioned. Unfortunately, the large sources of mountain supply are rapidly becoming appropriated by towns to which a water of rare purity and great softness is a primary need for its manufactures; not to speak of health requirements. We who live in London lack that public spirit which guides such municipalities as that of Liverpool. There is a tendency to regard our metropolitan water-supplies as in no danger of failing in either quantity or quality. A selfish section of the community still regards the Thames merely as a means of securing its own pleasure. At no time has there been greater need of precautions being taken to secure the Thames from human excremental pollution than at present, when the floating population in summer is so enormous, and where the introduction of fresh human excreta all along the river is a matter of almost complete certainty. You, in this great city, run no such risk, and are happy in the possession of that best help to a healthy life—a pure drinking water.
