**The examination of waters and water supplies / by John C. Thresh.**

# The Examination of Waters and Water Supplies

J. C. THRESH

To W. H. Bowerbank, L.L.D., F.R.S.

With the Author's Compliments.

# THE EXAMINATION

OF

# WATERS AND WATER SUPPLIES

BY

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# PREFACE

THE subjects discussed in this work have received a great deal of attention from me for many years, and it is possible that the results of my observations and experience may be of value to others interested in the important question of the protection of our water supplies from the risks of pollution.

When practising as a water analyst, before becoming a Medical Officer of Health, I strongly suspected that in deciding upon the character of a water supply we were laying far too much stress upon the results of chemical analyses of samples of water and far too little upon the examination of the sources from which they were derived. When, afterwards, my duties as Medical Officer afforded me the necessary opportunities for examining sources of supply, analysing the samples of water from such sources, and studying the effect of the water upon health, I was speedily convinced that the examination of the source of supply often afforded far more important information than could be obtained from the analytical results. This opinion has been strengthened with increase of experience. Opportunities have been afforded me of inspecting sources of supply in all parts of the kingdom, sources of the most diverse character and from every kind of geological formation from which water is obtainable. In numerous instances I have had to investigate supplies which have been the cause of outbreaks

of disease, and in many others to investigate the cause of some change rendering the water objectionable in character. In nearly all such cases I have found that the examination of the source of the water afforded information without which the chemical, bacteriological, or microscopical examination of the water could not have been correctly interpreted.

In recent years bacteriology has come to the aid of chemistry, and there is now a general opinion that a bacteriological examination is more important than a chemical analysis. This is undoubtedly true in certain cases, but not in all. A properly made bacteriological examination may often afford indications of pollution which no chemical analysis could possibly detect, but I am afraid that the inferences drawn from the results of many so-called bacteriological examinations are often as fallacious as those derived from the results of chemical analyses. When we find that waters used for long periods by large communities are condemned by bacteriologists as being dangerously polluted, and that the results obtained from the same water by different bacteriologists differ to an extent which is impossible in a chemical analysis, our faith in bacteriological examinations is somewhat shaken. In any case a proper bacteriological examination is far more tedious and more troublesome to perform than a chemical analysis, and the results are even more difficult to correctly interpret.

The microscopical and biological examination of matters suspended in drinking water has never received in this country the attention it deserves. Very often such an examination reveals more quickly and certainly the character of a water and some defects in its source than either a chemical or bacteriological analysis. In several instances such an examination has led, in my practice, to the discovery of sources of pollution which had been overlooked at a careful inspection. I have

endeavoured therefore in this book to give it the importance it deserves.

I have also been impressed with the desirability of making more complete chemical analyses. The ordinary methods adopted for the analysis of a water are sufficiently simple and reliable for many purposes, although much more skill and care are requisite to obtain concordant and accurate results than is generally imagined. The great difficulty, however, does not lie in obtaining results, but in correctly interpreting them; this requires an extended experience and an intimate knowledge of everything connected with the sources of supply.

The more complete chemical analyses to which I refer are of importance both from the sanitary and scientific point of view. Such analyses have rarely been made in the past on account of the great skill required and the tediousness of the processes. During the last eleven years, however, I have devised and tested a series of processes which now enable me to make such an analysis in a reasonable time, and which yield results sufficiently accurate for all practical purposes. These methods are fully described in this book, and a considerable number of analyses are appended showing the difference in character of waters from different geological sources, and the variations in waters from the same geological source. It is to be hoped that in future years this list will be considerably extended, as it will render great service to the geologist and to everyone interested in our underground sources of water supply.

The chief object of the work, however, is to show how to examine sources of supply, and how to use the information thus acquired in the interpretation of results obtained from the examination of the waters yielded by these sources, and to demonstrate that it is more important to consider the quality than the quantity of the organic and inorganic constituents

found in waters from whatever source derived. Standards may be useful to the beginner and the inexperienced, but are carefully to be avoided by the expert and experienced. They are chiefly advocated by those who have some 'process' or 'method' which they have devised and wish to commend, and so far all such processes have failed to stand the test of time. What is wanted is the application of common-sense to the subject of water examination. How can any analysis, however complete, tell us anything of the liability to pollution? Some of the purest waters I have ever examined have been liable to occasional pollution of the most serious character.

The importance of the systematic inspection of all sources of water supply is now fully recognised by the Local Government Board, and the President has requested the Commission on Sewage Disposal to make a recommendation dealing with the whole subject of water pollution. As a result the Commission has, in an interim report, expressed the opinion that Rivers Boards should be formed throughout the country. In the course of their inquiries they have found that water supplies are liable to other serious pollutions besides those which can be dealt with under the Rivers Pollution Prevention Act; and although in the case of the larger water undertakings the owners may be desirous of doing all that is possible to safeguard their sources of supply, they are satisfied that there are cases where the supervision of some superior authority is desirable in the interests of the public health. Over the Local Rivers Boards there would be a central authority, probably a special department of the Local Government Board, whose function would be to exercise a general supervision over the whole country in regard to the prevention of the pollution of water, and with power to order the purveyors of water, or other responsible parties, to adopt such means as in the opinion of the

Central Authority are reasonable and necessary for removing or diminishing the danger. There can be no doubt that ultimately this suggestion will be acted upon. In any case the opinion expressed confirms my views as to the importance of the systematic inspections of sources of supply. I do not wish to be misunderstood. I do not, for a moment, refuse to recognise the importance of chemical, bacteriological, or microscopical examinations of samples of water; I merely contend, that however great this importance, the examination of the source of supply is usually greater.

I am conscious of many imperfections in the book, but as it may serve a useful purpose, and covers ground not touched by any other work with which I am acquainted, I am emboldened to publish it.

I am greatly indebted to my friend Mr. PRATCHETT for the drawings made from water deposits, to my coadjutor Mr. M. PRIEST, F.I.C., and my assistants Drs. PUGH and SOWDEN for their help whilst the book has been passing through the press, to the Editors of 'Hygiene' for their permission to reproduce Jordan's Table of Water Bacteria, and to Dr. GARRETT for the loan of the blocks for Plate XIX.

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# THE EXAMINATION
OF
# WATERS AND WATER SUPPLIES

## PART I

### *THE EXAMINATION OF SOURCES FROM WHICH WATER IS DERIVED*

## CHAPTER I

### SOURCES OF SUPPLY

THE examination of the source from which a supply of water for domestic purposes is derived is often more important than an examination of the water itself; pollution is frequently intermittent and a water, generally of great chemical and bacteriological purity but liable to occasional contamination, is eminently unsafe, either as a public or private supply. Moreover, there are limits to the powers of analysts to detect impurity, or, having detected it, to decide whether it is of an innocuous or positively harmful character. Obviously, therefore, no report on the safety of a supply can be complete without a careful examination of its source. This examination, supplemented by chemical, bacteriological, and microscopical analyses, will enable a reliable opinion to be given, as the results of the examination will render possible a correct interpretation of the analytical results.

Such an examination implies some knowledge of geology, as without this it is frequently impossible to locate the points at which impurities may gain access to the water, or to form an opinion as to whether a given source is adequately protected or not. There must be some knowledge of the nature and extent of the water-bearing stratum, and of the impermeable stratum below it, and also of that above it, if the supply is from a deep source. The locality and nature of any faults must also be studied, together with the angle of inclination of the strata and the direction of the fissures.

The geological maps of the Ordnance Survey are indispensable for this purpose. These maps are all on the scale of one inch to the mile. The 'solid' maps show the distribution of the solid rock formations, the 'drift' maps show the superficial deposits overlying them, the rock formation being coloured only where there is no drift. In parts of the East of England, where the superficial deposits are thick and widely spread, only the drift edition is published. From near Scarborough southward, over the East and South-east of England, the drift edition is the more useful for reference when considering the question of water supply, unless a supply from a deep source is contemplated, when the solid edition will be also required. For surface water-supplies the ordinary maps, 6 inches or 25 inches to the mile, showing the contours and surface level at various points, are also required, as from these the catchment or drainage areas can be delineated. The handbooks supplied with each set of maps must also be consulted, and the knowledge thus obtained corroborated and extended by personal exploration of the locality.

The following table, which enumerates all the more important strata found in the British Isles, from above downwards, is one which I frequently find useful for consultation, but it must be remembered that probably in no one locality do all these beds exist. Some are missing in one district, others in another; in certain districts some attain a considerable thickness, whilst in others they have so thinned out as to be

unimportant. I have therefore appended a few notes to the more important formations, which may be of value, but they will frequently have to be supplemented by reference to advanced text-books on Geology.

SERIES OF BRITISH STRATA COMMENCING AT THE SURFACE

| | |
|---|---|
| POST-TERTIARY— | |
| | Alluvial deposits, blown sands, &c. |
| | Glacial and post-glacial sands and gravels, boulder clay. |
| TERTIARY— | |
| Pliocene . . . | . The crags (sands and shells) of Norfolk, Suffolk, and Essex. |
| Miocene . . . | Almost unrepresented in Great Britain. |
| Eocene . . | . Sands, clays, marls, &c., with limestone in their beds. Hampshire and Isle of Wight. |
| | Upper Bagshot sand. |
| | Barton clay. |
| | Middle Bagshot bed. |
| | Bracklesham beds. |
| | Lower Bagshot beds. Clays and sands. |
| | London clay. |
| | Oldhaven, Woolwich, and Reading beds and Thanet sands. |
| SECONDARY OR MESOZOIC— | |
| Upper Cretaceous . | . Upper chalk with flints. |
| | Lower chalk without flints. |
| | Chalk marl. |
| | Upper greensand. |
| | Gault. |
| Lower Cretaceous . | . Lower greensand, Folkestone, Sandgate and Hythe beds, and Atherfield clay. |
| | Weald clay. |
| | Hastings beds, Tunbridge Wells sand, Wadhurst clay, Ashdown sands. |
| Jurassic . . . | . Upper or Portland oolites. |
| Hard sandstones and limestone alternating with clay and shales. | Purbeck beds. Portland stone and sand. |
| | Kimeridge clay. |
| | Middle or Oxford oolite. Coral rag and calcareous grit. |
| | Oxford clay. |
| Lower or Bath Oolite. | Great oolite. Cornbrash, Forest marble, Bath or great oolite, Northampton sands. |
| | Fuller's earth. |
| | Inferior oolite. Lincolnshire limestone, Northampton sand. |
| Lias . . . . | . Upper lias (shaly clay), middle lias (argillaceous limestone, sands and clays), lower lias as) middle lias). |

SERIES OF BRITISH STRATA COMMENCING AT THE SURFACE—(*continued*)

| | |
|---|---|
| Triassic— | |
| Keuper | Red marl. Contains beds of rock salt and gypsum. |
| | Keuper sandstone. |
| Bunter | Upper mottled sandstones. |
| | Pebble beds. |
| | Lower mottled sandstones. |
| Permian— | |
| Upper Permian | Red sandstone, clays and gypsum. |
| | Magnesian limestone. |
| | Red and variegated sandstone. |
| Lower Permian | Red sandstone, marl, breccia, and conglomerate. |

NOTE.—The Permian and Triassic series are often included in one group as the 'New Red Sandstone.'

| | |
|---|---|
| PRIMARY OR PALÆOZOIC— | |
| Carboniferous | Coal measures. Sandstones, clays, coal, shales, flagstone and ironstone. |
| | Millstone grit. |
| | Sandstones with thin seams of shale, coal, and limestone. |
| | Carboniferous or mountain limestone. |
| | Yoredale rocks (limestone chiefly). |
| | Thick limestone. |
| | Limestone and shales. |
| Old Red Sandstone | Red sandstones, shales and conglomerates. |
| Devonian | Grey slate and limestone. |
| | Grey unfossiliferous slate. |
| | Soft slate with bands of limestone and sandstone. |
| Silurian | Ludlow rocks. Sandstone, limestone, shale. |
| | Wenlock limestone and shale. |
| | Llandovery shale and sandstone. |
| Lower Silurian | Shales, slate, sandstone, &c. |
| Cambrian | Slates, sandstones, &c. |
| EOZOIC— | |
| | Gneiss and crystalline schistose rock. |

**Post-tertiary Sands and Gravels.**—These superficial deposits are more widely distributed than any older stratum, and vary in thickness from a few inches to 150 or even 200 feet. Most shallow wells are sunk in this drift, and the water therefrom varies much in character in different localities. Usually on the same gravel patch the unpolluted water is fairly uniform in character, and samples of such must be taken as standards with which to compare water obtained from other portions. Care must be taken in selecting typical wells or

springs for this purpose that the water does not come from the direction of a village or farmyard, or other such possible source of contamination. Springs are common at the edges of these patches, but they are rarely of any magnitude.

**Boulder Clay.**—In some districts this clay attains a thickness of 150 feet or more. It is not absolutely impervious. It usually yields a very hard water, and this sometimes has an odour of sulphuretted hydrogen. Water is often said to be derived from the boulder clay when it actually comes from an earlier drift of sand lying immediately beneath it.[1] (72.)

**The Crags of East Anglia.**—These shelly sands are very limited in area, and yield comparatively little water. Very often they are impregnated with sea-water, and occasionally they are ferruginous. Springs are comparatively rare. (75.)

**The Bagshot Sands**, found in the Isle of Wight, capping many hills near London, and forming the Frimley and Chobham Ridges, the heaths of Bagshot, Hartford Bridge, and Sandhurst, usually yield a soft water, which is sometimes ferruginous. Many patches yield water containing little or no calcium carbonate, and acting markedly on lead, zinc, and iron. Round the edges of patches of these sands the water oozes away, and springs are numerous but small. In the London Basin this formation varies from 100 to 350 feet in thickness, and extends over an area of more than 200 square miles. (76.)

**London Clay.**—This bed attains a thickness of 450 feet, but thins out completely at the edges of the Basin. It is very impervious, yet in places the upper surface has become loamy, and shallow wells sunk in this loam may yield a little water. In these cases the clay is usually found intersected with laminæ of crystals of gypsum, and the water is excessively hard; it may also contain a considerable quantity of salt. (71.)

**Oldhaven, Woolwich, and Reading Beds.**—These lie at the base of the London clay, and as a rule yield little, if any, water, but I know of at least one case in which a considerable quantity of water enters a deep well from these beds. The water is highly charged with magnesium salts. (89.)

[1] The figures in brackets refer to the analyses at the end of the book.

**The Thanet Sands** consist of an argillaceous greyish greensand, of variable thickness. Under London they are about 20 feet thick, in West Kent over 60 feet. The outcrop has a very limited area, and I know of no springs arising therefrom. The yield of water is very variable. Some bored wells yield about 100,000 gallons per day. The sand is so fine that bore tubes are easily silted up, but possibly by means of the recently introduced air-lift pumps water will be obtained more freely than is possible with the pumps usually employed. Save near the outcrop, the water is soft and alkaline, and identical with that yielded by the chalk beneath. This is not surprising, since there is no impervious stratum between the two. Near the Essex coast the water is often hard, and contains much magnesia, and at some places further inland the water is even more highly charged with salt and magnesium and calcium sulphates. I suspect that these latter waters are really derived from the Woolwich and Reading beds. (46–60.)

**Chalk.**—'The chalk extends from Flamborough Head inland, forming the Yorkshire Wolds, and thence running beneath the Humber near Hull to form the Lincolnshire Wolds. It constitutes the foundation of the greater part of Norfolk and Suffolk, but is in these counties very much concealed by glacial drifts, and does not there appear in such conspicuous hills as those which extend from Royston and Luton Downs to the Chiltern Hills, the Marlborough Downs, and Salisbury Plain. Thence the chalk stretches out irregularly to the west beyond Dorchester, and is found in outliers near Chard, Seaton, and Sidmouth. Eastward of Salisbury Plain the chalk forms a large extent of Hampshire; it is found in the Isle of Wight, and borders the Wealden district, forming the cliffs from Margate to Folkestone on the north and those from Beachy Head to Brighton and Littlehampton on the south. It is also exposed at Gravesend and Grays Thurrocks' (Woodward). In the London Basin it extends over an area of over 2,000 square miles, and has a thickness of 500 to 1,000 feet. It is probably the most important water-bearing stratum

in this country. The water chiefly travels through fissures, hence polluting matter may be carried very considerable distances. Water is obtained from it by shallow and deep wells, and by driving adits to cut a number of fissures. Springs are numerous, and often yield enormous quantities of water. Along the outcrop of the gault the springs are not so large as those at a lower level, where the chalk passes under the London clay, and again where it approaches the sea level.

The waters derived from the chalk may be divided into two classes—the calcareous and the alkaline. The former are usually 'hard,' but the hardness is chiefly 'temporary;' whilst the latter are very soft, and contain sodium carbonate. The 'alkaline' waters only occur where the chalk lies buried beneath a thick mass of London clay, in all other places the water is 'calcareous.'

Pure chalk water is especially characterised by its palatability, its brilliancy and freedom from colour; but in some districts in East Yorkshire, Norfolk, and Suffolk, it is not unusual to find it containing so much ferrous carbonate as to be unfit for use without prior chemical treatment to remove the iron. These waters are merely dull and yellowish when first drawn, but speedily become turbid and brown when exposed to air. (Alkaline waters 1–15, calcareous 16–45.)

**Upper Greensand.**—The chalk marl is often so impervious as to separate the water in the chalk from that in the upper greensand. This formation is but little developed near London, but becomes of importance in Wiltshire. At White Nore Cliff, in Dorsetshire, it has a thickness of 100 feet. It averages 60 feet in thickness in the Wealden district. 'At Petersfield it is 80 feet, at Eastbourne 40 feet, at Godalming 50 feet, and at Nutfield 40 feet. It is exposed north of Folkestone and at East Wear Bay with a thickness of less than 20 feet. It is essentially a water-bearing stratum' (Woodward). The water varies much in character, but is usually markedly calcareous, and in certain localities it is ferruginous.

**Lower Greensand.**—The upper and lower greensand are

separated by the gault, a stratum of clay 100 to 200 feet in thickness. The outcrop extends from Folkestone, in a band of varying width, westward through Ashford, Maidstone, and Reigate to Farnham. It then trends southward to Petersfield, and finally eastward to the coast at Eastbourne. The southern half of the Isle of Wight is in great part formed of the lower greensand. There is a limited outcrop near Leighton Buzzard, to the north of London. The total area of the lower greensand in the London Basin is about 500 square miles, and its thickness is from 200 to 500 feet. The Folkestone beds are very ferruginous. At Reigate the sands attain a thickness of 450 feet, in Bedfordshire 250 feet. In both cases the dip is towards London, yet this stratum is apparently absent under the metropolis, as borings have failed to find it. Springs are not numerous in this formation, but there are copious springs arising from the greensand near Sevenoaks, Dorking, Weston Street, and Farnham, the water being doubtless thrown out at the outcrop of the Weald clay. The Royal Commission on Water Supply (1869) reported that the water from the lower greensand was 'excellent for all domestic purposes, being bright and limpid, of a degree of hardness varying only from 3° to 9° of Clark's test, and generally very free from organic matter.'

There are many exceptions, however, to this rule. Unfortunately also these sands often yield a water containing an amount of ferrous carbonate which seriously affects its utility for domestic purposes. (90–97.)

**Hastings Beds.**—These are separated from the lower greensands by the Weald clay. The beds are of some thickness, but very limited in extent. The only water I have examined from these beds was from a bore sunk through some 800 feet of overlying strata, and it proved to be of an alkaline character, resembling the water from the deep chalk under Essex and London. (88.)

**The Upper and Middle Oolite** contain permeable beds which, however, give rise to no considerable springs and are only of local importance as sources of water supply.

**The Lower Oolite** is separated from the Middle Oolite by the Oxford clay, which varies in thickness from 300 to 600 feet. This clay contains calcium carbonate and iron sulphide (pyrites). The Great Oolite (Lincolnshire, Northamptonshire, Gloucestershire, and Oxfordshire) is from 250 to 300 feet in thickness and consists of beds of shelly limestone and marly clay. Within the Thames Basin they have a collecting area of about 300 square miles, and give rise to numerous fine springs. The water is usually thrown out by the outcrop of Fuller's earth. Below the Fuller's earth is a series of beds, the most important of which is the Lincolnshire Oolite, which, in that county, attains a thickness of 200 feet. It thins out towards Kettering. This inferior oolite and underlying sands are about 320 feet thick in the neighbourhood of Cheltenham, and thin off, to disappear under Oxfordshire. It follows, therefore, that a good deal of water is imprisoned in these strata, although springs of considerable volume are common at the base of the hills of this formation. The water naturally contains much calcium carbonate, and in all respects resembles water from the superficial chalk. Where the water is imprisoned, however, it undergoes an entire change of character, becoming alkaline, now resembling the water from the deep chalk of Essex and London. (98–108.)

The oolite probably rivals the chalk as a source of water supply, both in quality and quantity. There is greater danger, however, of polluting matter being carried long distances, as from the compact character of the limestone the water can only travel through and accumulate in its fissures.

**The Lias** 'forms a conspicuous band stretching across England from Whitby and Redcar, on the coast of Yorkshire, to Lyme Regis, on the coast of Dorset, the harder rocks forming gentle escarpments which overlook the vales formed in the softer or clayey strata' (Woodward). It consists of beds of clay, shale, limestone, and marlstone. In certain districts this formation yields a considerable quantity of water, and springs of large volume are not infrequent. The water is

usually very hard, but most of the hardness is easily removable by boiling.

**The Triassic Rocks (New Red Sandstone)** 'form part of the plain of York, and stretch through Nottinghamshire, Lincolnshire, Derbyshire, Cheshire, Staffordshire, Warwickshire, Worcestershire, and Gloucestershire, and there is an outlying mass near Carlisle' (Woodward). These strata are of very great importance as a source of water supply, ranking next to the chalk and oolites. An immense number of shallow wells are sunk in it, and many towns are supplied with water from deep wells and springs in this formation. The sand granules of which it is composed are cemented together by calcium sulphate and carbonate; hence the water is usually very hard, and much of the hardness may not be removable by boiling. The hardness is also often due, in part, to the presence of magnesium salts. In the neighbourhood of salt deposits the water may contain much salt, elsewhere the chlorides are very low. (109–111.) The Royal Commission on Water Supply reported that the unpolluted waters from this formation are clear, bright, colourless, palatable, and wholesome, well adapted for all domestic purposes except washing, for which most of them are too hard.

**Permian Series.**—The sandstones of this series are sometimes included in the term 'New Red Sandstone' or called the Lower Red Sandstone. The sandstone occurs in Yorkshire, west of Doncaster; in Cumberland, at St. Bees' Head and Corby Castle; in Durham, at Claksheugh; in Lancashire, at Astley; also at Penrith, around Wolverhampton, south of Shrewsbury, west of Birmingham, and around the Dudley coalfield. The water obtained therefrom resembles that from the New Red Sandstone proper.

**The Magnesium Limestone or Dolomite** has a thickness of 300 feet in Durham, and this thickness is maintained to Pontefract, the series gradually diminishing in thickness to about 120 feet near Annersley, South Notts (Woodward). The water is usually very hard, and the permanent hardness is sometimes considerable.

**Coal Measures.**—These are not important water-bearing strata, although immense volumes of water are often pumped from coal mines. The water varies greatly in character, but usually it is too hard and contains too much saline matter to be suitable for domestic purposes. (112–113.)

**Millstone Grit.**—This formation consists of coarse and fine sandstones, shales, and conglomerate, which crop out at the edge of the coalfields, from South Wales to the middle of Scotland. In Lancashire the Millstone Grit contains thin coal seams and is estimated to have a thickness of from 3,500 to 5,000 feet. It is comparatively unimportant as a source of water supply, being too dense and impermeable. Springs arise from fissures, and in a few places water is obtained from deep borings. The water varies much in character, but is usually moderately soft. (114–115.)

**Mountain Limestone.**—The carboniferous or mountain limestone is a very extensive formation, rich in mineral veins, forming the axis of the Pennine Chain. The stratum is much fissured, and springs occur of all volumes from a mere trickle to a decided river. The river Aire arises from springs near Malham. The fissures are sometimes so large and contain so large a volume of flowing water as to constitute underground rivers. Usually the water is very clear and palatable, but it is often too hard for domestic purposes. Occasionally the water is discoloured by peat, and not infrequently it contains traces of iron.

**Old Red Sandstone.**—This formation extends from near Bridgnorth in Shropshire, southward, through a considerable portion of the counties of Hereford, Monmouth, and Brecon into Glamorgan, Carmarthen, and Pembroke (Woodward). It contains very little soluble matter, and therefore as a rule the waters obtained from its fissures are moderately soft and well adapted for domestic purposes.

**The Devonian** slates and limestone occur in West Somerset, Devon, and Cornwall, the Silurian and Cambrian rocks in Wales and the Lake District, and the Eozoic rocks are probably represented at Malvern, Charnwood Forest, Anglesea,

Holyhead, and the adjacent parts of Carnarvonshire. These rocks are very hard, impervious, and insoluble; hence such water as may be found in fissures, or which issue therefrom as springs, contains very little saline matter and is usually very soft. Comparatively little water is obtained from the rocks, but from their surfaces enormous quantities of water run off rapidly, and, filling hollows in the mountains, form lakes, several of which are now being utilised for the supplies of cities long distances away. Of the Igneous rocks, granite is the only one which occurs over any extended area. In the south-east of Ireland there is a mass of granite 70 miles in length and from 7 to 17 miles in width. Large intrusive blocks of granite occur in the South of Scotland and in Devon and Cornwall.

The geological edition of the maps of the Ordnance Survey includes sections in various directions, showing the thickness of the strata, the known faults, &c., and the 'Handbook' and other publications give all the well sections which could at the time of the survey be obtained. Frequently local Field Clubs and Natural History Associations issue 'Transactions' containing information of the utmost value. Often also there are persons interested in local geology who can supply useful information; but beware of the oldest inhabitant, as his uncorroborated testimony is rarely to be trusted.

In examining water supplies some knowledge of engineering is also necessary in order to know what points should receive attention when examining storage and service reservoirs, water mains, hydrants, sewer-flushing arrangements, &c. In fact, an intimate knowledge is implied of everything which pertains to the subject of water supply, and I must at least assume that the reader has made himself thoroughly acquainted with the matters dealt with in my work on 'Water and Water Supplies.'

Important as the inspection of a source of supply may be, we cannot afford to ignore the information which may be obtained by analysis, chemical and bacteriological, of the water

itself and the microscopic examination of any sedimentary matter found in it. These analyses may give results of an unsatisfactory character or show that the water is variable in character, and their careful study may afford a clue leading to the discovery of some unsuspected source of danger. On rare occasions a water may be found of such a character as to be considered unsafe for domestic purposes, yet no possible source of pollution be discovered upon examining its source. In many instances in which analyses have indicated pollution, defective sewers, unsuspected cesspools, &c., have ultimately been discovered when a thorough examination has been made. Such causes of pollution could only be detected by excavations around the source of the supply, which would never have been made had not the analytical results indicated 'danger.'

When supplies are derived from wells, superficial or deep, it is requisite that analyses should be systematically made and recorded, especially if the wells are within a short distance of human habitations, farms, or sewers. In the cases where waters are derived from sources known to be polluted—such as contaminated rivers, which sources would be obviously unsafe were the water not properly collected, stored for sedimentation, and filtered—it is necessary that the various processes of purification be carefully supervised and that samples of the water derived from the filters be examined bacteriologically at frequent intervals.

It follows, therefore, from what has been said, that under one set of circumstances analyses of a water are of more importance than examinations of its source, and under others that the examination of the source is the more important. In very few instances can either the one or the other be entirely ignored.

As I regard the inspection of the source as being of primary importance, I purpose dealing with this subject before referring to the analyses, more especially as it is, in nearly all cases, necessary to know something of the source of a water if the results of the various analyses are to be correctly interpreted.

## CHAPTER II

### EXAMINATION OF SHALLOW AND DEEP WELLS AND SPRINGS

ONLY a very small percentage of the shallow wells in this country are either satisfactorily placed or properly constructed, and often a most cursory examination is sufficient to show that pollution is possible. In other cases a more detailed survey is necessary, including the opening of the well and possibly of the ground in the vicinity, to search for drains, cesspools, &c., within the drainage area. The extent of this area depends upon the nature of the subsoil, upon the depth of the well, upon the depression of the water level produced by the abstraction of the maximum amount of water required per day, and upon the direction of flow of the ground water. This applies to all shallow wells, that is, to all wells sunk in a superficial permeable stratum, whatever the depth.

The more porous the subsoil, the larger the drainage area or area of depression produced by the abstraction of water, and *vice versa*. In no case is it safe to regard this area as less than the area of a circle the radius of which is twenty times the depression of the water level produced by pumping, and in running sand and fissured rocks it may be greater. If, for example, the depression produced is only 1 foot, the drainage area should be taken as extending over a radius of not less than 20 feet from the well as the centre. When the ground water surface has a marked slope, the portion of the drainage area which most requires protection is that where the water level is highest. The surface of the ground water round a well when depressed by pumping has the form of an inverted cone, the sides near the well being steep and gradually rounding off into the nearly horizontal surface of the subsoil water. The

velocity of the flow of the water towards the well at any point varies with the distance of that point from the well, the velocity decreasing more rapidly than the inverse of the square of the distance. For example, if within 3 feet of the well the movement of the water is at the rate of 3 inches per second (probably a higher velocity than ever occurs through any porous stratum), at 30 feet the movement of the water could not be more than 1 foot in 400 seconds, and at 90 feet the rate would be less than 1 foot in an hour. At a certain distance from the well, therefore, the movement of the water through the soil is slower than the rate of filtration through sand in any artificial system of purification.

The depth of the well, or rather of the ground water, should also be considered, since the nearer this approaches the ground surface the greater the risk of contamination. Where the water level when at its highest is only 2 or 3 feet from the ground surface it will be almost impossible to render the water safe unless the whole of the area of depression is protected. Where the highest point reached by the ground water is 60 or 70 feet from the surface, and the ground is compact, percolation will be so slow that purification is ensured before water from the surface reaches this level. In such a case a very limited protective area is necessary.

As an example of the method of determining the extent of the area to be protected, suppose that in a sandy subsoil, with a ground water level at its highest several feet from the surface, a well is sunk from which 45,000 gallons per day are abstracted and that the maximum depression produced is 9 feet. Each foot of saturated sand yields about 1½ gallon of water. To yield 45,000 gallons, therefore, 30,000 cubic feet of the subsoil would be drained. The volume of a cone being the area of its base multiplied into one-third of its height, it follows that if the volume be 30,000 cubic feet and the height 9 feet, the area of the base of the cone of depression would be (assuming the sides to be straight) 10,000 square feet, representing a circle with a radius of 57 feet. The cone, however, has not straight but curved sides, yet for all practical purposes the cone is included

in the area above given, since beyond that radius the flow of water becomes so slow that efficient filtration must result. A protective area of 20 to 30 yards radius, kept free from all polluting matter, would probably suffice to render the water from this well quite safe, but it would undoubtedly be better to have an outer protective zone either uncultivated or simply laid down to pasture.

Where the ground is fissured it is impossible to define the protective area, but the directions of the fissures and of the flow of water therein should be determined and particular attention paid to the ground above the well where the fissures come to the surface. If the well is fed by underground drains, the depth and direction of these should be ascertained, and the whole of the area drained should be examined for evidence of the presence of polluting matter. In or near towns and villages, and near farmyards, the whole of the water in the subsoil over an extended area may have become polluted. In such a case it is useless to expect to obtain a supply of wholesome water from any shallow well, however carefully constructed or protected.

In examining a water supply from the subsoil the well should be opened out to ascertain how it is covered and constructed, how the pump pipe or rising main enters; the condition of the sides should be examined to ascertain if there are traces of water entering from near the surface, or whether the rootlets of trees have penetrated into the well. The depth of the water from the ground surface, the depth of the water in the well, and the depression caused by pumping may then, if desired, be ascertained. Samples of water taken respectively from near the surface and near the bottom of the well may upon examination give information of importance. If water is observed entering at more than one point, samples from each may be collected and compared. If the pump is defective, the well may be polluted by water used for priming. I have seen ditch water poured into the pump cistern for this purpose under the impression that the first few strokes of the pump, when in action, would remove all the impurities. That such is

not the case can easily be demonstrated by priming the pump with a solution of permanganate of potassium. It will be found that the whole of the water in the well has become tinted, and it may be days before the colour disappears. (For construction of shallow wells, *vide* p. 31.)

In deep wells—that is, wells bored through an impermeable stratum to water-bearing rocks beneath—pollution is chiefly to be sought for near the surface, and the upper portion of the well and the surface of the ground require examination, as in the case of a shallow well. If the outcrop of the water-bearing stratum is under the sea, indications of sea-water infiltration must be sought for in the saline constituents of the water. If the outcrop is at no great distance, possible sources of pollution should be sought for upon it.

In small supplies, whether from deep or shallow wells, where the pump is fixed over or near the well, the condition of the paving and ground around and the nature and condition of the arrangement for conveying away the waste water require examination. I have seen a well placed in a recess used frequently as a urinal, and the paving was so defective that the polluting matter could readily gain access to the well. The position of all drains, cesspits, cesspools, &c., should be noted, and their condition ascertained. If there is reason to believe that any such are within the drainage area of the well, the supply cannot be considered safe unless these drains, &c. are actually known to be perfect. Some time ago I had occasion to examine the water supply to a large house where typhoid fever and diphtheria had occurred. The water had been examined on several occasions by analysts and pronounced satisfactory. My suspicions were aroused by the very excessive amount of nitrates present, although in every other respect the analytical results were satisfactory. Upon tracing the main drain it was found to terminate in a large cesspool, hitherto unsuspected, within about 10 feet of the well. The cesspool was immediately at the back of a dairy and the well just in front. The cesspool was abolished and the drains

diverted. Very soon afterwards, the well for the first time failed. This is an instance of the marvellous purifying action of the subsoil, as there was no doubt that the well had been chiefly fed from the cesspool, which had no outlet. The cesspool was acting as a perfect septic tank and the ground around as an aerobic filter. Quite recently I had to report, after a chemical examination, very unfavourably on a water from a deep well supplying a village. The well was within about 50 yards of a churchyard, but I was assured that the water came from the Thanet sands beneath the London clay, which at that point was about 100 feet thick. Upon opening the well the upper 10 feet was found to be constructed of brickwork well rendered in cement and perfectly sound, but immediately below there were signs of water entering through the interstices between the unsteyned bricks. I had the well pumped out and the top of the bore tube exposed. A sample of water was taken from the tube at a considerable depth and found to be perfectly satisfactory, and entirely different from the water pumped from the well. There was found to be a considerable amount of alluvium above the clay, and from this the impure water was pouring into the well. At the rectory in the same village the water from the deep well was ascertained to be polluted, by pouring paraffin oil on the ground by the side of the suction pipe, as the exact position of the well was not known. In a day or two the paraffin had given its flavour to the water, and impurities were found to have reached the well from the kitchen drain along the track of the pump pipe.

Wells on low-lying ground liable to flood require careful protection, and special construction. If after a flood the water from the well is turbid, danger is indicated. If the flood water is from a tidal river, the water may become brackish. Since the damage to certain of the sea walls along the banks of the tidal streams in Essex, many deep wells have been ruined by the access of salt water. A rise and fall in level of the water in such a well synchronising with the rise and fall in the tide indicates a somewhat free communication between the well

and the river or sea. This may or may not be dangerous in character, depending greatly upon the pollution or otherwise of the tidal water and the extent of the depression caused by pumping.

When the water in a well becomes turbid after heavy rain there is obviously some defect which requires prompt attention, since if coarse particulate matter can be washed into the well, pathogenic organisms, if present, could get in also. A few years ago an outbreak of typhoid fever occurred in a small town in Essex. It was limited to persons who obtained water from a tank or well which discharged the water through a small stand-pipe lower down the road. The Medical Officer of Health sent the water to an analyst for examination. It was clear and bright, and gave such good results upon examination that the chemist not only declared it good, but went out of his way to say that it could not possibly have caused typhoid fever. As other cases occurred amongst the users of this water, I was consulted, and soon obtained evidence that the water had recently become very turbid after heavy rain. Fortunately a similar downpour occurred within a few days, and a sample of the turbid water was sent to me. There could be no question of its impurity. The District Council, somewhat reluctantly, gave orders for a thorough examination of the source of the water, and it was then found that the drain from the Isolation Hospital, in which there had been a case of typhoid fever some weeks prior to the outbreak, was defective at a point close to the source of the water. The defect was a break across the top of the drain, and when the drain became nearly full the contents got into the ground around and could be traced to the well.

In tracing such connections for discovering defects near the upper surface of a well, and along the track of the pump pipe or rising main, it is sometimes advisable to use solutions which, either on account of their colour or taste or chemical properties, can be easily identified, even when very largely diluted with water. A strong alkaline solution of fluorescin is very useful for this purpose, as also is paraffin oil, which penetrates

the soil rapidly. If either of these liquids is poured in some quantity on the ground round the top of the well and over the track of the pump pipe, it can easily be seen when it begins to trickle into the well, provided the well is opened out and illuminated. The more quickly the advent of the test liquid the more free is the opportunity for pollution. As the liquid becomes absorbed by the ground, buckets of water should be used to wash it downwards. If the test liquid does not make its appearance in the well until after the lapse of many days, it is probable that the filtration efficiency of the ground would be sufficient to ensure safety. If the well is not opened, water must be drawn from it from time to time and examined. In such a case I prefer to use a solution of fluorescin in brine, as the liquid, being denser than the water in the well, tends to sink, and is more quickly diffused through the water in the well. It is an advantage also to keep the water level depressed as low as possible during the whole period of observation. This facilitates the entrance of impurities, and renders them more easy of detection, since the volume of water in the well is reduced. I recently examined a well in a garden adjoining a private house. The top of the well was covered with a large stone slab just above the ground surface, and the pump was fixed over the slab, rendering it difficult to open the well. It was upwards of 30 feet deep, and the water-level was some 25 feet below the ground surface. The subsoil was brick earth over sand and gravel. The water upon analysis was found to be very hard, to contain a large amount of nitrates, but very little organic matter as indicated by the ammonias and oxygen absorbed. As the ground was manured right up to and around the pump save at one point, and the stone covering was shaken every time the pump was used, I did not regard the arrangement as satisfactory. A solution of fluorescin was poured all around the pump, and followed from time to time by pailfuls of water pumped from the well. In thirty-six hours the tint of the fluorescin was quite evident in the water derived from the pump.

Common salt alone may be used, several pounds being spread over the ground surface, and water poured over it from time to time. The amount of chlorine in the water prior to the experiment being known, any marked increase will probably be due to percolation of the brine. It must be remembered, however, that the amount of chlorine in shallow wells often varies considerably from time to time and at different depths. Some time ago I examined the water from a shallow well, and found that the chlorine in a sample from the surface was small in amount, whilst in that from the bottom it was very excessive. In a deep well I found on one occasion a difference corresponding to over 300 grains of chloride of sodium per gallon. The water from the borehole was brackish, whereas that from the surface was rain-water, which drained from the paved yard into the well. The inferences to be drawn from variations in the character of a water at different times and at different levels are not always obvious, but an explanation should always be sought.

An interesting instance whereby the source of the polluting matter entering a well was traced by aid of salt is given in Dr. Page's report to the Local Government Board on an outbreak of typhoid fever at New Herrington, Durham. The well was sunk in fissured strata, which outcropped some three quarters of a mile away. Upon this outcrop there was a farm, the sewage from which disappeared through some of these fissures. When the well was examined it was found that the walls were not impervious, and that a small feeder entered on the south side at a distance of 45 feet from the surface, issuing from the brickwork at a rate of 22 gallons per minute. A sample from this 'feeder' upon analysis gave indications of organic impurity, and the chlorine per gallon was 3·4 grains, as compared with 2·2 grains in the well water. In looking round for the probable source of this water, Dr. Page visited the farm above mentioned. He says: 'The farmhouse and buildings are upon the magnesium limestone, the beds of which dip towards the north. Owing to subsidences caused by

the colliery working below, fissures extending to the surface exist in the locality. The drainage of the farm buildings, of a cottage, and of the farmhouse itself (in which latter there is a water-closet) is conveyed to a tank. The overflow from this tank escapes and disappears down an adjoining fissure in the ground. To determine whether a connection existed between this fissure (three-quarters of a mile away from the well) at Herrington Hill farm and the water-bearing strata supplying the "staple" well, I suggested that common salt should be dissolved and thrown down the fissure. Instructions were given to this effect, and two tons of salt were accordingly thrown down on May 11. . . . From May 24 a series of daily testings of the relative amounts of chlorine in the water of the reservoir and of the "feeder" was made. The chlorine in the water of the reservoir varied from 2·3 to 2·8 grains per gallon, that in the "feeder" from 4 to 6 grains per gallon. On May 29, with a view to placing beyond doubt whether the increase of chlorine thus shown was due to the salt thrown down the crevice at Herrington Hill, 5 tons of salt were washed down the crevice with a hose-pipe running for 12 hours, during which time it was estimated that some 100 tons of water were discharged. On the following day the chlorine present in the water of the "feeder" rose to 15 grains per gallon. The testing was continued for a few days longer, and on June 5 the chlorine reached the maximum amount of 24 grains per gallon. During the next few days it fell again to the former amount. The connection between the two localities was thus conclusively established, and the source of excremental contamination of the water supply demonstrated.'

A solution of lithium chloride may be used instead of common salt, inasmuch as salts of this metal are rarely if ever found in ordinary well waters, and when present even in very minute quantities can be detected in the saline residue, left on evaporation of the water, by spectroscopic analysis. The salt is quite harmless, but the expense is prohibitive if a large quantity is to be used. Permanganate of potash is useless, as

it is so readily reduced by contact with the organic matter in the soil. Paraffin oil is very cheap and penetrates rapidly, but when it has once got into a well it is exceedingly difficult to remove all traces of it.

I prefer to use fluorescin, since it is very soluble in water, has great colorific power, is easily identified, and a trace of it left in the well water is perfectly harmless. One gramme dissolved, with the addition of a little alkali, in a litre of water forms an intensely fluorescent solution, and one cubic centimetre of this mixed with 50 litres of water exhibits an unmistakable fluorescence when the water is viewed in a filled litre flask. One part therefore may be said to sensibly affect 50 million parts of water, or in other words 1 grain will impart a visible fluorescence to over 500 gallons of water. This will give an idea of the amount to be used in any particular experiment.

Abyssinian tube wells require that the ground surface around should be protected. Such a well sunk in the middle of a garden, where the subsoil water level is only a few feet from the surface, cannot be expected to yield a pure water. The tube is generally shaken by the action of the pump, and impurities may gain access through the loosened soil round the tube. The pump should be firmly fixed, the ground immediately around rendered impervious, and a proper arrangement made for conveying away the waste water. If there are doubts about the satisfactory character of the surroundings, pour a solution of fluorescin around the tube or where the defects are suspected, and follow this with water as fast as the ground absorbs it. Collect samples from time to time during a few hours' practically continuous pumping and examine. The solution is often found to be easily driven down by the atmospheric pressure, when pumping is going on.

The use of aniline dyes and of common salt or other chemicals in solution is, however, limited, since if poured upon the ground surface they must, sooner or later, be carried down into the ground water, and if used in sufficient quantity be

discoverable therein. On the other hand, if not used in sufficient quantity they may become so diluted as to escape detection, in either case leading to erroneous conclusions. The *materies morbi* of water-borne diseases is not matter in solution but organisms in suspension, and the former may reach a water supply whilst the latter are held back by the efficiency of the natural filtration. Many experiments, therefore, have been made to avoid this source of error by using such substances as flour, finely ground mineral colouring matters, &c., suspended in water, but the results generally have been unsatisfactory. Calcined magnesia I find gives the best results, being removable with difficulty, but bacteria may penetrate soil capable of keeping back even so finely divided a substance as this.

The most generally useful bacillus for experimental purposes is, probably, the bacillus prodigiosus, as it admits of very easy identification, is capable of surviving in the struggle for existence amongst earth bacteria, is very rarely found in any water supply, and is destitute of any pathogenic property. It must be remembered that it is an undesirable organism to have in a house, and that if premises become infected by it there may be considerable difficulty experienced in getting rid of it. During the past summer I was consulted by the proprietor of an hotel, who complained that all food stored in his larders became covered with a bright red slimy material in the course of twenty-four to thirty-six hours. I found the red material consisted of masses of bacillus prodigiosus. Bakeries sometimes become infected by it. A little care therefore is necessary in its use, and I should hesitate about infecting a town supply of water with the organism. This has, however, recently been done at Turin, where Abba has been experimenting on the collecting area from which the water in the subsoil is abstracted for supplying the city. Emulsions of the bacillus spread upon the ground over and near the subsoil drains collecting the water infected the water in from two to seven hours when the ground was kept flooded with water. When

the ground was not artificially irrigated and the cultures were spread on the soil immediately above the collecting drains, which were laid at a depth of 9 feet, a rainfall of 1½ inches in twenty-four hours failed to infect the water in two days, but the organism made its appearance in samples of tap water taken in the city a month afterwards. It had rained on the eighteen previous days. Abba concluded from his experiments that under ordinary circumstances the bacillus prodigiosus would not pass into the water supply, but that heavy and persistent rains would carry it down into the subsoil water. He affirms that this affords valuable indications of the influence of heavy rainfalls in washing any contaminating organisms that may be present on such a gathering ground into the water supply. He found the bacillus prodigiosus a more delicate test for this purpose than the aniline colours. The following is the mode of procedure followed by Abba, Orlandi, and Rondelli at Turin. An agar culture of the bacillus was suspended in 7 or 8 cubic centimetres of sterile water, and a few drops of the emulsion poured into each of a number of Petri dishes, in which 10 c.c. of nutrient gelatine had been placed. After incubation at 22° C. for twenty-four hours the gelatine was deep red in colour and quite liquefied, but growth was allowed to continue for forty-eight hours, when the mixture was washed into flasks. Trenches were cut in the soil and the contents of one or more flasks mixed with a considerable volume of water were poured in, or a small embankment of clay was constructed round the experimental area and the dilute emulsion poured on the ground enclosed. Water was then used for keeping the trench or enclosed area flooded for several hours. The water from the source under examination was sampled every hour, and 100 c.c. of each sample converted into broth by the addition of a sterilised solution of extract of meat, and kept incubated for twenty-four hours at 20° to 22° C. At the end of this time a little of the turbid broth was poured over the surface of sterile potatoes, and the latter incubated at the above-mentioned temperature. Where

the bacillus sought for was present, the surface of the potato acquired a characteristic red colour. A detailed account of Abba's experiments will be found in the 'Zeitschrift für Hygiene und Infektions-Krankheiten,' vol. xxxi. 1899, p. 66, and an abstract by Prof. E. J. McWeeney in the 'Journal of State Medicine,' January 1900, p. 47.

Where deep-bored wells lined with tubes are used and the tube forms the suction pipe of the pump, there is danger of insuction of subsoil water if the tube is defective. The action of the pump is to withdraw the atmospheric pressure from within the tube, and the external pressure will force air or water through the most minute defects, through apertures so minute that under ordinary circumstances neither would have passed. When this action has once been set up, the openings are bound to increase in calibre, and insuction becomes still more easy. To detect such insuction depress the water level as far as possible by continuous pumping, then pour a solution of fluorescin into a cavity dug round the bore-tube. Continue the pumping and examine in a litre flask or large colourless glass bottle samples of the water raised from time to time. After such continuous pumping, the water should be examined occasionally for some days. In an investigation of this character made by Dr. G. Turner, at the Suffolk Asylum, a solution of chloride of lithium was used, and the insuction proved by the detection spectroscopically of lithium in the water raised by the pump.

It may here be stated that insuction of water through defective water mains can often be detected in a similar manner, that is, by saturating the ground in the vicinity of the supposed defect with an alkaline solution of fluorescin and examining the water drawn from the main at a suitable point.

Well waters have on many occasions been found to be impregnated with coal gas which has escaped from defective mains. Such an occurrence is detected by the odour, and a search should be made for the gas main in order to localise the defect. The odour is very persistent, and if all the affected soil

cannot be removed the well will probably have to be abandoned. As the soil around gas mains almost invariably becomes saturated with coal gas, the proximity of such mains, in selecting a site for a well, should be avoided as far as possible.

Much of what has been said with reference to wells applies equally to springs. Superficial springs are fed by subsoil water, and can only be polluted on the gathering ground of the subsoil water, at points above the level of the springs. Attention, therefore, should be chiefly directed to the character of the surroundings of the springs on the upper side.

The water supplying ascending springs will probably have travelled long distances in fissures in the rocks, and is exceedingly difficult to trace. In Derbyshire small streams are often found to disappear down 'shaks' or crevices in the limestone, and attempts to discover where the water ultimately emerges, by throwing down salt or flour, generally end in failure. These limestone beds often contain large subterranean caverns which act as reservoirs of water, and the material inserted in the fissures becomes too highly diluted ever to be discovered. Suspended matters doubtless have time to settle. In other districts such underground streams have been traced by aid of soluble salts. The source of the water feeding the springs at Lausen in Switzerland which caused an outbreak of typhoid fever was traced by the use of common salt. Flour had been thrown down the suspected fissure on the opposite side of the hill, but failed to make its appearance in the spring water. When salt was employed the chlorine in the water markedly increased.

In several instances I have succeeded in tracing the connection between certain fissures and springs. On the last occasion, referred to in a later section, I succeeded by using common salt, after being unsuccessful with fluorescin. What extent of ground around a spring should be under control for the prevention of pollution is often very difficult to decide. A spring is, in many respects, an underground stream flowing along lines of minimal resistance due to fissuring of the strata, or, in the case of sand and gravel beds, to the washing away of the finer particles.

I recently had to examine a public supply derived from a subsoil spring which, in dry weather, yielded water very copiously. The water gave most satisfactory results both upon chemical and bacteriological analysis. After heavy rains, the adjoining meadows were liable to flooding, and upon such occasions the water became turbid and remained so for days. The chemical analysis then showed some deterioration in the quality of the water, and a marked increase in the nitrates. The bacteriological examination revealed the presence of organisms which could only have been derived from sewage or manure. Upon examining the neighbourhood above the spring in the direction from which the subsoil water was travelling I found about 300 yards away quite an area of highly manured market gardens. The whole phenomenon was now explicable. The heavy rains and flooding of the land washed the manurial matter, with its associated microbes, and the products of its oxidation (nitrates), into and through the subsoil at a faster rate than purification could be effected, and the polluted water finding its way into a line of little resistance passed on without undergoing further change to the spring. Obviously such a source of supply is fraught with danger, a danger the greater on account of the feeling of security likely to be engendered by repeated reports as to the excellent results obtained upon analysis.

The way in which polluted matter, containing bacteria, may under certain circumstances travel a considerable distance even in the subsoil is shown by the following experiment. A trough, 3 feet deep, 1 foot wide, and 24 feet long, was prepared and the bottom covered with small shingle and sand to the depth of one or two inches. The trough was then filled up with fine sand packed tightly. Into a cavity in the sand at one end water was poured until the whole of the sand was saturated. A tap at the opposite end was then turned so that the water drained slowly away. More water, to which an emulsion of a growth of the bacillus prodigiosus had been added, was poured into the cavity, and samples of the water trickling from the

opposite end of the trough were collected every three hours. Within 24 hours the bacillus prodigiosus was found in this water. As it was not found in the water taken from the sand at various points, it must have travelled along with the water through the shingle and sand below, which obviously had not become so compact as to act as an efficient filter.

In wells in which water can be seen entering freely at certain points, this water is obviously travelling along lines of little resistance, and any contamination entering along these lines would almost certainly reach the well.

In examining springs arising from fissured rocks a study of the local geological conditions must be made to ascertain, if possible, where polluting matter might gain access to the water, and this area should be most carefully examined. When the springs arise from sand or gravel beds it is only the more immediate vicinity which requires examining. An area of from 1 to 7, 8, or even 10 acres above the spring should be free from all manurial matter, the extent of the area and its form depending upon the amount of flow, the direction from which the water is coming, the rapidity with which the ground rises above the spring, &c. The portion of the area more immediately affecting the spring should be so enclosed as to prevent the access of cattle and keep away intruders who might accidentally or wilfully defile the water. Small springs utilised for the supply of water to but one or a few houses are often found totally unprotected, and many so-called springs are really subsoil drains sometimes draining highly manured land. Such springs cannot be considered satisfactory sources of supply. Some effort should at least be made to protect the immediate area so that cattle cannot gain access, and so that surface water carrying manurial matter cannot mingle with the stream. Occasionally the water from a series of springs along an outcrop may be collected. This may necessitate each spring being separately protected, or if the springs are in a group one large area may suffice. In a recent investigation I had to recommend that some 20 acres of ground should be acquired to

protect a series of springs yielding about half a million gallons of water per day, but I only considered it necessary to completely fence off about 3 acres, the remainder being allowed to be used as pasture land. The growth of trees should not be encouraged near springs or wells. Rats and moles should be exterminated. However satisfactory such a source of supply may appear, it is desirable that chemical and bacteriological analyses of the water should be made at intervals, samples being taken at different seasons, but especially after heavy rains. If a heavy rainfall renders a spring water turbid, the source is rarely satisfactory, and if the water must be used efficient sand filtration should be insisted upon. It is much to be regretted that sanitary authorities do not possess the power to make bye-laws with reference to the protection of springs and wells, but if they would insist upon springs being properly protected and upon wells being properly constructed before granting water certificates to new houses some improvement would gradually be effected. At my suggestion the Chelmsford Rural District Council issued the following memorandum for the guidance of builders and others, and it has proved so useful that other authorities have followed their example.

'The Rural District Council of Chelmsford.

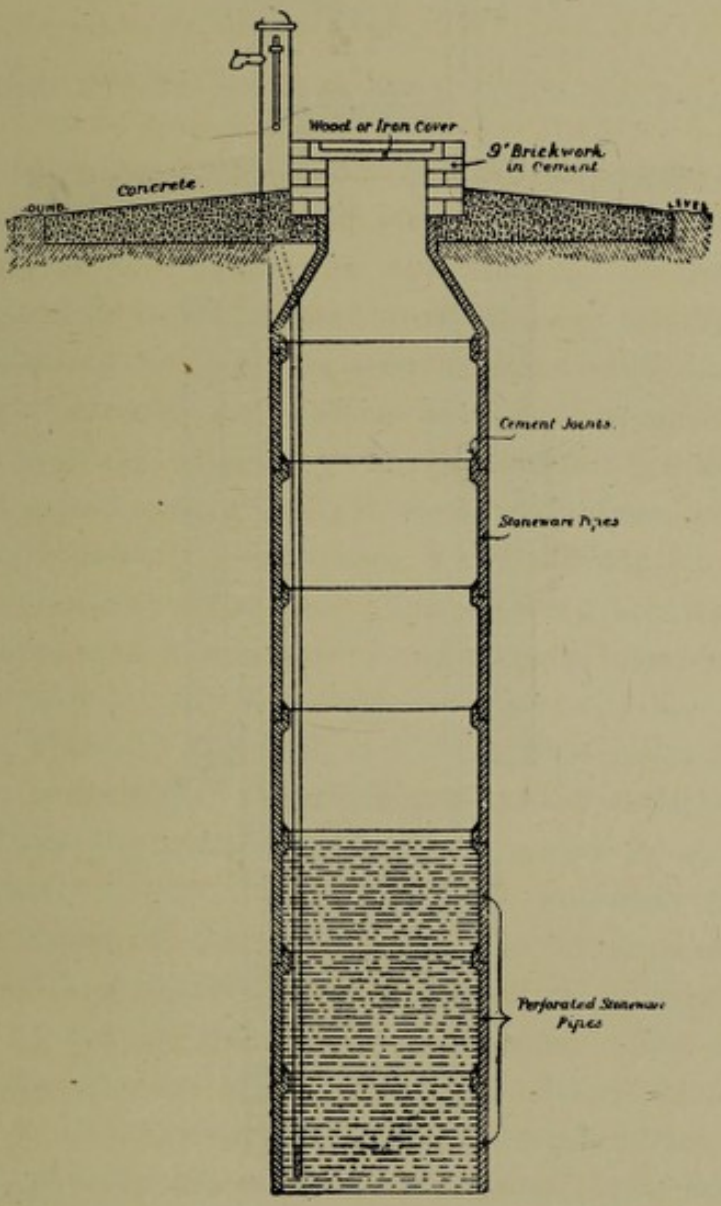
'*The Construction of Shallow Wells.*

'In the large majority of cases where shallow wells yield polluted water it is due to defects in the construction of the wells. The following suggestions are submitted by the Chelmsford Rural District Council, upon the advice of their Officers, for the construction of such wells. The water which enters a well at a depth of 6 to 12 feet, depending upon the porosity of the soil, is usually efficiently filtered and purified. Water entering at a less depth is nearly always liable to be imperfectly purified and unsatisfactory in quality. The nearer the ground surface at which water can enter the greater the danger of pollution.

'It follows therefore that the upper 6 to 12 feet of the well should be water-tight, and that the top should be so finished off that no surface water can possibly gain access. It is also very desirable that the top of the well should be brought up

'SPECIMEN

'CONSTRUCTION OF SHALLOW WELLS



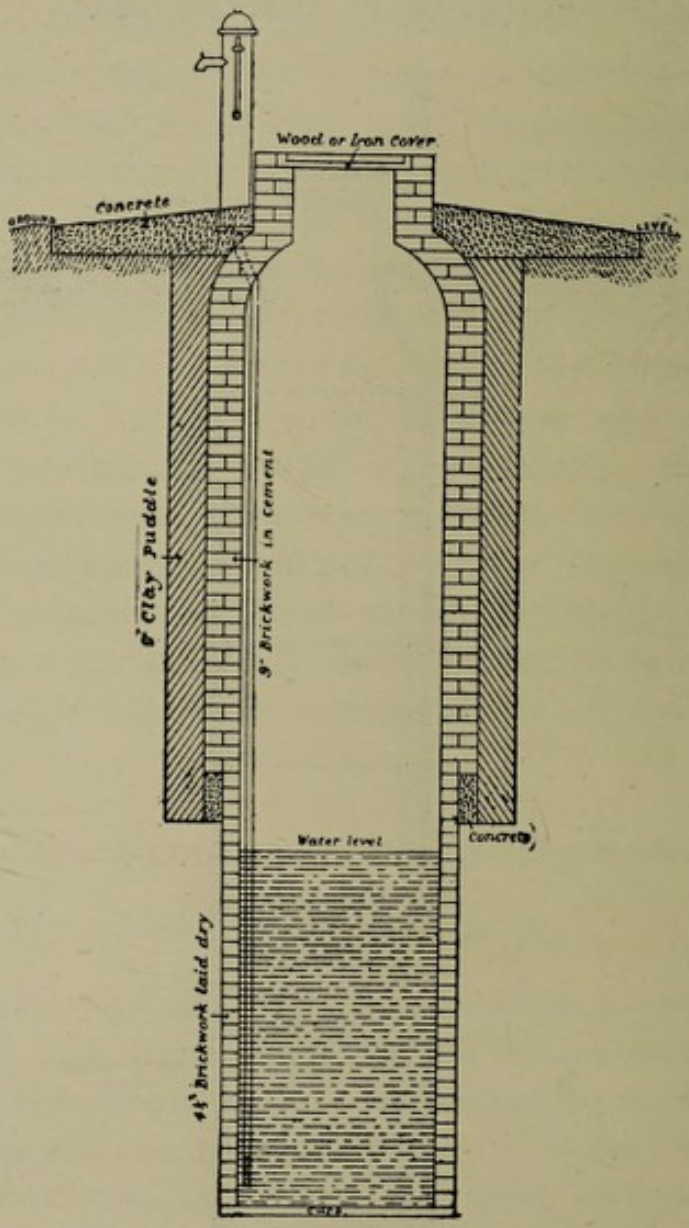

6 to 12 inches above the ground surface and covered with a proper flagstone or wood or iron cover.

'Plans showing two of the simplest methods of well construction are appended.

'As no new house can be occupied without a certificate from the Sanitary Authority to the effect that the house has a sufficient supply of wholesome water, it is important that

'SPECIMEN

'CONSTRUCTION OF SHALLOW WELLS




builders and others should pay particular attention to the above suggestions, and so avoid the risk of a certificate being refused.

'*Issued by Order of the Rural District Council of Chelmsford.*'

## CHAPTER III

### EXAMINATION OF THE SOURCES OF SURFACE WATER SUPPLIES

BEFORE expressing an opinion upon a surface water supply it is necessary (*a*) to make a thorough examination of the gathering ground, (*b*) to examine the surroundings of the storage reservoirs, and (*c*) to determine the efficiency of the filtration.

No collecting area can be considered entirely satisfactory unless the water authority is either the actual owner, or has in some way acquired complete sanitary control over the whole of it. Its extent can usually be ascertained from a study of the ordnance maps, but the nature of the surface &c. can only be learnt by actual inspection. The safest collecting area is doubtless that upon which there are the fewest inhabitants, the minimum amount of land under cultivation, the smallest number of works of any kind, and the fewest roads and footpaths. In this country there are few upland surfaces reasonably free from the possibility of pollution, and in many cases it is absolutely impossible for the water authority to obtain complete control of the watershed. The whole area should be examined and every stream or rivulet traced from where it enters the storage reservoir to its source. The drainage arrangements of every farm, house, and cottage should be investigated to discover what ultimately becomes of the sewage, whether it pollutes the nearest watercourse, or is carried by some sewer beyond the boundary of the collecting area. The land under cultivation should be visited to ascertain whether manure is used or sewage applied, and more especially if house refuse or the contents of pail closets or of privy cesspits are used

for manurial purposes. This investigation may be supplemented by chemical and bacteriological examination of samples of water taken from the various feeders both in dry and in wet weather. Prof. Sheridan Delepine lays considerable stress on the importance of bacteriological examinations. As there is no general standard of purity he selects feeders which are uncontaminated, examines the water bacteriologically, and takes the results as a 'natural standard.' 'To find such feeders,' he says, 'the bacteriologist of course inspects the gathering ground himself, and after noting the configuration and nature of the ground, the course of the feeder, its relation to the slope which it drains, the absence or presence of cultivated areas, of paths, of houses, the possibilities of human traffic, the presence of cattle or sheep, he can then determine whether the feeder inspected is likely to be contaminated or not. . . . It is necessarily free from any bacteria associated with decomposing organic matter, human or animal diseases (providing no carcase of a dead animal is found in its neighbourhood). Such a water should be good, provided no abnormal chemical constituents are present. Even under these conditions water is liable to variations, according to the state of the weather; during heavy rains it becomes mixed with surface soil and decayed vegetable matter, washed down from the surrounding slopes or carried away from the banks of the brook itself. Consequently, during and after stormy weather, even the water of a pure feeder contains a much larger number of bacteria than it would contain when the weather is fine and the stream is running smoothly. This increase of bacteria, which is not excessive when the surface soil is of a suitable nature, does not render the water dangerous health. Knowing the number and the kind of bacteria normally present in two or three uncontaminated feeders both during fine and rainy weather, one would therefore have standards by which to test the water collected on any other parts of the gathering ground, or taken from reservoirs within the limits of the same supply.'[1]

[1] *Journal of State Medicine*, vol. vi. pp. 145, 193, 241, 289.

By this method Professor Delepine has traced sources of pollution which had been overlooked by the persons who inspected the watersheds. One cannot help thinking, however, that had a fraction of the time spent on the bacteriological examinations been spent by a competent person in examining the collecting areas, the pollution would have been discovered. Yet as a supplement to such a thorough examination of the sources of the water, the bacteriological examination of the water is most important. If the bacteriological results are satisfactory and confirm the results of inspection, the evidence in favour of the safety of the water is probably as conclusive as it can be made. If, on the other hand, the bacteriological examination indicates contamination of some feeder, a further inspection must be made to ascertain if any source of pollution has been overlooked. A concealed drain may be discovered, or a dead animal may be found undergoing putrefaction in the stream.

Chemical analyses are of little use in such investigations, still the survey would not be complete without analyses of each of the main feeders. Surface water usually contains a very perceptible trace of vegetable matter, and may, in fact, be more or less discoloured by peat, and in such waters a small amount of sewage is tolerably certain to be overlooked, even upon the most careful analysis.

Moorland gathering grounds require special examination, to ascertain the extent of the area covered with peat and the presence of peat bogs. Peat occurs chiefly on the igneous and oldest rocks, the Cambrian, Silurian, and Devonian formations, and on the rocks of the coal measures. Water which has been in contact with peat takes up some organic acid apparently produced by the agency of bacteria, and the longer it remains in the peat the more acid it becomes. Such acid waters possess the power of dissolving lead, the plumbo-solvent power depending upon the amount of acid present. It may be found possible to cut off limited areas furnishing such acid waters, or springs may be detected yielding water containing sufficient

carbonates to neutralise the acids in the peaty water. By examining the streams draining different portions of the collecting area, information will be gained as to the character of the water from each portion. Although in dry weather such water may be neutral in reaction and have little or no action upon lead, the spring water gaining access neutralising the acid in the surface water, yet in rainy weather the same streams may yield waters with a markedly acid reaction, due to the preponderance of surface water from peaty ground. As the dry-weather flow will be comparatively small, the bulk of the water collected in reservoirs will be acid. Heavy storms wash out of the peat bogs water which has long been in contact with the peat, and which has a strongly acid reaction. Dr. Houston recommended in the case of proposed new waterworks, in which moorland water is to be collected, 'a careful survey of the physical characters of the gathering grounds, as well as the ascertaining of the proportion of spring water to surface water at different times of the year and under different conditions of rainfall, and the testing of the quality of the spring water and its power of neutralising acid, and the quality of the surface water, especially during wet weather and sudden storms following a period of drought.'

On areas already utilised and yielding acid waters, there is no doubt that in many cases the quality of the water could be improved by 'cutting out' special areas, and arranging to 'waste' the extremely acid waters, which would otherwise enter the reservoirs at the commencement of heavy storms. When the collection of an acid water cannot be avoided, arrangements should be made for filtering through some material capable of completely neutralising the acid, as without some such arrangement the consumers of the water run the risk of lead poisoning if the water is conveyed from the mains to the houses through lead pipes, as is almost universally the case in Lancashire and Yorkshire, where these acid waters abound.

In examining surface water supplies, the position of the

storage reservoirs and the condition of their immediate surroundings require special attention. The land nearest reservoirs, as on the banks of feeders, should not be cultivated, and it should be so protected by fencing as to prevent cattle gaining access. There are collecting areas in this country on which exist villages with churches and burial-grounds, and I have seen a large public elementary school within a few yards of a reservoir, into which the sewage from the schools indirectly discharged. If reservoirs in such positions must continue to be used, there should be an efficient system of sewers to carry the sewage from the village outside the collecting area, and subsoil drains to convey the subsoil water from the churchyard into the sewers.

Cases also are on record of house refuse and the contents of pail closets being used as manure on land abutting on reservoirs, and of paper and dust therefrom, blown about by the wind in dry weather, being seen floating on the surface of the water.

Footpaths or highways along the banks of reservoirs are objectionable, permitting of many forms of pollution, wilful or accidental. The shallower parts of the reservoir may be liable to become exposed during dry seasons, in which case the growth of low forms of vegetable life is encouraged and may result in the whole water supply being infected. If the ground around, sloping to the reservoir, cannot be kept absolutely free from manurial matter, it should be drained so that neither surface nor subsoil water, from portions so treated, can gain access to the reservoir.

Where a natural lake has been converted into a storage reservoir, it may be found that boats ply for hire thereon, or there may be a regular service of steamers, as on Loch Katrine. If such is the case the boats should be under the control of the authority and stringent regulations enforced to prevent pollution.

Bye-passes should be provided to carry away very turbid storm waters, and the reservoirs should be sufficiently large to tide over the longest drought; otherwise in prolonged dry

weather, when the water in the reservoir gets low, vegetable growths may occur and injuriously affect the character of the water.

It is probable that no surface water can be considered entirely satisfactory if not carefully filtered before distribution. There may be no danger of pollution from sewage or manure, but low forms of vegetable and animal life occasionally become very prevalent, and floods may cause turbidity. Where such unfiltered waters are supplied there are constant complaints, during the summer months especially, of unsightly appearance or disagreeable odours. Organisms which are not visible at the time of delivery may multiply so rapidly afterwards, that vessels in which the water is allowed to stand for a day or two become coated with a slimy deposit, or with a distinct green growth. What is meant by efficient filtration will be described in a later chapter. Any method adapted for straining or filtering the water should therefore be carefully inspected. The wire gauze arrangements so often used are not sufficient to prevent the lower forms of animal and vegetable life getting into the mains.

The supply of rain-water to cottages, farms, &c., may be considered as a surface water supply, the collecting area being an artificial one instead of a natural one. Whether a roof supply is satisfactory both in quality and quantity is a question often submitted to Medical Officers of Health when certificates are applied for under Section 6, P.H. (Water) Act 1878. There is probably no inhabited house in the British Islands the rainfall upon which is sufficient to supply the inmates with water for all domestic purposes, and I never sanction such a certificate being granted unless it is perfectly certain that no other source of supply is available. In such cases, however, if the rain-water is properly collected, and proper and sufficient provision made for its storage, the granting of certificates may be sanctioned. In other cases where the water from the public supply is very hard, the collection of rain-water is frequently resorted to, in order that it may be used for washing purposes. The

methods of collection and storage are rarely satisfactory; in fact, unless the water from the roofs of buildings is passed through a 'separator' which discharges the first washings into the drains, it is bound to be polluted with bird excrement, soot, &c. An examination of the rain-water tanks should not be overlooked, as they are often in a horribly offensive condition. The water therefrom may be used for purposes of personal ablution, and I have on several occasions suspected such filthy water of having set up erysipelatoid inflammation through an abrasion of the skin. Where suitable tanks are provided, and a rain-water separator used, a very good water may be obtained from the roofs of houses in country districts. Where such tanks are placed in gardens and supplied by drains laid under the paths there is nothing to prevent the bacillus of tetanus and other pathogenic organisms gaining access from the soil. Overflow pipes from rain-water tanks are not infrequently connected with the drains, and on more than one occasion I have found sewage backing up and entering a tank. Rain-water, however collected from the roofs of buildings, should be purified by filtration through a Pasteur or Berkefeld filter before being used for drinking purposes, but for other domestic purposes, if properly collected and stored, such filtration is unnecessary. Architects frequently provide underground filters for rain-water for the purpose of purifying it before it enters the storage tanks. I do not remember seeing a single satisfactory filter of this kind. Either the material is so coarse that little purification is effected, or so fine that it speedily becomes clogged and useless. They rarely receive any attention, and are generally found in a filthy condition.

## CHAPTER IV

### EXAMINATION OF RIVERS AND STREAMS

Rivers and streams are fed by surface, subsoil, and spring waters; hence the complete inspection of a river would involve the examination, practically, of the whole watershed above the intake, covering an area, in some cases, of hundreds of square miles. There may be a very large population on the watershed residing in towns and villages, besides scattered houses, farms, manufactories, mines, &c., all draining directly or indirectly into the river, and there may be a floating population on the river itself. A certain portion, or possibly nearly all the land, may be under cultivation, and more or less highly manured. In such cases pollution is inevitable, and many sanitarians hold that water from such a stream cannot under any circumstances be a satisfactory source of supply. Those who are interested in this subject should study carefully the evidence given before the Royal Commission appointed to inquire into the water supply of the Metropolis, and also their report published in 1893. Here the Rivers Thames and Lea were under consideration, the former with a population of over one million persons in the valley above the intake of the water companies and the latter with a population of about two hundred thousand. The pollution of the rivers is admitted, as is also the fact that some of the infective substances given off by persons suffering from zymotic diseases may and do find their way into the rivers. The following quotation gives briefly the opinions of the Commissioners and the reasons upon which they based their conclusions :—

'That the amount of such (infective) substances that thus

enter the Thames and the Lea is extremely small, and indeed infinitesimal in proportion to the enormous bulk of water with which it is then mixed, that there are moreover numerous conditions which lead to the destruction or elimination of the pathogenic bacteria during the flow down the stream, and afterwards during the sojourn of the water in the subsidence tanks and during the process of filtration: so that it is extremely doubtful, to say the least, whether a single one of these pathogenic bacteria will remain in the water as delivered to the consumer, or even in the unfiltered river water itself, that in spite of frequent examinations none have ever been detected in it, and that even in the improbable assumption that some few might exceptionally pass through the successive barriers to their entrance into the service pipes, they could not possibly be there in such number as to give rise to disease, which, according to all bacteriological researches, requires a certain quantity of such bacteria for its production.'

If the above conclusions are accepted the chief points to be attended to in investigating a river supply are:

1. The relative proportions of the polluting matter and the flow of the river when at its minimum.

2. The general character of the stream, the rate of flow, and the distance between the sources of pollution and the intake of the water.

3. The sufficiency of storage to allow of properly clarified water being distributed during periods of flood when the river water is turbid.

4. The efficiency of the filtration.

The Commissioners who considered all these points in connection with the Thames and the Lea state in the final section of their report, 'We are strongly of opinion that the water, as supplied to the consumer in London, is of a very high standard of purity and excellence, and that it is suitable in quality for all household purposes. We are well aware that a certain prejudice exists against the use of drinking water derived from the Thames and Lea, because these rivers are liable to

pollution, however perfect the subsequent purification either by natural or artificial means may be, but having regard to the experience of London during the last thirty years, and to the evidence given to us on the subject, we do not believe that any danger exists of the spread of disease by the use of this water, provided that there is adequate storage, and that the water is efficiently filtered before delivery to the consumers.

As a general rule rivers are inspected with the view of detecting sources of pollution in order to secure their removal. The stream should be carefully followed up and every tributary drain and ditch connected therewith noted, as well as the extent and character of the areas liable to flood, and the proximity of highly manured land, of sewage works, and of manufactories. Samples of all liquids being discharged therein, and of the river water at different points, should be taken and submitted to chemical and bacteriological examination. The possibility of sewers discharging under the surface, for purpose of concealment, should not be forgotten, nor should the fact that sewage may accumulate in ditches during dry seasons and the whole be washed into the river with the first heavy rainfall be overlooked. The amount of oxygen found in the water taken at different points may furnish valuable information as to the rapidity with which the process of self-purification is taking place. A report on the condition of the River Severn prepared by Professor Boyce and others for the Royal Commission on Sewage Disposal, and contained in their interim report, touches on several points connected with river examination, and is worth perusal by any one interested in the condition of our streams. The detection of all the sources of pollution in a river of any length is a matter of very considerable difficulty. Even if the whole length of the banks on both sides is examined, some intermittent or even continuous source of contamination may be overlooked. Chemical and bacteriological examinations of the water may in such cases lead to further investigation and the discovery of the cause of pollution. Recently, when examining an Essex river, I was led to believe that between two given

points some polluting matter which I had failed to discover was entering the stream. A further survey revealed the fact that the sewage from a large group of houses was conveyed to a tank in a field, and that it was supposed to be then disposed of by broad irrigation. The tenant of the land, instead of so treating the sewage, had cut a grip across the field which conveyed the raw sewage directly into the river. It entered through an opening in some dense brushwood, and could not be seen from the banks.

As the discharge of improperly treated sewage into streams is illegal, the person inspecting must have an intimate knowledge of the various processes of sewage purification, so as to be able to say whether the works are of such a character as to deal in the most effective manner with the sewage, both in dry weather and in periods of heavy rainfall. Such works also should be subject to constant and rigorous supervision. Unfortunately the most modern bacterial methods of sewage disposal fail to remove a large proportion of the bacteria in the sewage, and especially, apparently, of those belonging to the coli group. Where suitable land is available, there is no doubt an effluent of far greater bacterial purity can be obtained than has yet been effected by treatment of sewage on bacteria beds only, but I have recently examined effluents obtained from beds upon which the sewage was spread by a sprinkling arrangement which were very little inferior to those obtained by land treatment. Where barges, boats, &c., ply upon a river from which water is taken for the supply of any community, power should be obtained to make regulations for preventing pollution by the pumping out of bilge water or the casting of refuse into the stream.

The formation of Local Rivers Boards under a Central Board, as suggested by the Royal Commission on Sewage Disposal, will probably result in their being given greatly increased powers for the prevention of the pollution of rivers and of sources of water supply generally.

In many localities rivers are more polluted by effluents

from manufactories, quarries, mines, &c., than by sewage. It should be ascertained whether there is any infringement of the Rivers Pollution Act, either by the casting in of solid refuse, or the inflow of liquid effluents. This implies a knowledge of the best practical means of purifying the waste liquors from works of the most diverse character, and, as in the case of sewage works, the exercise of constant supervision to see that the best means of purification have been adopted, and that they are properly used. The existence of bye-passes permitting untreated, or but partially treated sewage, or manufacturers' refuse, being conveyed to the river must always be regarded with suspicion, and if possible steps should be taken to secure their removal.

But when everything possible has been done to secure the most efficient purification of such waste products, rivers receiving sewage and manufacturing effluents can never be regarded as really satisfactory sources of water supply, but as in most cases they must continue to be so used, the arrangements for collecting the water, for storage, and for filtration, should receive special attention. The storage reservoirs provided should be so large as to admit of a supply of purified water being maintained during periods of heavy rainfall without any water being taken from the river whilst it is in a turbid condition. It has been suggested that this storage should equal 56 days' supply (Balfour Commission). In any case, at the height of a flood the water, which will contain all the washings from ditches, and possibly all the sewage from the various works within the drainage area, and much of the mud from the bed of the river, should not be collected. The admission of such turbid and polluted water would defile all the water in the storage reservoirs for a considerable period.

All river water supplies should be filtered before being delivered to the consumers. If the filter beds are of sand, the number of such beds and their size should be such as to permit of a full supply of properly filtered water being maintained under all circumstances. There should be arrangements for

regulating the rate of filtration, and for taking samples of the filtrate from each separate bed. Where patent filters are used, the efficiency can only be ascertained by systematic bacteriological examination of the water passing through them (*vide* section on the biology of sand filtration, and on the bacteriological examination of water).

## CHAPTER V

### EXAMINATION OF SERVICE RESERVOIRS, WATER MAINS, &c.

SERVICE reservoirs may be improperly constructed or inadequately protected. Where excavated in the ground the upper edges may not be raised above the ground level, hence frogs and other animals may get in, and heavy rainfalls may wash in objectionable matter. During the past year I have examined two such reservoirs. In the first instance a serious and widespread outbreak of diarrhœa occurred among the users of water which passed through a service tank. There had been an exceptionally heavy fall of rain a few days before the outbreak occurred, and when the tank was examined I found a good deal of earth and sand had been washed in from the adjacent road, and from a patch of garden ground adjoining one side of the reservoir. There were also many worms and other objectionable forms of animal life at the bottom of the tank. When the reservoir was 'cut out' for cleaning and improving, the epidemic came to an abrupt termination. In the second case consumers of the water complained that the water when drawn from the taps frequently contained small worms and other visible organisms. The service tank was surrounded by a narrow footpath, and beyond this the ground was raised in the form of an embankment, the slope being covered with grass. Here again the reservoir when examined was found to contain soil, worms, &c., which had undoubtedly been washed in from the ground around. The raising of the edges of the tank well above the ground level would prevent pollution of this character.

Such reservoirs are better covered so as to prevent the

access of light, rain, bird droppings, animals, insects, dust, &c. If light gains access there is danger of algoid growth manifesting itself and causing trouble, and if uncovered all kinds of objectionable matters may gain access. The overflow from such a tank should be traced. I found on one occasion an overflow pipe very improperly trapped and connected with a public sewer. Even with a proper trap this is an objectionable arrangement, as water may overflow so rarely that the evaporation of the water in the trap would cause it to be unsealed and therefore useless.

Water engineers now avoid 'dead ends' as far as possible, the mains being made to intercommunicate wherever possible so as to ensure constant circulation. Near 'dead ends' there is always a tendency for sedimentary matter to be deposited, for bacterial and fungoid growth to develop, and for rust to form and accumulate. Frequent flushing in a great measure will prevent any annoyance being caused to the consumers of the water, but the flushing may be neglected, and if not neglected much unnecessary waste of water occurs.

New mains often give rise to complaints, the tarry matter with which the pipes are coated inside communicating a distinct odour and flavour to the water. This may continue for a few weeks, or a year or more, according to the character of the coating and the amount of water passing through the pipes. Occasionally also the water becomes discoloured from this cause. This is due to the coating either being of an unsuitable character, or not being properly applied, or to the pipes being used before the coating has firmly hardened. The last complaint of this kind into which I examined was one in which the water was quite unfit for use owing to its being discoloured and offensive in odour. I found the pipes had been imported from Belgium. Occasionally the tow used for caulking the joints of new mains affects the flavour of the water for a time. Water pipes are often deposited in ditches by the roadside until they can be laid. Here polluting matter may gain access, and if, after fixing, the mains are not thoroughly

flushed for a period, the contaminating matter may be imbibed by the consumers.

Inquiries on these points should be made whenever the cause of any change in the character of a water supplied from mains is being investigated.

Where the water is very soft, and especially if derived from peaty moorlands, the action of the water on the service pipes will require attention, and more particularly if these pipes are of lead. Many waters corrode the iron mains, sometimes causing perforation, at others coating the pipes with oxide. This coating may become an incrustation, the incrustation increasing in thickness as the iron of the main itself becomes thinner, until either the main gives way or its calibre becomes so limited that the necessary quantity of water will no longer pass. When such a water is being used the mains require frequent testing and examination.

Interesting finds are often made when old water mains are examined. Quite recently some mains removed at Poplar were found to be encrusted with fresh-water mollusca. No less than eleven species were found, but Locard discovered many more species in the water mains of Paris.

As with efficient filtration it is difficult to see how such organisms could gain access to the mains, their presence shows that the water supply has not at all times been satisfactory.

Impurities may enter water mains through defective joints, cracks, and perforations, and also at ball hydrants and air-valves. The condition of the water mains should be, as far as possible, ascertained, especially if they are old, the ground being opened out at selected places for this purpose. Where ball hydrants are in use or air-valves fixed, their position should be ascertained, since if polluting matter can gain access to them it is certain, sooner or later, to get into the mains. The danger of pollution arising from defective mains, ball hydrants, &c., is much less when the supply of water is 'constant' and under considerable pressure. Insuction is much more likely to occur if the supply is 'intermittent,' but may take place even with a

constant supply if the pressure varies, or if there is a contraction just beyond the defect. Moreover with a constant supply the water must be occasionally turned off for repairs, &c. At the point where insuction is suspected the ground should be saturated with strong fluorescin solution, and a watch kept upon the water drawn from a suitable point beyond. Occasionally a branch pipe direct from the main is connected with the manhole of a sewer, and the water used for flushing purposes. This is an objectionable arrangement, as with a defective tap, or with a tap left 'on,' sewer air may be drawn into the mains. The houses supplied by a particular main can be identified by injecting a solution of potassium permanganate into the main and then ascertaining the houses to which a tinted water is being supplied. In a house in which there are several cisterns the pipes from which cannot be directly traced the tap connected with each can be identified by tinting the cistern waters with innocuous colouring matters such as potassium permanganate and fluorescin.

In some old towns, water-closets still exist which are flushed with water directly from the main, the 'stool' tap being fixed on the seat of the closet, the end terminating within the pan itself. Insuction of filth in such cases has been proved by plugging the trap beneath the closet and filling the pan with a solution of potassium permanganate. In one recorded case the coloured liquid was drawn into the mains, yet no trace ever appeared in the water taken therefrom. Probably the permanganate was decolourised by the rust deposited in the mains or the colour lost on account of excessive dilution. The investigation of the distributing arrangements in a house should include first an examination of the storage cisterns (if any) to ascertain if they are of objectionable material, if they are in easily accessible and suitable positions, and are clean and properly connected. Next all the pipes communicating with the cistern should be traced, more especially to discover whether there are any direct connections with water-closets, slop-sinks, or urinals, or whether there are any overflows

terminating in objectionable positions. The position of the tap or taps from which drinking-water is drawn should be ascertained, and the supply pipe traced to find whether the water comes directly from the main or from a cistern.

Comparison of the results obtained by analyses of samples of water taken directly from the main and from the tap supplying water for drinking purposes is often useful. Recently on making such analyses in connection with the water supply of a large public institution I found the supply from the main quite satisfactory, whilst that from the tap was impure. Upon examination it was found that the water passed through a cistern containing the remains of a decomposing bird.

# PART II

## *VARIOUS METHODS OF EXAMINING WATER AND THE INTERPRETATION OF THE RESULTS OF SUCH EXAMINATIONS*

## CHAPTER VI

### OBJECTS AND METHODS OF ANALYSIS

CONFINING our attention at present entirely to chemical analyses, it must be admitted that such analyses are generally made to decide whether a water from a given source is suitable for domestic purposes, and whether it can be used without the risk of conveying disease, but as such an analysis, however carefully made and however complete, can tell us little or nothing about the liability to contamination, it is obvious that it is impossible to judge from the analytical results alone whether any source will yield a water which can be used without risk; yet I constantly see waters reported to be good and wholesome which I know are eminently unsafe, and occasionally I hear of waters being condemned which I know are wholesome and quite free from liability to pollution. By chemical methods gross pollution can be detected, but, as will be demonstrated later, slight traces of sewage cannot be detected, and larger traces may be confounded with harmless vegetable matter. By analyses, however, variation in character can be discovered, and whether the saline constituents are in quantity and quality harmless and unobjectionable or not can be determined.

Analyses may also be undertaken for comparative purposes, as in selecting a source of supply. Systematic analyses of water from a given source may be made in order to ascertain

the extent of the variation in quality, the effect of excessive or deficient rainfall, the effect of continuous pumping, &c. In well sinking or boring the various springs tapped are examined to ascertain whether they should be excluded or admitted. Sometimes analyses are made to discover the cause of some change observed in the water such as may be due to its action on iron or lead pipes or to the insuction of subsoil water into the mains. Or a water may be specially examined to determine what action, if any, it has upon the metals of which cisterns and mains are usually composed, or the saline constituents may be determined to ascertain whether the water is suitable for particular manufacturing purposes such as brewing and dyeing, or for general boiler purposes.

Special examinations are required if the water is believed to contain certain substances conferring medicinal properties. Occasionally special attention is devoted to the analysis of the gases dissolved in the water to ascertain whether the water is fully oxygenated or whether some change is going on accompanied by the absorption of oxygen, as in determining the purifying effect of flow in a river.

In considering the suitability of a water for a public supply it is not desirable to ignore the requirements of important industries, especially if these will be dependent upon such supply for the water used in their manufacturing processes.

In most towns there are numerous factories using steam power, and for boiler purposes a soft water, providing it is free from acid, has many advantages—in fact such a water is most generally useful for all purposes.

An acid water corrodes boiler-plates, and the greater the degree of acidity the more marked is the action.

An alkaline water—that is, one containing sodium carbonate—is well adapted for use in steam boilers provided it is not in other respects objectionable, but for many dyeing processes such waters are very undesirable. It is asserted that the strongly alkaline waters used in many parts of Essex have an injurious effect upon plants if used for watering purposes.

Hard waters affect boilers in different ways, according to the nature of the salts causing the hardness. Magnesium and calcium chlorides are particularly objectionable, as at the high temperature attained decomposition takes place, and the hydrochloric acid produced corrodes the boiler plates. Sulphate of calcium is practically insoluble in superheated water, and is deposited in a hard crystalline condition on the boiler-plates, forming an incrustation which not only is difficult to remove, but also causes a great waste of heat. If the water contains clayey matter also, the incrustation is harder and still more objectionable. Calcium and magnesium carbonates are deposited rapidly after the water enters the boiler, but rarely form a scale. They sink in the form of more or less gritty particles, which are easily removed by 'blowing off.' Sulphate of magnesium in reasonable quantities appears to be unobjectionable in boiler waters. Waters in which the hardness is chiefly due to earthy carbonates are not suitable for many dyeing purposes, forming insoluble compounds with certain aniline dyes, which 'speckle' the fabric. Such waters are also objectionable for hide-washing in tanneries, since the hides having been soaked in lime, carbonate of lime is deposited in the skins, and retards the washing process.

The same objection applies to waters containing sodium carbonate. Waters hard from the presence of calcium sulphate, and containing from 2 to 3 parts of magnesium as carbonate or sulphate, are especially adapted for brewing pale ales, but magnesium chloride is an objectionable constituent in a water used for this purpose. Soft water, on the other hand, is preferable for brewing dark ales, stout, and porter. All hard waters are objectionable for washing and scouring purposes.

An excess of chlorides is said to be objectionable in water used for tanning and brewing ; a water which contains much chloride of sodium is without effect upon boiler-plates, but tends to corrode brass fittings, and if stored in cisterns, it acts upon the metal at the water-line.

Iron is a very objectionable constituent in a water used for

dyeing purposes, or for scouring, paper-making &c., the oxide being deposited and staining the materials. Water containing any kind of sedimentary matter cannot be used in making the finer qualities of paper.

Waters containing nitrates in considerable quantity have an injurious effect on boilers, the metal becoming oxidised, and ammonia being given off with the steam. For baking and dairy purposes, and for the manufacture of high-class gelatine and other articles likely to be used for human consumption, the water should be of good quality bacteriologically as well as chemically.

Speaking generally, however, the water best adapted for ordinary domestic purposes is the best for technical purposes.

Nearly all waters contain salts of calcium, magnesium, potassium, sodium, and ammonium, in the form of carbonates, sulphates, chlorides, and nitrates. More rarely traces of lead, zinc, or iron may be found, and nitrates and phosphates. It must be remembered, however, that any soluble salt known to occur in nature may be found dissolved in natural waters, but salts other than those enumerated occur so rarely, that they are never sought for in an ordinary analysis.

For most sanitary purposes it is sufficient to ascertain that the salts present are not objectionable either in quality or quantity, and that the water does not contain more than a mere trace of organic matter. When the suitability of a water for any manufacturing purpose is also being considered, a more complete analysis is necessary, including the estimation of all the principal anions and cathions. The physical examination usually precedes the chemical, as the detection of any unusual colour, odour, or taste, or the presence of a deposit, would indicate the necessity for some special examination, or might aid in interpreting the results of the chemical analysis.

Where the object is to detect minute quantities of pollution by sewage or matter of manurial origin, a bacteriological examination is imperative, as the evidence which will be adduced later shows that it is quite beyond the power of the

chemist to detect small quantities of such contaminating matter, or rather to distinguish it from organic matter derived from harmless sources.

A bacteriological examination, however, affords no information with reference to the character of the water in other respects; hence it is only of use after a chemical analysis has shown that the water contains no excessive amount of saline matter, and no salts of an objectionable character. Where this is already known, bacteriological examinations need not always be supplemented or preceded by chemical analyses. In all cases where a public supply is under supervision, and only a limited number of examinations can be afforded, bacteriological examinations should be made systematically, and a chemical analysis at intervals.

Where the safety of a supply depends upon the efficiency of filtration bacteriological examinations are especially important, as by such examinations only can the action of the filters be demonstrated.

It is obvious, therefore, that chemical and bacteriological examinations have their special uses, and that one can rarely replace the other. For sanitary purposes the bacteriological examination is the more important, but in most cases it requires to be supplemented by a chemical analysis, to ascertain that the water does not possess too great soap-destroying power, or any other objectionable chemical qualities.

From time to time waters are found to become infected with low forms of vegetable or animal life, which render them unsightly in appearance, or impart an odour or taste which may be anything but agreeable. In such cases a microscopical and biological examination is necessary. Usually the microscope will reveal the offending organism and give a clue to its identity; but these lower forms of life are so protean in character that occasionally their identification can only be effected after a careful study of their life-history. In certain seasons such occurrences are more common than in others. Recently I received, within a few days of each other, samples

from two different public supplies, which had become discoloured from the growth of a unicellular alga, usually known as the Chlorococcus. In one case the growth had occurred in the reservoir, and in the other it had taken place in a filter bed which had been disused for a time. The sand near the surface had become completely covered with the growth, and when the water was again turned on the filter, the organisms were carried through into the general supply.

In America, considerable stress is laid upon the systematic examination of surface waters by biological methods, the number and genera (or sometimes species) of the organisms found being recorded. In this country little study has been made of the low forms of life (save the bacteria) which occur in water, although more reliable information as to the character of a water can be obtained sometimes by this method than by any other.

Before proceeding to discuss the results obtainable by the various methods of analysis, let me once more emphasise the importance of the inspection of the source of supply, both in detecting possible sources of pollution and in enabling correct inferences to be drawn from the results of the chemical, bacteriological, and microscopical examinations. This is now being recognised by sanitarians generally. In fact, Gruber, of Vienna, lays so great stress upon an examination of the source, as to assert that in ordinary cases even a bacteriological examination of the water can be dispensed with, and Flugge considers that an inspection of the source and arrangements of the water supply, carried out with the unaided senses, is the most desirable method, and seldom needs to be supplemented by chemical, bacteriological, or microscopical investigations. Dr. Brown reporting to the Massachusetts Board of Health (1890) says:—'To determine whether or not a water has been polluted by sewage, a chemical analysis is sometimes insufficient, sometimes it is superfluous. It does not need a chemical examination to decide whether a stream has been polluted by sewage when one can see the sewage flowing into it.' And, again,

'Standards are relics of days in which the harmfulness of a water was supposed to be the direct result of the injurious action of specific substances found in it. The theory of to-day is that it is (in the large majority of cases) to the presence of micro-organisms in water that its harmful influence is due, and that the results of chemical analysis have their highest value in the light that they throw on the quality of the water from the standpoint of bacterial contamination.' 'An opinion regarding the wholesomeness of a water must be based on all the information obtainable about it, such as location, environment, and source of the water, and the character and population of the drainage area.'

Before describing the various processes involved in the examination of samples of water, it is desirable first to consider what information is obtainable by each of such processes. It is only when this is known that the analyst is in a position to decide what processes to adopt in any particular case, and to correctly interpret the results of his examination. These various processes may be divided into four groups, viz., Physical, Chemical, Bacteriological, and Microscopical and Biological, and I propose considering them in this order.

## CHAPTER VII

### INTERPRETATION OF THE RESULTS OF THE PHYSICAL EXAMINATION

THE physical examination includes colour, brilliancy or degree of turbidity, odour, and taste. Occasionally a determination of the specific gravity is desirable, but such a determination is only of interest when waters highly charged with saline matters are being examined.

**Colour.**—All waters, clarified by filtration if necessary, submitted for examination will exhibit some colour when examined in bulk, as in a glass tube two feet long. The purest waters exhibit a pale sky blue tint only, the less pure have a colour shading from greenish blue to yellow and reddish brown. As a rule, waters with a decidedly yellow colour will be found to contain appreciable traces of organic matter, and when waters from the same source, as from a river, are being regularly examined, the variations in colour often serve as indices of the quality. The red-brown colour due to peat is very characteristic, and the presence of traces of iron may often be inferred from the yellowish red tint. Any unusual colour observed would indicate a special examination to ascertain its cause.

The colour of the water supplied by the various London water companies is recorded by Sir W. Crookes and Professor Dewar in their monthly reports to the Water Examiner, under the Metropolis Water Act, 1871. In a note appended to the table giving the results of the colour-test, they say: 'The ratios show the proportion of brown to blue in the water, the figures representing millimetres in thickness of the respective standard solutions. Thus 10 : 20 would express a colour composed of 10 millimetres of brown solution superposed on 20 millimetres of blue solution.'

The following table, compiled from the returns for March 1903, show that there is some general correlation between the colour and the amount of organic matter in the various London supplies. The figures are the averages for the month :—

| Water Company | Colour Brown Blue | Oxygen required by organic matter |
|---|---|---|
| New River . . . . . | 11·5 : 20 | ·035 |
| East London . . . . . | 19·8 : 20 | ·059 |
| Chelsea . . . . . | 18·6 : 20 | ·052 |
| West Middlesex . . . . . | 19·4 : 20 | ·056 |
| Lambeth . . . . . | 25·5 : 20 | ·072 |
| Grand Junction . . . . . | 23·2 : 20 | ·070 |
| Southwark and Vauxhall . . . . | 21·7 : 20 | ·058 |

The next table, giving the results of the daily examination of two of the supplies, shows, however, that there are many exceptions to the rule that the depth of the brown tint varies with the amount of the organic impurity.

| Date of Collection | New River Co. | | East London Co. | |
|---|---|---|---|---|
| | Colour Proportion of Brown to 20 Blue | Oxygen required by organic matter | Colour Proportion of Brown to 20 Blue | Oxygen required by organic matter |
| March 2 . | 5 | 0·015 | 20 | 0·045 |
| March 3 . | 5 | 0·018 | 17 | 0·045 |
| March 4 . | 4 | 0·018 | 17 | 0·045 |
| March 5 . | 5 | 0·018 | 17 | 0·045 |
| March 6 . | 6 | 0·015 | 18 | 0·037 |
| March 7 . | 6 | 0·022 | 17 | 0·041 |
| March 9 . | 16 | 0·037 | 18 | 0·045 |
| March 10 . | 14 | 0·049 | 20 | 0·049 |
| March 11 . | 18 | 0·049 | 21 | 0·046 |
| March 12 . | 20 | 0·061 | 23 | 0·057 |
| March 13 . | 26 | 0·056 | 26 | 0·060 |
| March 14 . | 28 | 0·049 | 30 | 0·064 |
| March 16 . | 20 | 0·054 | 27 | 0·070 |
| March 17 . | 16 | 0·054 | 21 | 0·072 |
| March 18 . | 15 | 0·041 | 20 | 0·067 |
| March 19 . | 13 | 0·037 | 20 | 0·067 |
| March 20 . | 12 | 0·043 | 20 | 0·074 |
| March 21 . | 13 | 0·039 | 20 | 0·070 |
| March 23 . | 11 | 0·030 | 20 | 0·075 |
| March 24 . | 10 | 0·030 | 18 | 0·071 |
| March 25 . | 8 | 0·030 | 18 | 0·073 |
| March 26 . | 6 | 0·030 | 16 | 0·069 |
| March 27 . | 6 | 0·022 | 18 | 0·060 |
| March 28 . | 6 | 0·026 | 17 | 0·060 |
| March 30 . | 6 | 0·026 | 19 | 0·064 |
| March 31 . | 5 | 0·033 | 16 | 0·064 |

The oxygen absorbed is expressed in grains per gallon.

With experience, fairly correct inferences as to the quality of a water may often be drawn from an examination of its colour. The Medical Officer of Health or Sanitary Inspector making inspections of districts supplied with water from shallow wells or similar sources of supply may be guided in their selection of samples for analysis by viewing some of the water in a deep tumbler placed on a sheet of white paper. Those in which a yellow tint is observed are the most likely to be impure, and therefore to require further examination.

**Brilliancy or Turbidity.**—A water from a public supply should always be free from visible floating particles, and be bright and clear even when viewed in bulk. If such is not the case the cause should be ascertained. Waters which at one time are clear and bright, and at others dull or turbid, should always be looked upon with suspicion. If particulate matter can gain access to the source of the water, then obviously the specific organisms causing disease may also be admitted. Turbidity appearing soon after rain, especially if the source is in proximity to drains, cesspools, ditches, or manured ground, indicates serious danger of pollution, and therefore a most unsatisfactory source of supply. In such a case the sample selected for further examination should be taken when the water is turbid. Owners of wells often express their anxiety to have a 'fair' sample examined, and for this purpose collect it when the water is brightest.

An analysis of such a sample may be seriously misleading, and reliance thereon has often proved disastrous. The strength of a chain is that of its weakest link, and the quality of a water supply is measured by the worst sample which can at any time be obtained from it. The turbidity may be due to suspended chalk or oxy-carbonate of iron, in which case it disappears when treated with acid. Clay is unaffected by dilute acid, and the water clarifies very slowly on standing. A chemical and microscopical examination is generally needed to show the nature of the suspended matter, and such examinations often yield valuable information.

The cause of a temporary discoloration or of some odour may usually be discovered by aid of the microscope, and sewage contamination is occasionally revealed by the discovery of starch granules, and of vegetable and animal fibres (silk, cotton, wool, &c.). Quite recently considerable alarm was experienced by the customers of a water company and by the directors of the company on account of the appearance of minute 'worms' in the water from the mains. As the source could not be discovered I was called in, and found the so-called 'worms' to be the larvæ of gnats which had been deposited in an uncovered service reservoir.

Water from wells recently sunk often contains suspended mineral matters, but after use for some time such waters generally become clear, the finest particles of mineral matter in the water-bearing strata having been removed by the continuous flow of water into the well. An analysis of a water taken from a new well always requires careful consideration to correctly predict the character of the ultimate supply.

Waters containing traces of iron salts in solution may be perfectly bright when first drawn, yet speedily become turbid and more or less brown upon standing in contact with air, in consequence of the formation of more highly oxidised and insoluble salts. Usually such waters have become turbid before reaching the laboratory, in which case the turbidity disappears quickly on the addition of a little acid, and the further addition of a suitable reagent reveals the presence of iron.

**Odour.**—No water can be satisfactory as a public supply or as a domestic supply if it possesses an odour of any kind. Even when warmed and shaken no odour should be obvious. A possible exception is in the case of moorland waters containing a trace of peat, but even such a water would be objectionable if when warmed the odour were very decided. Occasionally waters are met with which are of a high degree of purity, and free from any excess of saline matter, yet have a more or less decided odour of sulphuretted hydrogen. These

waters occur locally, and especially in districts on the boulder clay. The smell disappears quickly when the water is allowed to stand exposed to the air. The offensive gas is probably produced by the reduction of sulphates, but whether by some inorganic reducing agent or by living organisms, I have not been able to ascertain. Wells yielding such waters are always discarded sooner or later under the impression that the water is sewage-polluted, and no series of chemical analyses can remove the impression.

River waters often have a faint earthy smell, but in such cases the water is almost invariably polluted with sewage or manurial matter. Decomposing animals may impart an unpleasant odour to water. Small eels have been known to get into water mains, and dying there have tainted the water. Dead fish may affect pond water, and animals which have been accidentally drowned in house cisterns may only be discovered by their effect upon the water passing through. In most cases, however, when a water becomes tainted the odour is due to some low form of vegetable life, and it is often difficult to decide to what particular organism this is due. The odorous substance may be the volatile products formed by the living plant, and these may either be excreted during life or be liberated only when disintegration occurs; or the odour may be due to putrefactive changes occurring in the organic matter in the water due to the development of certain bacteria. In some cases the odour is accentuated by heating, and is persistent, in others the odour speedily disappears when the water is warmed.

The organisms producing odours are usually found first in open reservoirs and, if the water is not efficiently filtered, they find their way into the mains, where in the absence of light and air they perish and undergo putrefactive changes. Hence the reservoir water may be odourless while that delivered to the houses may have a vile odour. The autumn is the usual time for such organisms to appear, but the special conditions leading to the infection of a large volume of water are not

known. A few years ago quite a number of wells in Essex developed odours during the autumn, which I attributed to a general infection by a species of crenothrix. All these waters contained a trace of iron, and were not of a high degree of organic purity, but most of them were free from suspicion of sewage pollution, although the odour was strongly suggestive of sewage.

A list of the organisms to which the production of odours in drinking waters has been attributed is given in the section on the microscopical examination of water, and further details of this subject may be found in my book on 'Water and Water Supplies,' Chapter VIII. Since my attention has been called to the matter I have concluded that the acquisition of an odour by a water supply is not so rare as is usually believed, though apparently much more rare in this country than in others, where less trouble is taken to secure and maintain a pure supply. Unless the odour is so marked as to give rise to numerous complaints, it is ignored, and as in most cases the odour disappears in a few weeks, a thorough examination is rarely deemed necessary. I have received many samples of water for examination on account of some peculiar odour having been observed, yet these samples when received at the laboratory were quite free from smell. In numerous instances I have not been able to explain this fact, but in other instances I have found that it was the water first drawn from a pump or tap which had the curious odour, the water drawn afterwards being quite free from smell. In these cases the smell has been suggestive of impure hydrogen produced by the action of zinc or iron on a dilute acid, and I have found that certain waters allowed to stand a few hours in an iron pipe or galvanised iron pipe have acquired this odour, which speedily disappears when the water is exposed to air. Certain well waters in Essex acquire this odour if allowed to stand all night in a covered pail of galvanised iron.

Frequently samples of water sent in unclean or imperfectly cleansed bottles have a decided odour, it may be of beer, of

wine, of spirits, or sour milk, and in one case the water had not only the odour of carbolic acid, but upon examination it was found to contain an appreciable trace of that poison. To examine such samples is often a mere waste of time, or worse, as the results may lead to an erroneous inference. It is exceedingly difficult to explain to the senders of the samples that the analysis of such a water cannot be satisfactory. 'Surely,' said one man, 'you can tell the difference between a drop of whisky and a drop of sewage.' How can an analyst admit the limitation of his powers under such circumstances? Some years ago a gentleman brought me a sample of water taken from his pump. The water, he said, had recently become turbid and acquired an offensive smell. I found the water had a distinct odour of putrid sewage, and I advised him to spend his guineas in having the well and its surroundings examined. I received neither fee nor thanks for my advice. I have since concluded that in such cases it is better to take the fee and, after making the analysis, give the advice. The advice, having been paid for, is then much more likely to be acted upon.

**Taste.**—Odorous waters are usually said also to have a peculiar taste, but doubtless this is often imaginary. As I very rarely taste a sample of water sent for analysis, I cannot speak with authority on the subject. Rain-water, until well aerated, has undoubtedly a mawkish taste. Peaty waters also have a characteristic flavour, and ferruginous waters always leave an inky flavour in the mouth. Water containing an unusual quantity of chloride, whether derived from the water-bearing stratum or from infiltration of sea-water, may have a brackish taste. The susceptibility of various palates to the presence of salt varies very considerably. When sea-water has been infiltrating into a public water supply, some persons have detected it and complained when the amount of salt did not exceed 20 grains per gallon; others have not noticed it until it has reached 50 or more grains per gallon. Last year I had to decide whether the water from a deep well in the chalk, on

which nearly a thousand pounds had been expended, was suitable for a public supply. It contained 83 grains of sodium chloride per gallon. The taste of the salt was distinctly evident to me, but many persons who tasted it could not detect it. I expressed the opinion that such a water was not suitable for a public supply, and this opinion was upheld on appeal to the Local Government Board. The sequel is worth mentioning. Another site was selected in the same parish, and a second bore put down. This yielded a very much more abundant supply, and the water only contained 48 grains of salt per gallon, a permissible quantity. In this instance it was known that the deep wells to the north all yielded brackish water, whereas those to the south contained much less salt. The engineer, however, had sunk the well towards the north of the parish because of the ground being higher, and therefore suitable for having the well and the service reservoir in the same curtilage. I selected the low-lying ground to the extreme south because my experience had taught me that water was more freely obtainable there, where the chalk was only covered by a thin bed of clay, and that the water was less likely to be saline.

## CHAPTER VIII

### INTERPRETATION OF RESULTS OF CHEMICAL EXAMINATIONS

(*a*) **Reaction.**—As a matter of routine, it is desirable to ascertain whether a water has an acid reaction or possesses the power of neutralising acid, since if it does not possess this power, it may have an action upon metals, and it is important to determine whether this is the case or not. The waters which act upon lead, iron, or zinc are those which either are distinctly acid in reaction, or contain less than two or three parts of sodium, magnesium, or calcium carbonate per 100,000. Such waters have not more than two or three degrees of temporary hardness. A water of low temporary hardness may, however, contain sufficient sodium carbonate in solution to prevent any action on metals. (*Vide* section on the action of waters on metals.)

(*b*) **Residue left on the Evaporation of a Water.**—In good waters the residue left on evaporation over the water-bath is quite free from colour. In other waters the opacity of the residue and the effects produced by more strongly heating it (decrepitation, fusion, discoloration, &c.), all convey information to the intelligent and experienced observer. Charring indicates the presence of organic matter, and, if accompanied by a disagreeable odour, shows that probably this organic matter is of animal origin. When merely a trace of such matter is present, there may only be an evanescent browning or blackening, usually most evident towards the periphery of the saline residue. When there is an abundance of nitrates present, the organic matter may be decomposed without any obvious charring or discoloration. The presence of iron is usually indicated by the brown tint of the residue, rendered

more evident upon ignition. If the analyst uses constantly the same quantity of water for evaporation, he can at a glance tell if the saline residue is excessive in amount, and often it is merely necessary to state whether this saline residue is excessive or otherwise, without determining its exact amount. For this purpose some knowledge of the source of a water is necessary. An upland surface water should leave an exceedingly small residue, five or six parts per 100,000, whereas water from the chalk and other formations may give many times this quantity. In Essex we have large public supplies deriving water from the Thanet sands and chalk, giving as much as 150 parts of solid residue per 100,000. The quality as well as the quantity of the saline constituents is of importance; hence, if the determination of the hardness, chlorides, and nitrates does not account for nearly the whole of the saline matter, a more complete analysis is desirable. For example, the Essex waters above referred to often have a hardness of a few degrees only, and contain the merest trace of nitrates, while the chlorides may not account for half the total saline matter. Further analysis shows that the waters contain large quantities of sodium carbonate and sulphate, neither of which is estimated in an ordinary analysis.

A properly made quantitative estimation of the total solids affords a valuable check on the results of the more detailed analysis, whilst a qualitative or rough quantitative estimation often affords interesting information with regard to the quality of the water.

The saline constituents found in waters from various sources are given in the Tables of Analyses. In an ordinary sanitary analysis, only the chlorides and nitrates are usually estimated, but the estimation of the total permanent and temporary hardness gives some rough indication of the amount of the calcium and magnesium compounds present. and of the proportion existing as carbonates. Tests are applied for detecting the presence of nitrites. When present, the amount is invariably very minute, and a quantitative estimation

is very rarely made. The above estimations frequently furnish all the information which is required with reference to the nature of the saline constituents of a water.

(*c*) **Chlorides.**—In most waters, the whole of the chlorine present is in combination with sodium as sodium chloride, but occasionally calcium and magnesium chlorides are also present. I have only found potassium chloride present in appreciable amount in waters containing such other constituents as would place them in the category of mineral waters. Such being the case, the amount of chloride present will closely approximate to the amount of chlorine multiplied by 1·65 (or divided by ·6), but it is usual to express the chlorides in terms of chlorine. Thus a water containing 6 parts of chlorine per 100,000 will contain approximately 10 grains of sodium chloride, if the whole is combined with sodium, and very little less than 10 grains of mixed chlorides if a small portion is combined with calcium or magnesium. The error only becomes marked if there is much magnesium chloride present, as is very rarely the case unless sea-water is gaining access to the supply examined. This is obvious from the fact that 35·5 parts of chlorine represents 58·5 of sodium chloride, 55·5 of calcium chloride, and 47·5 only of magnesium chloride, these salts containing 60·0, 64·0, and 74·6 per cent. of chlorine respectively.

Practically all soils and rocks contain chlorides, in quantities varying from the merest trace to the rock salt formation, which consists practically of pure sodium chloride. Hence all waters, including even the purest rain-water, which derives a trace from the air, contain chlorides. Besides their natural source, chlorides may, in the neighbourhood of the sea or tidal rivers, be derived from sea-water which has entered the water-bearing stratum. Sewage and urinary matter from stables and byres contain chlorides. Occasionally also land is salted for certain agricultural purposes, and I have known this appreciably affect the amount of chlorides in the subsoil water. Some years ago I examined a sample of water from a shallow well

sunk to supply a mansion, and found so much salt in it that I went over and examined the site. The well, which was only about eight feet deep, had been sunk in a field far from any possible source of pollution. There was nothing to explain the presence of all this salt, and another well, sunk in a different part of the field, yielded a water containing a far smaller quantity, yet much greater than the other shallow wells on this patch of gravel. The only possible explanation was the 'salting' of the field, but that this had been done was denied by the tenant of the field.

As a rule, however, the amount of chlorides from a given stratum and in a particular locality varies only within narrow limits, but in many districts the variation is sufficient to render it impossible to say that any slight difference observed is due to sewage contamination.

Urine contains nearly 1 per cent. of sodium chloride, and I estimate that the whole of the sewage of 1,000 people deposited on a square mile of porous gravel would not increase the amount of sodium chloride in the gravel water by, on an average, more than ·5 parts per 100,000. In Massachusetts an attempt has been made to map out the country into areas of equal chlorine contents in the unpolluted waters. The points of equal amounts when connected are termed *isochlors*. The waters near the coast contain about ·6 parts per 100,000 of chlorine, and proceeding westward from the coast this gradually falls to about one-eighth of the amount. Such small quantities of chlorides are rarely found in this country, and all attempts to map out isochlors have proved futile.

Over limited areas, where the water-bearing stratum is uniform in character and continuous, the amount of chlorides found in localities far removed from the possibility of pollution may be considered as the 'normal,' and any excess found elsewhere in water from the same stratum may be attributed to present or past pollution. In this country at least, it is practically impossible to obtain water from deep or shallow wells which has not, in its previous history, been in contact

with manured soil. The surface soil possesses such oxidising and purifying qualities, due chiefly to the nitrifying organisms therein, and the subsoil usually filters so effectively, that practically the whole of the organic matter and the bacteria derived from the sewage disappear before the water has travelled any considerable distance. As the presence of ashes indicates that there has been a fire, and therefore that organic matter has been consumed, so the presence of an excess of chlorides and, as we shall see later, of nitrates in water, indicates that the water has contained organic matter derived from sewage or manure, but that it has been oxidised or burnt. Unless some of this organic matter remains unoxidised, or the bacteria which accompany it are not removed by the natural process of filtration, the water may be perfectly wholesome. The chlorides and nitrates are the ashes of the organic matter of sewage, as carbonates, silicates, &c., are the ashes of wood.

Several times I have had occasion to examine the water from every well in a parish, in which case I have always found great variations in the amount of chlorides, the amount increasing towards the centre of population, and in the direction of the flow of the subsoil waters. Taking 4 parts of chlorine per 100,000 as the normal, the amount often increases to 20 or upwards. In all cases this increase of chlorine is accompanied by an increase of nitrates, and in most cases by an increase in the amount of ammoniacal and organic matter. Obviously with such an amount of chlorides, derivable from no other source than sewage as far as could be ascertained, the ground water must have consisted almost entirely of sewage more or less purified. Such a polluted subsoil is utterly unfitted to serve as a source of water supply. As a rule sewage contains about 5 parts of chlorine per 100,000 above that found in the water supply, allowing 30 gallons of water per head per day; hence in cases such as the above, where the chlorine rises to 20 parts, the amount of water used daily must have been very small, or the same water must have been used over and over again, each time becoming more highly charged with sewage

or the products of its oxidation. A remarkable instance of this sort of thing came under my notice some years ago. A certain farmhouse was notoriously unhealthy. The inmates had suffered at various times from diphtheria and typhoid fever. The water had been examined, and was reported to be satisfactory. Upon examining the premises I found there was a watercloset in the house, which was in good order, but where the contents were discharged was unknown. The drains were said to be satisfactory and never to get blocked, and upon tracing them I found that they discharged into a dry-steyned cesspool without overflow about 4 yards from the well, both sunk in the gravel, which here was 20 feet or more in thickness. This well yielded an unfailing supply of water, which was used for all domestic purposes, and upon analysis it was found to be remarkably free from organic matter. It was said to be always cool, bright, and sparkling, probably due to its containing a very excessive amount of chlorides and nitrates, derived from the sewage percolating into the subsoil, and I expressed the opinion that the water was a concentrated, purified sewage. This was not believed at the time, but when the cesspool was filled in and the sewage carried elsewhere, the well ran dry. There is no doubt that in this case the same water was used over and over again. After being defiled by the closet, slops, &c., it ran into the cesspool, then filtered through the soil, in its progress the organic matters becoming completely oxidised, and ultimately it found its way back to the well, to be utilised again for domestic purposes. Doubtless at times, possibly after heavy rains, the cesspool contents filtered too rapidly for complete purification to be effected, and this impure water may have been the cause of the ill-health amongst those who consumed it.

The same kind of thing is going on in thousands of villages where the cesspools allow their contents to percolate into the subsoil water which supplies the wells from which the domestic supply is obtained. Were it not for the remarkable purifying action of the soil, epidemics of typhoid fever would be far

more common. As it is, communities continue to use such waters, and often on account of their cool and pleasant taste, and bright sparkling appearance, they prefer them, even after a public supply of pure water has been laid on.

Near the sea the influx of sea-water will be indicated by an increase in the chlorides, but to prove this it is necessary to estimate the magnesium in various samples to ascertain if this increases *pari passu* with the chlorine. The 'hardness' will increase also, the temporary hardness very slightly, the permanent hardness more markedly. Analyses Nos. 55 and 111 may be referred to as examples of waters affected by impregnation of the subsoil with tidal water. The chlorine in sea-water is about 1,885 parts in 100,000; hence the infiltration of 1 per cent. will increase the chlorine in a water by 18·85 parts per 100,000. The chlorides in tidal rivers vary very considerably, decreasing as the river is ascended. Between Woolwich and Leigh, on the Thames, I have found it to vary from 900 to 1,800 parts per 100,000, but higher up the river it becomes very much less. The detection of the presence of tidal water is of especial importance if such water is known to be sewage-polluted, but here again the percolation through the soil or rock may have removed practically every trace of organic matter. Analyses Nos. 33, 44, and 111 are of waters affected by the influx of very impure Thames water below the outfall of the London Sewage Works, yet only on one occasion have I detected anything indicative of sewage contamination, although I have made more than 100 analyses, chemical and bacteriological.

Occasionally the decrease in the amount of chlorides in a well water has some significance. In more than one instance I have detected the infiltration of subsoil water into a deep well by the chlorides decreasing. Many Essex deep wells contain a considerable amount of sodium chloride, and in the same well this varies very slightly from year to year. If subsoil water gains access to such wells the chlorides are proportionatly decreased. The presence of so much sodium

chloride in these well waters has in more than one instance led the analyst astray. In a recent case the chemist gave at length his reasons for believing that the excessive amount was due to sewage pollution. As a matter of fact the well from which the water was derived was about 1,000 feet deep, bored in the open country far from any habitation, where sewage pollution was absolutely impossible. It was one of the purest of natural waters, free from the slightest indication of contamination by either sewage or manure.

In Essex several public supplies contain from 50 to 70 parts of sodium chloride per 100,000, and appear to be quite unobjectionable. I think, however, that when the amount reaches 70 parts and is distinctly perceptible to the palate the limit permissible has been reached. A very much smaller quantity of calcium or magnesium chloride would render a water absolutely useless for many domestic purposes on account of its soap-destroying power, and I should consider even 4 or 5 parts of these salts per 100,000 to be objectionable. These chlorides have a corroding effect on steam boilers; hence where the water is to be used for boilers and other manufacturing purposes, as well as for a domestic supply, their presence is extremely undesirable.

Paper works and other manufactories often discharge large quantities of effluents containing chlorides, and the possibility of any excess found in a river or stream being due to such a cause must not be forgotten.

(*d*) **Nitrates.**—The amount of nitric acid combined with bases present in potable waters is expressed in several different ways. Some chemists express it as hydrogen nitrate ($HNO_3$),[1] others as nitric anhydride ($N_2O_5$), but the majority now express it as nitric nitrogen or nitrogen in nitrates. As one part of nitrogen represents 4·5 of hydrogen nitrate and 3·9 of nitric anhydride, obviously it should always be most distinctly stated

[1] Chemical nomenclature has undergone many changes during the present generation, and both the compounds above referred to have been called nitric acid.

what the figures given represent. This is not always done, and difficulty sometimes arises in interpreting analyses from this cause. Throughout this work the term 'nitric nitrogen' will be used to represent the amount of nitrogen present in the nitrates found in water. For some reason there is often considerable discrepancy, as regards nitrates, in the results obtained by different analysts from the examination of the same water. It has been difficult for me sometimes to believe that all had had samples from the same source, yet the other determinations agreed so closely as to preclude any doubt.

It is very probable that practically the whole of the nitrates found in water is derived from the oxidation of nitrogenous organic matter of animal origin. Vegetable matter by oxidation in the soil yields very little nitric acid, whilst animal matter yields a large amount. The nitrogenous bodies of animal origin readily decomposing, probably the whole of the nitrogen ultimately becomes converted into nitric acid, which reacting upon the carbonates in the soil forms the nitrates found in subsoil and deep well waters. No doubt there are several stages in this decomposition, some being due to the action of the bacteria found in soil, and others to chemical action merely. The breaking down of proteid matter results first in the formation of ammonia, this by nitrifying organisms is converted into nitrous acid, and further oxidation leads to the formation of nitric acid.

The Rivers Pollution Commissioners found that 97 per cent. of the combined nitrogen in London sewage was converted into nitrates by slow percolation through five feet of gravelly soil. As average London sewage contains 10 parts of combined nitrogen in 100,000 parts, the latter amount of sewage would yield 9·7 parts of nitric nitrogen. A water containing 10 per cent. of such purified sewage would yield about 1 part of nitric nitrogen per 100,000. The purest rain-water contains a trace of nitrates, on an average equivalent to ·03 part nitric nitrogen per 100,000. This is probably due to the oxidation of atmospheric nitrogen during electric discharges. Vegetable

matter in its comparatively slow decay produces very little nitric acid ; hence, as no other source of nitrates is widely distributed, most of the nitrates found in water must have been derived from animal matter, and therefore, in the great majority of cases, from manure and sewage. At one time I was considerably puzzled by the large amount of nitrates found in a certain water supply in Yorkshire, but I ultimately found that the well was sunk near some trenches which had been filled with bodies after one of the battles during the Civil War. Bones in quantity were found here on sinking a pit, and when pumping was going on at the works the water level in the pit gradually fell, to rise again when the pumping ceased. In another instance when a well was being sunk, a curious stratum containing much organic matter was reached, the water from which was loaded with nitrates. The opinion of the geological expert was that the bed was an old guano deposit. A short time ago I found that the nitrates in the water from a well supplying a country house had considerably increased, and upon inquiry learnt that the owner had had a lame hunter shot and buried in the vine border not many yards away.

The nitric nitrogen occurring in waters used for domestic purposes varies from none to 7 or more parts per 100,000, though few waters are found with either of these extremes. I know a few deep wells, the waters from which are apparently free from nitrates, and the few samples which I have met with containing as much as 7 parts of nitric nitrogen per 100,000 have been from shallow wells, such as those above referred to. On account of this great variation, some analysts ignore the presence of nitrates, regarding the indications afforded by the determinations as having no value. For my part, I do not see how any one can express an opinion upon a water without knowing approximately the amount of nitrates present, and something about their most probable source. Waters from the Essex gravel beds contain from about ·4 to 1·5 parts of nitric nitrogen per 100,000, the difference being due to the extent to which the soil is manured. There is also a seasonal

variation in waters from the same spring or well, but not nearly so marked as the variation in different gravels. No standard can possibly be adopted as to the amount of nitrates permissible in a potable water. The nitrates are as harmless as the chlorides, and though excess of both indicates previous sewage or manurial pollution, if the sources from which they are derived are sufficiently remote, their presence may be ignored. Chemical analyses cannot be depended upon to tell us anything about the proximity or otherwise of the source of pollution, and most serious epidemics of typhoid fever have occurred amongst populations using water containing very small amounts of nitrates; on the other hand, to my knowledge, many large villages using water containing from 1·5 to 5 parts of nitric nitrogen per 100,000 for the last twenty years at least, have remained free from typhoid fever, save when an occasional case has been introduced from without.

Notwithstanding this, a water cannot be recommended for domestic use which contains much more nitrates than appears to be the normal in the best waters from that particular water-bearing stratum. Any excess necessitates a careful investigation of the source of the water.

When animal matter undergoes decomposition in the absence of air, and in the presence of water containing nitrates, these latter are deoxidised and disappear, consequently nitrates are rarely if ever found in putrid sewage. Ferruginous sand may also reduce nitrates to ammonia, and all growing crops absorb nitrates from the soil. Hence the amount of nitrates in a water may not represent the whole of the previous pollution to which it has been subjected. In the Journal of the Chemical Society, August, 1886, appears a paper by Dr. Munro on 'The Formation and Destruction of Nitrates and Nitrites in Artificial Solutions and in River and Well Waters.' In this paper Dr. Munro says: 'An excessive quantity of nitrates in water is very generally regarded with suspicion. I am not aware, however, that the *absence* of nitrate has been pointed

out as a ground of condemnation. Clear rain-water and the water of mountain streams often contain but a trace of nitrate; well and river water must, however, contain more than a trace, unless some cause has brought about the destruction of previously existing nitrate. This cause is the access of fermentable organic matter to the water, and in most cases the fermentable organic matter is derived from sewage. When, therefore, a water contains enough mineral matter to demonstrate its percolation through soil, and at the same time is free from nitrate, or contains only a trace, barely recognisable by diphenylamine, the occurrence of a destructive fermentation may be inferred. These cases are not uncommon among well waters.' I do not agree with Dr. Munro in thinking these cases are common amongst well waters, but as they doubtless do occur, care requires to be exercised in expressing an opinion, even when the amount of nitrates present is very small.

MM. Gayon and Dupetit have made a special study of two organisms, which they call Bacterium denitrificans '*a*' and '*b*,' which reduce nitres with the production of nitrogen gas. They were obtained from a sample of sewage. They are facultative aerobes, and in the absence of a free supply of oxygen they reduce nitrates, and if, and only if, there is nitrogenous organic matter also present they produce ammonia. Nitrites are said to be first formed, but a minute quantity only is discoverable, and this quickly disappears. Where nitrates are in process of formation or of reduction, traces of nitrites are generally found, hence some analysts lay great stress on the test for the presence of nitrites. It is generally advisable to submit a water containing an excess of nitrates to a bacteriological examination, the sample being taken a day or two after a heavy rainfall, in order to ascertain whether both soil purification and filtration are efficient. A water which contains any excess of nitrates, and which is liable to become turbid or opalescent after a heavy rain, should be unhesitatingly regarded as unsafe for domestic purposes.

(*e*) **Nitrites.**—Nitrites are nearly always found in sewage

effluents from the so-called bacteria beds. Their presence indicates that the organic matter in the sewage is undergoing active oxidation or nitrification, and that the process is not complete. Hence, as nitrites are rarely found under other conditions, a water containing a trace, however slight, must be regarded with grave suspicion, unless some other source is found from which they have more probably been derived.

Dr. Munro, in the paper previously quoted, says: 'Although nitrite is very easily formed both by oxidising and reducing fermentations, it is very rarely present in natural waters, except in very minute traces. It may exist in a water because the conditions do not favour complete nitrification of the ammonia, and in this case the water may be clear; or because of a bacterial reduction of the nitrates, caused by an influx of almost any organic matter—in this case the water is not clear. The reason why nitrite formed by reduction is not often found in well waters is that in most cases the organic matter provoking the reduction consists of sewage, and . . . sewage contains bacteria, which speedily destroys both nitrate and nitrite with liberation of nitrogen gas.'

In partially purified sewage containing nitrites, an excessive amount of free ammonia is also found, but unfortunately other sources of nitrites besides sewage also produce ammonia, so that this fact does not throw any light on the origin of the nitrites. As previously stated, many waters containing nitrates, if allowed to stand in contact with iron, zinc, or lead in pipes or cisterns, act upon the metal, the nitrates being in part reduced to nitrites and ammonia. Ferruginous sand may also effect this reduction. In such cases careful tests will detect some trace of the metal in solution. Unless, therefore, indications are obtained of the presence of an inorganic reducing substance, the nitrites must be attributed to the imperfect oxidation of animal matter, and the water be condemned as unwholesome or dangerous.

The possibility of nitrites being derived from any other source than sewage or manure is too often ignored, and has led to many waters of perfectly satisfactory quality being

reported as sewage-polluted. That this reduction of nitrites by metals is a comparatively frequent source of nitrites, I have proved by numerous experiments made for the purpose; and when applying tests to ascertain the action of water on metals, I have practically always found that the oxidation of the metal was accompanied by the reduction of the nitrates.

Besides the micro-organisms found in sewage and manures, which, in the absence of air, are capable of deriving the oxygen necessary for their development from any nitrates present, there are, probably, similar reducing organisms not derived from such objectionable sources; for occasionally I have met with a water containing traces of nitrites, which I have been compelled to conclude from the examination of the source could not be derived from sewage or manure, and which did not appear to be due to any reducing action from contact with metals. A water of this kind should only be passed as safe after a most careful examination of the source of supply has proved sewage and manure contamination to be impossible. I have also found nitrites in waters from newly constructed wells (*vide* section on this subject), apparently due to some reducing agent in the brickwork, since after a time the water yielded by these wells has been quite free therefrom. The amount of nitrite in a water is very rarely determined, as such a determination serves no useful purpose. It varies from day to day, and almost from hour to hour. A potable water which contained more nitrites than any sample I had before examined was tested by me daily. The nitrites gradually diminished, and in about a week had entirely disappeared.

(*f*) **Phosphates.**—Proteid matter, whether of vegetable or animal origin, during its oxidation yields a trace of phosphates, which consequently are found in all fertile soils, but calcium phosphate being a very insoluble salt, only a minute quantity can be held in solution in a potable water. If present, they merely confirm the much more reliable and definite indications given by the nitrates and chlorides. For this reason few

analysts trouble to examine for phosphates. Unless great care is taken in the analysis to decompose all silicates and remove the silica, traces of the latter may be confounded with minute traces of phosphates. This is, I suspect, the reason why some analysts detect traces of phosphates in waters in which other analysts fail to detect any. They are, no doubt, occasionally found in more than minute traces, but from a practical point of view the trouble involved in their detection is merely time wasted. Hehner suggests ·5 part of $P_2O_5$ per million as the limit for good waters, but many excellent waters contain more than this amount. He regards its presence as evidence of pollution, but thinks that its absence does not necessarily indicate purity, since it is so readily removed from solution by iron or aluminum salts.

(*g*) **Hardness.**—For ordinary sanitary purposes, it is not always necessary to estimate the amount of calcium and magnesium compounds present. It suffices usually if the soap-destroying power of these salts is determined. The soap-destroying or curdling power is of importance, as it affects the utility of the water for most domestic purposes. If excessive, it curdles soap to such an extent as to cause great waste, and it may render the water practically useless for washing purposes. For household purposes generally, a water with but little soap-destroying power is desirable, but there is no proof that such a water is better for the health of the persons using it. An excessively hard water has been accused of causing kidney disease, dyspepsia, etc., but on most unreliable evidence. A French Commission arrived at the conclusion that a moderately hard water was the best, and that persons residing in districts supplied with such water had a better physique than those living in districts where soft water was used, and a Vienna Commission expressed the same opinions. The River Pollution Commissioners, after a lengthy investigation, came to the conclusion that, ' where the chief sanitary conditions prevail with tolerable uniformity, the rate of mortality is practically uninfluenced by the softness or hardness of the water supplied to

different towns, and the average rate of mortality in the different water divisions varies far less than the actual mortality in the different towns of the same division.' The late Dr. B. Ward Richardson believed that the hard waters in certain watering-places often affected the health of the visitors, causing dyspeptic symptoms. Probably this temporary indisposition is merely due to a change in the character of the water used, since I have found exactly the same series of symptoms occur in watering-places where the water is very soft, amongst the visitors who have been accustomed to the use of hard waters. The Loch Katrine water, which is very soft, is said to have caused an increased prevalence of rickets in Glasgow, but the Medical Officer of Health informs me that there is no vestige of proof that such is the case.

Hard waters deposit more or less calcium and magnesium carbonates and sulphates in kettles, pipes, and boilers in which they are boiled, and this furring causes great waste of heat and shortens the life of the utensils, and it has already been shown that for certain manufacturing and for boiler purposes hard waters are very objectionable.

The hardness due to the presence of magnesium and calcium carbonates is called 'temporary,' since, by boiling, the carbon dioxide which holds these salts in solution is driven off, and nearly the whole of the earthy carbonates is deposited. Every trace is not deposited, since neither salt is absolutely insoluble in water, and small quantities of magnesium carbonate or hydrated carbonate appear to be retained in solution by other salts contained in the water. The calcium and magnesium salts which are not deposited by boiling, such as the sulphates and chlorides, produce the hardness termed 'permanent.' A water saturated with calcium sulphate will deposit some of this salt upon boiling, since it is less soluble in hot water than in cold. If present in quantities far less than that of saturation, it is deposited when superheated under pressure, producing 'boiler scale.'

Nearly all waters possess both temporary and permanent

hardness, a portion only of the earthy salts being removable by boiling. Generally speaking, the less the permanent hardness, the better is the water adapted for domestic and manufacturing purposes; and a water in which the permanent hardness is due to magnesium salts is not considered so satisfactory as one in which the hardness is due to calcium salts.

Occasionally a water may contain sufficient iron or zinc salts to appreciably affect the hardness, but the presence of considerable quantities of sodium and potassium salts appears to have only a very slight effect upon the soap-destroying power. The so-called hardness represents the soap-destroying power, and nothing more, and the attempts which have been made to deduce from the hardness information with reference to the actual quantities of calcium and magnesium salts present have introduced many fallacies and caused great confusion. There are few waters which do not contain salts of magnesium, and the soap-destroying power of these salts is much greater, weight for weight, than that of the salts of calcium, and the character of the salts and their properties have a marked effect upon the analytical results. However the soap test is applied, usually approximate results only can be obtained, since the end reaction is not always well defined, becoming more and more indefinite as the proportion of magnesium salts increases. I have ceased to attempt to determine the hardness to less than half a degree, especially as different chemists obtain results from the same water differing by two or three or even more degrees. This frequently occurs in the same laboratory, using the same solutions and the same water. Any attempt, therefore, to express the degrees of hardness to the first decimal place is futile. So far as I can see, it is absolutely valueless, save to the person who wishes to impart an air of pretentiousness to his results. If it is desired to obtain information with reference to the amount and character of the calcium and magnesium salts present in a water, a proper quantitative analysis should be made, instead of running the risk of drawing erroneous conclusions from the results of the soap test. Examples showing the impossibility of determining

the calcium and magnesium salts by the soap test are given in a later section on the determination of the soap-destroying power of a water.

The hardness or soap-destroying power of a water is, in this country, usually expressed in degrees, each degree being equivalent to the amount of soap destroyed by 1 part of calcium carbonate, or rather of its equivalent in calcium chloride, in one gallon of water. The standard of 1 part in 100,000 parts of water, generally adopted in France and gradually being adopted in this country, is the one used in this work. To convert it into the grains per gallon standard multiply by ·7.

A water of less than 5° of hardness may be considered a very soft water, over 5° and under 10° a fairly soft water, over 10° and under 15° as neither hard nor soft, over 15° and under 20° as a moderately hard water, over 20° and under 30° a hard water, over 30° a very hard water.

When 30° is approached the water becomes very objectionable for washing purposes, but several towns in this country have public supplies of greater hardness.

An exceedingly soft water should always be examined to ascertain whether it has any action on lead, zinc, and iron, and any water with a temporary hardness below 4° should be similarly examined, as such waters usually act on these metals.

(*h*) **Metallic impurities (Iron, Zinc, Lead, Copper, Arsenic).** Natural water containing an appreciable amount of these metals would be classed as mineral waters. Many such are known, and some are used for medicinal purposes. Potable waters are often found containing traces of iron, and occasionally zinc and lead are detected; copper I have never met with, and arsenic only once, and that in the water from a well situated in a garden near a gravel path on which an arsenical weed-killer had been used.

*Iron.*—In potable waters the iron, in probably all cases, occurs as ferrous carbonate kept in solution by an excess of carbonic acid. Upon exposure to air oxidation quickly occurs, and the water becomes more or less brown and opalescent. If

more than a trace of iron is present a deposit of the oxidised product occurs. The unsightly appearance of such a water is generally sufficient to condemn it for domestic purposes. In certain localities where water has to be derived from the greensand this is practically the only water available, and either the unsightliness must be tolerated or some process of removing the iron adopted. If the water contains enough iron to impart the characteristic chalybeate taste, it probably could not be considered wholesome. Although I have never heard of any ill effects following the continued use of a water containing a trace of iron, I should expect headache and constipation to be produced amongst those unaccustomed to its use. For washing purposes such a water is very objectionable, as it stains the clothes, the so-called iron-mould being due to the deposition of iron oxide within the fibres of the material affected.

Water which has stood for some time in contact with iron, as in a bore pipe, may take up a minute trace of the metal, and when pumped may be turbid from the products of the oxidation of the pipe being carried forward in suspension in the water. If iron nails, for example, are placed in water the oxidising action is soon apparent, and the water becomes turbid. To prevent this action iron water mains are coated with a compound containing gas tar. It is often important to ascertain whether a trace of iron found in a water is a normal constituent or an accidental contamination. For this purpose it is necessary to obtain a sample of the water direct from its source. If this is a deep well and it is impossible to get any water save that which is derived from the bore tube, a sample should be taken after pumping has been vigorously maintained for some time, so as to remove all the water which has been standing in the tube, and as much as possible of any loosely adherent oxide. As a rule such pipes become protected by a film of rust, and in unprotected pipes this film may gradually increase in thickness until it very seriously impairs the flow of water. I have seen old 4-inch mains taken up in which the central cavity did not average more than 1 inch in diameter.

*Zinc.*—This metal occurs in a few natural waters, but is usually derived from the zinc coating of galvanised iron pipes and cisterns. There is no doubt waters containing traces of this metal are used continuously for long periods without causing any obvious ill effects. The water supply to a small hospital with which I was connected for some years always contained a trace of zinc, probably never more than half a grain of the carbonate per gallon, but I never observed any indications of its being deleterious, although such effects were looked for. The source of the metal was a length of galvanised iron pipe which led from the water main in the road to the hospital about a quarter of a mile away. In another instance I examined a sample of water because the medical attendant of the family using it suspected that it caused constipation, and found that it contained about three grains of zinc carbonate per gallon, derived from a galvanised iron pipe which had recently been laid to convey water from a distant spring to the house. A year afterwards the water was again examined, and found to contain large traces of the metal. The waters which exhibit this zinc solvent power may be soft or hard, but in every instance which has come to my knowledge or of which I can find any record the temporary hardness was very small, usually about 1°, never exceeding 4°.

The amount of zinc found in water acting upon a galvanised iron pipe or cistern will depend chiefly upon the length of time the water has been in contact with the metal. The water drawn first in the morning may contain considerable quantities, whereas that drawn later in the day may contain the merest trace. Zinc is not a desirable constituent of a potable water, and in the case of a water found to act upon that metal the use of galvanised iron should be avoided. Unfortunately such waters almost invariably, if not invariably, act also upon lead, and it is therefore still more important to avoid the use of lead pipes. Tar-coated iron pipes with a very short length of iron or tin service pipe can be used. Where long service pipes of galvanised iron have been laid down the drinking water should

be drawn directly from the main, and a considerable quantity always allowed to run to waste before collecting any for drinking purposes.

*Lead.*—The waters which act most energetically upon lead are those with an acid reaction derived from peaty moorlands. There are certain microbes associated with peat which are acid-producing, and impart acidity to the waters which have been in contact with the peat. Rain-water collected in the vicinity of towns has usually a slight acid reaction, and acts upon lead, the acid being derived from the products of combustion of coal. Some years ago, when investigating the effect of various manufacturing processes on the air of a country district on the borders of Derbyshire, I found that the rain which fell to the windward of certain kilns and furnaces had a strongly acid reaction, and a marked action upon lead. The free acid was apparently sulphuric, no doubt derived from the sulphur in the coal used. In peaty waters the acid is apparently organic. A water with an acid reaction should never be allowed to come in contact with lead.

Dr. Houston speaks of the action of neutral waters as 'erosive,' whilst that of distinctly acid waters he calls 'solvent,' and he thinks that 'the power of eroding lead is an inherent property of water containing dissolved oxygen.' 'All waters,' he says, 'do not erode lead because most of them contain substances which coat the bright surface of the metal, and so prevent any further action taking place. . . . Erosive ability *per se* is not to be regarded as an intrinsically dangerous quality of a water unless under special conditions and in the presence of bright lead.' The solvent action of a water depends upon the amount of free acid in the water, and it must be remembered that this varies very considerably from time to time. The extent of this variation can only be ascertained by examining a considerable number of samples at different seasons.

When such acid waters have to be used for public supplies, it is now becoming usual to pass them through beds of chalk

or limestone to neutralise the acidity. This does not in all cases entirely prevent the plumbo-solvent action, as a trace of carbonates in solution is not sufficient to prevent the action of a water upon lead. Where the carbonate is that of calcium or magnesium, about 4 parts per 100,000 are required before the action on lead entirely ceases.

Hard waters from the Bagshot beds frequently exhibit a marked erosive power, since the hardness is almost entirely of a permanent character. On the other hand, certain very soft waters which act powerfully on both tarnished and untarnished lead are supplying large communities, Glasgow and Manchester for example, without producing any evil effect. Professor W. A. Miller, F.R.S., considers that such waters, when passed through a pipe continuously, paint, as it were, the inside with a deposit of vegetable matter, which combines with the oxide of lead and so forms a closely adherent film, which prevents all action.

Others think they cause the inner surface of the pipe to become coated with a film of an oxycarbonate of lead more insoluble than the metal itself, and that when this is once formed all action of the water upon the lead ceases. These waters, however, have no markedly acid reaction like those which, derived from peaty moorlands, have had such a deleterious effect upon the inhabitants of certain towns in Lancashire and Yorkshire. In these towns lead poisoning was prevalent for a considerable period, doing immense damage to the health of the inhabitants, before its real nature was recognised, and its cause discovered. Dr. Hunter, describing the effects at Pudsey, says: 'Anæmia and debility were the most common symptoms. The debility was peculiar; the patients nearly always complained that they felt as if they would sink down from weakness, and that the least exertion would make them sweat freely. . . . The majority of the people had the blue gum line so characteristic of lead poisoning. Colic also was a common symptom. Paralysis was not common, but we had five or six cases of what might almost be called general paralysis, so

helpless were the patients, and in these cases drop-wrist was included.' Other effects produced are depression, melancholia, and actual insanity, constipation and indigestion, gout, kidney disease, and blindness. Still-births increase in number, and the children of lead-poisoned persons are rickety and ill-developed.

The amount of lead found in the waters producing the above effects varied from one-hundredth to one grain or more per gallon, the larger amount being found in the water drawn in the early morning after standing overnight in the lead service pipes. As lead is a cumulative poison, and persons vary in degree of susceptibility to its action, some being more susceptible than others, it follows that the use of water containing the slightest trace of this metal is fraught with danger. I have investigated cases of plumbism where the lead was derived from the lead suction pipe to the pumps, the whole of the water in the wells being contaminated. It is therefore very important, when examining a water, to determine its action upon lead whenever the temporary hardness is found to be under 4°. If any action takes place the users should be warned of the danger of using lead pipes, or lead cisterns, in any portion of the service. The so-called block-tin pipes often contain lead, and have repeatedly been found to impart a trace of that metal to water allowed to stand therein.

*Copper.*—I have never examined a sample of water containing copper, but one sample was sent to me for analysis on account of its supposed action on copper tubing. This water contained a rather large amount of chlorides, but I failed to discover anything to account for the alleged action.

*Arsenic.*—Many natural waters are known which contain traces of this poison, but it is never sought for in an ordinary analysis. Tests would only be applied when making a complete analysis, or when some illness causes suspicion to rest upon the water of containing an irritant poison. The slightest trace would naturally condemn any water for domestic purposes.

*Barium.*—A very minute trace of this metal occurs in some

Derbyshire springs, never sufficient, however, to have any significance.

(*i*) **Free Ammonia.**—Very few natural waters are found which do not contain some trace of ammonium salts. Except in acid rain and moorland water, it probably always exists as ammonium carbonate. By the distillation of such waters, with or without the addition of a little alkali, the ammonia is carried over in the distillate and is spoken of as 'free' ammonia, to distinguish it from a further quantity of ammonia, which can be obtained by adding a strong alkaline solution of potassium permanganate to the concentrated water, and continuing the distillation. This latter quantity is spoken of as the 'albuminoid' ammonia, a term which is misleading, since this ammonia does not exist in the water, but is produced by the decomposition of the nitrogenous organic matter by the alkaline permanganate.

To understand the significance of the free ammonia and of the quantity present, it is necessary to consider the various sources from which it may be derived. Rain and snow always contain a trace, the first fall containing most. The amount varies very considerably, from ·01 to ·2 part per 100,000, but is usually about ·06.

All fertile soils and all decaying vegetable and animal matter contain ammonia, yet rain falling upon manured ground may reach the subsoil water practically free from it, the nitrifying organisms having converted it into nitrates. Urine of men and animals yields large quantities of ammonium carbonate by fermentation, hence sewage is rich in ammonia. Nitrates by their reduction yield ammonia, consequently a water containing nitrates which has been subject to the reducing action of ferruginous salts, or of long lengths of metal pipes, may contain it.

Certain low forms of vegetable life, *e.g.* Crenothrix, produce ammonia in the water they infect, but whether produced during life or only by their death and decay is not yet determined.

Dr. Munro, in his studies on nitrification, observes that a large quantity of ammonia 'may disappear in a few days with a corresponding increase of nitrate; this is specially liable to occur in summer, and should a week elapse between the analyses of the same sample of water some very striking differences in the results would be manifest, although each analysis might be perfectly correct.' With reference to the presence in water of ammonia derived from other sources than manure or sewage he says: 'Ammonia may be present in the stagnant waters supporting confervoid growths, as a bye-product of the reduction of nitrate by various organisms.' He adds, however, 'Ammonia formed by reduction is not of frequent occurrence in well waters, unless it is accompanied by ammonia resulting from putrefaction.'

It is obvious, therefore, that the ammonia found in water may be derived from harmless sources, or from sources indicating serious pollution. Without knowing from what it is derived, it is obviously impossible to say whether it indicates serious contamination or not. The waters yielding most free ammonia come from the Thanet sands and chalk in certain parts of the London Basin, waters which are free from more than a minute trace of organic matter, and certainly free from the slightest suspicion of sewage pollution. Yet I have seen analysts' reports arguing that such large quantities of ammonia could only be derived from urine, and condemning the waters as sewage-polluted.

The amount of ammonia found in the water from a deep well may vary enormously from time to time, and I strongly suspect that the reducing action is due, not to the ferruginous sands, but to the reduction of the nitrates existing in the water by the metal of the bore pipes. This is confirmed by certain experiments made some time ago, when I found that the water first pumped from one of these deep wells contained a very large amount of ammonia, whereas that taken later in the day was nearly ammonia-free.

It is often difficult, if not impossible, to judge of the

character of a water by the amount of ammonia which it contains, but wherever the amount exceeds ·004 part per 100,000 an endeavour should be made to ascertain its origin Considered together with the amount yielded by the organic matter present, correct inferences can usually be drawn. Rain-waters collected from roofs may not only contain ammonia derived from the air, but a further quantity derived from the bird droppings, soot, and decaying vegetable matter which collects on housetops, in spouts, &c. Anything in excess of ·01 per 100,000 occurring in a water containing an excess of organic matter, almost certainly indicates sewage pollution, but upland surface waters being directly derived from the rainfall may contain ·01 part without being polluted, and moorland surface water, especially if peaty, may contain the same amount associated with more organic matter and yet be pure. Subsoil and spring waters should contain very little ammonia, if soil purification has been efficient. It is rare that a really satisfactory water contains more than ·006 part per 100,000. Deep well waters can only be judged from a knowledge of the amounts usually found in waters from the particular strata from which they are derived, and as such waters should contain an exceedingly minute trace of organic matter, if an excess of both ammonia and organic matter is found, pollution should be suspected. The Essex deep wells above referred to, which yield waters containing very variable and often very excessive amounts of ammonia when uncontaminated, contain very little or no organic matter. Pure river waters rarely contain more than ·004 part per 100,000, and any excess is probably due to sewage or drainage from manured land.

From the above observations it will be gathered that no correct inference can be drawn from the results of an estimation of the ammonia only. A water containing much ammonia may be free from manurial or sewage matter, whilst a water containing only a very small quantity may be polluted. Considered together with the amount of ammonia yielded by the organic matter present in the water, by distillation with a

strongly alkaline solution of potassium permanganate, valuable information is obtainable, often enabling us at once to detect sewage pollution, though rarely justifying us in pronouncing a water free from any trace of sewage or manurial contamination.

Even the very small quantity which is generally regarded as permissible may be derived directly from sewage, as will be shown in the next section; hence the great importance of possessing an intimate knowledge of the source of a water before attempting to interpret the significance of the amount of ammonia obtained therefrom.

(*j*) **Organic Matter.**—Leaving out of question for the present the living organisms, bacteria, &c., and any dead organic matter which may be suspended in the water and which would be subject to bacterioscopic or microscopic examination, the organic matter in solution must be of vegetable or animal origin. Practically the whole of this must have been derived from the lichens and low forms of vegetable life on rocks, mosses and peat on moorlands, the humus of fertile soil, excrement of animals, manurial matters, and possibly sewage. Decaying vegetation in streams, lakes, ponds and reservoirs may contribute to the organic matter. Whatever its source there is a natural tendency for it to disappear, the carbon being converted into carbonic acid, and the nitrogen into nitric acid, but in nearly every case a residuum remains which is apparently not easily fermentable or putrescible. 'The soil,' to quote Dr. Munro, 'is the abode of many ferments, some of them having opposed functions, but all lying in wait for suitable conditions which shall encourage one species for a little while until it has done its work and has brought about an alteration favourable in turn to the encouragement of another species. From the soil, these ferments pass into the waters, from which they are not completely removed even by filtration, and the nitric ferment, certainly one of the most subtle of them all, seems little affected by this process. The addition of any ordinary organic matter instantly excites activity in one

or other of these ferments, and the effect is soon visible to the eye by the impaired clearness of the water, and to chemical tests by the effect produced on the nitrate of the water.'

'The organic matter of potable waters can only be such organic matter as is unfermentable, or at any rate not rapidly or easily fermentable. . . . What two compounds, for example, could exhibit a greater contrast than gelatine and potassium thiocyanate? Yet the one is as readily broken down by soil ferments as the other.'

As all waters at some time in their history must have been in contact with organic matter, and as this organic matter speedily undergoes change, leaving a certain residuum not easily oxidised, it is obvious that an analysis may often afford very little information of any value. If pollution has been recent some of the more readily oxidisable matter may remain in the water and be detectable, but even then we may not be able to decide whether this is of vegetable or animal origin.

By no known process can the amount of organic matter in solution in potable water be estimated with any approach to accuracy. The difficulty of the problem is obvious when we reflect that very few such waters contain as much as half a grain of organic matter in the gallon. It is very doubtful whether this organic matter is ever of such a quality as to have any effect upon health, even if it is derived from sewage or manure. Hence an accurate determination of the quantity present would serve no practical purposes, as it is not so much the quantity but the quality which is of importance from the diagnostic point of view. As the quantity of organic matter is too small in most potable waters to be in itself a source of danger, whatever the quality, it might appear unnecessary to attempt either a qualitative or a quantitative analysis; but such is not the case, since from certain determinations information can be obtained which has a value as throwing some light on the source from which the organic matter is derived, and as indicating to a certain extent the amount of organic pollution.

As organic matter of vegetable origin is of little significance,

most of the tests applied in the analysis of water are for the purpose of attempting to differentiate between it and animal contamination. Some tests, while not professing to differentiate between the two, indicate whether the water contains any readily oxidisable matter or not. One such test consists in ascertaining what amount of oxygen the water is capable of taking up from an acid solution of potassium permanganate. Occasionally substances of mineral origin, the lower oxides of iron, nitrites and hydric sulphide, are present capable of absorbing oxygen from this salt, in which case it is necessary to first ascertain as approximately as possible how much is taken up by these substances; the remainder may then be attributed to the organic matter.

The following table was devised by the late Sir E. Frankland and Dr. Tidy, and the standards given have been generally adopted.

Amount of Oxygen absorbed in 100,000 parts of Water

| | Upland surface water | Other waters |
|---|---|---|
| Waters of great organic purity. | Not more than ·10 | Not more than ·05 |
| Water of medium purity . . | ,, ,, ·30 | ,, ,, ·15 |
| Waters of doubtful purity . | ,, ,, ·40 | ,, ,, ·20 |
| Impure water . . . . | More than ·40 | More than ·20 |

The amount of risk involved in using a water, unfortunately, does not always vary with the amount of oxidisable organic matter present, but if an excess is present, and especially if other results indicating contamination are high, the water must be considered as more or less unsatisfactory. One of the oldest and most difficult methods of examining the organic constituents of a potable water was devised by the late Sir E. Frankland, F.R.S., and is still used in a few laboratories. By this method the amount of carbon and nitrogen in the organic matter present in a water residue is determined, and from the results obtained inferences as to the extent and character of the pollution are drawn. The process is a eudiometric one, requiring a specially equipped laboratory and great care in manipulation, and even when conducted by those experienced in its use the errors of experiment are considerable. It

possesses no advantage whatever over simpler methods, and, no doubt, it will shortly only be remembered in chemical histories. Those who wish to learn more about this process may consult Frankland's 'Water Analysis.' It is still used by the Water Examiners under the 'Water Examiner, Metropolis Water Act, 1871,' and the results obtained given in their monthly reports, or I should not have further referred to it. Dr. Frankland's instructions for the interpretation of the results are somewhat as follows. The quality of a sample of potable water is to be decided chiefly, though not exclusively, 'from the proportion of organic elements which it contains, and from that of the organic carbon to organic nitrogen. The smaller the aggregate proportion of organic carbon and organic nitrogen, and the larger the proportion of organic carbon to organic nitrogen, the better, *cæteris paribus*, is the quality of the water. In the case of spring and deep well waters, however, little importance ought to be attached to the relative proportion of the organic elements, because in such waters the proportion of carbon to nitrogen is often low, even when the organic matter has been derived from vegetable sources. In these cases, however, the organic carbon ought not to much exceed 0·1 part in 100,000 of water.

'In surface water, on the other hand, the proportion of organic carbon to organic nitrogen almost always affords trustworthy evidence as to whether the organic matter is of animal or vegetable origin. If the proportion be as low as 3 : 1 the organic matter is of animal origin, if it be as high as 8 : 1 it is chiefly, if not exclusively, of vegetable origin. Between these proportions the analyst must be guided in his opinion by his knowledge of the surroundings of the source of the water, and by the presence or absence of evidence of previous sewage contamination.'

The Rivers Pollution Commissioners found in fresh peaty water that N : C=1 : 12, whilst in similar waters, which had been stored for a time in lakes N : C=1 : 6. After such water had been filtered through the subsoil N : C=1 : 3·3. In fresh

sewage the average of a large number of samples gave N : C=1 : 2·1. Highly polluted well waters, soakage from cesspools, &c., gave N : C=1 : 3·1. In sewage after filtration through soil N : C varied from 1 : 4·9 to 1 : 7·7. Obviously therefore the ratios of N to C 'in soluble vegetable and animal organic matter vary in opposite directions during oxidation—a fact which renders more difficult the decision as to whether the organic matter present in any given sample of water is of animal or vegetable origin.'

Frankland says, 'Subject to modifications from the other analytical determinations, the following classification will be useful in reporting upon the quality of samples of potable water.'

Total Organic Carbon and Nitrogen in 100,000 parts of Water

| | Upland surface water | Other than upland surface water |
|---|---|---|
| Class 1. Water of great organic purity . | Under 0·2 | Under 0·1 |
| Class 2. Water of medium purity . . | 0·2 to 0·4 | 0·1 to 0· |
| Class 3. Water of doubtful purity . . | 0·4 to 0·6 | 0·2 o 0·4 |
| Class 4. Impure water . . . . | Over 0·6 | Over 0 |

As waters 'of great organic purity' may disseminate typhoid fever, and waters classed as 'impure' may be quite harmless, little stress can be laid on these figures when called upon to decide definitely whether a water is safe or unsafe for use for domestic purposes.

Many other processes have been devised by chemists for approximately estimating the organic matter in water or for ascertaining its character. Attempts have been made to devise processes for detecting certain definite compounds such as cystin, the presence of which should indicate sewage contamination. None of these have ever been generally used, and there is no doubt that while most of them were utterly useless, others were certainly misleading. The most generally useful information concerning the soluble organic matter in water can be obtained by the process, first devised by Professor Wanklyn, for estimating the so-called 'albuminoid' ammonia.

Some clue to the nature or origin of the organic matter may

possibly be found by this process. It gives no definite indication as to the actual amount of organic matter present, since some bodies yield all their nitrogen as ammonia and others only an aliquot part. Albuminoid substances of animal origin contain about 17 per cent. of nitrogen, and some readily yield the whole in the form of ammonia, whilst others do not. Vegetable matters usually contain a much smaller proportion of nitrogen; hence the amount of albuminoid ammonia obtained upon the analysis of water is no indication of the actual amount of the organic substances present, and it is often impossible to say whether it is derived from a small amount of animal matter or a larger amount of vegetable matter.

It is usual to consider the free ammonia and albuminoid ammonia together, as their relative proportion is really more important than the actual quantities. The reason for this is that in all sewages and nearly all sewage effluents the amount of free ammonia greatly exceeds that of the albuminoid ammonia. This is well shown in the following examples:

In parts per 100,000

| — | Nitric nitrogen | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|---|
| B. H. crude sewage . . . . . | ·00 | 5·9 | 2·2 | 5·9 |
| A good effluent . . . . . | 2·9 | 1·5 | ·05 | 1·01 |

In the crude sewage the free ammonia is two and a half times as great as the albuminoid ammonia, whilst in the effluent it is thirty times as great. Hence in most cases when a water yields more free ammonia than albuminoid ammonia, the indications are that the water is more or less polluted with sewage.

Decaying vegetable matter in a water yields more albuminoid ammonia than free ammonia. For example an infusion of dead leaves and a peaty water gave the following results on analysis:

Parts per 100,000

| — | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|
| Infusion leaves . . . . . | ·003 | ·031 | ·814 |
| Peaty water . . . . . | ·001 | ·024 | ·19 |

Peaty water, to which has been added one per cent. of the sewage and one per cent. of the sewage effluent just referred to, would have given the following results respectively:

| Peaty water with | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|
| 1 per cent. sewage . . . . | 0·60 | ·046 | ·249 |
| 1 per cent. sewage effluent . . . . | 0·16 | ·024 | ·20 |

These results would indicate sewage pollution in each case, decided in the first and less definite in the second, since the free ammonia even in the second is far in excess of what is usually found in peaty waters.

Another sewage effluent recently examined by me, which contained thousands of the Bacillus coli communis and other sewage organisms per c.c., gave the following results:

| Nitric nitrogen | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|
| 4·44 | ·052 | ·096 | ·79 |

A mixture of this with 99 per cent. of distilled water gives a water which would be classed amongst those of the highest organic purity. One per cent. added to the tap water in my laboratory gave

| Nitric nitrogen | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|
| 1·04 | ·001 | ·002 | ·04 |

This analysis gives no indication whatever of sewage pollution, yet the water contained one per cent. of effluent, and a bacteriological examination revealed the presence of sewage organisms in abundance.

Water yielding over ·01 part per 100,000 of albuminoid ammonia, if associated with free ammonia to the extent of ·006, must be looked upon with grave suspicion. If the free ammonia reaches or exceeds ·008 and there is no indication of its being derived from a harmless source, recent sewage

pollution is strongly to be suspected. When the free ammonia is low and the albuminoid ammonia comparatively high, as in the case of peaty water, vegetable contamination is indicated, especially if the water yields this albuminoid ammonia slowly.

The whole of the organic nitrogen may be determined by Kjeldahl's process. This, though less troublesome than the eudiometric method, yet occupies more time and requires greater care than the estimation of the albuminoid ammonia. No doubt it would be more scientific to estimate the whole of the nitrogen than a part. The chemists to the Massachusetts State Board of Health say that 'the albuminoid ammonia, as determined in our usual practice, is, in amount, about one-half of the ammonia which the total organic matter would be capable of yielding.' Notwithstanding this they add: 'The determination of albuminoid ammonia does not in itself convey any information as to the character of the organic matter in water. Standards of purity based simply on the amount of albuminoid ammonia are of little or no value, since it is the quality of organic matter rather than its quantity that immediately concerns us.' Obviously, therefore, if the nitrogen bears such a definite relation to the albuminoid ammonia as they suggest, the determination of the nitrogen has no greater value than the estimation of the albuminoid ammonia. The general opinion, however, is that the nitrogen in the albuminoid ammonia bears no constant relation to the total nitrogen. Whether such is the case or not, no more definite conclusions can be drawn from the total nitrogen determination than from that of the albuminoid ammonia, and hence the simpler process continues to be generally adopted.

Sewage is a most complex mixture of excremental matters and other filth, dissolved and suspended in water. There is no one constituent which the chemist can detect in water which can be said with certainty to indicate the presence of sewage. Pollution, recent or remote, is inferred if an excessive amount of chlorides, nitrates, phosphates, ammonia, and organic matter is found in the water. But nearly all these substances

may be derived from other and perfectly harmless sources, and, as we have seen, a small amount of sewage may be present without increasing to any appreciable extent the amount of any of these constituents. Waters classed by the most eminent analysts as pure and wholesome have caused serious outbreaks of typhoid fever, whilst other waters, condemned on account of the presence of an excess of one or more of the compounds just mentioned, are used with absolute impunity. This chiefly arises from the fact that by no chemical process can it be determined whether the small amount of organic matter found in nearly all waters is of vegetable or animal origin. The organic constituents of sewage or manure may have undergone as complete oxidation as would ensue by perfect combustion in a furnace, whereby only the innocuous mineral matter remains to indicate that the water ever was polluted. If this oxidation has also been so fully supplemented by natural filtration that all the organisms present in the original polluting matter have been removed (but whether this is the case or not can only be ascertained by a bacteriological examination), the water must be considered of satisfactory quality.

In new wells constructed of brickwork on wooden curbs, the wood continues to impart a trace of organic matter to the water; the bricks also affect the water, the result being that waters from such wells are often condemned, whereas after a time they yield water of a satisfactory quality. This subject is of such importance, that I purpose dealing with it in a later portion of this section.

The necessity of acknowledging the limitations of the knowledge obtainable from the chemical analysis of a water is my excuse for further emphasising it by reference to other experiments, made to ascertain to what extent the results of an analysis can be relied upon.

In the following experiments the water used was derived from the water mains in Chelmsford Borough. With this was made a 1 per cent. infusion of tea, and various quantities of this filtered infusion were added to one litre of tap water. A sample

of the town sewage was obtained, and portions of this were added to another litre of water. The analytical results were as under, and show that the addition of tea infusion rendered the water more impure chemically than the corresponding quantities of sewage, and that whilst the ·1 per cent. sewage polluted water would have been passed as chemically of the highest degree of organic purity, the water containing a corresponding quantity of tea infusion would be regarded as of doubtful quality:

In parts per 100,000

| — | Chlorine | Free ammonia | Organic ammonia | Oxygen absorbed |
|---|---|---|---|---|
| Tap water, ·1 per cent. sewage . . | 16·0 | ·003 | ·0005 | ·0291 |
| Tap water, ·1 per cent. tea infusion . | 15·9 | ·0005 | ·0120 | ·190 |

The bacteriological results were very different. The Bacillus coli communis could be detected in 1 c.c. of the sewage-polluted water, and the Bacillus enteritidis sporogenes in 25 c.c.

Using a larger proportion of sewage and tea infusion, the chemical results were still unsatisfactory.

In parts per 100,000

| — | Chlorine | Free ammonia | Organic ammonia | Oxygen absorbed |
|---|---|---|---|---|
| Tap water, ·5 per cent. sewage . . | 16·3 | ·008 | ·005 | ·080 |
| Tap water, ·5 per cent. tea infusion . | 15·9 | ·003 | ·032 | ·940 |

By bacteriological examination the Bacillus enteritidis could be demonstrated in 5 c.c. of the sewage-polluted water.

I have frequently met with waters which, upon chemical examination, appeared to be polluted, although the sources from which they were derived were found to be practically free from any possibility of contamination. On the other hand, I have occasionally found waters of the highest degree of organic purity, which came from sources I felt bound to condemn on account of the possibility of pollution. Doubtless when such waters are examined at regular intervals by bacteriological methods, sooner or later indications of pollution are

found. As an instance I may record the case of a public water supply derived from the chalk formation. I regarded the source as being unsatisfactory for two reasons. In the first place there were numerous cesspits and farmyards on the collecting area besides other sources of contamination, and in the second there was danger of infiltration from a sewage-polluted river near. Yet in about forty examinations the organic matter had always been so low as to cause the water to be classed amongst those of the highest degree of organic purity. Bacteriologically the results were generally satisfactory, but after a recent spell of wet weather I was able to detect both the Bacillus coli and the Bacillus enteritidis in a sample. This sample gave the following results on analysis, showing that chemically it was of a very high degree of purity.

| Chlorine | Nitric nitrogen | Free ammonia | Organic ammonia | Oxygen absorbed |
|---|---|---|---|---|
| 1·05 | 12·9 | ·000 | ·002 | ·022 |

Other instances of a similar character will be referred to later.

At the instigation of the Local Government Board, Drs. Klein and Houston recently conducted an investigation 'in order more accurately to determine in regard to water the relative value of chemical and bacterioscopic analysis simultaneously conducted—to ascertain, that is, to what extent severally chemical and bacterioscopic examination of waters purposely sewage-polluted can yield definite indications of contamination. For analysing the experimentally polluted waters two processes were chosen which are in general use among chemists at the present day.

'Ammonia process (Wanklyn). 500 c.c. of the polluted water were examined in the ordinary way for free and albuminoid ammonia.

'Oxygen permanganate process (Tidy, Frankland, and others). 500 c.c. of the polluted water were dealt with, and the experiments were carried out at a temperature of 100° C. The chemical results are shown on Table I.

'In each case 1,000 c.c. of sterile distilled water were polluted with a definite quantity of crude sewage. Of the contaminated water 500 c.c. were used for the ammonia process and 500 c.c. for the oxygen permanganate process. In experiments 1, 2, 3, 4, the samples of sewage were obtained from a single source, and in experiment 5 from a second source, and in experiments 6, 7, 8, from a third source. In experiment 9 a natural water, known to be polluted with sewage, was selected for examination :

TABLE I.—SHOWING THE RESULTS OF THE CHEMICAL EXAMINATION OF DISTILLED WATER POLLUTED WITH VARYING AMOUNTS OF CRUDE SEWAGE

PARTS PER 100,000

| Exp. distilled water polluted with | Oxygen absorbed from permanganate in 1 hour at 100°C. | Free ammonia | Organic ammonia |
|---|---|---|---|
| 1. 1 per cent. crude sewage, dilution 1 in 100 . . . | ·3138 | ·0864 | ·0224 |
| 2. ·1 per cent. crude sewage, dilution 1 in 1,000 . . . | ·0848 | ·004 | ·001 |
| 3. ·01 per cent. crude sewage, dilution 1 in 10,000 . . . | ·0018 | ·0009 | ·0004 |
| 4. ·005 per cent. crude sewage, dilution 1 in 20,000 . . . | nil | nil | nil |
| 5. ·01 per cent. crude sewage, dilution 1 in 10,000 . . . | No record | ·003 | ·0026 |
| 6. 1·0 per cent. crude sewage, dilution 1 in 100 . . . | ·1375 | ·0213 | ·0062 |
| 7. ·1 per cent. crude sewage, dilution 1 in 1,000 . . . | ·0326 | ·0021 | ·0006 |
| 8. ·01 per cent. crude sewage, dilution 1 in 10,000 . . . | ·0119 | ? trace | ·0012 |
| 9. Thames water below Staines . | ·4628 | ·0054 | ·031 |

'In considering from the chemical point of view the results recorded in Table I. it is to be noted that,

'Judged by the oxygen-absorbed process at 100° C., experiment 1 denotes a water of medium purity, experiment 9 a water of suspicious organic purity. The rest of the experiments denote waters varying from medium purity to great organic purity, and that,

'Judged by the ammonia process, experiments 1 and 9 denote dirty waters, experiments 2, 3, 4, 5, 7, 8, waters of great purity, while experiment 6 denotes a water organically safe.

'It must be remembered, however, that most natural waters contain more than mere traces of organic matter. Indeed, many of them contain an amount which is not far short of placing them in the class of waters of doubtful purity. Hence additional pollution in the above way might bring them from the class of water of great purity into the class of waters which are of medium purity, or from the class of waters of medium purity into that which includes waters to be regarded with suspicion or even condemned.'

In all the above waters the bacterioscopic analysis showed the presence of both the Bacillus coli and Bacillus enteritidis sporogenes. It is obvious therefore that no water can be said to be absolutely free from sewage pollution as the result of chemical analysis. If the detection of such traces of pollution is the object of the investigation, a bacteriological examination is imperative.

(*k*) **American views** on the interpretation of the results of chemical analysis.

The following remarks on the Interpretation of Water Analysis are taken from the Report of the Massachusetts State Board of Health, and show that the results of their large experience coincide with those obtained in this country:

'In classifying waters from a sanitary standpoint, the most obvious and useful distinction is into waters which are polluted either directly or indirectly with sewage, or in general with the waste products of human life and industry, and those which are free from such contamination. The latter class of waters we will call "normal." Normal waters may differ widely in character from the pure, colourless, mountain stream to the brown water of swamps, but they have this in common, that they have never received any contamination connected with the life of man. It is not meant to be implied in this distinction that normal waters are necessarily good to drink, but they are never capable of producing those specific troubles which have their origin in disordered vital processes.

'The chemical analysis alone may sometimes fail to dis-

tinguish a normal from a sewage-contaminated surface water. In the following table are grouped together the results of the analyses of several normal and polluted waters, which have been selected to show that in some cases not only is no single determination conclusive as regards the origin and quality of a water, but that all the determinations taken together do not always suffice to give us the information we desire.

'Thus among the polluted waters are found some in which the albuminoid ammonia is lower than in the waters which are unpolluted. The same is also true of the free ammonia, the nitrates, nitrites, chlorine, &c. Again, the great variation in the amounts of these substances, even among the normal waters, shows that we have to deal with facts that do not necessarily carry their interpretation with them. But in all these cases a knowledge of the location and environment of these waters renders the results of the analyses intelligible, as we shall see later on.

'The presence of organic matter, or ammonia, and even a bad odour in a well water, does not necessarily imply that the ground water of the region is polluted. The trouble may be in the well itself, which may contain organic matter which has dropped in from the surface—insects, worms, and the like. In some wells the water at the bottom is stagnant. The water does not become bad on this account unless organic matter gets access to it, when putrefactive changes set in, owing to insufficient supply of dissolved oxygen, and the water becomes very foul. The remedy in such cases is very simple, namely, cleaning the well and protecting it carefully at the surface.

'At the beginning of this discussion we have spoken of the doubtful value of standards of purity of water based on the amount of the nitrogen compounds which it contains. In the case of ground waters there is an ideal standard of purity which is at the same time not an impossible one, namely complete freedom from unoxidised or partly oxidised compounds of nitrogen. We do not know, as has been already explained, that a water which reaches this standard is safe if at the same time

it contains much nitrogen completely oxidised, but we do know that as we depart from this standard we enter the region of known danger. It has been a very general custom hitherto to set limits for each of the substances beyond which the water should be regarded as polluted or as unfit for drinking.

'The application of these standards of purity made the interpretation of analyses a very simple matter but of very doubtful value. It has been thought worth while in the above discussion to show, in much detail, the one-sided and faulty deductions which may be made by giving too much weight to any one determination. Thus we have said that free ammonia is the evidence of decomposition of nitrogenous organic matter already begun, that it is the characteristic ingredient of sewage, that it is one of the most reliable indications of sewage pollution in water. And yet under certain conditions we have seen that a sewage-polluted water may be free from ammonia and that a normal water may contain it abundantly.

'Two lessons are to be learnt from this (and they cannot be too strongly emphasised), namely, first, that a single determination in a chemical analysis of a water cannot tell us what the real condition of the water is; and, second, that one complete analysis tells us only what was the condition of the water when the sample was taken.

'A single analysis, for instance, may be selected from the monthly examinations of Mystic Lake, which will show the water to be in a very good condition, with only the presence of the chlorine to indicate past pollution. Yet a glance at the series of analyses will show that this condition is unusual, and that the water contains, for the greater part of the year, products of decomposition of organic matter in considerable amount. Such facts do not detract from the value of the chemical analysis of waters, but show rather how easily a fatal mistake may be made by trusting to incomplete and infrequent analyses.

'The recorded and well-authenticated cases of illness result-

ing from drinking ground water are very numerous—far greater in number than those which can with certainty be referred to the use of waters of streams and lakes. Investigation of these cases shows almost invariably that the water of the well has received directly, or indirectly through the soil, the drainage of houses or cesspools. All wells in the vicinity of houses or barns are more or less exposed to such contamination, and it is a matter of the first importance to know how far the information derived from a chemical analysis will enable us to say whether or not a well water can be used with safety. If we regarded the organic matter, or the products of its decay, as the sole cause of danger, then we should have in the determination of the nitrogen compounds a perfectly satisfactory means of deciding whether the water is in a fit condition to use. From this point of view we should reject all water which contained free or albuminoid ammonia or nitrites, and accept only those which contained all the nitrogen in the form of nitrates.

'But if the danger is to be ascribed to the presence of bacteria in the water, the results of a chemical analysis offer, as in the case of surface waters, only indirect evidence of its condition.

'Where normal ground waters are not to be had, safety lies in time and distance from the source of pollution—the greater these are the greater the security from harm. Waters with very high nitrates are always to be regarded with suspicion, even though they show for a long period a good purification, for high nitrates indicate a nearness of the source of pollution which is a constant menace to the purity of the water. Where the margin of safety is small a slight change in the existing conditions may result in a sudden and serious pollution of the well. Moreover, from the standpoint of bacterial contamination we cannot feel secure, even when the chemical purification is practically complete, if the source of contamination is near.'

## TABLE OF ANALYSES OF NORMAL AND POLLUTED SURFACE WATERS

(*Massachusetts Reports*)

| No. | Appearance | | | Residue on evaporation | | | Ammonia | | Chlorine | Nitrogen as | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Turbidity | Sediment | Colour | Total | Loss on ignition | Fixed | Free | Albuminoid | | Nitrates | Nitrites |
| | | | | NORMAL WATERS (PARTS PER 100,000) | | | | | | | |
| 1 | None | Very slight | 0·00 | 5·00 | 0·70 | 4·30 | ·0000 | ·0022 | 0·08 | ·0060 | ·0000 |
| 2 | Decided | Heavy | 0·10 | 2·50 | 0·95 | 1·55 | ·0000 | ·0702 | 0·10 | ·0030 | ·0006 |
| 3 | Decided | Slight | 0·60 | 5·15 | 3·25 | 1·90 | ·0000 | ·1252 | 0·11 | ·0000 | ·0000 |
| 4 | Slight | Slight | 0·40 | 3·65 | 1·65 | 2·00 | ·0130 | ·0333 | 0·16 | ·0250 | ·0001 |
| 5 | Slight | None | 0·30 | 3·25 | 0·95 | 2·30 | ·0000 | ·0136 | 0·63 | ·0050 | ·0000 |
| 6 | Slight | None | 0·00 | 5·95 | 0·80 | 5·15 | ·0000 | ·0152 | 2·10 | ·0060 | ·0001 |
| | | | | POLLUTED WATERS | | | | | | | |
| 1 | Distinct | Considerable | 0·10 | 10·75 | 2·05 | 8·70 | ·0124 | ·0284 | 0·19 | ·0150 | ·0009 |
| 2 | Very slight | Very slight | 0·55 | 5·15 | 1·95 | 3·20 | ·0000 | ·0196 | 0·54 | ·0550 | ·0004 |
| 3 | Distinct | Slight | 0·10 | 5·00 | 0·85 | 4·15 | ·0016 | ·0198 | 0·58 | ·0200 | ·0004 |
| 4 | Slight | Slight | 0·15 | 10·25 | 1·20 | 9·05 | ·0000 | ·0262 | 2·09 | ·0170 | ·0010 |
| 5 | Slight | Slight | 0·15 | 12·70 | 2·10 | 10·60 | ·0664 | ·0263 | 2·41 | ·0800 | ·0025 |

(*l*) **French Standards.**—The French Consultative Committee of Hygiene has submitted a table of standards which is generally adopted in France. Its utility is very limited, and an unreasoning adoption of it would lead to serious errors. It is given here for what it is worth:

PARTS PER 100,000

| — | Pure waters | Potable waters | Suspicious waters | Bad waters |
|---|---|---|---|---|
| Nitric nitrogen . | ·00 | ·00 to ·10 | ·4 to ·8 | Over ·8 |
| Free ammonia . . | ·000 to ·005 | ·005 to ·010 | ·010 to ·015 | Over ·015 |
| Albuminoid ammonia | ·000 to ·005 | ·000 to ·005 (·005 to ·010 [1]) | ·005 to ·010 (·010 to ·015 [1]) | Over ·015 |
| Oxygen absorbed . | Under ·10 | ·10 to ·20 | ·30 to ·40 | Over ·40 |
| Chlorine . . . | Under 1·5 | 1·5 to 4·0 | 5·0 to 10·0 | Over 10·0 |
| Hardness . . . | 5° to 15° | 15° to 30° | Over 30° | Over 100° |

[1] These figures to be taken if there is little or no free ammonia present.

(*m*) **Table of Analyses.**—As I possess records of the sources of a large number of samples of water examined in my laboratories, I have selected a number of these and tabulated the results so that it is easy to compare the conclusions arrived at from the examination of the source and from the chemical analysis. In every case the source of supply was examined by myself either when the sample was taken or soon after the completion of the analysis. It will be found that whilst many correspond with the above standards for pure and bad waters, few agree with the intervening standard. A water is either 'safe' for use for domestic purposes or is 'unsafe,' and when the source is examined it is rarely necessary to use the terms 'doubtful' or 'suspicious.'

(*n*) **Water from New Wells.**—In rural districts no newly erected house can be inhabited until a certificate is obtained from the sanitary authority to the effect that it has within a reasonable distance an available supply of wholesome water sufficient for all domestic purposes. The usual source of supply is a shallow well. These wells are rarely properly constructed, and the necessary certificate should be withheld until

## ANALYSES OF WATERS FROM VARIOUS SOURCES. (Results in Parts per 100,000.)

| No. | Source | Possibilities of contamination | Chlorine | Nitric and nitrous nitrogen | Nitrites | Hardness | Free ammonia | Albuminoid ammonia | Oxygen absorbed | Bacteriological results | Reported |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Shallow well | Serious from farmyard | 18·3 | 3·0 | ·0 | 34° | ·002 | ·006 | ·026 | — | Unsafe |
| 2 | Subsoil | None, town supply | 2·6 | 1·4 | ·0 | 12° | ·002 | ·003 | ·019 | Good | Safe |
| 3 | As 2 | Quarter mile galv. iron pipe [1] | 2·6 | 1·2 | ·0 | 12° | ·024 | ·003 | ·145 | — | Zinc-contaminated |
| 4 | Shallow well | Farmyard (?) | ·5 | ·7 | ·0 | 40° | ·000 | ·004 | ·036 | — | Safe |
| 5 | Shallow well, new | None | 3·2 | ·25 | *t.* | 41° | ·064 | ·016 | ·300 | — | Safe |
| 6 | Spring | From ditch cont. sewage | 3·0 | ·9 | ·0 | 6° | ·002 | ·016 | — | — | Unsafe |
| 7 | Same as 6 | After rain | 3·4 | — | ·0 | 9° | ·018 | ·120 | — | — | Unsafe |
| 8 | New well | None apparent | 8·6 | 1·0 | *t.* | 23° | ·008 | ·020 | — | — | Safe |
| 9 | Same as 8 | 4 months later [2] | 3·9 | 1·0 | *t.* | 15° | ·024 | ·014 | — | — | Examine well |
| 10 | Same as 8 | After cleaning | 2·6 | 1·2 | ·0 | 9° | ·000 | ·012 | ·015 | — | Safe |
| 11 | Shallow well | None | 4·0 | ·07 | ·0 | 39 | ·016 | ·007 | — | — | Safe |
| 12 | Subsoil, P.S. | Long length galv. iron pipe | 3·4 | ·8 | *l.t.* | 10° | ·132 | ·006 | ·34 | Good | Contains zinc |
| 13 | Shallow well | None [3] | 2·3 | ·6 | *l.t.* | 8°·5 | ·018 | ·010 | — | Found crenothrix | Unsatisfactory |
| 14 | Same as 13 | Before crenothrix infection | 1·9 | ·6 | ·0 | 11° | ·000 | ·012 | — | — | Safe |
| 15 | Shallow well | Sewage from blocked drain dropping in [4] | 13·0 | 1·3 | *m.t.* | 31° | ·004 | ·006 | ·103 | — | Unsafe |
| 16 | Shallow well, new | Carefully selected site, bored | 10·7 | ·1 | *t.* | 17° | ·020 | ·024 | — | — | Safe |
| 17 | Shallow well, boulder clay | None, odour of $H_2S$ [5] | 2·3 | ·0 | ·0 | 30° | ·016 | ·008 | ·202 | — | Unsatisfactory |
| 18 | Deep well | None | 23·6 | ·14 | ·0 | 5° | ·019 | ·005 | ·080 | Good | Safe |
| 19 | Shallow well, new | None | 2·9 | ·98 | ·0 | 24° | ·018 | ·005 | ·128 | — | Safe |
| 20 | Well near 19 | None | 1·9 | ·83 | *m.t.* | 14° | ·002 | ·005 | ·020 | — | Safe |
| 21 | Deep well | None | 37·1 | ·2 | ·0 | 7° | ·016 | ·004 | — | Good | Safe |
| 22 | P. spring | A sewer near [6] | 4·0 | — | ·0 | — | *t.* | ·0042 | ·022 | — | Unsafe |
| 23 | Same as 22 | After heavy rain | 4·1 | ·2 | ·0 | 20° | ·080 | ·028 | ·175 | Sewage organisms | Polluted |
| 24 | Deep well | Defective near top, ditch near [7] | 38·6 | ·17 | ·0 | 7° | ·002 | ·004 | ·100 | — | Unsafe |
| 25 | New tube well | None | 9·7 | 1·2 | *t.* | 24° | ·064 | ·010 | ·09 | — | Large trace iron, safe |
| 26 | Deep well | Farmyard | 40·1 | ·43 | *t.* | 4° | ·020 | ·004 | ·108 | — | Unsafe |
| 27 | Deep well | Urinal near [8] | 33· | ·09 | ·0 | 4° | ·012 | ·012 | ·09 | — | Unsafe |
| 28 | Same as 27 | None | 33· | ·04 | ·0 | 7° | ·006 | ·005 | ·12 | — | Safe |
| 29 | Deep well | Top defective, dirty ditch very near | 50·8 | ·10 | ·0 | 6° | ·068 | ·003 | ·12 | — | Unsafe |
| 30 | As 29 | After a flood | 54·3 | ·43 | ·0 | 9° | ·052 | ·012 | — | — | Polluted |
| 31 | Spring | In ditch, seriously liable to pollution | 3·0 | 1·8 | ·0 | 11° | ·000 | ·012 | — | — | Unsafe |
| 32 | Spring | In ditch, seriously liable to pollution | 4·6 | ·6 | ·0 | 10° | ·005 | ·006 | 0·28 | — | Unsafe |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | Spring . . . | Carefully protected, supplying village . . . . . | 4·0 | ·54 | ·0 | 19° | ·012 | ·008 | ·155 | — | Good |
| 34 | Surface water . | A town supply, moorland [9] . . | ·9 | ·18 | ·0 | 10° | ·002 | ·013 | ·262 | No sewage organisms | Unsatisfactory |
| 35 | Spring . . . | At edge of hop plantation, inefficiently protected [10] . . . | 3·3 | 1·4 | ·0 | 19° | ·000 | ·0005 | ·016 | — | Dangerous |
| 36 | Shallow well . | None . . . . . | 1·7 | ·2 | ·0 | 16° | ·001 | ·009 | — | — | Safe |
| 37 | Same as 36 . . | Water had acquired a curious odour [11] . . . . . | 1·7 | ·1 | ·0 | 16° | ·000 | ·008 | — | — | Unsatisfactory |
| 38 | Deep well . . | None . . . . . | 3·7 | ·04 | ·0 | 31° | ·020 | ·003 | ·088 | — | Safe |
| 39 | Trial bore, 7 ft. . | None [12]. . . . . | 420· | ·17 | ·0 | 36° | ·012 | ·088 | — | — | Unfit for use |
| 40 | Trial bore, 7 ft. . | Close to No. 39 . . . . | 15·9 | ·2 | ·0 | 32° | ·001 | ·014 | — | — | Safe |
| 41 | Spring . . . | Well protected . . . . | 2·3 | 1·0 | ·0 | 7° | ·002 | ·006 | ·038 | Good | Safe |
| 42 | House tap . . | Same as 41 [13] . . . . | 3·0 | ·9 | *l.t.* | 14° | ·068 | ·004 | ·600 | — | Much zinc |
| 43 | Spring . . . | None, a town's supply [14] . . | 4·0 | 1·2 | ·0 | 16° | ·008 | ·005 | ·044 | Good | Safe |
| 44 | Chalk well . . | Cesspools, &c. [15] . . . . | 3·7 | ·4 | *l.t.* | 19° | ·056 | ·014 | ·213 | — | Unsafe |
| 45 | Deep well . . | Top imperfect, polluted subsoil . | 62·0 | ·2 | ·0 | 9° | ·105 | ·005 | ·039 | — | Unsafe |
| 46 | Same as 45 . . | Showing subsoil pollution [16] . | 31·4 | 3·6 | *t.* | 24° | ·002 | ·020 | — | — | Polluted |

[1] This water contained about 1 part of zinc per 100,000.

[2] This well when opened was found to contain some old ropes and sacking left behind by the workmen.

[3] This water had a disagreeable odour and contained a trace of iron.

[4] Not being able to account for the presence of the nitrites, I had the well opened, when the source of pollution was discovered.

[5] There was no possibility of sewage pollution in this case. As the water did not improve in character, the well was abandoned.

[6] This is the only analysis included which was not made in my laboratory. The chemist who made it certified that it was good and could not possibly be the cause of the typhoid fever which was raging amongst those who used it. I had regarded it as unsafe without an analysis, because it became turbid after rain. Later I examined a sample taken when the water was in a turbid condition with the result shown in No. 23.

[7] This water I regarded as unsafe because of its becoming turbid after rain. Shortly afterwards a case of typhoid fever occurred in the house supplied from this source, and when the well was opened traces of filth were found on the side nearest a ditch receiving sewage. The polluting matter only entered when a rainfall filled the ditch.

[8] From a public well. Corner near used by lads as a urinal. The corner was closed in and the water in the well pumped to waste. When the water again rose it gave the results recorded in No. 28.

[9] This water swarmed with Volvox globator.

[10] The spring water alleged to have caused the Maidstone epidemic. Taken while the epidemic was raging.

[11] This water was from a new well and had a very curious and decided odour. When the well was opened a sack of shavings was found in it.

[12] Water from a trial bore in superficial gravel in the centre of Essex. The source of the chlorides was never discovered. (*Vide* No. 40.)

[13] This water was condemned as sewage-polluted by an analyst of repute. He did not detect the presence of zinc. I examined the spring water (41) and the water after it reached the house through a length of galvanised iron piping with the above results.

[14] This water contained a minute trace of zinc. An analyst who had examined a sample taken from the same house with a new supply pipe of galvanised iron found a little more free ammonia and certified that the water was contaminated with sewage. Legal proceedings followed, and I was able to prove that the water was above suspicion of pollution.

[15] This well supplies a large population. When pumping is going on the water level is depressed for a considerable distance around, and there are many cesspools within the area of depression. I regard the source as unsafe.

[16] The well yielding the waters Nos. 45 and 46 is near a churchyard and in the centre of a very insanitary village. The section showed 15 feet of gravel and 100 or more feet of London clay, the water coming from the Thanet sands. The upper part of the well was undoubtedly defective, and there were obvious signs of subsoil water entering. At a later period when the subsoil had become charged with water I again examined the water from the well with the results recorded. It will be noted that the polluting subsoil water had decreased the amount of chlorides and of free ammonia, but increased the nitrates, hardness, and organic ammonia.

the well is made to the satisfaction of the Medical Officer of Health. When completed it should be examined, and if necessary a sample of water taken for analysis. This analysis will tell whether the water is too hard or contains an excessive amount of saline matter, but very often it has led to the well being condemned because the water contained too large a trace of organic matter, erroneously attributed to sewage or manurial matter. This has so often occurred when sewage or manurial contamination was practically impossible that some explanation was needed, and my late assistant, Dr. Dunlop, now Medical Officer of Health for the Borough of Torquay, carried out an investigation in my laboratory to ascertain the cause. The fact was previously well known, and had been attributed to workmen micturating in or near the well during construction, to dirt getting in from their boots, &c. On several occasions, when the water in a new well did not improve, a cause has been found on examination. I have discovered old rope, sacks, bits of wood, vegetable debris, &c., at the bottom of such wells.

As illustrations of the improvement in the character of water from new wells, Dr. Dunlop gave the following examples :

| Source | Date of analysis | Chlorine | Free ammonia | Albuminoid ammonia |
|---|---|---|---|---|
| New shallow well . . | 5–7–1893 | 19·3 | ·006 | ·006 |
| Same well . . . . | 1–12–1893 | 3·8 | ·001 | ·002 |
| New shallow well . . | 10–7–1895 | 3·4 | ·100 | ·028 |
| Same well . . . . | 27–11–1895 | 3·4 | ·005 | ·014 |
| Deep well . . . . | –3–1891 | 20·0 | ·100 | ·032 |
| Same well . . . . | –6–1891 | 32·1 | ·048 | ·005 |
| Same well . . . . | –9–1891 | 32·7 | ·001 | ·0015 |

The deep well was particularly interesting, as I knew that it had been constructed by a firm of the highest standing. Subsoil water had gained access to the bore during construction, and had apparently had a marked effect in lowering the chlorine in the water. It was six months before the water became quite normal. No doubt it would have improved much earlier had any large quantity been taken from the well,

but the amount used was very limited. Dr. Dunlop took samples of the materials actually used in the construction of a well, rejecting however a sample of cement which had been made with road scrapings, and after digesting these in water recorded the results. These were as under :—

| Description of sample | Chlorine | Free ammonia | Albuminoid ammonia | Nitrites |
|---|---|---|---|---|
| Tap water used in experiments . | 16·0 | ·000 | ·004 | ·00 |
| Tap water digested with portion of elm curb . . . . . | 16·0 | ·200 | ·100 | ·00 |
| Tap water digested with deal curb . | 17·9 | ·009 | ·030 | ·00 |
| Tap water with cement . . . | 16·0 | ·025 | ·032 | ·00 |
| Tap water with brick . . . | 16·0 | ·002 | ·016 | Trace |

The increase in the amount of chlorides in the infusion of deal led to further experiments showing that certain samples of this wood contain a considerable amount of salt; doubtless the original logs had floated for some time in salt water.

The brickwork appears to be responsible for the trace of nitrites often found in water from new wells. Dr. Dunlop concludes that 'the temporary pollution of wells sunk in clean soil is almost wholly due to the action of the water on the materials employed in the construction of the wells. This accounts for the great change for the better which such waters often undergo in a few weeks.'

# CHAPTER IX

## INTERPRETATION OF THE RESULTS OF MICROSCOPICAL AND BIOLOGICAL EXAMINATIONS

A MICROSCOPICAL examination of a potable water should be made whenever the sample shows any signs of turbidity or contains any visible suspended particles, since such an examination will reveal the nature of the suspended or deposited matter, and often assist greatly in the interpretation of the results of a chemical analysis. Where a supply, usually satisfactory, suddenly develops some colour, turbidity, or odour, the microscope almost invariably gives a clue to the cause. Frequently a chemical analysis is useless in such an investigation.

In the examination of streams, lakes, reservoirs, ponds, &c., suspected to be polluted, or known to be polluted, a biological examination may assist in determining the extent to which the water is affected by the filth discharged into it. Low forms of life may be found suspended in the water or growing attached to stones, twigs, water plants, &c., or floating in masses on the surface. These must be examined to ascertain whether they are organisms which only thrive in polluted waters and whose presence therefore proves contamination, or whether they are organisms which later in the season may decay and create a nuisance.

Sand filters occasionally give unsatisfactory results which may admit of explanation upon examination of the bed and a microscopic examination of the slime deposited upon it. The suspended matter submitted to microscopic examination may be (*a*) of mineral origin, or (*b*) of animal or vegetable origin, and in the latter case may be living or dead. Bacteria

requiring great magnifying power to render them visible and special methods for their identification are not included in a microscopical examination, nor in what is spoken of as a biological examination. These special methods are included under the term bacteriological or bacterioscopic examination.

A water sediment is submitted to the scrutiny of the microscope to obtain information for one or more of three purposes: (1) to detect contamination, (2) to elucidate the results of the chemical examination, and (3) to ascertain the cause of any odour, colour, or turbidity.

A public water supply, to be satisfactory, should be entirely free from visible suspended matter, living or dead. Most springs and deep wells yield a water of this character, and if properly stored and distributed, it should reach the consumers in its pristine purity. Storage in open reservoirs, or in reservoirs to which light has access, may result in vegetable or animal growths appearing, and an inadequate system of filtration may contribute both to the fauna and flora of a water. Subsoil waters, river waters, and lake waters usually require filtration; otherwise they will from time to time be delivered in a turbid condition, due to disturbance by heavy rains and floods or to the growth at some particular season of low forms of vegetable or, more rarely, animal life.

The presence of visible particulate matter almost invariably indicates some defect in the water supply, and its character often indicates the nature of the defect and permits of a remedy being suggested.

As chlorophyll is only produced under the influence of light, and diatoms only grow under similar conditions, the presence of diatoms or of green algæ in well water proves that some water which has been exposed to light has gained direct access to the well, it may be, along the track of the pump pipe or through some aperture near the top. Often the amount so entering is too small to affect the results of a chemical analysis, and without a microscopical examination a danger of this kind may easily be overlooked.

The examination of samples of water taken at regular intervals from large reservoirs will show to what extent such water is affected, at different seasons, by the growth of low forms of vegetable and animal life, and may prove the necessity for the adoption of a system of filtration, or for making improvements in the surroundings of the reservoir for the prevention of water being admitted from objectionable sources. If such waters become discoloured or acquire an odour or taste, a microscopic examination will be far more likely to reveal the cause than a chemical or bacterioscopic analysis.

The examination of water supplied from the mains may show that growths are taking place in the mains, probably at dead ends, and indicate the necessity for more frequent flushing or for some alteration in the connections to allow of more complete circulation. Green growths may indicate defects in the covering of service reservoirs, or of house cisterns. Where vegetable and animal debris is found in water from the house taps, but not from the mains, some defect in the house cistern is almost certain to exist.

The presence of particles of mineral matter alone may indicate surface contamination, or merely the nature of the stratum yielding the water.

The dead organic matter is usually so disintegrated as to be beyond the power of definite identification, and it may be associated with matters of mineral origin, clay, chalk, fine sand, oxide of iron, &c., rendering identification still more difficult.

Search should be made for substances which admit of recognition, such as epithelium, striped muscular fibre, dotted ducts of pine wood, starch granules, fibres of cotton, hemp, silk, wool, and other animal hair, ova, and dead or living vegetable and animal organisms. The presence of granules of wheat, potato, rice, and similar starches, of cotton and other vegetable fibres, of wool, &c., would indicate contamination with sewage or foul surface water. Hairs, scales, parts of insects, &c., may

indicate the existence of an uncovered and unprotected house cistern.

In Germany and in the United States of America considerable stress is laid upon the biological examination of waters, by which are meant the identification and approximate enumeration of the various low forms of animal and vegetable life (excluding the bacteria). Even an expert cannot name all the living constituents in a water sediment. Some organisms go through such strange transformations during their life-history that it is requisite to be acquainted not only with the fully developed forms but also with the various other forms assumed in the cycles of their careers. The Massachusetts State Board of Health have for years past published annually reports on the biological examination of all the public water supplies in the State. The object of these examinations, however, is not so much the detection of pollution as the study of the relation of the odours of a water to the organisms which it contains, the kinds of organisms found in water from different sources, their seasonal distribution, &c. These are all subjects of special interest in that State, where the majority of the water supplies are derived from surface sources, and often give rise to complaint on account of either their turbidity or odour or taste. In this country the conditions are different, and a detailed biological examination would rarely yield results at all commensurate with the labour expended. Even when a chemical and bacteriological examination of a potable water has been made, additional information can often be obtained from a biological examination.

The organisms of importance in the examination of water may be divided into three classes :—

(*a*) Those which, either in the living state or in process of decay, impart an odour or taste to the water ;

(*b*) Those which by their presence indicate that the water is polluted with sewage or manurial matter, or with organic waste from certain processes of manufacture, since they can only thrive in such polluted waters ;

(*c*) Those which can live only in water of considerable purity, and whose presence therefore contraindicates pollution from such sources as the above.

The number of organisms of any real importance is comparatively small, since the majority of those found in water afford no indication as to whether it is pure or impure.

Whipple[1] classifies the various odours which appear in potable waters as 'aromatic,' 'grassy,' and 'fishy,' and for convenience tabulates them and their causes as under:—

| Group | Organism | Natural odour |
|---|---|---|
| Aromatic odour | *Diatomaceæ*— | |
| | Asterionella | Aromatic, geranium, fishy |
| | Cyclotella | Faintly aromatic |
| | Diatoma | Faintly aromatic |
| | Meridion | Aromatic |
| | Tabellaria | Aromatic |
| | *Protozoa*— | |
| | Cryptomonas | Candied violets |
| | Mallomonas | Aromatic, violets, fishy |
| Grassy odour | *Cyanophyceæ*— | |
| | Anabæna | Grassy and mouldy, green corn, nasturtiums, &c. |
| | Rivularia | Grassy and mouldy |
| | Clathrocystis | Sweet, grassy |
| | Cælosphærium | Sweet, grassy |
| | Aphanizomenon | Grassy |
| Fishy odour | *Chlorophyceæ*— | |
| | Volvox | Fishy |
| | Eudorina | Faintly fishy |
| | Pandorina | Faintly fishy |
| | Dictyosphærium | Faintly fishy |
| | *Protozoa*— | |
| | Uroglena | Fishy and oily |
| | Synura | Ripe cucumber, bitter and spicy taste |
| | Dinobyron | Fishy like rockweed |
| | Bursaria | Irish moss, salt marsh, fishy |
| | Peridinium | Fishy like clam shells |
| | Glenodinium | Fishy |

To the above should be added Beggiatoa and certain species of Chara, which give the odour of sulphuretted hydrogen, and Crenothrix.

In an unfiltered water, which has suddenly developed an odour, the offending organism will probably be found in great

[1] *The Microscopy of Drinking Water*, p. 125.

numbers in the water as supplied to the consumers, whilst in a filtered water the organism will be more likely to be found on the filter beds or in the reservoirs.

Whipple does not think that the odour-producing organisms are injurious to persons in good health, but he adds: 'There is some reason to believe that people accustomed to drinking water free from organisms may be subjected to temporary intestinal disorders when they begin to drink water rich in microscopic organisms, just as people are affected by changing from a hard to a soft water and *vice versa*. It is possible that with young children and invalids such disorders may be more common than has been supposed.'

In Massachusetts a large proportion of the surface water supplies have at some time or other given rise to great annoyance by the development of an odour. Apparently, however, few of these waters were subject to filtration, since Whipple thinks one of the most efficient remedies is filtration. As most river and surface waters in this country are filtered before being delivered to the consumers, this may account for the comparatively few recorded instances of public supplies developing any odour.

Unpleasant odours may, however, develop in carefully filtered water. The water supplying Cheltenham is filtered, yet in the spring of 1896 the water became red and turbid, and acquired an offensive smell due to the development of a species of Crenothrix. It was first remarked on March 1st when the large bath at a public school was being filled. The odour was most marked in water which had been heated. When the reservoirs were inspected the whole of the water in one was found to be of a brown-red colour and turbid. The water in the other reservoirs remained quite normal throughout. A reddish deposit was found on the sand filter, and by the end of April this had accumulated to such an extent that the beds became choked. The sand scraped from the surface when exposed in heaps exuded a dark red semi-fluid matter with a 'foul privy' odour. By the middle of May the water in the

affected reservoir had acquired an olive purple tint, which gradually changed to green, and by June 10th the water had acquired its normal colour, though it still remained slightly turbid. The organisms had evidently traversed the filter bed and entered the mains. Dr. Garrett says: 'The ability of the spore cocci to reproduce themselves will account for their swarming in our reservoir, and for their reproduction in, at least, some portion of the pipes—in fact, the study of the visitation constitutes an object-lesson in the ease with which a microbe may develop in the mains of a water service, and pollute a water which has been carefully filtered before being turned into the pipes. There are generally certain portions of the waterpipes where the chance of such a development is greater than elsewhere. I refer particularly to "dead ends" or cul de sacs, where the water is liable to become stagnant. An intermittence in the supply of any part of the service possesses a similar disadvantage, by leading to the disturbance of any growth or deposit upon the pipes, which will then be washed through the house taps.' This Crenothrix appears capable of developing only in waters containing a trace of iron in solution, and it has given rise to trouble in many towns both in America and on the Continent. The organism found in the Cheltenham water corresponded in the main with the description given by Kuhn of the Crenothrix polyspora, but certain differences caused it to be regarded as a variety, and Dr. Garrett called it Crenothrix polyspora var. Cheltoniensis. There are, doubtless, several species of Crenothrix. At the present time I am investigating complaints made with reference to the water supply to a town in East Anglia. The water is unfiltered and derived from subsoil springs. The supply has for some time been intermittent, and recently complaints have been received of bits of substance resembling raw potato coming through the house pipes, together with oxide of iron. When the street hydrants are open quantities of this gelatinous material, in thin sheets, are washed through. When kept it acquires an offensive fishy odour. The growth appears to be a kind of Crenothrix,

and is now undergoing examination. The typical Crenothrix I have previously found in several subsoil waters submitted to me on account of their having acquired an unpleasant odour and appearance. In connection with Crenothrix infection it is interesting to note that Dr. Garrett found the organism had no effect upon health. He says: 'Although, for many weeks during which it was affected, the water from the Dowdeswell Reservoir continued to constitute the main supply to the town, and although there were many complaints of the odour, appearance, and unpalatability of the water, there was no evidence to prove that the organism, which was being consumed in great numbers, had any pathogenic influence.'

In 1891 the water supplying Bolton (Lancs.) acquired a 'fishy' odour and taste. The reservoirs were found to be swarming with a confervoid growth, to which Dr. Adams attributed the odour and taste. It proved to be the Conferva bombycina of Kutzig, an organism often found in ponds and ditches, but why this sudden infection of an immense volume of water should have occurred is difficult to explain. Dr. Adams regarded its growth as being fostered by the presence in the water of phosphates, derived from manure and sewage on the watershed area.

In 1898 the water in a large reservoir supplying another important Lancashire town became infected with the same organism. A sample of the water was submitted to me. There was little difficulty in identifying the nature of the growth. Upon visiting the reservoir I found the water was rather low, and that the growth was taking place in the shallows, and was being gradually diffused through the water in the reservoir towards the outlet. The supply was not filtered, and when fine muslin was tied over any of the house taps in the town it was easy to collect a considerable quantity of the confervoid growth. In passing through the mains the cells disintegrated and imparted a faint odour and taste to the water. The reservoir water containing the living plant was devoid of odour.

Of the organisms, other than bacteria, whose mere presence in a water indicates pollution of any definite character, there are few which occur with sufficient constancy, and in sufficient number, to render desirable a special search being made for their detection and identification. In deep and shallow well waters, and in spring waters, the occurrence of any of the low forms of animal and vegetable life such as we are considering indicates inadequate protection, or unnecessary exposure to light. Uncovered service reservoirs are very subject to algoid growths, and all kinds of minute animals may gain access. Covered tanks, if lighted, are also likely to become infected with green algæ. Uncovered house-cisterns may become the repository of all kinds of filth. Whilst writing this section I have investigated the water supply to a private house, which had in a few days acquired an opalescent appearance, and a 'suggestive' odour and taste. As the supply came from the public mains, and was known to be satisfactory, I at once suggested an examination of the cistern, which was placed near the ceiling in the scullery. This was found to contain a piece of pork (about 1 lb.), a quantity of bread, remains of a packet of dry soap, and pieces of wall paper. These must have been wilfully placed in the cistern by one of the servants. A biological examination of the water was unnecessary.

The following organisms should be sought for in streams into which sewage or trade effluents discharge. The four in the first column are all forms of what is popularly called the sewage fungus, because they are confounded with each other very frequently, and all are liable to occur in sewage farm and bacteria bed effluents, and in streams receiving sewage or organic trade refuse:

Sphærotilus natans
Leptomitus lacteus
Beggiatoa alba
Carchesium Lachmanii

Oscillatoria tenerrima
Oscillatoria brevis
Oscillatoria tenuis
Oscillatoria antliaria
Oscillatoria Frœlichii

Mez, who has made a special study of the organisms found in different kinds of water, states that the following are

frequently found, and that if they occur in abundance, their presence indicates some measure of pollution :

Amphimonas fusiformis
Amphimonas globosa
Anthophysa vegetans
Aspidisca costata
Aspidisca Lynceus
Bodo caudatus
Bodo minimus
Bodo mutabilis
Cercomonas crassicauda
Cercomonas lacryma
Chilodon Cucullus
Chilodon uncinatus
Colpidium Colpoda
Colpoda Cucullus
Dimorpha longicauda
Enchelys silesiaca
Euglena olivacea
Euglena velata
Euglena viridis
Euplotes Charon
Euplotes patella
Glaucoma scintillans
Hexamitus inflatus
Hexamitus rostratus
Lionotus fasciola
Loxophyllum Meleagris
Monas guttula
Monas vivipara
Monas vulgaris
Oikomonas mutabilis
Oikomonas Termo
Oxytricha fallax
Oxytricha pellionella
Paramaecium Aurelia
Paramaecium caudatum
Peranema trichophorum
Phyllomitus amylophagus
Pleuromonas jaculans
Polytoma uvella
Stylonychia Mytilus
Tetramitus rostratus
Trepomonas rotans
Trepomonas Steinii
Urocentrum turbo
Urostyla multipes
Urotricha farcta
Urotricha lagenula

The Sphærotilus natans, Leptomitus lacteus, and Carchesium Lachmanii form tufts of filaments, like bits of cotton wool, though often coloured, adhering to stones, twigs, water-plants, debris, &c., in running water. They are not found in crude sewage, as their growth requires that the water should be aërated. To the naked eye the resemblance is too close for any but a trained observer to distinguish between them.

The Sphærotilus natans flourishes best in waters polluted with the discharges from breweries, sugar refineries, starch works, tanneries, and sewage works. It is most abundant during the winter months, and its presence indicates excessive pollution.

The Leptomitus lacteus will not flourish in very impure water, but may grow luxuriantly in good sewage effluents. The Carchesium Lachmanii is a member of the animal kingdom, and has been little studied in this country. Dr. Mez refers to it in some detail as being especially characteristic of sewage

pollution. It is closely allied to the Vorticellæ, and has apparently hitherto been generally confounded therewith. Although chiefly prevalent during the colder months, it is also found in the summer months. Its presence does not necessarily imply a high degree of pollution, but the probability of serious contamination is accentuated if it is found associated with Leptomitus or Sphærotilus in the colder months, or with Beggiatoa or Oscillatoria in the warmer season. It rapidly dies when removed from its natural habitat, and, as it is much more difficult to recognise when all its movements have ceased than when living, it should be searched for within a few hours of collection.

**Beggiatoa alba.**—This fungus, which coats the bottoms of streams, &c., with a white or greyish velvety covering, is usually found in stagnant or slowly moving water containing sulphuretted hydrogen. It is not found nearly so frequently as many writers would lead us to infer. The so-called sewage fungus is commonly one or other of the organisms above described.

The Beggiatoa have been especially studied by Winogradsky and Cohn. Many different species have been described, all capable of secreting sulphur. In some instances this element may form 90 per cent. of the total weight of the dried organism. Winogradsky is of opinion that the sulphur is derived from the sulphuretted hydrogen found in the water, and that the Beggiatoa do not produce this compound. Cohn, on the other hand, thinks these organisms are capable of decomposing albuminous matter, and even sulphates, with the production of sulphuretted hydrogen. Certain it is that the Beggiatoa are only found in water containing this gas, and it appears to be immaterial whether the water contains organic impurities or not. Thus the growth is found in the water from natural sulphur springs, as well as from sewage-polluted streams. Save in the natural sulphur springs, sulphuretted hydrogen is chiefly found in the waters of marshes, polluted streams, and in stagnant shallow bogs, such as are found on the Danish

Zeeland coast and the Limanes, along the coast of the Black Sea. In all the latter cases it seems probable that the sulphuretted hydrogen results from the decomposition of organic matter, and possibly, under certain circumstances of sulphates, by bacteria. Hoppe-Seyler believed that bacteria decompose cellulose with the formation of marsh gas, and that the nascent gas, acting upon calcium sulphate, gives rise to calcium carbonate, sulphuretted hydrogen, and water.

The Beggiatoa then decompose the sulphuretted hydrogen, storing up the sulphur in the free state, and afterwards oxidising it as required into sulphates. In this way the sulphur cycle is completed, as the sulphates taken up by or found in the plants are deposited in the cells in the form of complex organic compounds. Wherever the Beggiatoa are found, pollution of the water by organic matter undergoing putrid decomposition is to be suspected, but inasmuch as sulphuretted hydrogen may, as we have seen, be derived from other sources, the presence of this organism is not absolute proof of pollution.

The second report of the Royal Commission on Sewage Disposal, published in 1902, contains a very interesting report on 'the pollution of the river Severn,' by Messrs. Boyce, MacConkey, Grünbaum, and Hill, which includes a section on the 'Sewage Fungus.' They have had opportunities of studying the various organisms included under the general name of 'sewage fungus,' found in various polluted streams.

At Dewsbury, where they first met with the fungus, it occurred at the mouth of the main effluent from the sewage farm. The effluent was clear; the tufts of fungus very long and of a rusty colour, from a deposit of oxide of iron. The form was subsequently identified as Leptomitus lacteus. At Birmingham, in the stream receiving the various effluents from the sewage works, it occurred in enormous quantities, and had to be removed by screens to prevent secondary decomposition. The discovery of the fungus in a stream near Shrewsbury led to the detection of a previously unsuspected source of pollution from a workhouse. This form proved to be Sphærotilus

natans, which was afterwards found in the river Alt, producing characteristic tufts attached to the stones at the bottom of the river. In text-books the sewage fungus is almost invariably described as being the Beggiatoa alba, an organism which I have rarely if ever found in sewage effluents. Apparently this is also the experience of Professor Boyce and his colleagues, since they do not refer to it in the following paragraph, which gives the result of their observations. 'Classed under the heading of "sewage fungus" are certain distinct growths, the most highly organised of which is the Leptomitus, one of the Saprolegniaceæ, and therefore comparatively high in the scale of fungi. Next to it comes the Sphærotilus, which may be placed among the more highly developed forms of bacteria. There are also several bacterial zooglea masses, which may assume a branching appearance and simulate a sewage fungus. . . . In polluted brooks all the appearance of the typical fungus was sometimes caused by extensive growths of a protozoon, the Carchesium Lachmanni.'

The presence of Sphærotilus they found indicated much greater pollution than the presence of Leptomitus, the latter only occurring in well-oxygenated and comparatively slightly polluted waters, whilst the former grows well in any oxygenated sewage effluent. The zooglea masses above referred to are regarded as being closely allied to the Sphærotilus, if not identical therewith, and 'flourish best where the stream of sewage is most active and thinnest.' They found the Carchesium Lachmanni in great masses under similar conditions to those of the Sphærotilus, and they regard all the above low forms of life as playing no unimportant part in the process of sewage purification. They also found the Euglena viridis in certain field drains, and in an effluent from a coke bed upon which sewage was being treated. The Sphærotilus is probably most frequently confounded with Beggiatoa by inexperienced observers. According to my experience, the latter is only found living in waters containing sulphuretted hydrogen, whilst the former rarely, if ever, occurs in such a water.

Recently, however, I found an organism closely resembling, if not identical with, the Sphærotilus, in water polluted by the waste liquor from a paper works. This polluted water had a decided odour of sulphuretted hydrogen, and contained a considerable amount of sulphates. Masses of these organisms from time to time become detached from the stones, &c., upon which they have been growing, and, floating on the surface of a stream, enter into decomposition and give off most offensive odours, that of sulphuretted hydrogen generally predominating.

**Oscillatoria.**—These filamentous algæ are almost ubiquitous. They are found in all streams, whether the water be pure or impure. The non-motile forms, however, are rarely found in unclean waters, whilst a few of the motile forms are, according to Mez, very characteristic of polluted waters. The latter are nearly always black, and cover the beds of streams or the damp sloping banks. Floating organic debris covered with these organisms often occurs in masses on the surface of polluted streams. At certain periods these smell most offensively, and are popularly looked upon as being composed of fæcal matter which has escaped from drains, sewers, or sewage works. They abound in the summer or autumn, differing therefore in seasonal distribution from the other organisms most frequently associated with polluted streams. They are undoubtedly nature's scavengers engaged in the destruction of offensive matters, and in preparing the way for the appearance of higher forms of vegetable and animal life. In examining streams other definite organisms, characteristic of particular kinds of pollution, have occasionally to be sought for, as, for example, yeast, when contamination by brewery refuse is suspected.

**Examination of Sand Filters.**—The examination of filter beds may be conveniently considered in this place, since a knowledge of the biology of sand filtration is essential, in order that such an examination may be intelligently conducted.

Assuming that the filter beds are properly constructed, sufficient in number, and carefully supervised, it is not unusual for a bed which may have been acting properly for days to

suddenly pass water containing an excessive number of bacteria. It is for this reason that daily observation of the water from each bed is so requisite, for which purpose some arrangement is necessary to enable samples to be taken of the filtered water, and to 'cut out' of the system any bed not working properly. Unless this is done, one filter may be passing an impure water for some time before it attracts attention, and when such a defect is discovered, without the arrangement for obtaining samples from each bed, it would be often difficult to localise it. The discovery of the cause, in consequence of which a bed suddenly loses its efficiency, often taxes to the utmost the skill and experience of the engineer and biologist; but a knowledge of the causes discovered and recorded in previous cases, and of the principles underlying the process of sand filtration, will generally enable the investigator to arrive at a satisfactory conclusion. Notwithstanding the importance of this subject it receives little attention in this country; but in Germany, Holland, and America a large amount of systematic work has been done. In many large works in these countries biologists are constantly employed making observations at properly equipped stations. Dr. Kemna, who has charge of the station at the Antwerp Waterworks, recently contributed an interesting and valuable paper on the Biology of Sand Filtration to a meeting of the Institute of Water Engineers, and I am indebted to his paper for much of the following information.

When a filter is started it at first acts only as a coarse strainer, but in two or three days a slimy layer forms upon the surface of the sand, and true filtration commences. Green and blue algæ have interwoven their filaments into one felted sheet, diatoms, with their siliceous frustules and gelatinous envelopes, fill up the meshes, zooglea adhere to every particle, and innumerable bacteria dot the whole mass. Besides the plants generally resting on the top of the sand there are others which float on account of their protoplasm containing oil globules or bubbles of gas. The bottom dwellers occasionally rise to the surface when the oxygen evolved during their rapid growth

accumulates in their entangled masses. When such masses are seen rising to the surface the yield of the filter should be at once diminished, or the filter be thrown out of work, as the bacteria in the filtered water markedly increase in number under those conditions. The floating species fall to the bottom when they die. They sometimes occur in enormous numbers, imparting a distinct colour to the water, in which case the filters speedily become choked, the quality of the water is impaired, and it may acquire an offensive odour. Practically all the odour-producing organisms are floating forms. The colouring matter of the green algæ gets liberated, and may form a scum on the surface of the water, sticking to everything like oil paint. There is apparently a certain regularity in the seasonal appearance of the plants constituting the filtering film. Diatoms abound all the year round, but are especially abundant in winter. Green algæ appear in spring, and develop to a large extent in summer. The blue algæ are numerous in the hottest months, but disappear in winter. Dr. Kemna finds at Antwerp that the dominant forms are Melosira varians, Fragilaria capucina, and Spirogyra tenuissima, the proportions being about five, four, and one respectively. A growth of Hydrodictyon, a green alga, with the cells in pentagonal meshes, may cover the whole, and when the filters are cleansed this growth may be rolled up like a carpet.

Dr. Kemna refers to the following organisms as giving trouble to the water engineer: the fresh-water sponge, Spongillia, is of frequent occurrence in ponds and reservoirs and, while living, tends to purify the water, but when dead it decays and gives off a most offensive odour. A fresh-water polyp, the Bryozoa, has a tendency to fix itself to iron, something like a growth of moss, and as it grows within a water main may considerably reduce its calibre, and impart 'a most awful taste to the water.' The Crenothrix may gain access to the filtered water, the growth appearing in tufts of yellowish or brownish colour, and may be so abundant as to block up lengths of mains. This has occurred at Rotterdam, Berlin, and elsewhere.

The Cladocera, the most common form of which is the water-flea, Daphnia, may breed in spring in such numbers as to render the reservoir water turbid, and their dead bodies may form a thick layer on the filter bed. Dr. Kemna tells of ten tons being screened from one reservoir in a single season. Two insects are mentioned as sometimes affecting sand filters. One is a kind of gnat, named Chironomus, having an aquatic larva of red colour, usually called the bloodworm. These burrow in the sand, but when they are transformed into winged insects they come to the surface, and the tubes remaining empty and open, the filtering surface is riddled with innumerable holes, and the number of microbes in the effluent suddenly increases. The eggs of the Chironomus are embedded in a gelatinous cord, and sometimes the sides of a filter at water level are covered all round with these streamers.

The second form is the hemipterous Corixa, resembling somewhat the water-boatman, Notonecta. These may be so abundant as to render the water on the surface of the filter turbid by their activity in tearing up the sediment. They do not, however, appear to disturb the filtering surface to such an extent as to impair the quality of the effluent. Dr. Kemna mentions two vertebrates which have given trouble. One is the eel, which, when young, may get into the air channels provided to allow air to escape when a dry bed is refilled, and then into the water beneath. These air pipes, he suggests, should be covered with fine wire gauze. The other is the stickleback, which spawns about the beginning of May. He mentions that on one occasion, towards the end of the month, the microbes in the filtered water at the Wælhem Works suddenly increased from an average of about 20 to over 200 per cubic centimetre. The filter was examined, and it was found that there were patches of sand with the surface perforated, each group of perforations being regularly distributed round a central larger hole. This central hole was covered up by threads of algæ, weighted with small pebbles, and under this covering there was a mass of eggs of the ordinary stickle-

back (*Gasterosteus aculeatus*). Probably the male, in searching for building materials, made the numerous small holes surrounding the nest.

The organisms forming the '*schlammdecke*' of a 'ripe' filter vary with the source of the water being filtered. Waters from uplands and uncultivated moorlands form a deposit of slime of a different character to that from waters from cultivated ground or from rivers flowing through fertile valleys. The latter often form a *schlammdecke* rich in filaments of fungoid origin. The same filter bed often yields from different portions of its surface organisms of different type. On such occasions an examination of the dry surface of the filter will show marked variations in colour; sometimes the whole surface is dotted over with more or less circular patches of a reddish or yellowish green, the remainder of the surface being of a uniform green. These patches obviously result from the growth of certain algæ from and around a spore or filament which has been arrested by the filter. The dead and living forms of algæ and of fungi, &c. found in the *schlammdecke* are well nigh innumerable and they are agglutinated together by bacterial zooglea.

The plates at the end of the section on the Microscopical and Biological Examination of Water illustrate all the more important animal and vegetable organisms, &c., referred to in this section. With one or two exceptions they are drawn from actual specimens which I have found in examining waters from various sources, and in examining the surface of sand filters. A study of them will show how difficult it is to determine the true nature of many of the objects revealed by the microscope. Fortunately it is not always necessary to specifically identify every organism discovered in order to correctly interpret the results of the examination.

## CHAPTER X

### THE INTERPRETATION OF THE RESULTS OF THE BACTERIOSCOPIC EXAMINATIONS OF WATERS

THE danger arising from the use of a polluted water is probably never due to the organic matter in solution, or to the dead organic matter in suspension, but to living organisms—bacteria. A chemical analysis can tell us nothing about the presence or absence of these, and, as we have seen, a water may contain very large numbers of such organisms, and yet be chemically of a very high degree of purity. It would appear, therefore, that, for the detection of dangerous pollution, a bacterioscopic examination is of greater importance than a chemical analysis, and that in some cases a chemical examination may be superfluous. Too great an importance must not, however, be attached to bacterioscopic results, since great care is required in their interpretation. Want of experience, or a too rigid adherence to empirical standards, may easily lead to erroneous conclusions. Some knowledge of the history of water is in most cases absolutely necessary in order to enable correct inferences to be drawn. We must know not only the source of the water, but the mode of its collection, the period which has elapsed since the sample was taken, the conditions under which it has been kept, &c. Even when the number of bacteria present in the sample is ascertained, it must not be forgotten that it is the nature rather than the number which it is of importance to determine. An immense number of different species of bacteria are found in water, and the majority are apparently quite harmless, their presence having no known significance. Many of them are exceedingly difficult to

recognise. Some, which, if present, it is of great importance to detect, so closely resemble others of no importance, that very considerable skill is required to effect the differentiation. Even those which are of importance because their presence usually indicates pollution may have been derived from harmless sources and their presence may have little real significance. Moreover, waters actually known to have caused, or to be causing, diseases such as enteric fever and cholera may be examined by the most expert bacteriologist without the specific organisms being detected, and a water liable to specific pollution may, even on repeated examination, be found free from the organisms indicating such pollution. Volumes have been written on the bacteriological examination of water, yet the sum total of the information available, bearing upon the interpretation of the results, is comparatively small. Our views are undergoing constant change, new methods are being constantly devised, and old ones discarded. It is not, therefore, my intention to cover the whole ground included in the study of bacteria found in water, but to limit my attention almost exclusively to the bacteria which are of importance in the examination of waters for the detection of pollution derived from sewage or of manurial origin. Such pollution may be very recent or may have occurred at some distant period in the history of the water. With the exception of rain water collected from clean rocky or moorland surfaces, probably all waters at some period in their history come in contact with and take up sewage or manurial matters. The extent of this pollution is chiefly indicated by the amount of nitrates present in the waters, and can only be ascertained by a chemical analysis. Bacteriology can tell us but little, if anything, of such past pollution. At the present time the utmost that can be expected of the bacteriologist is that he shall say whether a water does or does not contain certain organisms which are usually associated with sewage and manure, and which, either by themselves or by their association together, indicate pollution.

The character and scope of a bacteriological examination will, naturally, vary with the object for which it is performed. Such examinations may be made for any of the following purposes:

1. To detect pollution with sewage or manurial matter.

2. To ascertain the efficiency of a system of filtration or other method of water purification.

3. To ascertain the effect of flow upon rivers and streams, or of rainfall upon streams, springs, and wells.

4. To ascertain the cause of some change observed in a water.

5. To detect, if possible, specific organisms during the epidemic prevalence of some water-borne disease.

The bacteriological examinations made for the above-mentioned objects can be divided into two classes: (1) the determination of the number of bacteria present in a given quantity of the water; (2) the identification of particular organisms or groups of organisms and an approximate estimation of their number.

When bacteriology was first applied to the examination of water, the estimation of the number of organisms present was held to be of the highest importance. When this idea had been exploded, the number of different kinds of organisms rather than the total number was regarded as being the more important, but latterly this view has received less support, and now it is deemed absolutely necessary to examine a water for certain definite microbes, the number of other organisms present being considered of comparatively trifling importance.

1. **The number of Bacteria present in Water.**—The enumeration of the bacteria present in a water is of greatest importance when the object is to ascertain the effect of filtration, but to determine the efficiency of a system something more than an occasional bacteriological examination is required. The arrangements for filtering should be inspected. Almost any kind of filter may on occasions yield a satisfactorily filtered water, but what is or should be required to be known

is whether the apparatus or arrangement can be trusted to give a uniformly good water under all ordinary circumstances. I have examined installations which at first gave practically sterile water, but which after a time yielded a filtrate containing more organisms than the unfiltered water. As previously stated, no system can be considered satisfactory unless it is sufficiently large to filter considerably more than the amount daily required, thus admitting of one or more filters being thrown out of use for recharging, cleansing, and repairing. Each filter, or filter bed, should be complete in itself and be separately connected with the main or filtered water reservoir, so that samples of water can be obtained from each filter, and at any time a filter can be cut out of the system and the water directed into another channel. There should also be an arrangement for regulating the rate of filtration.

When properly constructed and worked there is no difficulty in producing with sand filters a water which will uniformly contain less than 100 micro-organisms per c.c. capable of growing upon nutrient jelly at 20° C. in four days. This is the standard suggested by Koch, and generally adopted. Of course, it is understood that the sample examined is taken direct from the filter and plated almost immediately, or has been kept in an artificially cooled receptacle whilst in transit from the works to the laboratory.

This condition should in all cases be fulfilled where the number of organisms in a sample of water is to be determined, since it is well known that a rapid multiplication may take place within twenty-four hours of the collection of a sample, especially in warm weather. If the temperature is maintained within a few degrees of 0° C., keeping for a few hours, or even twenty-four hours, appears to make very little difference. When the character and not the number of bacteria is the object of the examination, these precautions are not absolutely necessary; but in all cases it is desirable to commence the examination as soon as possible after collecting the sample. Filtration works which produce uniformly a water containing

less than 100 bacteria per c.c. may, if otherwise satisfactory, be considered efficient. The results obtained by the various London Water Companies, as given in the monthly reports, show what is regarded as efficient filtration by the water examiners.

*Abstract from Report on the Composition and Quality of Daily Samples of Water supplied to London, for the month ending October* 31, 1903.

Result of Bacteriological Examinations

| | Microbes per c.c. |
|---|---|
| 'New River, unfiltered (mean of 26 samples) | 843 |
| New River, filtered (mean of 56 samples) | 30 |
| Thames, unfiltered (mean of 27 samples) | 16,671 |
| Thames-derived water from the clear-water wells of eight Thames-derived supplies (mean of 214 samples) | 66 |
| Thames-derived water from the clear-water wells of eight Thames-derived supplies (mean of 214 samples) highest | 558 |
| Thames-derived water from the clear-water wells of eight Thames-derived supplies (mean of 214 samples) lowest | 0 |
| River Lea, unfiltered (mean of 27 samples) | 470 |
| River Lea, from the East London Water Co.'s clear-water wells (mean of 27 samples) | 25 |

'Of the 297 daily samples taken from the filter wells of the Metropolitan Water Companies, twelve samples, or 4 per cent., were sterile. Fifty-one samples, or 17 per cent., contained more than 100 microbes, and of these thirty-four samples contained more than 150 microbes per c.c. The fifty-one samples contained an average of 186 microbes per c.c. In September twenty-seven excess samples contained an average of 182 microbes per c.c. It will be noticed, therefore, that, although an excess in the number of microbes has been more frequent during the month, the average character of the samples has not deteriorated.'

I make it a rule always to examine filtered waters for objectionable microbes, as a filtered water containing organisms indicative of sewage pollution, such as the bacillus coli, and spores of the bacillus enteritidis sporogenes of Klein, in relative abundance, could scarcely be considered satisfactory, however few other organisms it might contain.

In unfiltered water the number of bacteria varies enormously, but there is no doubt that in really good waters from springs, shallow wells, and deep wells there are rarely 1,000 per c.c. The character of the source has always to be taken into consideration in such an investigation, as upland and moorland surfaces yield waters which normally contain more bacteria than waters from springs and deep wells. River waters vary from day to day, and a very slight rainfall often suffices to send up the number of bacteria present considerably. How little reliance may be placed upon the mere enumeration of the number of bacteria is shown by the different standards set up by different observers. A comparison of the following table, embodying the standards of Miquel and Macé, shows what contradictory conclusions would be drawn by analysts adopting the respective standards.

| | Miquel<br>Per c.c. | Macé<br>Per c.c. |
|---|---|---|
| Very pure water . . . . . | 0 to 10 | 0 to 10 |
| Very good water . . . . | 10 to 100 | 20 to 100 |
| Good or pure water . . . . | 100 to 1,000 | 100 to 200 |
| Passable water . . . . . | 1,000 to 10,000 | 200 to 500 |
| Impure water . . . . . | 10,000 to 100,000 | 500 to 1,000 |
| Very impure water . . . . | Over 100,000 | 1,000 and upwards |

Both agree that waters containing less than 200 bacteria per c.c. are of good quality, but above this number their standards are hopelessly at variance. What Miquel would regard as a pure water, Macé would consider as impure and approaching the very impure.

Obviously these standards are absurd, as it is the quality and not the quantity of bacteria present which alone can help us to form an opinion with reference to the safety or otherwise of water from a given source. I say 'help' deliberately, as the most satisfactory results, both quantitative and qualitative, may be obtained from a water the source of which may be liable to dangerous contamination and therefore the most satisfactory result obtained upon bacteriological examination does not in itself enable us to certify a water as pure or safe, but it will aid us in coming to a correct conclusion if the

particulars of the source from which the water is obtained are known. Of course there are occasions when a bacterioscopic analysis may indicate some hidden and previously unsuspected source of danger. As a rule such danger is indicated by the variations in the number and character of the bacteria present in a water when samples are taken under different conditions. Such variations are usually most marked and most significant after a heavy rainfall. The bacteriological effect of rainfall upon streams, springs, and wells, and the effect of floods have often to be studied before an opinion can be given upon them as sources of supply. The greater the effect of the rainfall or of floods, the more unsatisfactory is the stream, spring, or well, as a source of water supply; but if a careful examination of the source shows that this is satisfactory, and if few or no bacteria are found which can be identified as of intestinal origin, any turbidity produced by a heavy rain may be regarded as of a practically harmless character.

2. **Search for Special Organisms or Groups of Organisms.** (*a*) *Organisms of Intestinal Type.*—As we have already seen, the isolation and identification of organisms of intestinal origin are in the great majority of cases far more important than the mere determination of the number of microbes in a water. The organisms invariably selected for isolation and identification are (1) the bacillus coli communis, (2) the bacillus enteritidis sporogenes of Klein, and (3) streptococci. These bacteria, as we shall see later, are found in all sewages and manured soils. The bacillus coli communis, which is typical of the coli groups, is, undoubtedly, a widely distributed organism, and is said to be abundant everywhere. It is certainly found in the excrement of human beings in enormous numbers, as well as in the excrement of other mammals and birds. As it is capable of multiplying outside the body of an animal, it is obvious that it must be a common constituent of road dust, and may be conveyed by such dust and be deposited in reservoirs, cisterns, and other receptacles for water, and be found in and upon everything which such dust can reach.

Notwithstanding this, its vitality outside the body is not great. In dark damp places it may multiply for a time, but under less favourable conditions it does not survive long. Even in soil it is unable to compete with the normal bacteria, and in water it only survives for a limited period.

It is contained in all samples of sewage in great numbers (100,000 to 1,000,000 per c.c.), and in a sewage specifically infected with the typhoid bacillus it would be relatively far more abundant than the latter organism. It is also believed that the bacillus coli communis is far more resistant than the bacillus typhosus, and, therefore, that a water containing very few or none of the former cannot contain any of the latter. The experiments made by Majors Firth and Horrocks, and recorded in the 'British Medical Journal,' September 27th, 1902 ('On the Influence of Soil, &c., on Enteric Fever'), tend, however, to show that the bacillus typhosus is more resistant than is usually supposed. These observers found that it lived as well in virgin soil as in sewage-polluted soil, and they succeeded in recovering it from soil seventy-four days after inoculation. In dry sand, however, it only survived twenty-four days, and in peaty soil it did not live so long.

It is quite possible that under certain unknown conditions the bacillus typhosus may survive, or even multiply, in water, even after the disappearance of the bacillus coli communis; but the evidence of experience certainly tends strongly to prove that such conditions rarely, if ever, occur in nature; hence, until the opposite is proved, we may continue to regard the absence of the bacillus coli from a water as indicating the absence of the bacillus typhosus also.

Unfortunately much that has been written with reference to the presence of the bacillus coli in water has no importance, since observers have so often failed to describe the processes they employed, and the characteristics of the bacteria which they have regarded as the bacillus coli. In other cases the descriptions given show, beyond doubt, that more than one organism has been regarded as the bacillus coli. By some

described processes not more than a few thousands of the bacillus coli can be demonstrated in a cubic centimetre of crude sewage, whereas by others hundreds of thousands are indicated. Moreover there are certainly several types of this organism, and whilst some apparently regard all as varieties of the bacillus coli communis, others regard them as distinct species, and restrict that name to one particular form.

It is obvious, therefore, that, to avoid further confusion, some classification should be adopted, the name bacillus coli communis being restricted to an organism having certain very precise characteristics. It is now generally agreed that there is a fairly well-defined group of bacilli, the members of which have the following characters in common, as laid down by Klein, his conclusions being based upon the investigations of many observers:

'(*a*) They grow well on gelatine at ordinary temperature, although they grow, of course, better on agar at 37°C.; (*b*) they cause, when growing in broth cultures at 37°C. in twenty-four hours, uniform turbidity, due to their rapid multiplication; (*c*) they are capable of growing in broth, gelatine, or agar, to which ·05 per cent. phenol has been added; (*d*) they are capable of growing in the depth of the culture media (are, in effect, facultative anaërobes), although their growth on the surface—that is, exposed to oxygen of air—is quicker and more copious; (*e*) they do not at any time liquefy gelatine—namely, do not peptonise gelatine (this latter characteristic is of importance, since there have become known certain microbes which, in morphological and some cultural characters, resemble the coli bacilli in a marked degree, but which on continued observation, owing to their more or less slow liquefaction of the gelatine, can with certainty be distinguished from them); (*f*) growing on the surface of gelatine, their young colonies are flat, dry-looking, more or less translucent expansions, which can be best compared with a vine leaf—that is, a prominent excentric, or sometimes central thickened part, and a filmy crenate irregular peripheral portion; (*g*) in streak culture on gelatine they form a rapidly expanding flat, dry, more or less translucent

band, with irregular crenate margin; (*h*) under the microscope they are cylindrical rods, showing more or less pronounced motility; they do not stain by the Gram method.'

The above group of bacilli can be subdivided into three: the first, or coli communis group, including all the bacilli bearing the closest resemblance to the bacillus coli communis; the second, or enteritidis group, including the bacilli more nearly resembling the bacillus enteritidis of Gaertner; and the third, or typhoid group, those resembling the bacillus typhosus.

It may here be remarked that the bacillus enteritidis sporogenes of Klein, which will be frequently referred to later, is not a member of any of these groups. This must be carefully remembered, or confusion will arise from the similarity in the names of two very different organisms.

Klein and Houston, who have most fully studied the above groups, especially in their bearing upon the detection of pollution in water, define their classification as follows:—

1. *The Coli Communis Group.*—The bacilli included in this group are motile and possess a limited number of flagella, two, three, or more, the flagella being relatively coarse and a little wavy. They are capable of fermenting glucose and lactose, of curdling milk with the production of acid, of forming indol in broth cultures, of reducing neutral red with the production of a green fluorescence, of producing gas bubbles in glucose gelatine, and of forming a more or less brownish growth on steamed potato.

2. *The Enteritidis Group.*—The members of this group, on the other hand, possess numerous long, thin spiral flagella, ferment glucose but not lactose, do not curdle milk, but, whilst at first producing acid, afterwards render the milk alkaline; do not produce indol, form on steamed potato a translucent colourless growth, give gas bubbles in glucose gelatine, and reduce neutral red.

3. *The Typhoid Group.*—The members of this group possess long thin spiral flagella, are very motile, do not curdle milk or produce indol, do not ferment glucose or lactose or give gas

bubbles in glucose gelatine, or reduce neutral red. They are readily agglutinated by the blood of a typhoid-immunised animal in high dilutions.

The above subdivision of the more important intestinal organisms does not quite agree with that adopted by Professor Boyce and others, and contained in a report recently prepared by them for the Royal Commission on Sewage Disposal, concerning the river Severn in the Shrewsbury district. In consequence of the criticism to which their results have been exposed, they give the following summary of their investigation of this group :—

'Numerous organisms have been described under different names which really belong to the same family, and merely show insignificant variations from the original type. Experience has shown us that these variations are not constant, and consequently are not to be relied upon. Instead, therefore, of attempting to identify with its special variety every organism which we have isolated, we have endeavoured to gather them together into groups, and to differentiate the groups by reactions which are constant. One example of our method will suffice.

'A subculture of the original bacillus coli communis (Escherich) was obtained and worked out. It had the following biological characteristics :—

'*Morphology*.—A non-sporing, slightly motile organism, usually short, but with many long forms.

'It does not liquefy gelatine, and does not stain by Gram's method.

| | |
|---|---|
| Bile-salt glucose broth. | Acid and gas. |
| Glucose broth. | Acid and gas. |
| Lactose broth. | Acid and gas. |
| Mannite broth. | Acid and gas. |
| Cane-sugar broth. | No change. |
| Indol. | Usually present, but not always. |
| Milk. | Acid and clotting. |
| Agar and gelatine. | Moist, whitish or greyish growth, showing nothing characteristic. |

'Now the characters which so far have been shown to be constant are—

'1. The non-formation of spores.

'2. The non-liquefaction of gelatine.

'3. Acid production in milk.

'4. The reactions in the various sugars.

'Under the following heads, however, variations do occur:

'1. *Gram's Method.*—A. Schmidt has found that under certain circumstances members of the bacillus coli group retain Gram's stain.

'2. *Milk.*—The coagulation of milk is also somewhat unreliable, as we have isolated organisms which at first coagulated milk, but later did not, and *vice versa.*

'3. *Indol.*—The production of indol is very variable. The same organism will sometimes give the indol reaction, and sometimes fail to give it. The production of indol apparently depends upon some unknown quantity in the broth.

'4. Organisms have been isolated which correspond in all other particulars with bacillus coli communis, but which caused changes in saccharose broth.

'5. *Motility.*—This is another doubtful point, for the bacillus Neapolitanus gives the reactions of the group, and yet, so far as is known, is non-motile.

'6. *Flagella.*—The bacillus coli (Escherich) has usually four to eight flagella attached all round the organism, but bacillus coli communis forms have been described with only one terminal flagellum.

'For the above reasons, then, we would for the present define the B. coli communis group as consisting of organisms which have the following characteristics:—

'1. They are non-sporing and non-liquefying.

'2. They rarely stain by Gram's method.

'3. They produce both acid and gas with both glucose and lactose, and may do so with saccharose.

'4. They produce acid in milk, and usually also coagulate it.

'5. They produce acid and gas in bile-salt glucose broth.

'6. They grow well at a temperature of 42° C.

'We would, therefore, include in the B. coli communis group such organisms as—

'B. Neapolitanus (Emmerich).

'B. Acidi Lactici (Hüppe).

'B. Cavicida (Brieger).

'B. Capsulatus (Pfeiffer).

'Some organisms, such as B. pyogenes fœtidus, give all the reactions of B. coli communis except gas production. The position of these organisms is at present doubtful.

'Another group which suggests itself is the Gaertner group. It includes such organisms as the—

'B. Enteritidis (Gaertner).

'B. Psittacosis (Nocard).

'B. Choleræ Suum (Flexner)—

and differs from the B. coli communis group in causing no change in lactose or cane sugar, and in not clotting milk, but resembles the B. coli communis in its power of producing acid and gas in glucose and mannite media. A third group is the typhoid group, which produces only acid with glucose and mannite, and does not affect lactose or cane sugar. In milk there is either no change or only a slight acid production.'

Levy and Brun ('Archiv für Hygiene,' vol. xxxvi.) go so far as to assert that the 'true bacillus coli of fæcal origin' can only be identified positively by a demonstration of its virulence. This view has not been confirmed by other bacteriologists, and recently Dr. Savage ('Journal of Hygiene,' vol. iii. no. 3) has recorded a series of experiments, as a result of which he arrives at the following conclusion:—

'These experiments,' he says, 'lend no support to the view that the pathogenicity of isolated B. coli is of help in determining the potency for evil of the water examined. Virulence as a property of B. coli is, I believe, a very variable character, and one which can be readily lost, and with greater difficulty acquired, and the view advanced by some writers . . . that

toxicity is a specific distinguishing character, seems to be without foundation.'

The bacillus coli communis group, as defined by Boyce, would include several organisms of the intestinal type which would be excluded from that group in the classification adopted by Klein and Houston. To avoid any possibility of confusion, in this work the bacteria which are capable of growing freely in a bile-salt glucose broth, with the production of acid, are referred to as organisms of 'intestinal type,' although all the bacteria giving this reaction are not of intestinal origin. All non-spore-bearing bacilli capable of fermenting glucose and lactose, which are motile and do not liquefy gelatine, are regarded as belonging to the coli groups, of which three are recognised, 'A,' 'B,' and 'C' (*vide* Chart, Chap. XVII.). Group A contains the B. coli communis and its varieties, all of which produce acid and clot in milk and indol in peptone solution and do not stain by Gram's method. Group B contains such bacilli as differ from the former in one of these particulars only, whilst group C includes those which differ in two or more particulars.

The B. coli communis or 'A' group, corresponds closely to Klein's description of that organism, but it is certainly a 'group,' and not a definite species, as, by the use of dulcite, mannite, sucrose, and neutral red solutions, a further differentiation can be effected. At present no useful purpose would be served by defining further the members of this group, and the classification is one merely adopted for convenience in explaining the steps in the process to be described later for the bacteriological examination of water, and for the prevention of any misconception in the discussion on the interpretation of the results.

The bacillus coli communis, as defined by Klein, is the one which he and Houston find in such numbers in all sewage, and the one for which a special search should be made in the bacteriological examination of drinking waters. The presence of allied forms has, at present, no known significance, as we know little or nothing of their relation to sewage or similar filth.

In a recent paper, Dr. Klein gives very concisely his view with reference to the importance of careful identificatcn. He says :

'The detection, therefore, of the presence of coli-like bacilli, bearing no near resemblance to B. coli communis, does not permit any definite expression of opinion as to the probable, or even possible, derivation from sewage, or as to probable pollution with filth, of the material from which such microbe has been isolated. It is different, however, with the microbe above referred to in detail as B. coli communis—that is, the typical B. coli. As to this micro-organism, it is known for certain that its common habitat is the bowels of man and of the higher animals, and that domestic sewage and excremental matter, and everything directly or indirectly polluted with these matters, contain the B. coli communis—that is, the typical B. coli. In domestic sewage, this microbe is present to the extent of 100,000 to 800,000 per one c.cm. of the sewage, and Dr. Houston and myself have shown that sewage, added to sterile water in such small quantities as to defy chemical analysis, is readily detected by the bacterioscopic test—namely, the detection of B. coli communis.

'To summarise, then, the foregoing, the following propositions hold good :—

'1. The circumstance that a microbe shows the characters common to all groups of the coli tribe does not suffice to identify it for useful purposes. For proof that it is B. coli communis, or that it belongs to the group of B. Gaertner or B. typhosus group, it has to comply with the several tests agreed by all observers as characteristic of one or other of these groups.

'2. The fact that a microbe, owing to insufficient response to certain presented tests, can only be described as a coli-like microbe, is at present of indeterminate value in making a definite diagnosis of sewage or other pollution.

'3. B. coli communis is a microbe which has its habitat in bowel discharges—that is, excremental matters—and is contained therein in enormous numbers; its presence, therefore,

in any material in appreciable and relatively large amounts, is highly suggestive of sewage and excremental pollution.'

It will be observed that Klein does not regard the mere detection of the B. coli communis as being absolute proof of contamination, but its presence in 'appreciable and relatively large amounts' is 'highly suggestive of sewage and excremental pollution.' This is a most important qualification, and ignorance of it has led many analysts to condemn waters which I have been certain were free from any trace of sewage pollution. For the last few years I have made a systematic search for the B. coli communis in all waters submitted to me for bacterioscopic examination, and although I have, in the majority of cases, found that the presence of this organism was associated with pollution, even when the latter was not indicated by the chemical analysis, I have, on many occasions, found it in waters above suspicion of pollution. In one case, the water from a deep well supplying a certain town was found to contain the bacillus coli communis. Upon examining the sample sent me there was no difficulty in finding it in so small a quantity of the water as one cubic centimetre, but even on using a considerable quantity of the water the bacillus enteritidis sporogenes, which is always associated with the B. coli communis in sewage, could not be detected. I visited the town, and found the well was in the open country, far from any inhabited houses. The water was derived from the chalk, which at this point was covered by 300 to 400 feet of London clay, and the nearest outcrop was twelve miles away. A sample of the water from the rising main was collected, and upon examining it, the B. coli communis was found to be present. Chemically the water was of the highest standard of purity. I have examined several samples of the water since, but without detecting any organism of the coli groups. How the water became infected could not be ascertained, but as I was certain that under the circumstances the presence of the organism had no significance, I certified that, in my opinion, the water was of excellent quality, and free from sewage or manurial pollution.

On the other hand, the presence of this organism in a spring water led me to make such an examination that a serious source of pollution was discovered. The spring in question yields an enormous volume of water, and for years has supplied a town of some importance. Chemical analyses, made from time to time, had always given satisfactory results. When a bacteriological examination was made, the bacillus coli communis was found, and the Water Company were apprised of the fact. I was consulted, and samples were examined in my laboratory. At first the B. coli communis only was found, but at a later date the B. enteritidis sporogenes was also detected. I visited the spring, which issued from crevices in the mountain limestone, examined the country for miles round, and came to the conclusion that the pollution must be coming from a certain direction, and most probably from a point near the bend of the river where water might enter through fissures, and flow towards the spring. The river water contained both organisms, and the little soil covering the rocks where the suspicious fissures occurred simply swarmed with them. A strong alkaline solution of fluorescin was allowed to flow for twenty-four hours into the water over the fissure. This was speedily carried away, but no trace of it appeared in the spring water. I next caused half a ton of salt to be placed in the fissure, and a sample of water to be collected every three hours from the spring. The chlorine in the water increased within the twenty-four hours, and speedily fell to the normal after the whole of the salt had been dissolved. There could be no doubt that the organisms found in the spring water came from the river at the point examined, which was over a quarter of a mile from the spring.

In Derbyshire, a few years ago, I traced the pollution of a spring to the effluent from a sewage works, which entered the river about half a mile above the spring. Upon examining this river I found that between two given points, the volume of water in the stream, which was very low, and consisted chiefly of sewage effluent, had decreased. This obviously could only

have occurred by some of the water finding its way into a fissure. When the river bed here was concreted, the pollution ceased. The affected spring in this case not only contained sewage organisms, but gave indications of sewage pollution upon chemical analysis. As there were no houses or other sources of pollution near, the theory of sewage contamination had been scouted.

(*b*) *The Bacillus Enteritidis Sporogenes of Klein.*—The results of my experience do not lead me to regard the presence of the bacillus coli communis as absolute proof of sewage or manurial pollution, unless the presence of the spores of the B. enteritidis can also be demonstrated. Unfortunately, in sewage, the latter organism only occurs in comparatively small numbers. Houston rarely found more than 2,000 spores in a cubic centimetre, and often as few as 100.

This organism was first fully described by Klein, who found it in all sewages, in house manure, earth from manured fields, &c. He could not detect it in the dung of cows or pigs. Other observers, however, appear to find that it is very widely diffused, and assert that it occurs in many places where sewage or manurial contamination is improbable, if not impossible. Klein, however, has recently pointed out that many of these observers are mistaken, since they have confounded some other organism with the true enteritidis sporogenes. Here again, therefore, the utmost care is necessary to obtain reliable results.

The characteristics of the B. enteritidis sporogenes, as laid down by Klein, are as follows:—The bacilli are 0·8$\mu$ in thickness, and from 1·6$\mu$ to 4·8$\mu$ in length, but a few are longer than this, and they may form short chains. There are several long flagella at one or both ends. They readily form spores, which are, at first, glistening globules, generally near one end, but gradually increase in size, becoming oval bodies 1·6$\mu$ in length, and as much as 1·0$\mu$, or even 1·2$\mu$, in thickness. Stained in boiling fuchsin, and then in methyl blue, the spores become coloured dark pink, while the bacillary substance is stained blue. The bacillus is motile, and is an obligatory anaërobe. On

solidified serum the growth at 37° C. is copious, and the formation of spores sets in in two to three days, the serum being gradually liquefied. It grows well in agar to which 2 per cent. of grape sugar has been added. In sub-cultures in this medium it rapidly forms copious gas bubbles, by which the agar becomes split up and torn in different directions. It liquefies grape-sugar gelatine, with the formation of gas. The spores do not lose their power to germinate if exposed to 80° C. for fifteen minutes; they are, however, killed if immersed in boiling water for two minutes. Recently boiled milk, inoculated with the spores and incubated at 37° C. in a Buchner's tube, undergoes the following typical changes within twenty-four hours:— There is copious gas formation, by which the cream layer is deranged or entirely destroyed, the milk becoming changed into colourless, clear, or slightly turbid whey, on the surface of which accumulate faintly pinkish flocculi of casein; at the bottom and side of the tube are a few casein masses. The whey has an acid reaction and a strong smell of butyric acid. It is found to be swarming with the bacilli, but *these do not, at any time, form spores in milk cultures.* The whey, containing the bacilli, is pathogenic to rodents.

The presence of the spores of the bacillus enteritidis sporogenes unaccompanied by the bacillus coli communis, is not regarded either by Klein or by Houston as being sufficient to indicate actual pollution of a water. The spores being more resistant than their bacilli, their presence may possibly indicate previous contamination, but at a period so distant that this bacillus and the bacillus coli have failed to survive. In many instances I have found these spores in waters which did not contain the bacillus coli, but looking back at my reports I am now doubtful whether the organism found in such cases always was the true enteritidis sporogenes. In Klein's original description of this organism it was not stated that it did not produce spores when grown in milk in the way which he describes. I certainly remember in one instance where the milk reaction was somewhat typical that the bacillus present in the whey

was producing spores ; hence this was not the true B. enteritidis of Klein, though at the time I regarded it as such.

In the report of the Medical Officer to the Local Government Board for the year 1901–2 Dr. Klein gives the results of his experiments on the 'Differentiation of the several anaërobic microbes commonly present in the intestinal contents of man and other animals.' Three microbes are described: the B. enteritidis sporogenes, the B. butyricus (Botkin), and the B. cadaveris sporogenes. The two former, or rather their spores, are usually found associated in sewage and manurial matter and 'are notably present too in intestinal discharges of man and animals,' whilst the third occurs normally in the intestines of man and animals and is the 'principal instrument in the disintegration and dissolution of the viscera of the dead body.' This close association with filth and with decomposing animal matter makes their differentiation a matter of little importance in water analysis, as the presence of any one of them is significant of pollution. Such being the case, it is difficult to understand the following passage which occurs in Klein's report (p. 407): 'It is then association of the spores of these three anaërobes with which in the bacterioscopic examination of filth, or of materials polluted with filth or dust, we are constantly confronted—a circumstance which might, to the uninitiated, make correct diagnosis a matter of great difficulty and lead easily to error, as I shall have opportunity to show.' A careful perusal of the remainder of the report shows that the only danger to be apprehended is that the milk reaction not being quite definite, and the organism not being pathogenic to rodents, the water might be reported as containing no B. enteritidis sporogenes, whilst it might contain the B. cadaveris sporogenes, which is apparently equally significant of pollution. Unless an organism obtained from a water gives all the reactions of B. enteritidis sporogenes, it must now be wrong to definitely call it by this name; but for the purposes of the water analyst it will suffice if such reactions are obtained as identify it as being either that or one of the other allied organisms. The milk test in 48 hours practically suffices to detect the B. butyricus

or B. enteritidis sporogenes, but not to differentiate them, though the absence of a definite reaction in this time does not preclude the presence of the B. cadaveris sporogenes. The incubation should be continued for seven days to ascertain whether the change indicating the presence of the latter is produced. The following table is a slight modification of the one given by Klein of the essential differences between these three anaërobic microbes.

| I.—Bacillus enteritidis sporogenes | II.—Bacillus butyricus | III.—Bacillus cadaveris sporogenes |
|---|---|---|
| 1. Cylindrical rods, on the average 2·5—3·5$\mu$ long, 0·8—1·25$\mu$ broad, stains well by Gram's method, some individuals motile. | 1. Same as I. | 1. Cylindrical and thread-like, thinner and longer than I. and II., very motile, stains by Gram's method. |
| 2. Spores oval; stain after the several methods; situated in the middle of the rods more or less, 1·6$\mu$ long, 1$\mu$ broad. | 2. Same as I. | 2. Spores oval, terminal, drumsticks, stain after usual methods 1·6$\mu$ long, 1$\mu$ broad. |
| 3. On gelatine grows well, softens rapidly and slowly liquefies. | 3. Grows well on the surface of ordinary gelatine as a translucent mass of convoluted threads; does not liquefy the gelatine. | 3. Rapidly liquefying, putrid odour, numerous spores formed. |
| 4. In stab gelatine much gas produced; spherical colonies without filamentous projections; slowly liquefying. | 4. Forms spherical colonies with numerous horizontal filamentous projections; not liquefying; forms much gas. | 4. Much gas, rapidly liquefying, putrid odour. |
| 5. On the surface of agar grey round flat colonies, few crenations, no spores. | 5. Grey round flat colonies, margin thin and much crenate, no spores. | 5. Thready branched colonies, with or without finely granular plate, rapidly forming spores. |
| 6. Stab in agar, little tendency for forming lateral branching, much gas, no spores. | 6. Forms characteristic bundles of threads projecting laterally from the growth in the stab, much gas, no spores. | 6. Much gas, rapidly forming spores, conspicuous masses of threads growing out of stab. |
| 7. In milk rapid separation of acid whey and flocculi of casein, smell of butyric acid, no spores, much gas. | 7. Same as I. | 7. Milk is slowly decomposed, putrid odour, much gas, rapidly forming spores. |
| 8. Grows well on serum, slowly liquefying, some spores found. | 8. Grows well on serum, very slow softening. | 8. Rapidly liquefying, putrid odour, rapidly forming spores. |
| 9. Virulent for rodents. | 9. Not pathogenic for rodents. | 9. Not pathogenic for rodents. |

The absence of the spores of the bacillus enteritidis sporogenes in many waters containing members of the coli group in abundance is somewhat difficult to explain. I have frequently examined waters showing the presence of the bacillus coli communis in 1 c.c. in which the spores of the B. enteritidis sporogenes could not be detected in 500 c.c. Probably they would have been found if larger quantities of water had been used for the purpose. Dr. Houston thinks the spores, not being motile, may be more easily arrested by the soil through which water passes, and may have a tendency to attach themselves to small particles of insoluble matter floating in water and be carried down therewith. For this reason in a turbid water the presence of these spores may have little significance, unless there are also present other organisms indicative of pollution by sewage or manure, whilst in clear water the absence of the spores may be due to a filtration, too imperfect, however, to prevent the passage of such motile organisms as the B. coli communis and the B. typhosus. Whatever the explanation may be, I have undoubtedly found the spores of the B. enteritidis sporogenes more frequently associated with the B. coli communis in dull or turbid water than in bright waters.

Professor Boyce does not regard the B. enteritidis sporogenes of Klein as so reliable an indicator of sewage pollution as the B. coli communis, as he has failed to find it in river waters known to be polluted. He, however, does not accept the so-called typical milk reaction as conclusive proof of its presence unless its pathogenicity to guinea-pigs has also been demonstrated. He also regards it as being much more widely distributed than the B. coli. A test which requires confirmation by animal inoculation is of very little practical use, but I do not regard the test for pathogenicity as necessary. My experience has led me to lay considerable stress upon the milk test for the B. enteritidis sporogenes when applied as described by me in a later section. On the rare occasions on which this organism is found, and the B. coli communis cannot be detected, or the other occasions on which the B. coli

communis is found and the B. enteritidis sporogenes cannot be discovered, other considerations, especially the examination of the source of supply, or the examination of samples from the source taken under different conditions, have generally enabled me to draw safe inferences. In the great majority of instances, however, when the one organism is found the other is detected, if suitable quantities of water are used for the examination.

(*c*) *Streptococci.*—As the B. coli and the B. enteritidis sporogenes of Klein may be present in water not very recently polluted, Houston has made a further study of the subject and has come to the conclusion that recent contamination with sewage or with the washings of cultivated soil is more certainly indicated by the presence of streptococci. In his report to the Medical Officer of the Local Government Board (1899–1900), p. 458, he says :

'In studying the bacteriology of polluted soils, of crude sewage and sewage effluents, and of impure waters, I have endeavoured to find some organism, or class of micro-organism, which might be of value, if present in water, as indicating recent and objectionable pollution.

'In polluted soils, in crude sewage, in sewage effluents, and in impure waters, I have found streptococci and staphylococci to be present, often in great numbers.

'Although not discarding the class of germs known as staphylococci, I lay less stress upon them for the reason that they comprise hardy germs capable of persisting under circumstances the reverse of favourable.

'Streptococci, on the other hand, may, as a class, be thought of as germs especially liable to discouragement by unfavourable physical conditions, and indeed as surviving only when the conditions are almost ideally propitious. In the present state of our knowledge, therefore, the presence of streptococci in a substance, be it soil or sewage or water, suggests recent association of certain ingredients of that substance with an animal host. I say this because streptococci are known to inhabit the

alimentary tract, and for this reason that the large numbers which I have found, and habitually found, in crude sewage (1,000 or more per c.c.) lead me to conclude that the source of these germs is the recent evacuation of animals. I cannot, indeed, persuade myself that multiplication of extruded streptococci is likely to take place in raw sewage to any great extent, if at all: far more likely is it, in my belief, that they rapidly lose their vitality and die. Yet I am not claiming that all streptococci are delicate germs, for my own work is against such a view: nor am I asserting that the absence of streptococci in a water implies "purity or safety." But I contend that, in so far as streptococci, as a class, tend outside the animal body to rapidly lose their vitality and die, they are micro-organisms to be thought of as of recent animal outcome, and as not unlikely to be, moreover, pathogenic, so that, though their absence in a water may be of little moment, their presence therein is suggestive of recent pollution, and may therefore be of great importance. In brief, while not considering that the absence of streptococci implies "purity and safety" in a water supply, I am by way of urging somewhat strongly that their presence, at all events in any number, is positive evidence of a sort to go far to justify the bacteriologist in condemning a sample of water as unfit for domestic use.'

Assuming that extended observations confirm Dr. Houston's conclusions, the bacterioscopic examination of a water will include a search for the bacillus coli communis, for the bacillus enteritidis sporogenes, and also for streptococci. The discovery of the B. enteritidis spores alone may indicate contamination at a somewhat remote period; the presence of these spores associated with the bacillus coli communis, without streptococci, would more certainly indicate pollution, but much more recent in character, whilst the discovery of all three organisms would probably be conclusive proof of very recent contamination—that is, contamination of a very dangerous character.

My experience with streptococci has been very limited, but

in examining a number of waters recently, a streptococcus was found in a broth culture from one water in which neither the bacillus coli communis nor the bacillus enteritidis could be detected. I assumed that, in this instance, the presence of the organism had no significance, especially as there was no other reason for suspecting that the water was polluted. So far as I can see, the only advantage to be derived from an examination for streptococci is to ascertain whether pollution is very recent or somewhat remote. This is evidently Dr. Houston's own view, since in his report to the Medical Officer of the Local Government Board (1899–1900, p. 473) he says: 'Lest it should be asked: of what value is this test if it fails in the presence of pollution of sufficiently gross character to be demonstrated both by chemical means and by ordinary bacteriological tests? let it be remembered that no claims have been made that the absence of streptococci necessarily implies "purity or safety," but only that their presence is significant of animal pollution of recent sort. No conclusion whatever can be safely drawn from the absence of streptococci, although it may perhaps hereafter be established that the absence of streptococci from a considerable bulk of water (filter-brushing method) is negative evidence of very recent, and therefore presumably specially dangerous, animal pollution.'

Major Horrocks discussing the significance of the presence of streptococci ('Bacteriological Examination of Water,' p. 124) says: 'My experience does not support the contention that streptococci probably indicate a dangerous contamination. . . . The sewage streptococci appear to maintain their vitality in sewage for a much longer time than B. coli. Specimens of barrack sewage preserved in a laboratory cupboard for three months, and then diluted 1–100 or 1–1000 with tap water, show, when examined by the usual methods, large numbers of streptococci, but few or no bacillus coli. Old sewage from which B. coli has disappeared will be unlikely to present conditions favourable to the prolonged vitality of the B. typhosus or Sp. cholera. Consequently it appears that

streptococci alone cannot be considered as necessarily indicating a dangerous contamination. It is true that when the dilutions of old sewage are kept for a few days, the streptococci rapidly disappear, so their presence in a water supply undoubtedly indicates a recent contamination, but the contamination is not necessarily dangerous, unless the streptococci are accompanied by B. coli.'

I have confirmed the observation of Major Horrocks as to the comparatively rapid disappearance of the B. coli communis in sewage, and of streptococci in highly diluted sewage, and at present I am not inclined to regard the routine examination of a water for the presence of streptococci as being necessary. If I found them in the absence of B. coli communis and of the spores of the B. enteritidis sporogenes, I should regard their presence as being without any serious significance, and if found associated with the two above-mentioned organisms, it would merely confirm the conclusion at which I should have arrived had I not examined for streptococci.

(*d*) *Quantitative considerations.*—So far nothing has been said with reference to the quantitative side of the problem. There are few, if any, waters in which the bacillus coli cannot be found if a sufficient quantity of the water be taken for examination, and the other organisms above referred to may on occasions be found in pure waters, if samples are sufficiently often examined, and large quantities used for the purpose. As the detection of sewage or manurial contamination by bacteriological methods must depend upon the discovery of the bacteria characteristic of excremental matter, a very important point remains for discussion, viz. the amount of water which should be used for the examination. Chemical analysis cannot be depended upon to detect pollution with ·1 per cent. of sewage, or with 1 per cent. of most sewage effluents, which sewage effluents might practically contain all the organisms of the original sewage. Bacterioscopic analysis may be depended upon to detect a much smaller quantity of polluting matter. Unfortunately the number of the selected organisms found in

sewage varies enormously, and the proportion of each to the others varies in every sample. In relative abundance they occur in the following order: Bacillus coli communis, streptococci and spores of the Bacillus enteritidis sporogenes of Klein. Houston and Klein find the variations are within the following limits:

| | | |
|---|---|---|
| Bacillus coli communis . . . . | 100,000 to 800,000 | per c.c. |
| Streptococci . . . . . | 1,000 to 10,000 (?) | „ |
| Spores of B. enteritidis sporogenes . . | 100 to 2,000 | „ |

Assuming that efforts are limited to the detection of pollution corresponding to one-millionth part of sewage containing the minimum number of these organisms, it is obvious 10 c.c. of the water would be required to give indication of the presence of the bacillus coli, 1,000 c.c., or one litre, to afford evidence of streptococci, and ten litres for the detection of the spores of the B. enteritidis sporogenes.

On the other hand, assuming the polluting matter to contain the maximum number of the above organisms, one to two c.c. would suffice for the detection of the B. coli communis, 100 c.c. for streptococci, and 500 c.c. for the spores of the B. enteritidis sporogenes.

I am convinced that standards cannot be adopted for any waters, but there is very little doubt that a water which gives no indications of the presence of the B. coli communis in 10 c.c., of Streptococci in 50 c.c. (?), and of the spores of B. enteritidis sporogenes in 500 c.c., is at the time of examination so free from sewage pollution, that it may be certified as safe for all domestic purposes, providing its source is satisfactory.

This standard is attained by waters from all properly protected springs and from properly constructed deep wells. Upland and moorland surface waters, collected in reservoirs, I have regarded as satisfactory if they afforded no evidence of the presence of the Bacillus coli communis in a few c.c., and especially if the B. enteritidis sporogenes could not be detected in 250 c.c. Water which has been stored in a reservoir would not be expected to contain any streptococci, and if their presence

was discovered I should not know, at present, what inference to draw therefrom.

Shallow well waters present the gravest difficulty. If I were to expect them to satisfy the standard provisionally adopted for moorland waters, nearly every shallow well with which I am acquainted would have to be condemned. In these cases I lav far more stress upon the situation and construction of the well and the way in which the water enters than upon the bacterioscopic results. I have found, however, that nearly all wells which are properly constructed and which are at a little distance from highly manured ground, and the water from which does not become turbid after rain, yield waters affording no evidence of the presence of organisms of intestinal origin in 1 c.c. or of the spores of the B. enteritidis sporogenes in 250 c.c.

A recent report by Dr. Houston on the examination of thirty Chichester well waters is well worth careful consideration. It is contained in the report of the Medical Officer of Health to the Local Government Board (1900–1) and was undertaken on account of the excessive prevalence of typhoid fever in that town. It exemplifies the difficulty which arises in drawing correct inference after the most careful chemical and bacteriological analyses. Dr. Houston errs, if it may be called erring, in being too cautious in arriving at conclusions, and it is a question whether the chemical analyses of the waters, had the nitrates been determined, would not have afforded about the same amount of definite information as he obtained from the far more tedious bacteriological examinations.

The final conclusions at which he arrived are summarised as under. '*Chemical.* None of the thirty samples could have been reasonably condemned on the basis of the free ammonia, albuminoid ammonia, or oxygen absorbed from permanganate tests. Nearly all of them would have been classed as of great organic purity, though the amount of chlorine in a number of the samples was perhaps suspicious.'

## CHICHESTER WELL WATERS

*Compiled from Dr. Houston's Report*

| | In parts per 100,000 | | | | No. of Bacteria per c.c. | Gas in Gelatine shake culture in 24 hours at 20° C | | Bacillus coli | | B. Enteritidis sporogenes | | Streptococci |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Free Ammonia | Albuminoid Ammonia | Oxygen absorbed in 4 hours | Chlorine | | 10 c.c. | 100 c.c. | ·1 10 c.c. | 100 c.c. | 100 c.c. | 200 c.c. | 10 c.c. |
| 1 A | *t* | ·0064 | *t* | 4·1 | 300 | — | + | — + | ? | — | — | + |
| 2 B | *t* | ·0064 | ·015 | 2·0 | 1900 | — | + | + + | + | + | + | + |
| 3 C | *t* | ·006 | *t* | 2·7 | 170 | — | + | — — | + | — | — | — |
| 4 D¹ | *t* | ·0056 | *t* | 3·2 | 131 | — | — | + + | + | — | — | — |
| 5 D² | *t* | ·004 | *t* | 4·0 | 38 | — | — | — — | + | — | + | — |
| 6 E | *t* | ·004 | *t* | 2·3 | 14 | — | — | — — | + | — | — | — |
| 7 F | *t* | ·004 | *t* | 2·6 | 12 | — | — | — — | + | — | — | — |
| 8 G¹ | *t* | ·0048 | *t* | 2·1 | 40 | — | — | — — | + | — | — | — |
| 9 G² | *t* | ·004 | *t* | 2·2 | 7 | — | — | — — | + | — | — | — |
| 10 G³ | *t* | ·004 | *t* | 2·8 | 8 | — | — | — — | — | — | — | — |
| 11 H¹ | *t* | ·0052 | *t* | 2·6 | 13 | — | — | — — | — | — | — | — |
| 12 H² | *t* | ·004 | *t* | 2·5 | 4 | — | — | — — | — | — | — | — |
| 13 H³ | *t* | ·0024 | *t* | 2·8 | 10 | — | — | — — | — | — | — | — |
| 14 I¹ | *t* | ·0048 | *t* | 2·9 | 328 | — | + | + + | + | + | + | + |
| 15 I² | *t* | ·0064 | ·01 | 4·5 | 9880 | + | + | + + | + | — | — | + |
| 16 I³ | *t* | ·005 | *t* | 3·2 | 58 | | | — — | + | — | — | — |
| 17 J¹ | *t* | ·0056 | *t* | 2·8 | 180 | — | — | — + | + | — | + | ? |
| 18 J² | *t* | ·0056 | ·01 | 3·4 | 15 | — | — | — — | — | — | — | — |
| 19 K¹ | *t* | ·0048 | ·01 | 5·7 | 64 | — | — | — — | — | — | — | — |
| 20 K² | *t* | .0056 | *t* | 5·6 | 150 | — | — | — — | + | — | — | — |
| 21 K³ | *t* | ·004 | *t* | 3·2 | 14 | — | — | — + | + | — | — | — |
| 22 L¹ | *t* | ·0032 | *t* | 2·3 | 159 | — | — | — + | ? | — | — | — |
| 23 L² | *t* | ·004 | *t* | 2·3 | 196 | — | + | — — | + | — | — | — |
| 24 L³ | *t* | ·0027 | *t* | 2·5 | 160 | — | — | — — | ? | — | — | — |
| 25 M¹ | *t* | ·004 | *t* | 5·2 | 1090 | + | + | + + | + | — | — | + |
| 26 M² | *t* | ·0056 | ·011 | 7·3 | 400 | — | + | + + | + | — | — | — |
| 27 M³ | *t* | ·0064 | ·01 | 6·2 | 141 | — | — | — + | + | — | — | ? |
| 28 N¹ | *t* | ·0056 | *t* | 2·4 | 812 | — | — | — — | — | — | — | — |
| 29 N² | *t* | ·0032 | *t* | 2·6 | 880 | — | — | — + | — | — | — | — |
| 30 N³ | *t* | ·002 | *t* | 2·9 | 20 | — | — | — — | + | — | — | — |

NOTES.

The samples were from fourteen different wells, taken at various times between October 1900 and March 1901 inclusive.

*No. of Bacteria.*—Note variations in same well at different times. Dr. Houston says: 'On the basis of numbers, without any knowledge of the circumstances of the supply, a majority of the samples would have been considered either very pure, or sufficiently pure to escape condemnation; a few would have been regarded with suspicion, and a very few with marked disfavour.'

*Gas Production.*—Taking the following standard which Dr. Houston thinks reasonable—

\+ result with 10 c.c. . . . . probably impure
\+ „ 100 c.c.—with 10 c.c. . . of doubtful purity
— „ with 100 c.c. . . . comparatively safe,

only wells I and M would be classed as impure, and the rest as relatively safe.

*B. Coli.*—Dr. Houston says: 'How far one is justified in condemning a water containing coli-like microbes in 100 c.c., when these micro-organisms are absent from 10 c.c., is a moot point. It may, at all events, be safely said that samples G², H¹, H², H³, J², K¹, N¹, and L³ (?), were conspicuous as regards their purity, and that those samples which contained B. coli (or allied forms) in 100 c.c., but not in 10 c.c., were not wholly free from microbes seemingly of intestinal origin, and so could not be regarded as entirely unobjectionable in character.' The tests applied by Dr. Houston do not enable us to decide whether any of the organisms he regards as B. coli would be the true B. coli as described by Klein.

*B. Enteritidis sporogenes.*—Dr. Houston says: 'Absence of B.e.s. from 100 c.c. implies relative safety, but absence from even 200 c.c. need not necessarily in all cases be accepted as indicating absolute freedom from danger of a potential, if not actual, kind.'

*Streptococci.*—According to Dr. Houston's view, 'samples A, B, I¹, I², and M¹ showed evidence of recent fouling with matters of intestinal outcome.'

It will be observed that the chemical examination did not include the estimation of ammonia or nitrates.

'*Bacteriological.* 1. (*a*) Total no. of bacteria per c.c. in three samples 1,000 but less than 10,000, in thirteen samples 100 but less than 1,000, in eleven samples 10 but less than 100, in three samples less than 10.

'(*b*) "Gas" in gelatine "shake" cultures (twenty-four hours at 20° C). In two samples + 10 c.c. — 1 c.c., in six samples + 100c.c. — 10 c.c., in twenty-two samples — 100 c.c.

'(*c*) Bacillus coli (and allied forms).—In six samples + 0·1 c.c., in six samples + 10 c.c. — 0·1 c.c., in ten samples + 100 c.c. — 10 c.c., in eight samples — 100 c.c.

'(*d*) Spores of the bacillus enteritidis sporogenes (Klein).—In two samples + 100 c.c. — 10 c.c., in two samples + 20 c.c. — 100 c.c., in twenty-six samples — 200 c.c.

'(*e*) Streptococci.—In five samples + 10 c.c., in twenty-five samples — 10 c.c.

'2. These general results may be interpreted as indicating nothing more than that some of the waters were polluted and that others were of great bacterial purity.

'3. But it may be questioned whether they do not indicate something more than this—namely, that the waters in general were possessed of intrinsic biological qualities pointing to their late association with matter of intestinal sort.

'4. Biological qualities such as the above are not proper to waters derived from pure sources, moreover they are apt to be masked chemically by the mechanical filtering action of the soil.

'5. If this view be correct, immunity from danger in drinking such waters would be relative, not absolute.

'6. The circumstance that the inhabitants of Chichester drawing their water supply from these local wells have not seemingly suffered to any conspicuous extent from enteric fever in the past may possibly be referred, not to the complete absence of dangerous pollution of well waters, but to the beneficial mechanical action of the soil in reducing the amount of morbific poison contained in soil water.

'7. The facts observed by me at Chichester lend some support to Dr. Thomson's tentative hypothesis that soil plays some part in "fostering and localising" enteric fever in this town, inasmuch as the well waters representing the more or less perfectly filtered "washings" of soil nevertheless possessed certain biological qualities suggestive of fouling with matters of intestinal outcome, qualities not inconsistent with the supposition that possibly the soil at Chichester fosters in a higher degree than most soils "the vitality and morbific power of the infective material of enteric fever."

'8. B. typhosus could not be found in any of the samples examined. But B. coli (or closely allied forms) was found in a majority of the waters, and further a small percentage of these coli-like microbes gave a positive result with the agglutination test with human typhoid blood, with the blood of typhoid immunised pigs, or with blood of both sorts.'

A further report by Dr. Houston has been published by the Local Government Board (Report of Medical Officer, 1901–02) based on the chemical and bacteriological examination of another series of wells, some in the 'fever' and others in the 'non-fever' area. The results are just as inconclusive as before. The final conclusion at which he has arrived is that 'although the cause of the continued prevalence in serious amount of enteric fever in Chichester still remains obscure, there is some evidence in favour of the view that the well waters may play a part in spreading the disease,' and his sole recommendation is that, assuming his contentions to be correct, 'the wells be gradually closed, whether on the considerations embodied in the results of my analyses or on the results of the analyses of competent and independent experts. It is here assumed, as is alleged, that the public water service is satisfactory both as regards quality and quantity.'

When samples of water are submitted to an analyst or bacteriologist, some more definite opinion is desired from him than is given in the above reports. A Sanitary Authority could not take any action for closing a well upon these opinions, but

it is quite possible that more detailed analyses of the waters (especially a determination of the nitrates), a careful examination of the wells and their surroundings, inquiry as to turbidity appearing after rain, &c., would enable a competent observer to say which wells were dangerous and which were reasonably free from dangerous pollution.

To my mind the points made clear in the Table prepared from Dr. Houston's results are :—

1. That these results can only be correctly interpreted when the circumstances of each well are known. The report contains no description of the wells or their surroundings.

2. That when the circumstances of a source are not known, an opinion based upon a single examination of a sample of water from that source may be entirely erroneous and dangerously misleading.

3. That the most careful examination by the most expert bacteriologist does not in many cases enable him to say whether the source of a supply is 'safe' or 'unsafe.'

4. That the presence of so-called 'coli-like' organisms alone is not sufficient to condemn a water as being dangerously polluted.

5. That an inexperienced observer is more likely to incorrectly interpret the results of a bacteriological examination than those of a chemical analysis.

6. That more definite conclusions could have been drawn as to the character of these waters had the nitrates been estimated and a larger quantity of each examined for the presence of the spores of the bacillus enteritidis sporogenes.

7. Considering the fact that no case of illness had been attributed to the use of these waters, and that the analytical results were so satisfactory, no magistrate would condemn any of the wells on the bacteriological evidence.

There is no doubt, at the present time, Courts of Summary Jurisdiction pay greater regard to chemical than to bacteriological evidence, and this will continue to be the case until, by accumulated experience and increased knowledge, bacteriologists

become more in accord and are more precise in expressing their opinions. A magistrate is not impressed with the importance of the presence of the bacillus coli communis in a water when he hears of its ubiquitous character, and that scarcely any two bacteriologists agree as to what is the bacillus coli. To quote Dr. Houston: 'Some bacteriologists consider that no microbe should be classed as B. coli unless it responds to all of a number of positive tests in a specified and quite arbitrary period. Others go still farther and assert that no microbe failing to give an affirmative response to all of these tests is to be regarded as even an ally of the B. coli, or as in any way indicative of fouling (of any water) with objectionable animal matter. Remembering that sewage teems with coli-like microbes presenting every possible variation from the classical B. coli (some of them perhaps of greater importance than the ideal B. coli), and that some of the positive attributes originally possessed by these microbes may be easily lost or be maintained only in diminished degree under certain conditions, it seems unwise to place too much faith in these doctrines. Nevertheless, it is quite true that it is easy to drift into the opposite error, and consider microbes as B. coli which have no real kinship to that micro-organism and which bear no relation to pollution of animal outcome.'

Those who fall into the error last alluded to find the bacillus coli communis everywhere, those who go to the opposite extreme discover it very rarely. There can be no progress until there is greater precision, and I have found it absolutely necessary to limit the term B. coli communis to the organism described by Klein, the tests being applied in the manner described in a later section. The term 'coli-like' conveys no definite meaning and ought to be abandoned.

In the present defective state of our knowledge, it would probably be better to divide the bacteria found in water into groups, having certain definite characteristics in common, and to speak of each as belonging to one or other group.

My impression decidedly is that in water recently polluted by sewage, the B. enteritidis sporogenes and the B. coli communis can always be detected in reasonable amounts of the water if the degree of pollution is so great as to be dangerous, and that the more distant the date of the pollution the less likelihood there exists of discovering either, although bacteria of the other coli groups 'B' and 'C' may be detected. Probably it will be found that the longer the time the B. coli communis has been in the water the greater the change which will have taken place, one characteristic after another being lost, so that a bacillus which at first belonged to group 'A' and still later to group 'B' may later appear in group 'C.'

(*e*) *Search for specific organisms.*—On many occasions a search has to be made for some special disease-producing organism, usually the bacillus typhosus, rarely the vibrio choleræ. When the typhoid organism is added to a sample of water, there is as a rule very little difficulty in isolating it again and identifying it, but the difficulty of finding it in such impure waters as sewage appears to be at present insurmountable. The search for it in potable waters, in which its presence was gravely suspected, has usually been unsuccessful. On a few occasions, the discovery of its presence in waters suspected to be the cause of enteric fever has been announced, but the proofs afforded have rarely, if ever, been conclusive. One of the most painstaking and careful searches recorded is that made by Dr. Lorrain Smith in connection with the epidemic of typhoid fever in Belfast in 1898, and published in the form of a report. In January 1897 several cases of typhoid fever occurred within the catchment area of the Belfast water supply, and the discharges from the patients were thrown upon a manure heap which drained into an adjoining stream flowing into the reservoir. The bacteriological investigation was undertaken to ascertain whether the infected material had reached the water supply and was in actual operation during the epidemic which commenced in Belfast in the following March. From the

examination of the spleen of patients who had died from the disease, Dr. Lorrain Smith found evidence of the presence of bacilli identical with the typical bacillus of Eberth and the bacillus coli communis of Escherich. He then proceeded to examine the water supply to determine if one or both these bacilli were present in the water, over thirty samples being collected from infected houses. He failed to find the typhoid bacillus in any of these samples, but had no difficulty in isolating a large number of varieties of the bacillus coli communis. The conclusions at which he arrived were as follows :—

1. In the presence in the water of typical bacilli of the coli communis group we find evidence of contamination with intestinal excreta.

2. Certain of these bacilli exhibit their relationship to the process of infection in typhoid fever (*a*) by their lethal effect on small animals, (*b*) by showing the reaction of infection when exposed to the blood of typhoid patients.

He thinks that, short of discovering the typhoid bacillus in the water, and thereby giving absolute proof regarding the primary cause of the epidemic, no stronger bacteriological evidence could be adduced in favour of the conclusion that this contamination of the water was one of the causes of the outbreak of the disease in Belfast. In an appendix (E) he points out that the various experts who examined the Maidstone water during the epidemic in that town arrived at similar conclusions, and he emphasises the importance of the presence of the B. coli by quoting the opinion of Chantemesse and Widal that polluted waters owe their power to produce typhoid infection in a large measure to the presence of the coli bacillus.

The blood of a large proportion of the typhoid patients in Belfast reacted both to the typhoid bacilli and to the coli bacilli used in his experiments, consequently he adds, 'In the infection of typhoid fever there is apparently a double process in many instances.' The experiments he records appear also to indicate that there exists a definite relation between the presence

of the bacillus coli communis and the infection of typhoid fever. The races of B. coli which gave this reaction were isolated from the implicated water, and Dr. Lorrain Smith regards them as being identical with those found in the normal intestine.

A study of this report will convince anyone of the hopelessness of any but the most experienced bacteriologists attempting to demonstrate the presence of the B. typhosus in a drinking water. The search has been likened to the seeking of a needle in a stack of hay.

The search for vibrio choleræ is as difficult as that for the bacillus typhosus. When typical vibrios are added to water there is little difficulty, at first, in isolating and recognising them, but after a time the reactions of the organism appear to become so changed that its identification is practically impossible.

Vibrio choleræ occurs in the form of bent rods about $2\mu$ long and $0{\cdot}4\mu$ thick. They may be separated or joined together, sometimes forming screwlike chains. They possess one or two long terminal flagella, and are actively motile. They stain easily with carbol-fuchsin, but not by Gram's method.

The growth on gelatine plates is rapid, the colonies being visible in sixteen to twenty-four hours. These liquefy the gelatine, and sink into the centre of the depression. Later, the colonies which have an irregular margin seem as if covered with minute fragments of glass.

In a stab gelatine culture, the growth is at first threadlike, followed in twenty-four to thirty-six hours by the appearance of a small depression on the surface resembling an air bubble. Liquefaction is slow, and in the form of a flattened funnel.

In peptone salt solution at 37° C. turbidity is produced, with indications of a pellicle within twenty-four hours, and upon the addition of sulphuric acid a red colour may be obtained, the so-called cholera-red reaction.

A twenty-four hours' growth on agar, diffused through broth

and treated with ·5 to 1 per cent. of the serum from a rabbit, into which have been subcutaneously injected the cholera vibrios, gives the agglutinating reaction, the vibrios becoming motionless, and clumping together.

The following organisms which have been found in water closely resemble the cholera vibrio:—Vibrio Metschnikovii, vibrio proteus (Finkler and Prior), vibrio danubicus, vibrio aquatilis, vibrio albensis, vibrio Berolinensis. Besides these there are, apparently, a number of allied organisms found in sea water.

(*f*) *Organisms producing sulphuretted hydrogen.*—Very rarely, indeed, does any potable water acquire an odour or taste from the presence of bacteria. Such changes are usually brought about by the multiplication of higher forms of life. I have, however, had to examine waters having an odour of sulphuretted hydrogen, which odour I have attributed to the reduction of sulphates by bacteria. In Essex and elsewhere natural waters occur, having a faint odour of this gas, and well-sinkers from time to time encounter it in their boring or sinking operations. In some cases the sulphuretted hydrogen may be due to a purely chemical reaction; but in many, the more probable explanation is the decomposition of sulphates or albuminous matter by low forms of vegetable life. The odour is so often met with in marsh waters that it was at one time surmised that the vegetable matter in the water was capable of acting upon iron pyrites, with the formation of sulphuretted hydrogen. No doubt the organic matter is the source of much of the sulphuretted hydrogen found in sewage, but some is probably derived from the sulphates present. The gas is generally abundant in stale sewage, kept from contact with the air. Sewage containing brewery yeast is especially prone to this decomposition.

Using a gelatine medium, to which a little sodium ferro-tartrate rendered alkaline with sodium carbonate has been added, many organisms will be found to produce a black discoloration, due to the formation of ferrous sulphide. According

to Lehmann and Neumann,[1] the following bacteria produce sulphuretted hydrogen :—

| In moderate amount | Abundantly | Very abundantly |
|---|---|---|
| Streptococcus pyogenes. | Staph. pyog. aureus. | B. typhosus. |
| Sarcina flava. | B. acidi lactici. | Bt. vulgare. |
| B. diphtheriæ. | B. coli communis. | Bt. murisepticum. |
| B. pseudo-diphtheriæ. | B. Zopfii. | B. erysipelatos. |
| | B. Megatherium. | B. mesentericus. |
| | | B. tetani. |
| | | B. Chauvoei. |
| | | B. œdematis maligni |
| | | Vibrio choleræ. |
| | | V. danubicus. |
| | | V. berolinensis. |

As many of these organisms are found in sewage, the production of sulphuretted hydrogen therein is explained.

Certain of the Essex waters, with an odour of this gas, when added to such a medium (containing gelatine and iron), blacken the jelly after a time, but I know nothing of the characteristics of the organisms producing the reaction.

Beijerinck[2] has shown that the motile obligate anaërobic spirillum desulfuricans, which has only slight morphological characteristics, can decompose sulphates. Zelinsky[3] has described a motile bacillus found in ooze from the Black Sea, which gives rise to sulphuretted hydrogen, and Holschewnikoff found a slightly motile bacillus in the mud from the Wiesbaden filter beds with the same properties, and which he named Bacterium sulphureum. The descriptions given of these bacteria are very meagre, quite insufficient for their future identification. Odours due to Crenothrix, Beggiatoa, &c., have been referred to in a previous section.

Waters with an odour of sulphuretted hydrogen are too disgusting in character to be of use for domestic purposes. I have known persons use a polluted pond water rather than water from a well of considerable depth which had a faint odour of this gas, but was otherwise of excellent quality.

[1] *Bacteriology*, Table I.
[2] Lehmann and Neumann's *Bacteriology*, p. 77.
[3] Frankland's *Micro-organisms in Water*.

# PART III

## *ANALYTICAL PROCESSES AND METHODS OF EXAMINATION*

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## CHAPTER XI

### COLLECTION OF SAMPLES OF WATER

THE quantity required for chemical examination will vary according to the method of analysis adopted. Where it is merely desired to make a so-called sanitary analysis a litre is quite sufficient, provided no accident occurs during the carrying out of the processes. For most purposes two litres are ample and allow a margin for contingencies. The ordinary stoppered Winchester of pale green glass holds this quantity and answers very well. Dark-coloured bottles are to be avoided. I prefer strong white glass bottles and use two sizes, one-litre and two-litre respectively. The bottles should be used for no other purpose, and be rinsed with strong acid, and afterwards with water, before being sent out. For carrying about and sending by rail light wicker-work cases or wooden boxes in which the bottles stand upright are the safest and best. These can easily be made so as to be secured with a padlock if desired.

Wherever possible the bottle should be rinsed out two or three times with the water to be examined, before being finally filled. If this cannot be done the bottle should be well drained. The stopper should not be laid down, but kept in the hand and rinsed with the water before being inserted. The bottle should not be entirely filled, a small amount of air should be left in it. If completely filled, and the stopper firmly inserted, any

increase in temperature will cause the neck of the bottle to crack, and a decrease of temperature usually wedges in the stopper so tightly that it is difficult to remove it without a fracture.

Unless absolutely unavoidable, no funnel or jug should be used in filling the bottle, and the bottle should be so held that the water does not come in contact with the hand before entering.

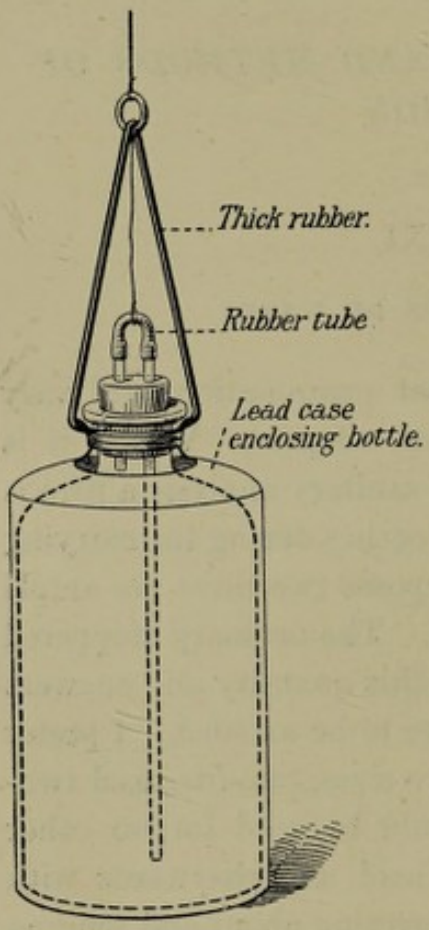



Fig. 1

In taking a sample from a tap or pump, water should be allowed to run to waste for a few minutes before filling the bottle, unless it is desired to ascertain whether the water is affected by standing in the mains or pump pipe. If such is the case it is best to take the sample first thing in the morning before any has been drawn for other purposes. In taking samples from springs and rivulets it is often necessary to make an excavation sufficiently large to hold the hand and bottle, and allow sufficient time for all matter disturbed to be washed away before taking the sample. Where the sample must be taken by immersing the bottle, as in ponds, cisterns, reservoirs, rivers, many wells, &c., I always use the simple apparatus shown in fig. 1. It is very easily put together, and can be used with equal facility for obtaining water from a great depth in a bore tube or well, and from an open tank or running stream.

A stoppered bottle of any size can be used, providing the leaden cylinder, partially closed in at the top, will go over it. The glass stopper is removed, and a rubber cork with two perforations inserted in its place. Through one perforation passes a piece of glass tubing about two inches long, and through the other a longer piece of tubing reaching to near the bottom of the bottle, and projecting about an inch above the rubber stopper. The projecting tubes are connected by a piece of rubber tubing about two inches long. The bottle is suspended by means

of a stout band of rubber about one foot long, such as is used for door springs, the free ends being secured tightly to the neck of the bottle by cord or catgut. A metal loop or swivel connects the rubber suspender with the cord or catgut used for lowering the bottle into the water. The loop or swivel is connected with the short piece of rubber tubing uniting the two glass tubes by a piece of string or catgut, of such length that when the bottle is suspended there is no pull upon the rubber tube, which, however, can easily be jerked off when a sharp pull is given to the suspending cord. The apparatus being arranged, it is lowered to the required depth, a sharp jerk is then given to the suspending cord, when the rubber tube is detached. Water enters through the longer tube and the air is expelled through the shorter tube. Bubbles of air can be seen or heard rising through the water until the bottle is full, or until only a little compressed air remains in the neck of the bottle. As the apparatus is raised, the air thus imprisoned expands, and prevents water from nearer the surface entering. Catgut serves better than cord for suspending the bottle, and if this is marked off in yards the depth to which the bottle has descended is known. Cord is useless for this purpose.

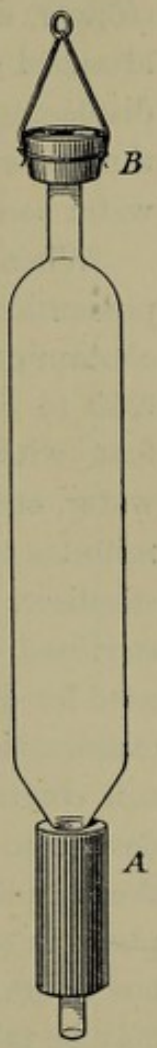


FIG. 2

The points requiring chief attention are to see that the rubber stopper is tightly inserted, and that the small piece of rubber tubing can be easily detached by a slight jerk.

When called upon unexpectedly to take a sample of water from a well in which the water level was about 100 feet below the ground level, and where it was desirable to fill the bottle some feet below the water surface, on account of the admixture with rain water, I succeeded by the following simple expedient. A 7-lb. weight was borrowed and attached by a cord to the bottle. Some balls of twine were obtained. One cord was securely attached to the neck of the bottle, and this lashed to the middle of a broomstick placed horizontally. The glass stopper was greased so that it could easily be pulled out and a second cord attached to it. Upon lowering the bottle the broomstick prevented it revolving, and the two cords did not therefore intertwine. When the bottle had sunk to the requisite depth the stopper was removed by briskly jerking the cord attached thereto.

Occasionally water has to be obtained from 2-in. tubes

driven for experimental purposes. In such cases the apparatus shown in fig. 2 and made out of a 200 or 250 c.c. pipette answers very well. A is a piece of lead pipe sufficiently heavy to sink the pipette. B is a perforated rubber stopper fitted on the upper end of the pipette and covered with a narrow strip of oiled silk. This is secured by string tied tightly round the stopper, and a loop should be left so that the apparatus can be attached to a cord. When the tube is lowered water enters, displacing the air through the oiled-silk valve. When raised the pressure on this valve closes it securely and prevents the water escaping.

When a water has to be examined bacteriologically special precautions must be taken to prevent the slightest risk of contamination. If collected in bottles these should be small (250 to 500 c.c. capacity [1]) and have been sterilised, by rinsing first with strong sulphuric acid and afterwards with boiled water, and finally by exposure to current steam for from 15 minutes to half an hour. They are then allowed to cool in the steriliser, the stoppers are inserted, and the whole wrapped in sterilised wool. The water collected in such bottles can be used for determining the number of bacteria present and for the examination for particular organisms, such as the bacillus coli communis or the bacillus enteritidis sporogenes. If it is desired to determine the number of bacteria present in a water, the sample should be taken straight to the laboratory and gelatine plates at once prepared. If there must be a delay even of a few hours, the bottles should be stored in ice. Special samples may be taken for this purpose in small sterilised tubes. The method of making and using these tubes is thus described by Professor Sheridan Delepine : [2]—

'Tubes made of moderately thick glass $\frac{3}{4}$ in. in diameter are closed at one end like test-tubes. The other end is drawn to a point, as shown in fig. 3A. These tubes are 7 to 8 in. in

[1] Occasionally a litre of water is required.

[2] 'Bacteriological Survey of "Surface" Water Supplies.' *Journal of State Medicine*, vol. vi. p. 194.

length, the wide part occupying about 6 in. They can hold about 20 cubic centimetres of water. They are prepared from tubing which has never been used, and has been thoroughly cleaned. The tube is sterilised by dry heat at the time of making. The drawn end forming the neck measures about $\frac{1}{2}$ in. in diameter; about 1 in. of the end is further drawn so as to reduce it to $\frac{1}{30}$ in. in diameter. The tube being so prepared is, after being allowed to cool, gently warmed again, and its open point immersed in pure water. As the tube cools, water is drawn into it on account of the contraction of the cooling air. When about 1 cubic centimetre has been thus sucked in, the point is removed from the water.

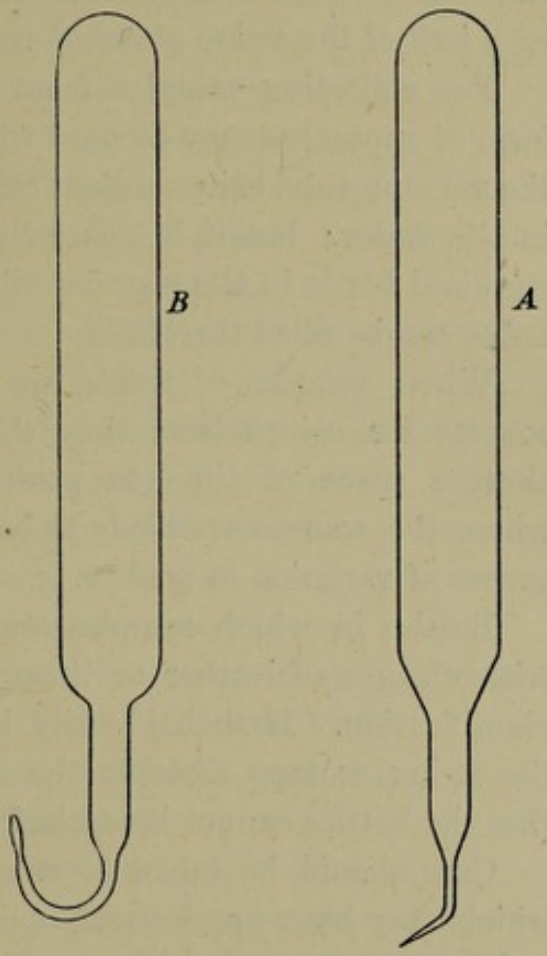


FIG. 3

'The water is then boiled rapidly in the tube until it has practically all been reduced to steam; the point is then quickly sealed in the flame of the blowpipe, the steam still escaping. (The flame heating the water is of course removed as soon as the sealing process has begun.)'

Tubes thus prepared may be kept in aluminium tubes closed at each end with rubber stoppers, and the metal tubes and contents sterilised in the usual way. When one of these tubes is to be used, the point is passed through the flame of a spirit lamp and then immersed $\frac{1}{2}$ to 1 in. below the surface of the water, and then nipped off by aid of a pair of sterilised forceps. As soon as the tube is nearly full the point is

removed and sealed in the flame of a spirit lamp, preferably by aid of a blowpipe.

When water has to be taken from a tap, a sterilised wide-mouthed bottle may be filled, and samples taken therefrom in the vacuum tubes in the manner described. Should it be desired to take samples from points difficult to reach, vacuum tubes with a bent neck, as in fig. 3 B, may be used. The tube can be fixed at the end of a rod, and the point broken off by a jerk of the twine attached thereto.

For collecting samples from wells, bore-tubes, &c., some form of apparatus may be used which permits of the point of the vacuum tube being broken off whilst the tube is suspended in the water; but it is generally more convenient to fill a sterilised bottle in the way described, and if necessary, vacuum tubes can be filled therefrom.

When samples of water are being taken from different sources for comparison, they should be collected within as short a space of time as possible. This especially applies where the sources are likely to be affected by rainfall or other causes of variation in quality.

Bottles in which samples are collected should be capped with clean washleather or linen, and duly labelled to secure identification. If such identity has to be afterwards proved, the string or tape securing the covering should be so sealed that the bottles cannot be opened without breaking the seal.

Care should be taken to record on the spot every detail which may have any bearing upon the results of the analyses to be undertaken, or which may be of importance in connection with the taking of the samples, or be of general or scientific interest.

In taking a sample from a stream, the following points should be recorded:—

1. Date and time when sample is taken.
2. In whose presence.
3. Exact point marked on Ordnance map.
4. Whether at or near middle or side, and which side.

5. Depth below surface.

6. Weather at the time, and particulars of any recent rainfall.

7. Whether the level of water is above or below average.

8. Observations with reference to any possible sources of pollution in the vicinity.

If a single sample only is being taken, it should be collected from beneath the surface near the middle of the stream.

In taking samples from an open well, record 1, 2, 3, as above, and in addition—

4. Approximate ground surface level above O. D.

5. Depth from ground level to surface of water.

6. Depth of water in well, and depth at which sample is taken.

7. The mode of construction of the well, including its covering.

8. Whether the appearance of the water is affected by heavy rains.

9. Any indications of pollution, discoloration of sides, &c.

10. Character of the surroundings, proximity to drains, sewers, stables, dustbins, piggeries, churchyard, &c.

11. And, if possible, section of well, and

12. Yield of water and effect of pumping.

As the character of the water in open wells often varies at different depths, it is best to lower the bottle rather rapidly under the surface of the water, so that it may, when filled, contain water from all parts of the well.

In taking samples from a large reservoir, one should be taken near the point of entry, and another near the exit of the water. If only one sample is to be collected, it is best to take it from beneath the surface, just over or very near the mouth of the trunk main or conduit.

When taking a sample from a house-tap connected with a public supply, it should always be noted whether the tap is directly connected with the main or with a cistern. If with the latter it should be examined, and particulars thereof recorded. The position of the main should also be noted, and the proximity to a dead-end or ball-hydrant ascertained if possible.

When samples of water are received for analysis, and there is any doubt about the way in which they have been collected, or about the cleanliness of the bottles used, or when the samples are sent in bottles closed with unclean corks, it is best to communicate with the sender and offer to despatch suitable bottles for fresh samples. The following is the form which I generally use, the sender of the sample being requested to furnish the information required.

PARTICULARS REQUIRED CONCERNING SOURCE, &c., OF WATER SENT FOR ANALYSIS

1. Name and address of person desiring the analysis.
2. Is a Chemical or Bacteriological examination required or both?
3. Reasons for wishing an analysis—if the water is suspected of causing ill-health, the symptoms should be stated.
4. Exact place from which the sample was taken. If from a house-tap, say whether drawn from a cistern or directly from the main.
5. State whether a well, spring, or stream, or a public supply.
6. If a well, state the depth.
7. If a well, state whether the bricks are set in cement, or are cement-lined or puddled behind.
8. State nature of subsoil from which water is derived.
9. State whether there are any drains or cesspools, or other possible sources of pollution, and distance from source of water.
10. Does the water become affected in appearance, odour, or taste, after a heavy rain?
11. Date on which sample was taken and sent.

When sending a sample of water for analysis, the above form should be filled in and sent by post.

Suitable bottles, thoroughly cleansed and ready for filling, will be sent on application.

In filling the bottles, carefully carry out the instructions given below for collecting the sample of water.

Samples should be dispatched immediately after being collected, and be addressed as under.

To this form are attached the following directions for securing the proper collection of the samples of water.

INSTRUCTIONS FOR COLLECTING SAMPLES OF WATER FOR ANALYSIS

1. The water should be collected in glass bottles having well-fitting stoppers and holding about half a gallon. White glass bottles preferred.

2. The bottles should be thoroughly cleansed, filled thrice with the water, and thrice emptied, before collecting the sample. The bottle should be completely filled, and then a little water poured away to make room for the stopper.

3. If the water is collected from a tap, the tap should be turned full on and the water allowed to run to waste for two minutes before collecting. If the water is to be taken from a cistern, pond, or stream, then, if possible, the stopper should be inserted in the empty bottle, and the whole bottle placed well under the surface of the water, the stopper removed and the bottle filled.

4. The stopper should be secured by covering with a piece of clean wash-leather, or by an india-rubber cap. If neither of these is available, clean linen may be used.

This represents, when filled in, about the minimum amount of information which is necessary, and can be supplemented by further inquiries if desired. The nature of these inquiries will depend upon the source of the water and may be inferred from a consideration of the sections referring to the examination of sources of water supply.

## CHAPTER XII

### THE PHYSICAL AND CHEMICAL EXAMINATION OF WATER FOR SANITARY PURPOSES

In very many cases, after the examination of the source from which a water is derived, a few simple tests will show whether the water is or is not suitable for domestic purposes. Where difficulties arise from a properly equipped laboratory not being available, and anything like a complete analysis being impossible, practically all the information necessary may be obtained by an analysis made as described by me in a pamphlet, entitled: 'A Simple Method of Water Analysis.' This method was originally designed, more especially, for the use of Medical Officers of Health in Rural Districts. The chemicals used are in the form of 'soloids,' and the processes require no special laboratory, and only the simplest possible apparatus. In fact, both chemicals and apparatus can be packed in a small case or bag, and be easily carried in the hand.

Usually, however, a more complete examination is desired, involving quantitative estimations by volumetric processes, together with qualitative tests for the presence of certain objectionable substances. Many Chemists and Medical Officers of Health are satisfied with an analysis which includes the estimation of the chlorine, the total hardness, the free and albuminoid ammonia, and tests for the presence of nitrites and nitrates. Others estimate also the nitrates and the 'oxygen absorbed,' and test for phosphates and objectionable metals. Others again make a rule of determining the total solids, since

this affords a check on the results of the analysis, any large difference between the total solids and the sum of the chlorides, nitrates, carbonates and sulphates (the two latter judged from the hardness results), indicating the necessity for further examination.

The results obtained are expressed in so many different ways that the comparison of analyses by different persons is often difficult and troublesome. Thus some express the nitrates present in terms of nitrogen, others as nitric anhydride, and others, again, as hydrogen nitrate or nitric acid. The frequent use of the word 'traces' also leads to confusion, as it undoubtedly is used differently by different people. Usually it signifies 'too small a quantity to be capable of determination;' but often it is used merely to indicate that a small amount of the substance is present, but that this amount was not estimated. The word ought to be used as rarely as possible, and then only when its significance cannot be misunderstood.

Again the results may be given in grains per gallon, parts per 100,000 or parts per million, or some results may be entered in grains per gallon, and others in parts per million in the same analysis. It is, in my opinion, best to express all the results in parts per 100,000, as being the most scientific and most generally useful. To convert these results into grains per gallon it is only necessary to multiply by ·7, while multiplication by 10 gives the results in parts per million.

In the majority of cases all the information required to form an opinion upon the character of a water can be obtained by determining the chlorine in chlorides, the nitrogen in nitrites and nitrates, the hardness, the free and organic ammonia, and by testing for the presence of nitrites. When necessary these can be supplemented by ascertaining the total solids and the oxygen absorbed, and applying tests for the presence of salts of iron, lead, and zinc. For the above reason I purpose describing first the various methods of making these determinations, reserving for a separate chapter the description of the processes for making an analysis of the saline constituents.

## I. PHYSICAL EXAMINATION

Under all circumstances it is desirable to note certain physical characters of the water, the colour, brightness or turbidity, and odour, while sometimes it may be desirable to ascertain whether the water has any appreciable taste.

(*a*) **Odour.**—When the stopper is first removed from the bottle containing the water an odour may be apparent. If not, put about 250 c.c. into a half-litre flask, warm to near 100° F., shake vigorously, remove the stopper, and again smell. If any odour is detected, describe it if possible.

(*b*) **Colour.**—This is usually ascertained by filling a tube two feet in length of white glass and with a flat end, and looking through the column of water at a sheet of white paper. It may be compared, if desired, though this is rarely necessary after a little experience, with a column of distilled water in a similar tube. Where the turbidity is sufficiently marked to mask the colour of the water, filtration may be resorted to; but, as a rule, it suffices to note the colour of the turbid liquid.

By using a special tintometer, the exact depth and tint of colour can be determined. The apparatus used in the examination of the London waters consists of two hollow wedges, one filled with a brown and the other with a blue solution, both of known composition. These wedges are made to slide across each other in front of a circular aperture in a sheet of metal. By this means any desired combination of brown and blue can be produced. Each prism is graduated along its length from 1 to 40, the figures representing in millimetres the thickness of the said standard solution at that particular part of the prism. Just below the level of the prisms and in a horizontal position is a two-foot tube to be filled with the water under examination. This tube has in front of it a circular aperture of the same size as the one in front of the prisms.

The stand supporting the prisms and water tube is placed horizontally in front of a uniformly lighted window, fitted by preference with ground glass. (Two ground-glass caps are supplied to take the place of the ground-glass window.) The

observer, standing, say, three or four feet from the instrument, sees two luminous discs, the lower one illuminated by light which has passed through two feet of the water under examination, and the upper one illuminated by light which passes through the respective thicknesses of the brown and blue solutions.

By sliding the prisms sideways, one way or the other, so as to obtain a colour produced by the mixture of brown and blue, it is easy to imitate with considerable accuracy the tint depth seen in the lower disc. A metal pointer fixed over the centre of the upper disc indicates on the prism scales the thickness, in millimetres, through which the light has passed to produce a colour which corresponds to that seen through two feet of the water. The results are recorded in the following way: Brown 31, Blue 20. This indicates that the colour of a stratum of two feet of the water under examination was represented by an admixture of these colours in the proportion stated.

In this country little stress is laid on the determination of the colour, but in America the colour and degree of turbidity of the chief public water supplies are systematically recorded, and quite a number of special instruments have been devised for these purposes.

(*c*) **Brightness or Turbidity.**—Viewing a considerable bulk in a colourless glass flask, the water may be described as 'brilliant,' 'bright,' 'clear,' 'dull,' 'slightly opalescent,' 'markedly opalescent,' or 'turbid.' Any visible particulate matter should be noted and examined under the microscope.

Occasionally it is desirable to estimate the amount of matter in suspension. If this is considerable, it can be ascertained by subtracting the weight of the residue left by the evaporation of 100 c.c. of the filtered water from the weight of the residue from the same amount of the unfiltered water. Usually, however, the amount is too small to be measured in this manner, in which case one or other of the following methods may be used.

*a.* Filter about a litre of the water through a very small filter made of specially hard paper. Wash the filter with distilled water. Make an opening with a sharp thick needle through

the apex of the filter, and wash the deposit into a small tared platinum or porcelain dish. Evaporate off the water and weigh the residue.

β. The following method was adopted by Professor Boyce and others in their examination of the Severn waters for the Royal Commission on Sewage Disposal. It unfortunately requires the use of a large centrifugal machine. 600 c.c. of the water are centrifugalised, the clear liquid pipetted or siphoned off, and the remainder transferred to a small specially constructed tube, the bottom of which is drawn out like a thermometer tube and graduated in ·01 c.c. 'The glass is filled and centrifugalised for 2½ minutes in a hand centrifuge making about 2,000 revolutions per minute; the result is that the deposit is forced into the graduated stem and the amount can be easily read off.'

γ. The above processes may be combined, the water being passed through a small filter as in A, and the residue washed into one of the graduated tubes, and the amount estimated as in B.

The deposit thus obtained can afterwards be submitted to chemical and microscopical examination.

The amount of matter in suspension producing a mere opalescence in a water is generally so small that its accurate estimation is impossible. For this reason, in America, instruments called 'turbidimeters' are used. Probably the best of these is one devised by Mr. C. Anthony, and described by him in the Journal of the New England Waterworks Association. It consists of a couple of parallel tubes 50 centimetres in length, one of which, closed at the ends by plates of glass, contains the water to be examined. Light, transmitted preferably through ground glass, reaches the eye in part through this water and in part direct after passing through a Nicol's prism. These two sources of light are observed through an eye-piece containing another Nicol's prism. By rotating the eye-piece, the illumination of that half of the field which receives its light direct can be varied, seeing that it has been polarised, until it matches the half receiving light through the standard thickness of water

under examination. Any degree of obscuration, from perfect transparency to absolute opacity, can be read upon the disc. This method permits of more accurate comparisons being made than any other yet devised.

## II. CHEMICAL EXAMINATION

### A. Acidity and Action upon Lead

As a matter of routine it is desirable to ascertain the reaction of a water, as, if acid, it will require the addition of an alkali in its subsequent treatment for the estimation of the ammonia. Litmus paper is useless for this purpose with moorland waters, though rain water caught in the proximity of towns often gives a reaction with it. In the former case the acid is probably organic, whereas in the latter it is inorganic. Lacmoid is the best indicator for free acid in water, since it is affected by both organic and inorganic acids.

By adding a drop of lacmoid solution to about 10 c.c. of water in a test tube, the purplish blue of the lacmoid changes to red in the presence of a minute trace of free acid. Houston says that moorland waters which give a neutral reaction with this indicator do not dissolve lead to any appreciable extent, whilst a peaty water with an acid reaction will be found to possess plumbo-solvent activity.

For actually estimating the acidity of a water Houston found lacmoid of little use as an indicator, and he gives the preference to phenol-phthalein, which he says, 'though liable to some objections, allows comparable results to be obtained.'

100 c.c. of the sample of water to which a few drops of the indicator have been added are titrated in a small flask with decinormal solution of sodium carbonate. 'The faintest excess of alkali shows itself by a pink coloration of the previously colourless liquid.' With care no doubt comparable results may be obtained, but the pink colour which at first is produced rapidly fades, and to produce a permanent pink tint more alkali must be added. Houston apparently regards the first

appearance of the colour as the end of the reaction. The amount of acid in the sample of water is represented in terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise the acid in the 100 c.c. of water.

In examining the moorland waters of Lancashire and Yorkshire Houston made many hundreds of estimations of the amount of free acid, and at the same time determined the lead-dissolving power of each sample of water. The following figures taken from Diagram C of his report to the Local Government Board show how the acidity and plumbo-solvency are related :

| Acidity in terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the water | Plumbo-solvency Mlgrms. of lead in 100 c.c. of the water after filtration through lead shot | Acidity in terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the water | Plumbo-solvency Mlgrms. of lead in 100 c.c. of the water after filtration through lead shot |
|---|---|---|---|
| ·18 | ·1 | ·9 | 2·4 |
| ·2 | ·28 | ·95 | 2·66 |
| ·27 | ·18 | 1·1 | 3·2 |
| ·3 | ·25 | 1·2 | 4·7 |
| ·4 | ·4 | 1·25 | 4·5 |
| ·45 | ·46 | 1·3 | 3·4 |
| ·5 | ·66 | 1·4 | 2·8 |
| ·52 | ·9 | 1·5 | 2·8 |
| ·68 | 1·34 | 1·58 | 3·0 |
| ·6 | ·92 | 1·7 | 5.6 |
| ·8 | 1·5 | 2·2 | 8·6 |
| ·85 | 1·9 | | |

The following are examples of the manner in which his results are recorded, and show how water from the same stream may vary with the season.

| Sample | Reaction with lacmoid | Acidity in terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ solution | Lead dissolved by 100,000 parts of water in filtering upwards through lead shot at rate of 50 c.c. in three minutes | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average |
| Beck. Dry weather | Neutral . . . | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Beck. Heavy weather | Very acid . . | 1·32 | 2·4 | 3·2 | 3·2 | 3·2 | 3·2 | 3·04 |

As the solvent action of water upon metals is chiefly dependent upon the presence of free acid, it may be asserted without further proof that an acid water will act upon all metals of which pipes are usually constructed, save copper (?) or tin. The extent of the action of acid waters upon lead may be determined by various methods, of which that devised by

Dr. Houston is undoubtedly the best, since it allows different waters to be compared with a fair amount of precision. It consists in permitting the water under examination to percolate upwards at a uniform rate through a column of lead shot, collecting the percolate in successive 50 c.c. and estimating the amount of lead therein. A special lead shot is used, as the ordinary article of commerce is an alloy. By continuing the percolation for a period, it can be ascertained whether the action is continuous or whether it tends to diminish. I have recently been examining a moorland water with which it is proposed to supply a large town. At first 100,000 parts of the water dissolved under Dr. Houston's conditions ·4 part of metal, but this gradually decreased, so that by the third day the amount of lead dissolved was too small to estimate, and on the fourth day lead could not be detected in the water.

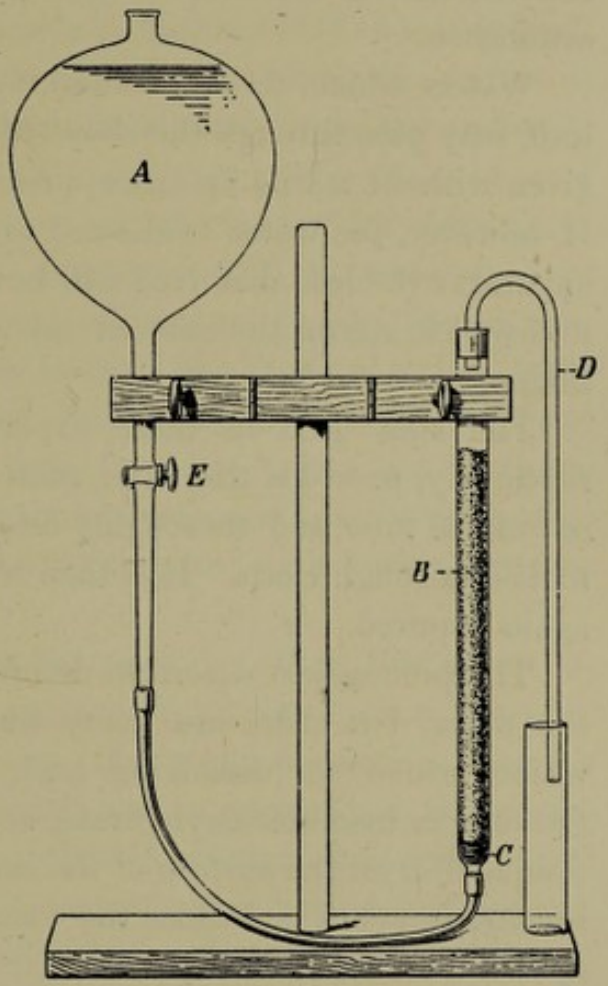



FIG. 4

The apparatus, as fitted up in my laboratory, is shown in Fig. 4. A is a bottle containing the water to be examined, B a cylindrical tube half inch in diameter and about 2 feet long, contracted at the base and containing 50 c.c. of shot resting upon a small plug of muslin or cotton wool, C. A glass tube, D, conducting the water which has traversed the column of lead

shot into the Nessler glasses. The apparatus is used in the following manner.

The large bottle A is filled with the water, and the tap E turned until the water issues freely. All air must be carefully driven out of the connecting tubes. The cock E is then regulated until the water dribbles through at the rate of 50 c.c. in three minutes, after which successive 50 c.c. are collected, and the lead therein estimated as described in the section on lead estimation.

Waters which, though containing no free acid, yet act upon lead, may pass through the above column of shot in the time given without taking up any appreciable quantity of the metal. If, however, the water is allowed to stand a few hours in the apparatus the lead dissolved will be measurable. In such cases it is well to record the amount taken up in a given number of hours.

The shot used in these experiments can be employed repeatedly, provided that after each determination it is taken out of the tube and thoroughly dried by rubbing between the folds of a rough cloth. It is then to be kept in a dry place until again required.

The process just described determines the solvent power of the water, but there are many waters without acid reaction which, whilst not dissolving lead, exert an 'erosive' action, forming an insoluble oxyhydrate, deposited at first as a greyish opaque film on the surface of the metal. Afterwards this may become detached and cause the water to become more or less opalescent. Occasionally the film becomes detached in the form of exceedingly thin scales, whilst with certain hard waters no reaction occurs beyond that of the formation of the protective coating on the surface of the lead.

This 'erosive' action is determined in the following manner.

Take a strip of sheet lead, half an inch in width, and scrape the surfaces until they are absolutely bright. Cut into lengths of 1 inch. Into each of a series of six test-tubes place 10 c.c.

of the water to be examined and a piece of the lead. Allow to stand, without agitation, and at the expiration of the first hour remove the lead from one of the tubes, add a drop of dilute hydrochloric acid, and warm if necessary to clear the liquid. Take an aliquot part, if the original liquid was turbid, dilute to 50 c.c. with distilled water, and estimate the lead colorimetrically, as described in a later section. The contents of the other tubes are examined at regular intervals.

Dr. Houston, who has made a special study of this subject, says: 'Waters in general erode lead only when the surface of the metal is bright; neutral moorland waters are naturally non-corrosive in character, although they may tend to be near the possession of this ability; acid moorland water may or may not possess erosive ability associated with plumbo-solvency; pure rain-water, snow-water, and neutral distilled water commonly erode lead in vigorous fashion; and natural waters, other than rain or moorland water, do not usually possess ability to erode lead. These statements, therefore, must not be interpreted in too literal a sense, but taken as of relative value only, and as founded on experiments conducted under laboratory conditions.'

As the result of experience it may be taken that where, in the above experiment, the surface of the lead remains bright, the water has no erosive power; that when the surface becomes tarnished, but the water is unaffected in appearance, the erosive power is so slight as to be negligible, whereas the production of a turbidity or formation of detached scales indicates an amount of erosive action of a decidedly dangerous character.

### B. Hardness or Soap-destroying Power

The hardness or soap-destroying power of a water depends almost entirely upon the amount of calcium and magnesium salts present. Occasionally there is sufficient zinc or iron present in the form of carbonate or sulphate to increase the soap-destroying power, and the presence of much free carbonic acid gas and of

unusually large quantities of sodium salts is not without effect. The unit of soap-destroying power is one-tenth of that possessed by 100 c.c. of water containing 10 mlgr. of calcium carbonate (or its equivalent of calcium chloride) in solution. The amount of soap destroyed by 1 mlgr. of that salt is not exactly one-tenth of that destroyed by 10 mlgr.; hence tables have been constructed which pretend to show the amount of calcium carbonate equivalent to the soap solution used. What good purpose is served by such a table I have never been able to divine. The unit above suggested and generally adopted has a definite meaning and practical use. A water of 8° hardness will waste twice as much soap as one of 4°, and only half as much as one of 16°, &c. Beyond this it means nothing definite, but it gives a rough idea of the amount of calcium and magnesium salts present, and this rough approximation is very often quite sufficient for the purpose of the analyst. If it is not, it is far more satisfactory to determine the amount of these salts by the methods proper for their estimation than to attempt to calculate it from the results of the soap test.

The hardness left after boiling may or may not be entirely due to sulphates and chlorides. The whole of the carbonates is not always deposited during the boiling process.

The futility of attempting to determine the amount of the carbonates and sulphates of calcium and magnesium by the soap test is exemplified by the following experimental results. The first series were made with artificially prepared solutions to ascertain if the amount of magnesium salt present in a water could be determined by the soap test after removal of the calcium salts by the addition of ammonium oxalate as described in various text-books. The results show that the process is unreliable.

| $CaCO_3$ per 100 c.c. | $MgCO_3$ | Hardness | Hardness after treatment with ammonium oxalate |
|---|---|---|---|
| Mlgr. | Mlgr. | | |
| 5·0 | 2·5 | 9·0 | 1·0 |
| 6·6 | 3·3 | 11·0 | ·5 |
| 5·0 | 20·0 | 35·0 | 21·0 |

Obviously in these cases the hardness remaining after the precipitation of the calcium as oxalate bears no definite relation to the magnesium salt present. This is further confirmed by the following table of experimental results showing that the soap-destroying power of 1 mlgr. of magnesium carbonate is not constant.

| Calcium salts as $CaCO_3$ | Magnesium salts as $MgCO_3$ | Total hardness | Calculated hardness corresponding to 1 mlgr. $MgCO_3$ |
|---|---|---|---|
| 5·0 | 5·0 | 12·0 | 1·4 |
| 2·5 | 2·5 | 6·0 | 1·4 |
| 3·25 | 3·25 | 7·5 | 1·3 |
| 5·0 | 2·0 | 9·0 | 2·0 |
| 6·0 | 6·0 | 13·0 | 1·2 |
| 10·0 | 2·5 | 14·0 | 1·6 |
| 10·0 | 5·0 | 15·0 | 1·0 |
| 10·0 | 4·0 | 15·0 | 1·25 |

The end reaction in many of the above cases was difficult to determine.

Similarly the results I have obtained with natural waters, the mineral constituents of which were carefully determined, also show that no definite conclusions as to the salts present in the water can be drawn from a determination of the temporary and total hardness.

I am quite convinced that the hardness of a water cannot be relied upon to indicate anything more than its soap-destroying power, and where a knowledge is desired of the saline constituents it is far better to make a proper quantitative analysis.

The standard 'degree' of hardness unfortunately differs in various countries, but the one I have adopted is that generally employed in France. It can be approximately converted into Clark's (English) degrees by multiplying by ·7, since Clark's standard was 1 grain of $CaCO_3$ in one gallon of water.

**Estimation of the total hardness.**—*Reagent.* Standardised solution of soap.

*Apparatus.*—Burette and stoppered 200 c.c. bottle.

*Process.*—Place 100 c.c. of the water in the bottle and run in the soap solution one cubic centimetre at a time until,

after vigorous agitation, a lather is formed which persists for two minutes when the bottle is laid on its side. The lather should, in amount, resemble that produced when 1 c.c. of the soap solution is shaken with 100 c.c. of distilled water. When a lather begins to form, the soap solution can be added in smaller quantities until the requisite permanency is attained. If the water exceeds 16° in hardness, the operation must be stopped and recommenced, using 50 c.c. or 25 c.c. of the original water diluted to 100 c.c. with distilled water. To shorten the process it has been suggested that, at first, a rough experiment should be made, adding the soap solution 5 c.c. at a time. In the second experiment the soap solution is run in more boldly at first and afterwards in small quantities. The results, however, do not always correspond with those obtained when the soap solution is added more gradually, and this latter method is to be preferred.

As 1 c.c. of soap solution is required to produce a lather in the absence of lime and magnesium salts, the degree of hardness or soap-destroying power is one less than the number of c.c. of soap solution used. Where a diluted water has been used, this, of course, gives the hardness of the dilution, and the hardness of the water will be twice or four times that of the dilution according as 50 or 25 c.c. of the water have been used.

Waters which contain a considerable quantity of magnesium salts may form a distinct curd with the soap. Such waters require copious dilution. Even then the end reaction is difficult to determine, and much experience is required to obtain concordant results. Sometimes a lather will appear to be permanent upon standing, yet if the solution is gently agitated, it disappears, and cannot be reproduced until more soap has been added. In such cases the addition of soap solution must be continued until the frothing is really permanent for two minutes, and, if it disappears within five minutes, it should reappear on shaking.

**Determination of the Permanent and Temporary Hardness.**—For this an Erlenmeyer's flask of 200 c.c. capacity is

required. 100 c.c. of the water are placed in the flask and boiled gently for half an hour, distilled water being added from time to time to replace that lost by evaporation.[1] The water is then allowed to cool, passed through a filter paper, made up to the original volume, and the hardness determined in the manner just described. This is the permanent hardness, and the difference between it and the total hardness is the temporary hardness.

As previously stated the temporary hardness is that removed by boiling, and does not correspond to the whole of the carbonates of calcium and magnesium present, since, after boiling, the water retains a trace of calcium carbonate (this salt not being absolutely insoluble in pure water), and may contain several mlgrms. of magnesium carbonate.

Some chemists estimate the temporary hardness from the amount of combined carbonic acid in the water, in the manner described in the section relating to that determination. The equivalent of $CaCO_3$ being ascertained, this is regarded as the temporary hardness, and the difference between this and the total hardness gives the permanent hardness. The results so obtained obviously may differ considerably from those obtained by the more rational process, especially if the water contains magnesium carbonate. When waters contain sodium carbonate, as is very often the case in the deep well waters of Essex and elsewhere, the process is quite inapplicable. It is best, therefore, to adhere to the soap method, which is universally applicable.

### C. Chlorine in Chlorides

The quantity of chlorine existing as chlorides, whether large or small, admits of determination in a very simple manner by the use of a standard solution of silver nitrate, using potassium chromate as an indicator.

**Method of Estimation.** *Apparatus required.*—Burette

[1] If the water is concentrated too highly, calcium sulphate may be deposited and vitiate the results.

graduated in ·1 c.c. A deep white porcelain dish (200 c.c.) and glass rod.

*Reagents required.*—Standard solution of silver nitrate each c.c. of which corresponds to 1 mlgr. of chlorine. Solution of potassium chromate (5 per cent.).

*Process.*—To 100 c.c. of the water in the porcelain dish add 1 c.c. of the solution of potassium chromate. Run in the silver solution carefully until after stirring a faint dirty red colour appears and remains permanent. Then from a graduated cylinder or pipette run in more of the water until the clear yellow tint just reappears. The number of mlgrms. of chlorine in 100 c.c. of water plus half the further amount added, very approximately corresponds to the number of c.c. of silver nitrate used.

The reaction involved in the above determination consists, in the first place, in the formation of the white insoluble silver chloride, and, when all the chlorine is thus precipitated, the excess of silver is thrown down as red silver chromate. When the silver solution is added to the water containing the potassium chromate, both silver chloride and silver chromate are precipitated; at first the chromate is rapidly decomposed by the chloride remaining in solution, but as the amount of unprecipitated chloride decreases the decomposition of the silver chromate becomes slower and slower, indicating the approach of the end of the reaction. An excess of silver nitrate must be used to produce the red colour, and this excess varies, within certain limits, with the amount of potassium chromate added. With too small a quantity of chromate the readings are too high. Why this should be so is difficult to explain. It is quite possible to have a difference of 1 mlgr. in a chlorine determination, due to the improper use of the indicator.

Whilst a deficiency of chromate is to be avoided, an excess is undesirable, as it obscures the delicacy of the end reaction.

The silver solution used is, in the first instance, always in excess of the amount of chlorine present, but when the titration is completed as described, the results are reliable. In the

following experiments a solution of pure sodium chloride was used, of such strength that each c.c. corresponded to 1 mlgr. of chlorine. Various quantities of this solution were diluted with distilled water to 200 c.c.; 100 c.c. were titrated; after adding the silver nitrate, more of the dilution was added until the red colour disappeared:—

| Chlorine in 100 c.c. | C.c. of silver nitrate solution used | Amount of water in c.c. corresponding thereto | Chlorine found |
|---|---|---|---|
| mlgr. | | | |
| 1·0 | 1·15 | 100 + $\frac{20}{23}$ | 1·05 |
| 1·75 | 1·85 | 100 + $\frac{12}{23}$ | 1·75 |
| 3·0 | 3·2 | 100 + $\frac{8}{23}$ | 3·1 |
| 5·0 | 5·15 | 100 + $\frac{5}{23}$ | 5·05 |
| 7·5 | 7·7 | 100 + $\frac{4}{23}$ | 7·6 |
| 8·0 | 8·3 | 100 + $\frac{3}{23}$ | 8·1 |
| 10·0 | 10·2 | 100 + $\frac{2}{23}$ | 10·0 |
| 12·0 | 12·2 | 100 + $\frac{2}{23}$ | 12·0 |
| 20·0 | 20·4 | 100 + $\frac{1}{23}$ | 20·1 |

With proper care it is rarely necessary to concentrate a water before determining the chlorine; but where very great accuracy is desired, water containing less than 1·0 of chlorine in 100,000 should be evaporated, 500 c.c. or 250 c.c. being reduced to 100. Without evaporation the error need not exceed ·1 mlgr. of chlorine. With a little experience the change in colour from decided yellow to a pale dirty red is readily observed. When coloured waters are being examined, such as those containing peaty matters, the delicacy of the reaction is impaired, and concentration of the water is usually necessary. Such waters also have at times an acid reaction, in which case a little sodium carbonate must be added before running in the silver nitrate. Sewage-polluted waters, and waters containing traces of sulphuretted hydrogen, can only be titrated after special treatment. Boiling a short time after the addition of a little lime water, the subsequent addition of sufficient sodium bicarbonate to precipitate the excess of lime, and filtration, usually suffice to remove the substances which interfere with the reactions. The titration, of course, must take place after the water, thus treated, has become quite cold.

## D. Nitrites

The quantity of nitrogen as nitrites found in potable waters rarely amounts to one part in a million, but even this small quantity admits of being easily detected and estimated.

**Detection of Nitrites.** *Reagents required.*—Solutions of potassium iodide and of starch. Dilute hydrochloric acid (1 in 6). The reaction depends upon the liberation of iodine from the iodide by the nitrous acid. The oxide of nitrogen produced then acts as a carrier of oxygen from the air, and thus a continuous increase in the amount of iodine set free occurs. The reaction is most delicate when the water is saturated with air; hence before adding the reagents the water should be thoroughly aërated by agitation.

*Process.*—To 50 c.c. of the aërated water add 1 c.c. each of the acid, of the iodide and of the starch solutions. If no blue colour develops in two minutes, nitrites may be considered to be absent. With one part of nitrous nitrogen in one million a dark blue colour is produced instantly, with one in three millions the colour appears in a few seconds, and with one in ten millions in about thirty seconds.

Ferric salts also liberate iodine from potassium iodide when present in any quantity, but no potable water ever contains sufficient to produce the reaction. Reducing agents, such as sulphuretted hydrogen, may prevent the reaction, but I have not yet met with a water in which both nitrites and sulphides were present.

A solution of potassium iodide and freshly prepared solution of starch may be used, but the reaction therewith is neither so delicate nor reliable as that with the specially prepared starch solution. I have tried numerous formulæ for starch solutions, and find the only one which can be relied upon is that given in the Appendix.

**Quantitative Tests :** (*a*) **Iodide Test.**—The test just described

can be made quantitative by comparing the colour produced by the reagents with that of a nitrite solution of known strength. The only special reagent required is a standard solution of sodium nitrite, 1 c.c. = 1 mlgr. $NO_2$.

From the standard solution of sodium nitrite prepare a solution containing one part of $NO_2$ in two millions of water. This can be done by mixing 1 c.c. of the nitrite solution with 999 c.c. of the well-aërated tap-water free from nitrites, and diluting 500 c.c. of this to 1 litre. When 1 c.c. of dilute acid and 1 c.c. of the iodide and of the starch solutions are added to 50 c.c. of the dilution, a blue colour appears in a few seconds, and gradually increases in intensity. The iodide solution should be added last.

Well aërate by agitation the sample of water to be examined, and test as above described. If the blue colour develops more quickly than the standard, dilute with aërated tap-water, and repeat the experiment until the water and the standard correspond in strength, the reagents being added to each of the two Nessler glasses as nearly as possible simultaneously. If the blue colour develops more slowly than in the standard, the standard is further diluted until the two correspond. The reaction is affected by the quantity of acid and of iodide solution used, so that care must be taken to use the same amount in each case.

The action of the dissolved oxygen and of the oxygen of the air is greatly retarded if a little solution of ferrous ammonium sulphate be added to the waters before acidifying. This renders a comparison of the colours produced less difficult. Aëration of the water, in this case, is not necessary.

The following experimental results show the degree of accuracy attainable by this process :—

| Amount of $NO_2$ per litre in milligrammes | Amount found by experiment | Amount of $NO_2$ per litre in milligrammes | Amount found by experiment |
|---|---|---|---|
| ·24 | ·24 | 1·68 | 1·44 |
| ·48 | ·45 | 3·18 | 3·00 |
| ·48 | ·54 | 3·60 | 3·00 |
| ·60 | ·54 | 3·60 | 3.60 |

(*b*) **Metaphenylenediamine Test** (Griess's). *Reagents required.*—Solution of metaphenylenediamine (diamidobenzol). Dilute sulphuric acid (1 in 3). Standard solution of sodium nitrite.

*Apparatus required.*—Nessler glasses and pipettes. The reaction depends upon the production of Bismarck brown by the action of the free nitrous acid on the diamidobenzol. The test is not so delicate as that with iodide and starch, and the colour produced does not darken so rapidly. Both these points are in favour of this process when the water to be examined contains more than 1 part of $NO_2$ in a million. Make a standard water by adding 1 c.c. of the nitrite solution to 2 litres of well-aërated tap-water.

Take 50 c.c. of the water to be examined, and the same quantity of the standard, and to each add 1 c.c. of acid and 1 c.c. of the diamidobenzol solution. Allow to stand a short time for the red-brown colour to develop. Repeat the experiment, diluting the stronger solution until both correspond.

The following results were obtained by this process :—

| $NO_2$ taken in milligrammes per litre of water | Amount of $NO_2$ found | $NO_2$ taken in milligrammes per litre of water | Amount of $NO_2$ found |
|---|---|---|---|
| ·3 | ·3 | ·9 | ·93 |
| ·33 | ·36 | 1·8 | 1·95 |
| ·51 | ·45 | 2·1 | 2·1 |
| ·815 | ·60 | 2·55 | 2·5 |
| ·72 | ·72 | 3·0 | 3·0 |

(*c*) **Naphthylamine Test** (Ilosvay's). *Reagents required.*—Solution of sulphanilic acid. Solution of naphthylamine. Standard solution of sodium nitrite. This is really a modification of Griess's test. It is more delicate, but the results are more affected by variations in the quantities of reagents used.

The examination is conducted as above described, using 2 c.c. of each reagent for 50 c.c. of water. The following results were obtained by experiment :—

| Amount of $NO_2$ in mlgr. per litre | Amount of $NO_2$ found | Amount of $NO_2$ in mlgr. per litre | Amount of $NO_2$ found |
|---|---|---|---|
| ·036 | ·037 | ·129 | ·144 |
| ·105 | ·111 | ·24 | ·228 |
| ·207 | ·210 | ·55 | ·56 |

Each of the three methods described is sufficiently reliable for all practical purposes. The reagents used in (*b*) and (*c*) gradually undergo change by keeping, and are useful for no other purpose than the detection and estimation of nitrites. (*a*) requires no special reagent, and is best for use with coloured waters, for which reasons I always employ it.

The delicacy of the tests as above applied is such that with a water containing in 1 litre ·3 mlgr. of $NO_2$ (corresponding approximately to ·1 of nitrogen), the iodide test gives a distinct reaction in half a minute, Ilosvay's in two minutes, and Griess's in thirty minutes.

Larger quantities of nitrites than can be determined by the above methods are rarely, if ever, found in potable waters; but of the various methods which may be employed when large quantities are present, I prefer the following :—

*Requisites.*—Flask, fitted with caoutchouc stopper, with two perforations. Tubes for connecting with gas supply. Solutions of iodide and starch. Dilute sulphuric acid. Bicarbonate of soda. Standardised solution of sodium thiosulphate (1 c.c. should correspond to about 1 mlgr. of iodine). Place 250 c.c. of the water in a flask holding about half a litre, add about ·5 gram of pure sodium bicarbonate, and boil vigorously to expel all the dissolved oxygen. Insert the stopper, connect up with the gas supply, and withdraw the flame. Allow to get quite cold in a current of coal gas, and then add, without the introduction of air, 2 c.c. of dilute sulphuric acid (25 per cent.), and a crystal of potassium iodide dissolved in 1 c.c. of starch solution. Finally run in the thiosulphate solution until the blue colour disappears.

The first reaction which takes place is represented by the following equation :—

$$2HNO_2 + 2HI = 2NO + 2H_2O + I_2.$$

As 127 parts of iodine correspond to 47 parts of $HNO_2$, 46 parts of $NO_2$ and 14 of N, the amount of nitrite in the water is easily calculated.

I use this process for the quantitative analysis of the sodium nitrite employed in making the standard nitrite solution, and recently when examining various commercial samples of sodium nitrite obtained from different wholesale houses of repute, the following results were obtained :—

SAMPLE FROM A

| Amount $NaNO_2$ taken | Amount found | Per cent. | Mean |
|---|---|---|---|
| ·1 | ·1000 | 100·0 | |
| ·2 | ·1993 | 99·65 | 99·9 |
| ·1 | ·1001 | 100·1 | |

SAMPLE FROM B

| | | | |
|---|---|---|---|
| ·1 | ·0957 | 95·7 | |
| ·2 | ·1920 | 96·0 | 95·8 |
| ·1 | ·0956 | 95·6 | |

SAMPLE FROM C

| | | | |
|---|---|---|---|
| ·1 | ·0979 | 97·9 | |
| ·2 | ·1945 | 97·25 | 97·8 |
| ·1 | ·0982 | 98·2 | |

SAMPLE FROM D

| | | | |
|---|---|---|---|
| ·2 | ·1999 | 100 | 100 |
| ·2 | ·2002 | 100·1 | |

This process is useless for determining very minute quantities of nitrites, as the oxygen dissolved in the reagents used, especially in the thiosulphate solution, in the presence of the products of the reduction of the nitrite, liberates an equivalent of iodine, and vitiates the results. Moreover there appears to be a great difficulty in driving off the last trace of dissolved oxygen, even by prolonged boiling. The evolution of $CO_2$ from the bicarbonate upon the addition of the acid facilitates this expulsion.

## E. NITRATES

I regard an analysis as incomplete without a determination of the nitric nitrogen, although it is not always necessary to make an exact quantitative analysis. Where an analysis is likely to

be submitted to others for consideration, much uncertainty, however, is caused by the use of such terms as 'trace,' 'minute trace,' &c., and it is desirable, therefore, that the quantity be numerically expressed, so that others considering the results can draw their own conclusions.

In no other determination do results differ so widely. On more than one occasion I have had to give an opinion upon a water which had been submitted to various well-known analysts. The other determinations recorded in the analyses have usually been concordant, but the nitric nitrogen has varied enormously. This has not been due to any change in the character of the water, as in some instances the samples were taken at the same time. The difference appears to be due to the methods employed. The only process in which I have perfect confidence is one in which the nitrates are reduced to, and determined as, ammonia.

The hydrogen necessary for the reduction may be obtained by the action of either an acid or alkali upon the zinc-copper couple. The reaction probably takes place in three stages :—

$$HNO_3 + H_2 = H_2O + HNO_2$$
$$2HNO_2 + H_2 = 2H_2O + 2NO$$
$$2NO + 5H_2 = 2NH_3 + 2H_2O$$

The test can be applied in various ways, but in all cases, in order to ascertain the quantity of water to be used, the following rough estimation is first made of the amount of nitrates present:—

To 50 c.c. of the water in a Nessler cylinder add 1 c.c. of dilute sulphuric acid (1 in 4) and 1 c.c. of the solution of starch, and a minute crystal of potassium iodide. No indication of nitrites being found, add a few mlgrms. of zinc dust, previously shaken with a little distilled water, and mix thoroughly. When nitrates are present in small quantities a blue colour slowly develops, with larger quantities the colour appears more quickly, and when the nitrates present exceed 1 of nitric nitrogen per 100,000, the colour appears almost instantly. With solutions

of potassium nitrate of various strengths, I obtained the following results:—

| Nitric nitrogen per 100,000. | | | |
|---|---|---|---|
| ·10 | A distinct blue colour appeared in | a little under one minute. |
| ·25 | „ | „ | about half a minute. |
| ·50 | „ | „ | from eight to ten seconds. |
| 1·0 | „ | „ | three or four seconds. |

In many cases this rough method gives sufficiently approximate results without further labour. Care should be taken to add just sufficient zinc dust to cause a slight turbidity. If the water contains nitrites, these must be removed before applying this test by digesting 100 c.c. of the water for an hour at 30° C. with about 1 c.c. of sulphuric acid (25 per cent.) and about ·1 gram of urea. In this case no further addition of acid must be made before introducing the iodide and zinc dust.

When the colour takes some minutes to make its appearance, 100 c.c. of the water are used for determination. When the colour appears almost instantly, 10 c.c. are sufficient. Where the amount of nitrate appears to be very excessive, 5 c.c. may suffice.

(1) **Reduction of the Nitrate to Ammonia in the presence of Acid.** *Apparatus required.*—Small flask of 50 to 120 c.c. capacity. The usual distilling apparatus.

*Reagents required.*—Granulated zinc. Solution of copper sulphate. Dilute hydrochloric acid. Solution of caustic soda, free from ammonia, or solution of pure sodium carbonate. Nessler solution and standard solution of ammonium chloride.

Place in the small flask sufficient granulated zinc to cover the bottom. Wash the zinc first with sulphuric acid (25 per cent.), then with distilled water. Cover the zinc with distilled water, add about 2 c.c. of saturated solution of copper sulphate, and allow to stand for a few minutes until the zinc is completely covered with a black deposit of copper. Again wash with several quantities of distilled water, but carefully so

as not to remove the coating of copper. Having, by a preliminary experiment, ascertained how much of the water to be examined should be used, measure this quantity into the flask. Acidulate with one drop of dilute hydrochloric acid (1 in 6), and allow to stand on a hot plate. From time to time add a little more acid so as to maintain a slight but visible evolution of hydrogen in exceedingly minute bubbles. Keep warm for about an hour, by which time the whole of the nitrates and nitrites will be reduced to ammonia.

Whilst this reduction is taking place, about 250 c.c. of good tap-water to which 5 c.c. of caustic soda solution (10 per cent.), or of saturated solution of sodium carbonate, has been added, are placed in a distillatory flask, and 50 c.c. of water distilled over. This removes any free ammonia from the apparatus and the alkaline water. Now pour the water which has been digested with the copper zinc couple into the flask, using a little pure distilled water for rinsing the zinc, and taking care not to introduce any of the metal into the distillatory apparatus.

Distil over 50 c.c., and nesslerise. If the distillate contains more than ·05 of ammonia, a second 50 c.c. should be distilled, and the ammonia therein estimated.

From the ammonia thus found the equivalent of nitrogen, or $N_2O_5$ or $NO_3$, is easily calculated.

The apparatus can be used for examining other samples of water which have been treated with copper-zinc, distilled water being added, if necessary, to maintain a volume of about 250 c.c. in the flask prior to commencing the distillation.

The amount of free ammonia in a potable water is usually so small as not to appreciably affect the results, but should a water contain much ammonia, the necessary correction can easily be made, or the free ammonia may be boiled off before introducing the water into the reducing flask.

The following results were obtained with solution of

potassium nitrate of known strength. The temperature of the hot plate was about 150° F.

| Nitric nitrogen in mlgrs. per 100 c.c. | | Nitric nitrogen found |
|---|---|---|
| 1·40 | (Digested thirty minutes) | 1·45 |
| 1·40 | (Digested sixty minutes) | 1·40 |
| 1·00 | | ·98 |
| ·56 | | ·56 |
| ·46 | | ·49 |
| ·32 | | ·32 |
| ·20 | | ·198 |
| ·10 | | ·108 |
| ·10 | | ·104 |
| ·05 | | ·055 |

(2) **Reduction of the Nitrates in an Alkaline Solution.**—The following process was used by me for a lengthened period, and gave very satisfactory results. I abandoned it for the one just described, because I found that waters containing organic matter gave off a little ammonia when boiled with such a strong alkaline solution, and that it was difficult to obtain caustic potash of sufficient purity. Some samples of caustic soda and potash yield large quantities of ammonia when distilled with copper-zinc, and this has to be removed before the solution can be used.

*Reagents and Apparatus as before.*—Place about 20 grams of granulated zinc in the distillatory flask, and coat with copper in the manner above described. Wash the couple, and introduce into the flask 250 c.c. of distilled water and 50 c.c. of 10 per cent. caustic soda or potash solution. Distil until the distillate is free from ammonia. Now add to the liquid remaining in the flask the measured quantity of the water to be examined, and sufficient distilled water to make the volume up to about 300 c.c. Distil 100 c.c. and nesslerise. The nitrates in the added water are completely reduced to ammonia, and are thus estimated. A number of waters can be estimated in succession without the copper-zinc losing its reducing power.

This is illustrated by the following example, which is only

one of many series of similar experiments. The same alkaline solution was used throughout :—

| Time | Nitric N. used | 1st 50 c.c. | 2nd 50 c.c | 3rd 50 c.c. | Total | Nitric N. calculated |
|---|---|---|---|---|---|---|
| Saturday morning . | ·20 | ·20 | ·04 | ·005 | .245 | ·202 |
| Saturday noon . . | ·10 | ·077 | ·046 | ·000 | ·123 | ·101 |
| Saturday afternoon . | ·20 | ·185 | ·060 | ·005 | ·250 | ·206 |
| Monday morning . . | | A | sample | of | water | ·73 |
| Monday morning . . | | A | sample | of | water | 1·24 |
| Monday noon . . | ·10 | ·088 | ·028 | — | ·116 | ·096 |

The results obtained using potassium nitrate of known strength were invariably satisfactory. The following are given as examples :—

| Nitric N. in 100 c.c. of solution In mlgrs. | N. found | Nitric N. in 100 c.c. of solution In mlgrs. | N. found |
|---|---|---|---|
| ·00 | ·00 | ·20 | ·190 and ·198 |
| ·01 | ·011 | ·30 | ·296 |
| ·02 | ·019 | ·60 | ·573 |
| ·03 | ·028 and ·030 | 1·00 | ·98 |
| ·05 | ·047 and ·050 | 2·0 | 1·96 |
| ·10 | ·100 and ·101 | 2·3 | 2·32 |

The zinc-copper couple may be made with zinc dust or zinc foil. The zinc dust, however, almost invariably contains some compound of nitrogen which yields ammonia when heated with alkali, and foil zinc possesses no advantage over the granulated metal ; in fact, unless each piece is crumpled, the sheet zinc is not so reliable.

The following method dispenses with distillation and gives very good results :—

Proceed exactly as in the first process for the reduction of the nitrates. Then dilute to 49 or 99 c.c. and add a dilute solution of caustic soda or potash drop by drop until zinc hydrate is precipitated and the reaction is faintly alkaline to phenolphthalein. Filter through a washed paper or allow to clear by subsidence ; take an aliquot part and nesserlise. The

following table shows the results obtainable by this process, using a solution of potassium nitrate in distilled water :—

| Nitric N. in 100 c.c. of solution In mlgrs. | N. found | Nitric N. in 100 c.c. of solution In mlgrs. | N. found |
|---|---|---|---|
| ·05 | ·055 | ·80 | ·77 |
| ·10 | ·108 | 1·0 | ·98 |
| ·16 | ·14 and ·15 | 1·6 | 1·51 |
| ·20 | ·198 | 3·92 | 3·95 |
| ·40 | ·41 | | |

Certain waters, however, are difficult to compare, becoming on the addition of the Nessler solution slightly turbid, or giving a colour a little different from that obtained with distilled water. In such cases the use of oxalic acid, instead of hydrochloric acid, in the reducing process possesses an advantage. The process is one of the most rapid, and when a number of waters have to be examined and a very accurate estimation of the nitrates is not necessary, it answers extremely well. By using a copper-zinc couple made with zinc dust, the reduction of the nitrates is effected in a few minutes, but the zinc must be first freed from nitrogen compounds, and this is often difficult. My mode of procedure is as follows :—Place about 1 gram of zinc dust in a stoppered tube and shake with about 10 to 20 c.c. of water. Add drop by drop with continued agitation solution of copper sulphate until the zinc is quite black and settles rapidly. Pour off the supernatant liquid and wash several times with warm distilled water until the clear liquid poured off is no longer appreciably affected by Nessler's solution. The copper-zinc thus prepared can be used for examining two waters in succession.

To the copper-zinc add 5 to 20 c.c. of the water to be examined, the measured quantity taken depending upon the richness in nitrates ; warm by immersing the tube in hot water, and shake continuously for about two minutes, by which time the reduction will be complete. Wash a small filter paper thoroughly, filter the supernatant fluid after adding a little caustic soda solution, and wash with distilled water until 50 c.c. are obtained. Nesslerise the filtrate in the usual way.

By this process a number of waters can be examined in an hour. In all these processes the nitrites as well as the nitrates are reduced. The nitrogen in the nitrites must if necessary be separately estimated and deducted from the results obtained. The nitrogen in the free ammonia must also be subtracted, if the water used contains sufficient to affect the results and the ammonia has not been removed by evaporation.

(3) **Indigo Process.**—The apparent simplicity of the process for estimating nitrates by the oxidation of indigo causes it to be employed in many laboratories. It is however absolutely useless for estimating small quantities of nitrates, and the amount of indigo oxidised bears no constant relation to the amount of nitrate present in the water. The presence of organic matter interferes more decidedly than in the processes previously described, and, however carefully the experiments are conducted, the results cannot be relied upon. Sufficiently accurate results for most purposes can be obtained if the waters used are concentrated (or if necessary diluted) to an approximate standard, and if every detail in the process is carefully followed.

I have tried various methods, some much more complex, others a little more simple, than the one about to be described, and have arrived at the conclusion, after taking everything into consideration, that this is the best. Where numerous samples have to be examined and fairly approximate results only are desired, it may be employed; but I far prefer taking the little extra trouble involved in using the zinc copper process (No. 1) and obtaining results in which I have every confidence.

*Apparatus required.*—A water bath containing a strong solution of calcium chloride. A deep glass or earthenware jar of about 200 c.c. capacity. A burette. A 25 c c. cylinder. Pipettes. Thermometer graduated to 150° C.

*Reagents required.*—A standardised solution of indigo. Pure sulphuric acid. The process is conducted exactly in the way described for standardising the indigo solution, using a water which has been so concentrated or diluted with distilled water that each 100 c.c. contains between ·5 and 2·0 mlgrms.

of nitric N. The jar is placed in the water bath, kept at a temperature of 120° C. so that the lower half is immersed in the calcium chloride solution ; 50 c.c. of strong sulphuric acid are poured into the jar and 25 c.c. of the water added quickly from a pipette, the mixture being stirred with the bulb of the thermometer. The mixture may acquire a temperature of from 110° to 120° C. Now add the indigo solution from a burette, drop by drop, at the rate of about 1 drop per second. If the first 2 c.c. are decolorised, the indigo may then be added faster until the darkening of the colour of the solution indicates that the end of the reaction is being approached. Then add more slowly until a faint blue-green tint appears, and persists for a minute. The amount of indigo solution used is then read off, and the table obtained from the standardisation of the indigo consulted. In the following examples the indigo solution had been standardised as under :—

| Nitric nitrogen in 100 c.c. solution | Indigo solution used for 25 c.c. of the solution |
|---|---|
| ·2 mlgr. | ·1 c.c. |
| ·3 „ | 1·2 „ |
| ·5 „ | 2·1 „ |
| ·75 „ | 3·1 „ |
| 1·0 „ | 4·1 „ |
| 1·25 „ | 4·7 „ |
| 1·5 „ | 5·5 „ |
| 2·0 „ | 7·5 „ |

*Note.*—With less than ·2 part of nitrogen per 100,000 no indigo was decolorised ; with over 3 parts per 100,000 concordant results could not be obtained.

The results obtained with the waters used are shown in the following table :—

| Nitric nitrogen in water used | Nitric nitrogen found by indigo process |
|---|---|
| 87 parts per 100,000 | ·93 parts per 100,000 |
| ·66 „ „ | ·72 „ „ |
| 1·30 „ „ | 1·25 „ „ |
| ·75 „ „ | ·80 „ „ |
| 1·15 „ „ | 1·06 „ „ |
| 2·0 „ „ | 2·0 „ „ |

For a more elaborate process Sutton's 'Volumetric Analysis,' sixth edition, pp. 239 to 247, may be consulted. A

somewhat simpler process is described in Lehman's 'Methods of Practical Hygiene,' translated by Crookes, vol. i. pp. 323 to 327. It should be noted that nitrites interfere with the above reaction, and vitiate the results obtained, as no correction can be made. The nitrites, however, may be removed by digesting the 100 c.c. of the water for an hour with acid and urea, as described on p. 202.

(4) **Phenolsulphonic Acid Process.**—This process depends upon the action of nitric acid on phenolsulphonic acid, producing picric acid, and the estimation of the picric acid colorimetrically after converting into the ammonium salt, or preferably into the potassium or sodium salt.

*Reagents required.*—Solution of phenolsulphonic acid. Standard solution of potassium nitrate, 10 c.c.=·1 mlgr. N. Solution of potassium or sodium hydrate.

*Apparatus required.*—Beakers of about 50 c.c. capacity. Water bath. Pipettes. Nessler cylinders.

*Process.*—The waters to be examined should be concentrated or diluted until 100 c.c. contain from ·5 to 1·5 of nitric N. In one beaker 10 c.c. of the water, thus prepared if necessary, are placed, and in the other 10 c.c. of the standard solution of potassium nitrate. Both are placed on the water bath and evaporated to dryness. Over each dry residue 2 c.c. of the phenolsulphonic acid are discharged from a pipette and the beaker rotated until the residue is dissolved. Allow to remain 5 minutes on the water bath. Add to each a little water, then an excess of solution of potash or soda,[1] and dilute to 50 c.c. in the Nessler cylinders. The resulting solutions are of a yellow colour, and the strength of the standard being known, that of the water is determined in the usual way.

The colour produced is often of a browner tint than that of a solution of pure potassium picrate, hence it cannot be accurately compared with such a standard. With waters containing

[1] Ammonia may be used, but it is not advisable in a laboratory where water analyses are conducted.

organic matter or a trace of iron, there is often a perceptible difference in tint between the standard and the water solution, and moreover the liquids on standing slowly change colour, becoming more and more brownish green. Hence a fresh standard has to be prepared for each water if the best results are desired.

Some chemists only use 1 c.c. of phenolsulphonic acid for each determination, others use 3 c.c. Some digest for 3 minutes, others for 15.

Fairly good results are usually obtained, but occasionally for some reason there is an appreciable error. It is a process which I should never think of using, and it is described simply because it is still employed by many analysts. I invariably employ process No. 1, save when time is an important factor, when I use No. 3.

The following experimental results show very well the relative value of the various processes. An assistant prepared 500 c.c. of water by adding to pure distilled water a little sewage, free from nitrates, some calcium chloride, and magnesium sulphate. To this he added a carefully measured volume of solution of potassium nitrate, each c.c. corresponding to 1 mlgr. nitric nitrogen. The amount of nitrate added was unknown to me. The results obtained by the various processes were as under :—

| Process employed | Amount of water used | Nitrogen found per 100 c.c. In mlgrs. |
|---|---|---|
| Indigo | 10 c.c. | 1·3 |
| „ | 20 „ | 1·37 |
| Phenolsulphonic acid | 10 „ | 1·5 |
| „ „ | 5 „ | 1·2 |
| Copper-zinc without distillation | 10 „ | 1·23 |
| „ „ | 10 „ | 1·13 |
| „ „ | 10 „ | 1·16 |
| Copper-zinc with distillation | 10 „ | 1·16 |
| „ „ | 10 „ | 1·21 |

The results varied from 1·13 to 1·5 per 100,000.

My assistant had added to the ½ litre of water 5·8 c.c. of nitrate solution corresponding to 1·16 N per 100,000.

Subsequently a sample of water received for analysis was examined, which contained more nitrates than any so-called potable water I had then met with.

The results were as under :—

| Process used | Nitrogen per 100,000 |
|---|---|
| Zinc-copper and distillation . . . . . | 12·3 |
| „ without distillation . . . . . | 11·6 |
| Indigo . . . . . | 12·0 |
| Phenolsulphonic acid . . . . . | 10·2 |

I regard the first as being most nearly correct.

## F. Phosphates

As has already been stated, phosphates are rarely present in potable waters in appreciable quantities, and their detection and estimation afford no indications of value.

When a water is examined for phosphates, it is usual to simply ascertain their absence or their presence in 'minute traces,' 'traces,' or 'heavy traces.'

The following process is reliable, since it ensures the removal of silica, which otherwise may mislead by giving a reaction which can be mistaken for a 'minute trace' of phosphate. It is due, in my opinion, to the neglect of this precaution that some analysts so often discover traces where I can detect none.

*Reagent required.*—Solution of ammonium molybdate in nitric acid.

*Process.*—Strongly acidulate 100 c.c. of the water with nitric acid and evaporate to dryness in a porcelain capsule. Heat the residue to 120° C in the hot-air oven for a quarter of an hour, then dissolve in 3 c.c. of distilled water to which 2 or 3 drops of nitric acid have been added. Place 5 c.c. of the ammonium molybdate solution in a test tube and heat to about 60° C. Pour in the solution of the water residue (unless distinctly turbid it is unnecessary to filter) and set aside in a warm place

for about 15 minutes. The development of a yellow colour but no precipitate indicates a 'minute trace,' a decided turbidity 'a trace,' and a distinct precipitate a 'heavy trace,' of phosphoric acid.

If the total solids in the water have been estimated by the evaporation of 100 c.c. in a platinum dish, the residue may, after solution in a little dilute nitric acid, be transferred to a small porcelain capsule for evaporation to dryness, &c., and be used for this determination. If the evaporation in the presence of acid were conducted in the platinum dish, the chlorine liberated by the action of the nitric acid on the chlorides present would attack the metal, and a trace of platinic chloride be formed, possibly sufficient to impart a faint yellow tint to the solution.

The amount of phosphoric acid present may be approximately estimated by using a standard solution of sodium phosphate, of which 1 c.c. = ·1 mlgr. of the anion $PO_4$, and diluting various amounts of this with water to 3 c.c., adding 2 or 3 drops of strong nitric acid, and proceeding as already described. These standards can then be compared with the results obtained with the water under examination.

### G. Ammonia

The so-called free ammonia found in nearly all waters exists probably in combination with some acid, but upon boiling, any carbonate present causes its expulsion as ammonium carbonate. In the absence of carbonates the addition of a little recently ignited sodium carbonate to the water is necessary before distilling. Unless, therefore, a water is known to contain carbonates, it should be tested by the addition of a drop of lacmoid solution to about 20 c.c; if acid the water will acquire a faint red tint; if carbonates are present the tint will be decidedly blue.

*Reagents required.*—An abundance of ammonia-free distilled water. Standard solution of ammonium chloride, 1 c.c. = ·01 mlgr. of ammonia. Nessler solution.

*Apparatus.*—Retort or boiling flask and condenser. 50 c.c. and 100 c.c. Nessler cylinders. Burette or pipettes for the standard ammonia solution. Pipette holding about 2 c.c. for measuring the Nessler solution. 250 c.c. measuring flask.

The following illustration (fig. 5) is taken from the apparatus used in my laboratory.

For measuring the Nessler solution, and mixing it with the water, I use a 2 c.c. pipette which has been cut so that it admits and discharges very freely. When the bulb is inserted in the Nessler solution, it immediately fills, and by closing the upper end with the finger the requisite quantity can be readily removed and discharged. This avoids any disturbance of the deposit which usually forms at the bottom of the bottle containing the reagent.

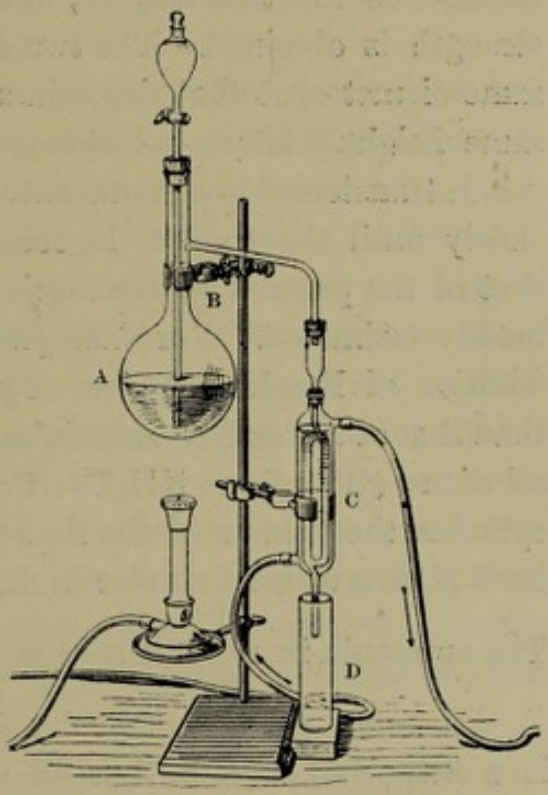



FIG. 5.—A, flask with tubulure, holding about 600 c.c. and supported by a clamp, B; C, glass vertical condenser with support; D, Nessler cylinder.

*Process.* — Introduce into the flask 250 c.c. of the water to be examined and distil. The distillation at first should be slow and kept as regular as possible. If there is any doubt about the apparatus being ammonia-free, or if any ammonia has been recently used in the laboratory, it is best to put a little good tap-water into the flask and distil until the distillate, when tested with Nessler reagent, proves to be quite free from ammonia. The flask may be cleansed by rinsing first with a little strong hydrochloric acid and afterwards with successive quantities of good tap-water until every trace of acid has been removed.

The distillate is collected in cylinders marked at 50 c.c.

When the first 50 has come over, about 2 c.c. of the Nessler solution are added to it and well mixed. Into a second similar cylinder a measured quantity of the ammonium chloride solution is diluted to 50 c.c. with ammonia-free water, and to the mixture 2 c.c. of the Nessler solution are added. If the two liquids after standing two or three minutes have approximately the same tint, the standard will serve for the estimation. If there is a marked difference fresh standards must be made, weaker or stronger as the case may be, until one of approximately equal strength is obtained. The two cylinders used must be of the same diameter, so that the columns of liquids are exactly the same height. If one solution is a little darker than another, this is transferred to a graduated cylinder, and then poured back slowly until the tint of the column exactly corresponds with that of the paler. The strength of either solution can then be readily estimated. For example, the distillate (50 c.c.), after addition of Nessler solution, acquires a colour a little darker than that of a standard containing 5 c.c. of ammonium chloride solution (·05 mlgr. $NH_3$). Transferred to the measuring cylinder, the volume of the liquid is 52 c.c., and 48 c.c. poured back gives a column similar in depth of colour to the standard. The ammonia in the distillate is $\frac{52}{48} \times \cdot 05 = \cdot 054$ mlgr.

Assuming, on the other hand, that the standard solution is a little darker, and that 48 c.c. = the 52 c.c. of distillate and Nessler solution, the ammonia in the distillate would then be $\frac{48}{52} \times \cdot 05 = \cdot 046$ mlgr.

If a distillate contains much more than ·10 ammonia in the 50 c.c., it cannot be very accurately nesslerised. If great accuracy is desired, it is better to start afresh and use an aliquot part of the 50 c.c. distillate diluted. To avoid this loss of time, it is well to nesslerise a little of the water without distillation. If the addition of the Nessler solution gives a visible yellow tint, it is evident that the concentrated distillate will require dilution to permit of the ammonia being estimated.

If the first 50 c.c. contain not more than ·02 or ·03 of ammonia, the second 50 c.c. will practically be ammonia-free; but when the first contains more than the above amount, a second 50 c.c. should be collected, and examined. After distilling the second quantity, the residue left in the flask can be used for estimating the amount of ammonia produced by the action of a strongly alkaline solution of potassium permanganate upon the organic matter in solution, as described in the next section. This ammonia is usually spoken of as 'albuminoid' or 'organic' ammonia.

On the Continent this latter process is but rarely used, and the free ammonia is generally estimated without resorting to distillation by the following process:—

*Requisites.*—250 c.c. stoppered flask, and a solution of sodium hydrate and carbonate (containing about 5 per cent. of each), previously boiled, so as to free it from all traces of ammonia. About 200 c.c. of the water are introduced into the flask, and 5 c.c. of the alkaline solution added. The stopper is then inserted, the flask well shaken, and set aside for about twelve hours. At the end of this time the calcium and magnesium salts are deposited, and portions of the clear liquid can be drawn off by means of a pipette, and the ammonia directly estimated by the addition of Nessler solution in the manner above described.

Many waters can be nesslerised without even this preliminary treatment, but the results are not nearly so accurate as when the ammonia is concentrated by distillation. For some purposes, however, the information obtained may be sufficient. The amount of ammonia in 250 c.c. having thus been determined, the amount present in parts per 100,000 and parts per million is easily calculated.

Some waters yield a distillate having a decided odour, and giving with the Nessler solution a colour slightly different from that yielded by ammonia. These waters probably contain traces of compound ammonias, and are always of a suspicious character.

### H. Albuminoid or Organic Ammonia

The process adopted for obtaining this rough index of the amount of organic matter in solution is always conducted with the water from which the free ammonia has been driven off by distillation, and the ammonia produced by the action of the permanganate is estimated in the distillate in the manner just described. The apparatus required is that which is used for the free-ammonia determination, and the only additional reagent is a strong alkaline solution of potassium permanganate. After removing the 100 c.c. of the water by distillation in estimating the free ammonia, there remain in the flask 150 c.c. of the concentrated water. To this are added, best by aid of a suitable stoppered funnel, 25 c.c. of the alkaline solution, and the distillation is slowly resumed. Two successive 50 c.c. are drawn over, and the ammonia contained therein estimated. This represents the amount yielded by the 250 c.c. of the water.

The water, after the addition of alkali, often boils intermittently, and is then said to 'bump.' This may easily lead to a loss of a little ammonia, or to a fracture of a flask. The 'bumping' may generally be avoided by introducing into the flask a few small pieces of recently ignited pumice or pipe stem, or by adding short pieces of capillary glass tubing, each of which has been sealed at *one end*.

There are numerous modifications of these processes for determining the free and organic ammonia, all devised with one view, that of increasing the accuracy of the results. These refinements take away from the simplicity of the process without any compensating advantage. The minute errors avoided are utterly inconsequential in interpreting the results, as has been demonstrated in the section treating of the interpretation of analyses.

A stoppered retort and Liebig's condenser can be used, but the arrangement is cumbersome. The apparatus figured takes up little space, and is very convenient. Care should be taken

to employ rubber stoppers and tubing which have been used for no other purpose, and to be certain that the whole apparatus is ammonia-free. If not used for a few days, it is always advisable to distil a little clean water until the distillate is ammonia-free, and then rinse out the flask before introducing the water to be examined.

### I. Estimation of the Organic Nitrogen

For reasons previously given some few chemists prefer to estimate the total nitrogen in the organic matter present in a water. The determination, if properly made, is tedious and troublesome, and the results are of no greater value than those obtained by the simpler processes for the estimation of the organic and albuminoid ammonia. Very few experiments convinced me of this fact, and I have never adopted it as a routine process. The safety of a water does not depend upon its containing a little less or a little more nitrogenous matter; it may contain relatively large amounts and yet be perfectly wholesome, and it may contain very small amounts and yet be dangerously polluted. Neither the albuminoid ammonia nor the total nitrogen determinations can be depended upon to detect minute quantities of sewage in water, and when more information is wanted than can be obtained by the ordinary method of chemical analysis, it should be obtained by a bacteriological examination.

The process requires the use of special flasks, very pure concentrated sulphuric acid, and the alkaline solution of potassium permanganate. A blank experiment should be made with the reagents used, and the ammonia obtained deducted from that found in the final distillate from the water examined.

Five hundred c.c. of the water are introduced into the ordinary distillatory apparatus, and the distillation continued until only about 100 c.c. remain. This is transferred to a Kjeldahl flask, and 10 c.c. of the pure concentrated sulphuric acid added. Evaporation is continued on a sand bath in a fume

chamber (free from any trace of ammonia vapour) until acid fumes are given off, and the liquid has acquired a pale yellow colour. A few milligrams of powdered potassium permanganate are then added, and the heating continued until the liquid is of a decided green colour. It is then allowed to cool, and, after the addition of 200 c.c. of ammonia-free distilled water, it is transferred to the distillation flask, into which 100 c.c. of caustic soda solution (No. 45), or of alkaline permanganate, are poured. The ammonia formed by the action of the strong acid on the organic matter is then distilled off, and nesslerised in the usual manner. Or the Nessler cylinder, into which the water is to be distilled, may contain a little distilled water, slightly acidified with hydrochloric acid, and the end of the condensation tube made to terminate below the surface of the acidulated water. By this method, and by distilling the first 50 c.c. very slowly, any loss of ammonia can be avoided. When 200 c.c. have distilled over, 50 c.c. of the distillate, rendered alkaline if the latter method of collection has been used, may be nesslerised. The ammonia found in the 50 c.c., multiplied by 8, gives the amount of ammonia obtainable from a litre of the water, and to convert this into nitrogen it is only necessary to multiply by $\frac{14}{17}$. The amount found in the blank experiment being deducted, the nitrogen derived from the organic matter in the water is known.

*Example.*—A water which yielded ·008 part of organic ammonia was submitted to Kjeldahl's process. The blank experiment showed that the ammonia yielded by the chemicals was ·035 mlgr.

Five hundred c.c. of water were taken, and the ammonia found in 50 c.c. of the distillate of 200 c.c. was ·035 mlgr., or in the whole 200 c.c., ·140 mlgr. From this had to be deducted ·035 mlgr. found in the chemicals, leaving ·105 mlgr. as being derived from the 500 c.c. of water. This corresponds to ·087 mlgr. of nitrogen. The organic nitrogen, therefore, was ·174 mlgr. per litre, or ·0174 part per 100,000.

The method is, undoubtedly, much more scientific than

that of determining the organic ammonia, and notwithstanding its tedious character, the necessity for using a fume cupboard, &c., it would long ago have been generally adopted had it possessed any advantage over the less scientific, but simpler process.

The nitrogen in nitrates and nitrites is not included in this determination, nor does their presence in such quantities as are ordinarily found in potable waters appear to affect the results. Many modifications have been suggested, all introducing additional possible sources of error and complicating the process; it is not necessary, therefore, to make any further reference to them.

### J. Oxygen Absorbed

All waters when strongly acidulated with sulphuric acid and digested with a little permanganate of potash absorb from this salt more or less oxygen, the amount of which can be determined if the amount of available oxygen in the permanganate added is known and the amount left after the action of the water is determined. The difference gives the oxygen absorbed by the constituents of the water. Some very pure waters absorb very little indeed, less than ·1 mlgr. per litre, while others containing organic matter in solution absorb many times this amount. Although, strictly speaking, an index neither to the quantity nor to the quality of the organic matter, yet, as the amount absorbed varies in different waters, being usually very small in pure waters and comparatively large in impure waters, the determination is not without value. Certain inorganic substances occasionally found in waters also reduce permanganates, such as nitrites, ferrous salts, and sulphides. These act on the permanganate with rapidity, whilst the organic matter acts very slowly. When any of these substances are present, two determinations are generally made, one to ascertain the amount of oxygen absorbed by the inorganic matter, and the other to estimate the total absorbed oxygen, and the difference is taken as being the amount consumed by the organic matter.

The total oxygen consumed varies greatly in the same water, the chief factors being time and temperature; but the degree of acidity and the intensity of the light are not unimportant. For results to be comparable, therefore, they must have been obtained by identical processes. Some chemists, and these are in the majority, maintain the water at 80° F. for three hours, whilst others prolong the time to four hours. Some digest at the room temperature, considering the temperature of the laboratory to be sufficiently constant, whilst others again prefer a temperature of 122° F. or 212° F. and reduce the time to from fifteen minutes to one hour. Continental chemists make very little use of the process, and some prefer to use an alkaline rather than an acid solution. I have tried all the processes in use and many others which have been suggested, but have not found that any yield more reliable results than the following slight modification of the process recommended by the late Dr. Tidy, which was again a modification of Forchammer's method. My method differs only from Tidy's in that I prefer working at 98° F. instead of 80° F., because that is the temperature of the ordinary warm incubator now found in every properly equipped laboratory. In the incubator also the absence of light is secured, so that the conditions are easily kept uniform.

*Apparatus and Reagents required.*—Standard solution of potassium permanganate, 1 c.c.=·1 mlgr. available oxygen. Solution of sodium thiosulphate, 1·0 gram to the litre. Solutions of potassium iodide and of starch. Solution of sulphuric acid 25 per cent. Stoppered bottles or flasks holding about 400 c.c. Burettes, pipettes &c. Two hundred and fifty c.c. of the water to be examined heated to 98° F. are measured into one of the bottles or flasks, which should have been previously cleaned with acid, &c. To this are added 10 c.c. of the solution of potassium permanganate and 10 c.c. of the sulphuric acid, and, the stopper being inserted, the bottle is placed in an incubator kept at about 98° F. Let it remain there for three hours, examining it from time to time to see that a decided pink

colour remains. If the colour tend to disappear, add a second 10 c.c. of permanganate solution, as this should always be present in marked excess. Whilst this is 'incubating,' place 250 c.c. of recently distilled water in a second flask, add 10 c.c. of the acid, 10 c.c. of the permanganate, and 1 c.c. of 5 per cent. solution of potassium iodide and titrate with the thiosulphate solution, using starch as an indicator. The amount of solution used corresponds to 1 mlgr. of available oxygen, or to 10 c.c. of the permanganate solution. The thiosulphate solution not keeping well, this standardisation should be repeated with every fresh batch of waters or every few days. On no account should the thiosulphate solution be made with a water containing nitrates, for, if so, nitrites will be formed and vitiate the experiment.

The water, after the lapse of three hours, is removed from the incubator, and quickly reduced to the room temperature by immersing the bottle in cold water. The iodide is then added, and the excess of permanganate estimated. In this determination, it is most important to cool the water, as the amount of thiosulphate required to destroy the blue colour of the iodide of starch is markedly affected by the temperature. This is another of the causes, not generally recognised, of the differences in the amount of oxygen absorbed found by different analysts when examining the same water.

If it is desired to estimate the oxygen absorbed by the inorganic matter, the water may be warmed to 98° F., and the acid and permanganate added as before. The mixture is allowed to stand for 5 minutes, then cooled rapidly, and the unreduced permanganate estimated. In examining potable waters this determination is rarely required.

Prof. Thorpe, in examining the water supplied by the London water companies, not only estimates the oxygen absorbed at 80° F. in 4 hours, but also that absorbed at 122° F. (50° C.) in 1 hour. *Vide* tables of analyses at the end of this section. At the latter temperature the results are invariably a little higher than at the former, and I find they very closely

correspond to the results obtained by digesting for 3 hours at 98° F. Where time is important, and a suitable arrangement provided for keeping the water at 50° C., this process may be adopted. For the results to be comparable with those obtained by digesting at 98° F. for 3 hours the same precautions must be observed, viz. digesting in the dark and cooling the water before determining the unreduced permanganate.

Performed in the above manner, concordant results are obtained. Occasionally it is found that the blue colour quickly returns after titration with thiosulphate. This appears to be due to a trace of nitrous acid in the thiosulphate solution, and indicates that fresh solutions are required.

The following are examples of results obtained with various waters :—

1. A deep well water of known purity.

The thiosulphate solution on standardising required 28·7 c.c. to decolorise the iodine liberated by 10 c.c. of the permanganate solution.

The water, after the addition of acid and permanganate and being maintained for 3 hours at 98° F., required 27·6 c.c. of thiosulphate solution.

$$28{\cdot}7 : 1 :: (28{\cdot}7 - 27{\cdot}6) : x \text{ oxygen absorbed by the 250 c.c. of water.}$$

$$x = {\cdot}0383 \text{ mlgr.}$$

corresponding to ·153 mlgr. per litre, or ·0153 part per 100,000.

2. A peaty moorland water, free from suspicion of manurial or sewage contamination.

Thiosulphate solution 30·1 c.c. = 10 c.c. permanganate. After oxidation, the thiosulphate solution used = 16·4 c.c.

$$30{\cdot}1 : 1 :: (30{\cdot}1 - 16{\cdot}4) : x = {\cdot}455 \text{ mlgr.},$$

or 1·82 parts per million, or ·182 part per 100,000.

3. A shallow well water undoubtedly contaminated by leakage from house drain.

Thiosulphate solution 29·0 c.c. = 10 c.c. permanganate. After oxidation, the thiosulphate solution used = 18·2.

$$29{\cdot}0 : 1 :: (29{\cdot}0 - 18{\cdot}2) : x = {\cdot}3724,$$

or 1·489 parts per million, or ·149 part per 100,000.

The general formula for the calculation is—

$$\frac{a-b}{a} \times 4 = \text{parts per million},$$

where $a$ = the number of c.c. of thiosulphate solution equivalent to 10 c.c. of the permanganate solution, and $b$ = the number of c.c. of the thiosulphate solution used at the end of the incubation. If 20 c.c. or 30 c.c. of the permanganate solution have been added, then the numerator becomes $2a-b$ or $3a-b$.

Results obtained under one set of circumstances cannot be compared with those obtained under others. The oxygen absorbed by the same waters varies, as has been stated, and the effect of certain of the factors influencing the results are shown in the following experimental results:

*Example* 1.—Tap-water containing ·1 per cent. of Sewage Effluent

| Oxygen absorbed in Parts per 100,000 | |
|---|---|
| Digestion for four hours at room temperature (about 65° F.) | ·0262 |
| „ „ in incubator (about 98° F.) | ·0303 |
| Kept for one hour at 212° F. | ·1520 |

*Example* 2.—Tap-water

| | |
|---|---|
| At room temperature | ·0151 |
| At 98° F. | ·0262 |
| At 212° F. | ·0840 |

These and similar results show that there is no approximately constant factor for converting results obtained in one way into those obtained in another.

*Example* 3

| | Polluted well water | Peaty water | Tap-water 5 per cent of sewage effluent |
|---|---|---|---|
| Four hours at 98° F. | ·364 | ·163 | ·061 |
| Boiled for fifteen minutes | ·740 | ·300 | ·132 |

The effect of exposure to sunlight on the amount of oxygen

absorbed varies considerably with different waters. With very good waters absorbing little oxygen the difference produced is slight, but in presence of organic matter the result of exposure is to increase the amount of oxygen absorbed. A water to which permanganate has been added, and which remains pink and bright in the dark, often becomes brown and turbid if exposed to bright sunlight. The results obtained by different exposures are shown in the following table. All the experiments were made at as nearly as possible the same temperature, the bottle in the dark being in black paper or in a cardboard box, side by side with the exposed bottle.

Oxygen absorbed in Parts per 100,000

| | In incubator at 98° | In dark at room temperature | Exposed at room temperature to bright light |
|---|---|---|---|
| A well water containing vegetable matter . | — | ·058 | ·186 |
| Chalk spring . . . | ·116 | ·072 | ·165 |
| An impure water . . | — | ·179 | ·233 |
| New River Co. water . | — | ·0107 | ·0131 |
| New River Co. water . | — | ·0132 | ·0166 |

Many waters absorb more oxygen from a strongly alkaline solution of permanganate than from an acid solution, and I at one time thought that this was especially the case when the waters were sewage-polluted. A long series of experiments, however, demonstrated that this difference could not be depended upon to distinguish between 'recent' and 'previous' sewage pollution, or between organic matter of vegetable and of animal origin.

In the following experiments the oxygen absorbed in the acid solution was determined in the way above described, after standing four hours at 80° F., whilst the alkaline solutions were made by adding 10 c.c. of 20 per cent. solution of sodium hydrate in place of the acid. After standing four hours at 80° F., they were rendered acid by the addition of dilute sulphuric acid, and the titration with thiosulphate completed in the usual way.

In Parts per 100,000

| | Oxygen, absorbed from acid permanganate | Oxygen, absorbed from alkaline permanganate |
|---|---|---|
| Dilute infusion of deal shavings | 1·71 | 1·66 |
| " " " | ·528 | ·532 |
| Infusion of decayed leaves | ·084 | ·099 |
| " " | ·122 | ·132 |
| " " | ·160 | ·144 |
| " " | ·128 | ·124 |
| Water plus urine | ·385 | ·180 |
| " " | ·224 | ·212 |
| " " | ·328 | ·208 |
| " " | ·332 | ·296 |
| " " | ·256 | ·164 |
| Sewage-polluted river water | ·540 | ·700 |
| " " | 1·360 | 1·510 |
| Tap-water | ·058 | ·053 |
| Tap-water + sewage effluent | ·288 | ·362 |

Similar experiments made with alkaline solutions of different strengths, and with alkaline carbonates instead of hydrates, all tended to prove that the results were of no value for indicating the nature of the organic matter, and that for purposes of comparison the processes possessed no advantage over the one usually employed, and were more troublesome to perform.

When many samples have to be compared, and time is an important factor, the oxygen absorbed by the water at 212° F. in fifteen minutes may be determined, but such occasions must be exceptional.

The reactions which take place in these various processes may be represented by the following equations :—

$$4KMnO_4 + 6H_2SO_4 = 2K_2SO_4 + 4MnSO_4 + 6H_2O + 5O_2$$

$$O_2 + 4HI = 2H_2O + 2I_2$$

$$I_2 + 2Na_2S_2O_3 = Na_2S_4O_6 + 2NaI$$

## K. Detection and Estimation of Iron

Water containing even a small trace of iron usually becomes opalescent upon exposure to air. This is apparently due to the absorption of oxygen and the formation of an insoluble

oxycarbonate from the soluble bicarbonate. If it is desired merely to ascertain the presence or absence of a minute trace of iron salt, the method I adopt is as follows:

To 50 c.c. of the water, previously agitated, add 1 c.c. of dilute sulphuric acid (1 in 4) and drop by drop a solution of potassium permanganate (1 c.c. = ·1 mlgr. O), until the faintest possible red tinge is discernible and persists for some minutes. The application of heat may be necessary, if the water is turbid, to ensure the solution of the iron and its conversion to the ferric state; filtration through paper removes the last trace of permanganate. Now add 1 c.c. of the solution of potassium ferrocyanide, when a blue tint will be produced if more than one part of iron is present in ten million parts of water, corresponding to ·01 part per 100,000. The amount of iron present may be estimated by making a solution which gives with the ferrocyanide a colour of equal intensity. For this purpose the standard solution of iron, each c.c. of which corresponds to ·1 mlgr. of Fe, may be used. This is diluted with varying quantities of distilled water, and to each 50 c.c. 1 c.c. of dilute sulphuric acid and 1 c.c. of the ferrocyanide solution are added. If necessary the process must be repeated until the standard solution and the water have the same tint. If the difference is but slight, the exact amount may be determined by varying the lengths of the columns and making the necessary calculation. If the water gives a dark blue colour with the ferrocyanide, it should be diluted with a definite quantity of water until the tint produced admits of being easily compared.

I have found this the simplest and most accurate method for determining the amount of iron present. The following table shows that the results are sufficiently accurate for all practical purposes.

| Amount of iron in 100 c.c. | Amount found |
|---|---|
| ·032 mlgr. | ·032 mlgr. |
| ·041 ,, | ·0375 ,, |
| ·041 ,, | ·040 ,, |
| ·090 ,, | ·080 ,, |
| ·200 | ·200 ,, |

If the water has been heated to effect solution, it must be allowed to become quite cold before the quantitative tests are applied.

A little bromine water may be used instead of the permanganate for the oxidation of the iron and the excess removed by boiling, but this possesses no advantage over the process just described. Nitric acid is also often used for effecting oxidation before adding the ferrocyanide, but I have not found it as reliable in quantitative estimations as could be desired.

The ferrocyanide solution should not have been kept any length of time. A freshly prepared solution is to be preferred.

### L. Detection and Estimation of Zinc

The test applied for the detection of iron will almost certainly have given indications of the presence of zinc, if any compound of this metal be present, by the appearance of an opalescence due to the formation of the very insoluble zinc ferrocyanide. The test can be repeated, omitting the addition of the potassium permanganate. With ·05 mlgr. of zinc in 100 c.c. a decided opalescence will appear in a few minutes, with ·1 mlgr. the turbidity is obvious in about 1 minute, whilst with 1 mlgr. the turbidity appears in a few seconds. The amount of zinc present can be estimated by adding successively to 50 c.c. of the water 1 c.c. of dilute sulphuric acid and 1 c.c. of solution of potassium ferrocyanide. The opalescence produced is then imitated by adding the same quantities of reagents to water to which known quantities of solution of zinc sulphate (1 c.c. = ·1 mlgr. Zn) have been added. The turbidity, save in excessively dilute solutions, reaches its maximum in about five minutes. Slight variations in the quantity of acid or ferrocyanide solution do not appear to affect the results, but the nature of the acid and the quantity are not without effect if a marked excess is employed, so that the experiment should be conducted as

described. The reaction is very delicate, and will with certainty detect 1 part of zinc in 2,000,000 of water even in the presence of a trace of iron. When the amount present exceeds 1 mlgr. in 100 c.c., it is advisable to dilute the water before estimating the zinc. The following table shows that the results obtained are sufficiently reliable.

| Zinc in 100 c.c. | Zinc estimated | Zinc in 100 c.c. | Zinc estimated |
|---|---|---|---|
| ·0875 mlgr. | ·100 | ·50 mlgr | ·50 |
| ·10 „ | ·075 | ·56 | ·50 |
| ·21 „ | ·200 | ·70 „ | ·75 |
| ·25 „ | ·280 | | |

The presence of any appreciable quantity of zinc is also indicated when the water is being boiled or evaporated. A peculiar opalescence is usually observed after ebullition has set in, and when the water is being evaporated a characteristic film appears on its surface.

### M. Detection and Estimation of Copper

This metal also is detected by the ferrocyanide test. The copper ferrocyanide produced imparts a reddish-brown tint to the water, and the amount of the metal present can be approximately estimated by comparing the tint produced with that formed in solutions of known strength. Using 50 c.c. of water in an ordinary Nessler cylinder, this test will detect ·025 mlgr. of copper in 100 c.c.

The presence of iron interferes with this reaction, but that of lead does not. If iron be present and lead absent, the copper may be estimated by the addition of $H_2S$ or an alkaline sulphide to an acid solution in the manner described under 'Lead,' using a standard solution of a copper salt in place of that of lead.

Copper is very rarely present, but I have detected it in an acid moorland water which had passed through a copper cylinder.

## N. Detection and Estimation of Lead

Lead may be tested for in water in various ways.

1. By acidulating with acetic acid and adding a few drops of solution of potassium chromate.

2. By acidulating with hydrochloric acid and treating with sulphuretted hydrogen.

3. By acidulating with hydrochloric acid and adding a few drops of calcium polysulphide solution.

The first test cannot always be relied upon. Under some circumstances it will give a turbidity with a water containing ·03 mlgr. of lead per 100 c.c., whilst under others it will give no indications of the presence of ·1 mlgr. As a confirmatory test, using a concentrated water, it is, however, of value. It is not affected by the presence of copper.

The sulphuretted hydrogen test is more delicate than the chromate test, but it does not distinguish between lead and copper, and as other metals give a discoloration with $H_2S$ in an acid solution, the result, if positive, should always be confirmed by evaporating a portion of the water, and submitting it to the chromate test.

The third test is the one I invariably employ, as it is as delicate as the $H_2S$ test, and does not necessitate the use of any offensive reagent. Very faintly acidulate with hydrochloric acid 100 c.c. of the water in a Nessler cylinder, and add a droplet of the sulphide solution.[1] In the absence of lead a barely perceptible milk-white turbidity is produced.

If ·05 mlgr. of lead be present in 100 c.c. of the water, a very faint red-brown tint develops, easily discernible upon comparing it with that produced when the reagents are added to a pure water, the cylinders being placed on a white tile.

Upon standing sufficiently long a little sulphur is deposited

[1] Just sufficient to produce a perceptible opalescence in a few seconds. An excess of the sulphide obscures the reaction, and an excess of acid decreases the delicacy of the test.

as a layer on the bottom of the cylinder. In the absence of any coloured sulphide this layer is quite white, whereas if lead or any metal forming a coloured sulphide is present, the sulphur is tinted.

Assuming a coloured precipitate to be produced, the chromate test should be applied, after evaporation if only a minute trace is indicated. The production of an opalescence confirms the presence of lead.

This test is easily rendered quantitative, using a standard solution of a lead salt (1 c.c. = ·1 mlgr. Pb), and adding varying quantities of this to 100 c.c. of water until a solution is produced giving the same depth of tint when treated with the sulphide solution.

Freshly prepared ammonium sulphide is an equally delicate reagent, and possesses the advantage of not rendering the liquid to which it is added turbid. Its use in a laboratory devoted to water analysis is, however, not desirable. The calcium sulphide solution is easily made and keeps fairly well, and its use is unattended with the evolution of any odorous gases. Using this reagent, the following tests were made to prove its suitability for quantitative work :—

| Amount of lead in 100 c.c. of water | Amount found |
|---|---|
| ·40 mlgr. | ·40 mlgr. |
| ·28 ,, | ·26 ,, |
| ·20 ,, | ·20 ,, |
| ·14 ,, | ·12 ,, |
| ·12 ,, | ·10 ,, |
| ·08 ,, | ·08 ,, |
| ·08 ,, | ·09 ,, |
| ·02 ,, | ·02 ,, |

Waters containing an excessive amount of lead may require dilution, and those containing exceedingly minute amounts require concentration before adding the sulphide for the quantitative determination. The best strength for purposes of comparison is about ·2 to ·5 mlgr. of Pb in 100 c.c. of water.

### O. Detection and Estimation of Arsenic

I have only once had occasion to test for arsenic in a potable water. The water was derived from a well in a garden adjoining a path which was very free from weeds. I casually heard that a weed killer had been used, and I suspected that this was an alkaline arsenite. Upon evaporating a considerable quantity of the water and applying Marsh's test I had no difficulty in discovering the presence of this poison. No doubt the quantity could be estimated by the methods adopted for ascertaining the amount present in beers. The gas liberated in the Marsh's apparatus is, with precautions, passed through a piece of hard narrow tubing heated at one point. The mirror produced is then compared with similar mirrors obtained from solutions containing known quantities of arsenic.

### P. Detection and Estimation of Sulphuretted Hydrogen

The most delicate test for the presence of this gas is the smell. Where this is pronounced the addition of a little acid and of a few drops of the solution of lead acetate will produce a marked discoloration. Some waters have a decidedly suggestive smell of this gas, yet do not give any positive reaction with lead acetate. In one such case the first portion of the distillate from the acidified water gave a decided reaction when a lead salt was added. The hydric sulphide somewhat rapidly absorbs oxygen, with liberation of sulphur and the disappearance of the odour.

The amount of $H_2S$ present may be estimated by *very faintly* acidulating 500 c.c. of the water with dilute sulphuric acid, adding a little solution of starch, and running in a centinormal solution of iodine until a blue tint appears. A little of the water is then added from a graduated tube until the colour disappears. The iodine used corresponds to the $H_2S$ present in 500 c.c.

plus half the amount required to decolorise the iodide of starch.

The following is an example of such a determination. The water was derived from the boulder clay in the north-west of Essex, and had a strong odour of sulphuretted hydrogen.

To produce a blue tint with 500 c.c. of the water, to which 5 c.c. of starch solution had been added, required 9 c.c. of centinormal solution of iodine. The addition afterwards of 8 c.c. of the water decolorised the solution, the reaction being $I_2 + H_2S = 2HI + S$.

One c.c. of the iodine solution was equivalent to ·17 mlgr. of $H_2S$ and $500 + \frac{8}{2}$ c.c. contained $9 \times ·17$ mlgr. of $H_2S = 3·1$ mlgr. per litre.

Alkaline sulphur waters which have undergone change by exposure to the air may be evaporated to dryness after the addition of a little sodium hydrate and potassium nitrate, gently ignited, and the $SO_4$ in the residue determined. The difference between the sulphates in the original water and in the ignited residue is due to the sulphur existing in other forms of combination.

# CHAPTER XIII

## ESTIMATION OF THE SALINE CONSTITUENTS

It has previously been stated that for many purposes it is desirable to know something of the nature of the saline constituents of a water. Without such analyses as will give this information the variations in the character of waters from deep sources cannot be followed or understood. The complete analysis of waters from definite geological strata gives information of considerable scientific importance, and it is much to be regretted that records of so few analyses of this character are available. In studying the waters derived from the Thanet sands and the chalk in the various parts of Essex, I have had to make hundreds of such analyses, and have gradually improved the processes until now several analyses can be made in the time formerly occupied in making one. The results are sufficiently accurate for all practical purposes, and certainly more accurate than many analyses carried out by more tedious methods. The following analyses of a deep-well water were submitted to me some time ago, and a study of them will not be without interest. When the well was first sunk a sample was submitted to an analyst, and his results are recorded in column 1. After the completion of the works a sample was sent to another well-known analyst, and his results are recorded in column 2. This differed so much from No. 1 that a further sample was submitted to a third analyst, and his results are recorded in column 3. Some years later, when I examined the water, the results of the three previous analyses were submitted for my opinion. My results are recorded in column 4.

ANALYSES OF WATER FROM A DEEP WELL

IN GRAINS PER GALLON

| | No. 1 | No. 2 | No. 3 | No. 4 |
|---|---|---|---|---|
| Calcium carbonate | — | ·475 | ·595 | ·3 |
| Calcium chloride | ·71 | — | — | — |
| Magnesium carbonate | — | ·199 | ·161 | ·10 |
| Magnesium chloride | ·04 | — | — | — |
| Sodium carbonate | 46·40 | 43·347 | 45·885 | 45·6 |
| Sodium sulphate | — | — | ·644 | — |
| Sodium chloride | 16·72 | 2·529 | 16·726 | 17·4 |
| Potassium chloride | — | 19·039 | — | — |
| Sodium nitrate | — | 2·123 | ·147 | ·2 |
| Alumina and silica | — | ·648 | ·588 | — |
| Error &c. | — | ·061 | — | 1·4 |
| Total solids by weighing | 65·73 | 65·799 | 64.743 | 65·0 |
| Total solids by addition | 63·87 | 68·421 | 64·746 | 63·6 |

In the first analysis the acids and bases have been combined in such a way as to indicate that the water contained the chlorides of calcium and magnesium in the presence of a large excess of sodium carbonate; potassium salts and sulphates were not detected, and the cause of the difference between the total solids found by weighing the water residue and found by addition of the constituents, is not referred to.

In the second analysis, which is much more pretentious, the solids by addition amount to much more than by actual determination, a certain proof of some error. The water examined before and after No. 2 contained no potassium salts and the merest trace of nitrates, and the same condition obtained when I examined the water. Inasmuch as the total solids, directly determined, have remained practically the same, there is very little doubt that the water remains constant in character and the differences are due to errors in the analyses.

No. 3 shows the presence of a trace of sulphate. This was not found in either No. 1 or 2. The absence of any such trace is so singular that in my analysis I examined the concentrated water, but found no indications of its presence. The chlorine in the chlorides was found in Nos. 2 and 4 to be a little higher than in Nos. 1 and 3.

Where such variations are found in analyses made by well-known chemists, it is obviously useless giving results pretend-

ing to show an approach to accuracy beyond the first place of decimals.

For practical purposes it almost invariably suffices to determine the calcium and magnesium and the ions of carbonates, sulphates, chlorides, and nitrates, but the potassium and sodium may be determined where it is desired either to make a more complete analysis or to check off the results. On occasions other determinations may be necessary, as of Fe, Pb, Al, Br,I, $SiO_2$, &c.

### Determination of the total Solids

The estimation of the total solids is usually regarded as one of the simplest in the domain of water analyses, whereas it is one requiring the greatest amount of skill and experience. In comparing results obtained by different analysts from the same water, the discrepancies are often most marked, yet it is not unusual to find the results expressed to the one-thousandth part of a grain per gallon.

I use platinum dishes capable of holding about 60 to 70 c.c. and weighing about 35 grammes. After being polished with a little fine sand soap and thoroughly cleansed with acid and water, the dish is placed on the water bath for a few minutes, care being taken that nothing splashes on to the bottom of the dish. It is then removed, dried with a clean absorbent cloth, placed in a hot-air oven and kept at 180° C. for a few minutes. Finally it is placed in a desiccator, allowed to stand therein for five minutes, and then weighed to ·1 mlgr. The tare being recorded, it is again placed on the water bath. A 100 c.c. stoppered flask is filled with the water to be examined and about 25 c.c. poured into the dish. When this has nearly all evaporated, a similar quantity is added and so on until all is in the dish. The flask is then rinsed with a few c.c. of distilled water which are poured into the dish. The dish is allowed to remain about a quarter of an hour on the bath after it appears dry, is then carefully wiped outside, placed in the air oven at

180° C. for an hour, removed to the desiccator and five minutes later weighed.

If much time is lost in weighing, and the residue is obviously absorbing moisture, as indicated by the increasing weight, the dish should be returned to the air oven for five or ten minutes and again allowed to cool, and weighed. I have adopted 180° C. because at this temperature magnesium sulphate retains a definite proportion of water and calcium sulphate loses the whole of its water of crystallisation, the results consequently being much more uniform and satisfactory than at a lower temperature. They are always sufficiently accurate for the quantitative estimation of the saline constituents, and it is very rarely necessary to check the results by converting the salts into sulphates, as described later.

After weighing, the bottom of the dish may be gently heated over a naked Bunsen flame to ascertain whether the residue chars or undergoes any change on heating. Weighing after ignition to ascertain the 'loss' appears to me to be a waste of time, as it gives no information of any value.

The water residue, after moistening with hydrochloric acid, may be used for examination by the flame test, using a blue glass for detecting potassium, or the spectroscope for the detection of the rarer metals. Or it may be used for testing for traces of lead, iron, or zinc, where the original water gave no reaction indicating the presence of these metals.

Certain waters contain magnesium chloride, and when such is the case some chlorine is lost during the drying process. A correction may be made for this by estimating the chlorine in the dried residue, and adding to the total solids the amount of chlorine lost, less its equivalent of oxygen. As magnesium sulphate retains one molecule of water when dried at 180° C., this is included in the undetermined portion. Calcium chloride is not rendered absolutely anhydrous at 180° C., nor is magnesium nitrate. Magnesium carbonate also appears to retain a little water, the dried precipitate being a hydrated carbonate. For these and other reasons the total solids obtained

by drying can never exactly correspond with the total of the ions as directly determined. I prefer, therefore, to give the results of all the determinations without attempting any corrections.

A better confirmation of the analytical results may possibly be obtained by moistening the residue left upon evaporation with dilute sulphuric acid (1 in 4), and carefully heating on a hot plate until fumes are no longer evolved. The residue is then gently ignited and weighed. The result gives the total weight of all the bases as sulphates, plus the weight of the silica. This is no real check on the determination of the cations, and I doubt very much the utility of the process. I have tried it on several occasions when there was an unusual discrepancy between the total of the saline constituents and the total solids, but it has never led to the detection of any error, or thrown any light on the cause of the discrepancy.

Another method which I used systematically for some time when taking the total solids of water containing $MgSO_4$, $MgCl_2$, or $CaCl_2$, was to add to the water before evaporation a quantity of decinormal solution of sodium carbonate, rather more than sufficient to decompose any of the above salts which might be present, and after weighing the dried residue to deduct the weight of the sodium carbonate added. Although, as a rule, the total solids as thus determined approached more nearly the total of the saline constituents of the water, and the process of weighing was facilitated, I have of late discontinued it, not regarding the results as of any more value than those obtained in the usual way.

With unpolluted waters the results of the direct and indirect determinations closely correspond; it is only with polluted waters that the difference between the total solids and the total of the saline constituents is at all marked, and such waters are rarely worth the trouble of an extended examination.

### Estimation of Calcium and Magnesium

These metals are determined in the same portion of water, the magnesium being estimated after the removal of the calcium.

No special apparatus or reagent is required for the calcium estimation.

The amount of water taken is usually 200 c.c., but 100 will suffice if the hardness of the water exceeds 20 degrees.

The water is placed in a flask of about 400 c.c. capacity, and, 1 c.c. of dilute hydrochloric acid having been added, is concentrated by evaporation to about 50 c.c. Whilst still hot, dilute solution of ammonia is dropped in until the liquid has a distinct ammoniacal odour, then 2 c.c. of a saturated solution of ammonium oxalate are added and the mixture is allowed to stand on the hot plate for one hour. The clear liquid is then passed through a small exhausted filter paper and the precipitate finally washed on to the paper. The flask is rinsed out three or four times with small quantities (about 5 c.c.) of distilled water, the rinsings being passed through the filter. Finally the last trace of ammonium oxalate is removed from the paper and precipitate by a fine stream of water from a wash-bottle. The filtrate should not exceed 100 c.c. A little calcium oxalate adheres to the side of the flask, but this is of no consequence, as the next step is to wash the precipitate from the filter back into this flask. This is done by perforating the filter and washing the precipitate through. Drop dilute hydrochloric acid on to the filter paper and wash with boiling distilled water. Repeat this thrice. By this means all the calcium oxalate in or on the filter paper is washed into the flask. The liquid in the flask may measure 40 to 50 c.c. Add to it 5 c.c. of dilute sulphuric acid and heat to about 50° C. The whole of the calcium oxalate is dissolved.

Now run in volumetric solution of potassium permanganate (1 c.c. = ·1 mlgr. O) until a faint pink tint is produced. Note the number of c.c. required. From the amount of

oxygen consumed the amount of calcium present is easily calculated.

$$CaC_2O_4 + H_2SO_4 + O = CaSO_4 + 2CO_2 + H_2O.$$

From this equation it is obvious that 16 parts of oxygen correspond to 40 of calcium, therefore each c.c. of the permanganate solution corresponds to ·25 mlgr. of calcium. In other words, the number of c.c. of permanganate solution used divided by 4 gives the amount of calcium in milligrams in the quantity of water used.

In exceptional cases where the water contains an appreciable quantity of iron a faintly coloured precipitate appears when the liquid is rendered alkaline with ammonia. This may be filtered out if thought desirable, but my experience leads me to doubt whether this is necessary.

As previously stated the magnesium is determined in the filtrate from the calcium oxalate precipitate. The filtrate is allowed to get cold and made up to exactly 100 c.c. The amount of this required for the experiment depends upon the amount of magnesium present. I find it best to use such a quantity as contains approximately ·5 mlgr. Mg.

To ascertain about the quantity to be taken, place a few c.c. in a test tube and add 2 or 3 drops of the solution of ammonium phosphate. If a copious precipitate is produced on shaking, 25 c.c. or less of the solution will be required; if only a faint precipitate, 50 c.c. or more may be used. Or 25 c.c. may be first used, and if this is too much or too little, a second experiment can be made using the right quantity of liquid.

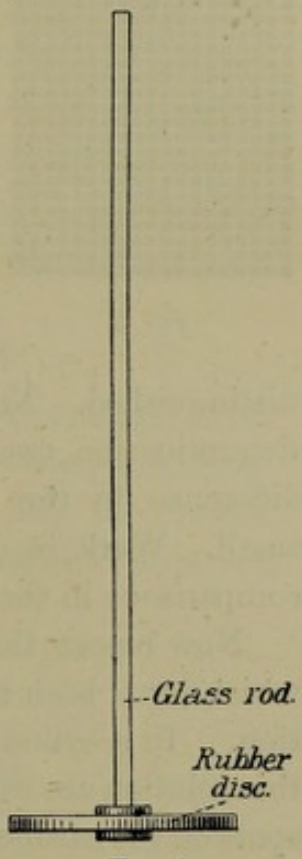


Fig. 6

The apparatus required includes

1. A long stirrer or plunger, made by cementing or other-

wise fixing on the end of a glass rod a piece of sheet india-rubber, a little less in diameter than the 100 c.c. cylinder in which the experiment is to be made.

2. A sheet of white cardboard with black dots as shown in fig. 7.

The only special reagent is a solution of magnesium sulphate each c.c. of which corresponds to ·25 mlgr. magnesium. Take 25 c.c. of the filtrate from the calcium precipitate, and dilute it to 100 c.c. in a Nessler cylinder. Add 2 c.c. of the ammoniacal solution of ammonium phosphate, and immediately commence a rapid up and down movement with the plunger. This must be continued for two minutes. The magnesium ammonium phosphate produced is in such an exceedingly fine state of division that it shows very little tendency to deposit. After standing a few seconds for the air bubbles to rise, pour the liquid steadily and slowly down the side of a short 50 c.c. graduated cylinder standing upon the black spots on the white paper until a point is reached when the dots can no longer be separately distinguished. Note the number of c.c. required and repeat the determination two or three times, and take the average. The difference in the readings, with a little experience, is very small. Work in diffused white light and make the various comparisons in the same position and in the same light.

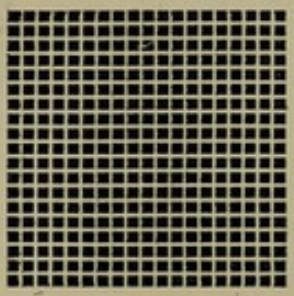


Fig. 7

Now repeat this process, using 98 c.c. of distilled water to which have been added 2 c.c of the standard magnesium solution. In a cylinder 2·5 ctm. in diameter from 20 to 22 c.c. of this solution are required (according to the light) to obscure the spots on the cardboard disc. If the liquid being examined takes much less, or much more, than this, prepare a fresh solution, stronger or weaker as the case may be, and repeat the experiment. If, for example, the first dilution obscures the dots with only 10 c.c., it is obviously about twice the strength required, while if, on the other hand, it requires about 40 c.c., it is only half

the strength. It is not necessary to prepare a fresh standard, as the one first made merely requires stirring for use in the second experiment. The following details of a determination will illustrate how the calculations based on the experimental results are made.

Two hundred c.c. of water were originally taken. After precipitation of the calcium the liquid was made up to 100 c.c. The preliminary test showed that the solution would require dilution; 25 c.c. diluted to 100 c.c. were compared with a standard solution containing ·5 mlgr. Mg in 100 c.c.

Amounts of Solution required to Obscure the Disc

| | Standard | Solution |
|---|---|---|
| | 22 | 24·5 |
| | 21·5 | 25 |
| | 22 | 24 |
| Mean | 21·8 | 24·5 |

The standard was obviously the stronger in the proportion of 24·5 to 21·8; the 100 c.c. of solution used for the experiment therefore contained $\frac{21{\cdot}8}{24{\cdot}5} \times {\cdot}5 = {\cdot}445$ mlgr. Mg.

This amount was contained in 25 c.c. of the stronger solution, which represented 50 c.c. of the original water, and therefore the original water contained ·89 mlgr. Mg in 100 c.c. The following series of estimations show the degree of accuracy obtainable by these processes.

Determination of Calcium

| Amount taken | Amount found |
|---|---|
| 4·0 mlgr. | 4·1 mlgr. |
| 8·0 „ | 7·9 „ |
| 16·0 „ | 16·1 „ |

Determination of Magnesium

| Amount taken | Amount found |
|---|---|
| ·25 mlgr. | ·245 mlgr. |
| ·5 „ | ·51 „ |
| ·6 „ | ·62 „ |
| 2·5 „ | 2·5 „ |

DETERMINATION OF CALCIUM AND MAGNESIUM

| 100 c.c. of the water contained in mlgr. | | Found | |
|---|---|---|---|
| Ca | Mg | Ca | Mg |
| 4·0 | 1·43 | 3·96 | 1·43 |
| 4·0 | 1·43 | 3·84 | 1·38 |
| 8·0 | ·0 | 8·2 | ·0 |
| ·8 | ·0 | ·8 | ·0 |
| 12·0 | 4·3 | 11·9 | 4·2 |
| 10·0 | 2·9 | 9·8 | 3·0 |
| 8·0 | 1·4 | 8·0 | 1·4 |
| 10·0 | 2·9 | 10·1 | 3·0 |
| 8·0 | ·0 | 7·9 | ·0 |

I have made several hundreds of analyses by these methods, and on several occasions have determined the calcium and magnesium gravimetrically. The results have always been quite satisfactory, and the time taken is only a tithe of that required for a gravimetric analysis.

To ascertain the length of time necessary for the complete precipitation of the calcium by the ammonium oxalate, three experiments were started, and the calcium and magnesium determined in each after standing one, two, and fourteen hours respectively. The results were as under:

| Amounts of Ca and Mg taken in mlgr. | | Time of standing | Amounts of Ca and Mg found in mlgr. | |
|---|---|---|---|---|
| Ca | Mg | | Ca | Mg |
| 9·3 | 2·0 | 1 hour | 9·3 | 1·92 |
| 9·3 | 2·0 | 2 hours | 9·3 | 2·04 |
| 9·3 | 2·0 | 14 hours | 9·3 | 1·92 |

Obviously, therefore, there is no necessity for the liquid to stand more than one hour after the addition of the ammonium oxalate. The amount of ammonium oxalate added, provided it is in excess, is of little consequence. The amount given in the text more than suffices for any water which can be called 'potable.'

## ESTIMATION OF POTASSIUM AND SODIUM

An accurate determination of these metals requires great care. The method frequently adopted of calculating the two from the weight of the mixed chlorides, and the determination of the chlorine therein, is absolutely unreliable, since when

such small quantities are being dealt with, an error of even one-tenth of a milligram in either experiment seriously affects the result. In the results of analyses submitted to me, whilst the calcium and magnesium determinations have usually corresponded closely, the amounts of potassium and sodium have differed greatly, and this I attribute to the above method of analysis having been adopted.

The following results were obtained in attempting to determine the amounts of potassium and sodium by this method in a solution containing also calcium and magnesium salts. The formulæ employed in the calculations were :—

$a$ = the weight of mixed chlorides obtained,

$b$ = the amount of chlorine therein.

Let $x$ = the amount of potassium chloride in $a$

then $x = \frac{\cdot 6065a - b}{\cdot 1311}$;

also $x \times \cdot 5246$ = the amount of potassium,

$(a - x) \times \cdot 3935$ = the amount of sodium.

| | Amount taken in gram. | Amount found 1 | 2 | 3 |
|---|---|---|---|---|
| Potassium . . . . . | ·01395 | ·0169 | ·0165 | ·01275 |
| KCl . . . . . | ·0266 | ·0322 | ·0315 | ·0243 |
| Sodium . . . . . | ·01535 | ·0129 | ·1358 | ·01495 |
| NaCl . . . . . | ·0390 | ·0328 | ·0345 | ·0380 |

The results are far from being accurate, and using smaller quantities of potassium salts the inaccuracies were even greater. As the amount of potassium in potable waters is usually very small, I am persuaded that the process is useless for the purpose of water analysis.

The following process for separating the potassium and sodium salts and estimating the amount of each I have finally adopted after a trial extending over several years. It gives results which are more reliable than any others I have tried. Its satisfactory character will be demonstrated later by the results of experiments made for this purpose.

As it is desirable to know the amount of magnesium and of sulphates in the water before commencing the determination

of the potassium and sodium, it is better to complete the estimation of the magnesium and of the sulphates whilst the water required for the potassium and sodium estimation is being evaporated.

Take 200 c.c. of the water and evaporate in a platinum dish on the water bath to about 50 c.c. Then add sufficient solution of barium chloride (1 c.c.=2 mlgr. $SO_4$) to decompose all the sulphates present, and after a little further evaporation add 2·5 c.c. of fresh lime water, made from pure calcium oxide, for each mlgr. of Mg contained in the water. Continue the evaporation until only about 10 c.c. remain. Filter through a very small exhausted filter paper into a test tube, and wash the residue in the dish and on the paper with successive small quantities of hot distilled water. Not more than 10 or 15 c.c. need be used. Heat the filtrate to boiling point, add drop by drop solution of ammonium carbonate until it produces no further precipitate, then add a droplet of solution of ammonium oxalate. The precipitate at boiling-point falls rapidly, and after standing a quarter of an hour the clear liquid is filtered through a small exhausted paper into a dish, and the residue washed with a few c.c. of water. Evaporate the filtrate to dryness on the water bath, and gently ignite to drive off all the ammonium salts. When the dish is cool moisten the residue with one or two drops of strong hydrochloric acid and evaporate to dryness. If the water contains more than a trace of nitrates, this process should be repeated twice to convert all the nitrates into chlorides. Dissolve the residue in about 5 c.c. of water, filter as before into a small tared platinum crucible or dish, evaporate to dryness on the water bath, then heat to 120° C. for a few minutes, allow to cool, and weigh. The results give the weight of the potassium and sodium as chlorides.

Dissolve the residue in the smallest possible quantity of water, and add 1 c.c. of the solution of platinic chloride for every 30 mlgr. of the mixed chlorides. This ensures the conversion of the whole of the chlorides into double salts. Evaporate until only a moist crystalline residue remains.

When cold pour over it 5 c.c. of strong methylated spirit, allow to stand ten minutes, and pour off the spirit, passing it through a very small filter. Repeat this process again and again, transfer the precipitate to the filter, and continue the addition of spirit until the washings are quite free from colour. The first and second washings may be transferred to the bottle for waste platinum solutions and residues; the subsequent washings should be collected separately, so that the point may easily be recognised at which the washings become colourless. Let the filter dry in a warm place. Dissolve the potassium platinic chloride in a little hot water, washing the filter thoroughly. To the coloured solution, which need not measure more than 10 to 20 c.c., add a very minute quantity of a zinc-copper couple, made with zinc dust (as described under nitrates), and allow to stand until the liquid is quite free from colour. Pour off the clear liquid into a porcelain dish, wash the residue with successive small quantities of water, add the washings to the liquid, and determine the chlorine therein volumetrically.

The chlorine found multiplied by ·368 gives the amount of potassium present; multiplied by ·701 it gives the weight of potassium chloride. The latter, deducted from the weight of the potassium and sodium chlorides, gives the amount of sodium chloride.

The following determinations show the accuracy of this method of determining small quantities of potassium. The salt used was potassium nitrate.

| Weight of potassium taken | | Amount found | |
|---|---|---|---|
| ·0056 gram. | | ·0053 gram. | |
| ·0056 | „ | ·0058 | „ |
| ·0056 | „ (with a little sodium salt) | ·0053 | „ |
| ·0056 | „ „ „ | ·0052 | „ |

In the following determinations a mixture of potassium nitrate and sodium carbonate was used.

| Taken | | | | Found | | | |
|---|---|---|---|---|---|---|---|
| K | | Na | | K | | Na | |
| ·0056 gram. | | ·0476 gram. | | ·00566 gram. | | ·0469 gram. | |
| ·0014 | „ | ·0030 (+ $MgSO_4$ + $CaCl_2$) | | ·0015 | „ | ·0029 | „ |
| ·0112 | „ | ·0306 | „ „ | ·0106 | „ | ·0308 | „ |
| ·01395 | „ | ·0390 | „ „ | ·01375 | „ | ·0388 | „ |

The amount of potassium salts found in potable waters is usually so small that it is rarely worth the trouble of determining. If upon applying the flame test the potassium coloration is very evanescent, and if the total saline constituents, assuming potassium to be absent, closely approach the total solids obtained by weighing, it is not necessary for any practical purpose to attempt the estimation of the potassium.

The quantities found in waters from different sources will be found in a later table. Possibly it is not without significance that most potassium is found in water containing an excessive amount of nitrates.

The following table is taken from records of the analyses of a series of samples of water taken at monthly intervals from a chalk well which was affected by the infiltration of sea water, and which therefore contained considerable amounts of magnesium salts.

The amount of water used was invariably 200 c.c., and the first two columns give the actual results (in mlgr.) obtained, from which those in the second two columns are calculated per 100 c.c.

| KCl+NaCl obtained | Cl in platinic salt as determined | K calculated | Na per 100 c.c. |
|---|---|---|---|
| Mlgr. | Mlgr. | Mlgr. | Mlgr. |
| 74·0 | 5·5 | 1·0 | 13·8 |
| 80·5 | 6·5 | 1·2 | 14·95 |
| 63·7 | 5·4 | 1·0 | 11·3 |
| 31·0 | 3·6 | ·65 | 5·6 |
| 80·6 | 7·6 | 1·4 | 14·8 |
| 70·5 | 5·7 | 1·05 | 13·1 |
| 64·5 | 4·9 | ·9 | 12·0 |
| 68·0 | 5·5 | 1·0 | 12·6 |
| 62·5 | 4·7 | ·86 | 11·2 |

## ESTIMATION OF ACIDS OR ANIONS

### Carbonates (Negative Ion or Anion, $CO_3$)

The following process for the estimation of $CO_3$ necessitates the use of a tall white glass cylinder of 250 c.c. capacity, of a sufficiently long agitating rod with a rubber disc at the end,

similar to that used in the magnesium determination, of a standard solution of sulphuric acid (1 c.c. = 2 mlgr. $CO_3$), and of a very delicate and dilute solution of methyl orange. The latter indicator varies much in delicacy, and a sample should be obtained giving a decided reaction with ·1 c.c. of the standard acid in 200 c.c. of freshly distilled water. The amount of indicator used is also a matter of importance. With too much the end reaction is obscured, with too little the reaction is not sufficiently definite. Before applying the process, a few experiments should be made in order to acquire the requisite skill in observing the change from orange to red. At first this is a little difficult, but subsequently it becomes comparatively easy, and the results given below show that they are concordant and reliable.

Into the cylinder above mentioned introduce 5 or 10 c.c. of the standard acid and sufficient of the dilute methyl orange solution to give it a decided red colour. Then pour in slowly, and with continuous agitation, the water to be examined until the red colour is discharged and the paler yellow tint appears. Note the number of c.c. of water added, and pour in more water to the 205 or 210 c.c. mark, according to the amount of acid used. Now run in the acid from a burette until the red tint again appears, and note the amount of acid used. Finally pour in more of the water until the red tint is just discharged. The readings on the graduated jar will give the amount of water used.

The following are the details of an experiment:—

Acid taken 5 c.c. = 10 mlgr. $CO_3$.

Water required to remove the red tint 165 c.c.

The water, therefore, contained approximately 6 mlgr. $CO_3$ in 100 c.c.

The water when made up to 200 c.c. required 1·2 c.c. more acid to restore red colour, and 8 c.c. of water removed the red tint.

$$\frac{200+208}{\text{c.c. water}} = 2 \times 6{\cdot}2 = 12{\cdot}4 \text{ mlgr. } CO_3.$$

$\therefore$ 100 c.c. water contained 6·07 mlgr. $CO_3$.

The water used was distilled water containing 6 mlgr. $CO_3$ as sodium carbonate in 100 c.c.

In a series of experiments in which only the first reading, the production of a red tint, was recorded, the following results were obtained :—

| Mlgr. of CO, in 100 c.c. | | Mlgr. of CO, found |
|---|---|---|
| 2·66 | in distilled water | 2·7 |
| 5·3 | ,, | 5·4 |
| 5·3 | ,, | 5·4 |
| 7·9 | ,, | 8·1 |
| 10·6 | ,, | 10·8 |
| 13·3 | ,, | 13·5 |
| 13·3 | ,, | 13·2 |
| 26·6 | ,, | 27·0 |

This method of observation gave, with one exception, results uniformly too high, which fact led to the adoption of the method described, in which the mean of two observations is taken. Using this process the following results were obtained :—

| Mlgr. $CO_3$ in 100 c.c. | | | Mlgr. $CO_3$ found |
|---|---|---|---|
| 9·6 | in distilled water | | 9·5 |
| 9·6 | ,, | | 9·6 |
| 6·9 | ,, | | 6·96 |
| 2·8 | ,, | | 2·8 |
| 2·8 | ,, | + $CaCl_2$ + $MgSO_4$ | 2·7 |
| 5·6 | ,, | ,, ,, | 5·52 |
| 2·9 | ,, | ,, ,, | 2·96 |
| 40·4 | ,, | ,, ,, | 40·2 |
| 9·6 | ,, | ,, ,, | 9·5 |
| 5·9 | ,, | + $Na_2SO_4$ | 5.84 |
| 2·1 | , | ,, | 2·16 |
| 5·1 as $CaCO_3$ dissolved in water + $CO_2$ | | | 5·2 |

The above results are, in my opinion, conclusive proof of the reliability of this method. The following modification may be preferred by those who experience a difficulty in defining the end reactions.

Take 200 c.c. of the water, add the methyl orange and run in the acid until an obvious red tint appears. Now divide the whole into two portions in tall Nessler glasses of exactly the same tint of glass, and into one pour, from a narrow measuring

cylinder or burette, more of the water until the red tint has disappeared. By comparison with the adjacent cylinder this is readily seen. The total water used corresponds to the amount of acid used. For example :—

Water taken 200 c.c.
Acid required to give a red tint 5·0 c.c.
Water added to half to destroy red tint 4·5 c.c.
204·5 c.c. water = 10 mlgr. $CO_3$ ∴ 100 c.c. = 4·89 mlgr. $CO_3$.
The water used contained 4·9 mlgr. $CO_3$ per 100 c.c.

As previously stated, the accuracy of the process depends chiefly on the delicacy of the methyl orange and on the amount of indicator used. I keep a strong solution of methyl orange and from this make a dilution of such strength that two drops (from the end of a pipette fixed in the cork of the containing bottle) suffice for each experiment. This imparts a slight but distinctly obvious yellow tint to 200 c.c. of water. The cylinders used should be of colourless glass, and a turbid water should be filtered before being titrated.

### Sulphates (Anion, $SO_4$)

The $SO_4$ may be determined rapidly by either of the following methods.

(1) **Turbidimetric.**—This requires the use of Nessler cylinders and a stirring rod with rubber disc on the end as used in previously described turbidimetric methods, dilute hydrochloric acid, solution of barium chloride, and a standard solution of sulphuric acid, the same as used in the $CO_3$ determination. (1 c.c. = 3·2 mlgr. $SO_4$).

The water to be examined should not contain more than 5 mlgr. $SO_4$ in 100 c.c. If it does, it should be diluted until the dilution contains between 3 and 4 mlgr. in that quantity.

Take 100 c.c. of distilled water in a Nessler cylinder, add 1 c.c. of the standard solution of sulphuric acid, 2 c.c. of dilute hydrochloric acid, and 1 c.c. of the barium chloride solution. Agitate vigorously and continuously for two minutes. Set aside.

Next take 100 c.c. of the water, or a known dilution, add the hydrochloric acid and barium chloride and agitate as before.

By aid of a graduated cylinder placed over the cardboard disc described under the determination of magnesium, ascertain the respective depths of the columns of the turbid mixtures required to entirely obliterate the squares, or the amount which leaves them just recognisable. If there is any considerable difference, the water must be diluted or concentrated until a sufficiently close approximation is obtained. The average of a number of readings should be taken.

If $a$ = the average number of c.c. of the standard,

$b$ = the average number of c.c. of the water,

then the amount of $SO_4$ in 100 c.c. of the water (or dilution) used is $3{\cdot}2 \times \frac{a}{b}$.

For example, a solution of a sulphate known to contain 3·8 mlgr. $SO_4$ in 100 c.c. was compared with the standard containing 3·2 mlgr. $SO_4$ per 100 c.c. The readings were as under :—

| | Standard | Water | |
|---|---|---|---|
| | 31 | 25·5 | readings to obliteration of squares |
| | 28 | 24·0 | „ to bare discernment of squares |
| | 31 | 25·5 | „ to obliteration of squares |
| Mean | 30 | 25·0 | |

$$3{\cdot}2\frac{30}{25} = 3{\cdot}84.$$

The following experiments show the accuracy of the process.

| $SO_4$ calculated in 100 c.c. Mlgr. | $SO_4$ found Mlgr. | $SO_4$ calculated in 100 c.c. Mlgr. | $SO_4$ found Mlgr. |
|---|---|---|---|
| ·95 | ·91 | 3·0 | 2·9 |
| 1·235 | 1·15 | 6·6 | 6·6 |
| 1·52 | 1·44 | 10·5 | 10·4 |
| 2·0 | 2·07 | | |

For waters containing small quantities of sulphates this very rapid process leaves nothing to be desired. Any slight error in the determination, however, is increased in calculating out the results in proportion to the dilution ; hence, when the

water to be examined contains over 10 mlgr. $SO_4$ per 100 c.c., as can be readily ascertained by a rough turbidimetric experiment, I prefer the volumetric method next to be described.

(2) **Volumetric Method.**—To perform this to the best advantage the amount of $SO_4$ in the water must be approximately known. This approximation is ascertained by the turbidimetric method. 100 c.c. or 200 c.c. of the water may be employed. This is evaporated in a flask to about 40 c.c. and a little dilute hydrochloric acid added. After boiling to drive off any $CO_2$, the volumetric solution of barium chloride is added in slight excess of that required to precipitate the whole of the $SO_4$. After standing about 10 minutes a very dilute solution of ammonia (free from carbonate) is added drop by drop until the liquid is faintly alkaline. It is again boiled for a few seconds and the volumetric solution of potassium chromate added, ·5 c.c. at a time, until the supernatant liquid has a decided yellow colour. The colour must be quite distinct. Allow to stand for a few minutes, then filter into a Nessler cylinder and dilute to 50 c.c. When cold the excess of chromate is determined by dropping the volumetric solution of chromate into 50 c.c. of water until the colour matches that of the filtrate. All the data required for determining the $SO_4$ in the water are now available. Using 200 c.c. of water, as I generally do, the following formula gives the amount of $SO_4$ in 100 c.c.

Let $a$ = the number of c.c. of barium chloride added,

$b$ = the number of c.c. chromate required to precipitate the excess of barium and colour the liquid, and

$c$ = the excess of chromate solution in c.c.

then $a-(b-c)=a+c-b$ = number of mlgr. $SO_4$ in 100 c.c.

The following is an example of a determination :—

By the turbidimetric test about 10 c.c. of the water to which acid and barium chloride had been added obscured the squares on the test disc. As about 30 c.c. are required with a water containing 3·2 mlgr. $SO_4$ in 100 c.c., the sample evidently contained about three times that amount, i.e. about

10 mlgr. per 100 c.c. In the experiment, therefore, 12 c.c. of solution of barium chloride were added. Afterwards 2·5 c.c. of chromate solution gave a distinct colour to the supernatant water, and the excess of chromate was found to correspond to ·9 c.c. Therefore

$$a=12,\ b=2{\cdot}5 \text{ and } c={\cdot}9$$

and $$a+c-b = 10{\cdot}4 \text{ mlgr. } SO_4 \text{ in 100 c.c.}$$

The following are experimental results obtained showing the very approximate accuracy of the process.

| $SO_4$ in 100 c.c. water Mlgr. | $SO_4$ found Mlgr. | $SO_4$ in 100 c.c. water Mlgr. | $SO_4$ found Mlgr. |
|---|---|---|---|
| 5·7 | 5·8 | 12·5 | 12·4 |
| 6·4 | 6·4 | 14·4 | 14·2 |
| 7·4 | 7·5 | 24·0 | 24·4 |
| 8·0 | 7·9 | 60·0 | 60·6 |
| 11·4 | 11·6 | | |

Occasionally I find the tint of the final filtrate differs from that of the diluted standard. In such cases it is advisable to add to each a few drops of hydrochloric acid, to convert the chromate into bichromate. The tints then are sufficiently alike to admit of the process being satisfactorily completed.

### Silica ($SiO_2$)

If it is desired to estimate the amount of silica present in a water, ½ or 1 litre should be rendered slightly acid with hydrochloric acid and evaporated to dryness in a platinum basin. The residue is moistened with hydrochloric acid and allowed to stand half an hour. The dish is then placed on the water bath and about 20 c.c. of water added. After a few minutes the acid solution and precipitate are transferred to a small filter and the latter is washed with hot water acidulated with hydrochloric acid until the filtrate no longer gives any cloudiness with solution of barium chloride. The filter paper is then dried, burnt and ignited in a tared platinum crucible, and the silica weighed.

It is very rarely necessary to determine the silica unless for some reason a very complete analysis is required. I have

occasionally estimated it when I have found the total of the saline constituents to fall markedly short of the total solids as ascertained by evaporation and weighing.

### Alumina ($Al_2O_3$)

Any alumina present may be determined in the filtrate from the silica precipitate. The liquid is evaporated to a low bulk (about 20 c.c.), a drop of nitric acid added and boiled to oxidise any trace of iron present. Add a little solution of ammonium chloride to prevent the precipitation of magnesia, and a very slight excess of solution of ammonia. On again boiling the alumina is precipitated, destitute of colour if pure, but of a brown tint if iron is present. The precipitate is transferred to a small filter, thoroughly washed, dried, and finally ignited in a tared crucible. The heating should be continued over the blowpipe for about five minutes. The weight of the residue will be that of the alumina plus any ferric oxide present. As the iron in the water will have previously been determined, the amount of ferric oxide present can be calculated and deducted; the remainder will represent the amount of alumina in the quantity of water originally evaporated.

The amount of alumina present in potable waters is usually infinitesimal, and unless some preliminary test has revealed its presence in appreciable quantity, no useful purpose is served in attempting to estimate it.

### Results of Analyses

The results obtained in making an analysis of a water for sanitary purposes are usually tabulated, and the forms employed are very varied. The one appended (see p. 309) is used in my laboratories, and is, I think, as intelligible as any I have seen, giving all the data necessary for forming an opinion on the quality of a water, from the chemical point of view.

When a more complete analysis has been made, and the chief anions and cations quantitatively determined, the analyst may simply give the results obtained or combine the ions to

represent the most probable saline constituents of the water. In the present state of our knowledge there are objections to both methods. Both are based on theories which are far from meeting with general acceptance. In this connection I may quote the following paragraphs from Ostwald on 'Solutions,' chapter vii. pp. 188–9. Referring to certain laws which have been found to be applicable for solutions of indifferent substances in various solvents, he shows that these do not apply to solutions of salts in water. He says: 'The behaviour of these substances is as if the solutions contained a considerably greater number of molecules of the dissolved substances than corresponds with their formulæ—i.e. as if the substances in solution were broken up into smaller molecules.

'The solutions which exhibit these deviations from the laws of vapour possess another characteristic peculiarity; they, and only they, are good conductors of the electric current, and they conduct electrolytically—i.e. the movement of electricity is accompanied by a movement of ponderable particles which are called "ions." By ions are understood the constituent parts of salts, acids, and bases, viz. on one side, the metals, the metal-like radicles such as $NH_4$ and hydrogen, and on the other side, the halogens, the acidic radicles such as $NO_3$ or $SO_4$, and hydroxyl. The positive electricity moves along with the first named, or positive ions, while the negative electricity accompanies the second, or negative, ions. The consideration of these relations, along with the deviations from the laws of vapour-pressure, leads to the supposition that *in their aqueous solutions the substances in question*, i.e. *the electrolytes, are already separated for the most part into their ions*. This conclusion was arrived at by Arrhenius; the conclusion, it must be admitted, is, to some extent, opposed to the views which generally prevail, but it is in agreement with quite a remarkable number of facts.' This was written in 1891, and further researches have only tended to confirm the opinion of Arrhenius.

An analysis giving only the amount of the ions does not, however, appear to be very satisfactory, and conveys little

information to the lay mind. It is advisable, therefore, always to give the probable combinations, by which are meant the salts most probably taken up by and dissolved in the water. This differs very little from the usual method of combining the ions in the order of insolubility of the salts formed by their combination. A table in the Appendix contains a list of salts which may enter into solution in natural waters, in the order of their insolubility, as given by Bunsen in his 'Instruction für die Ausführung der vom Grossherzogl. Bad. Ministerium des Innern angeordneten chemischen Untersuchung der Badischen Mineralwasser.' The number of such salts found in ordinary potable waters is small, and I determine them in the following order:

| | | | |
|---|---|---|---|
| 1. $CaCO_3$ | 5. $MgCO_3$ | 9. $Na_2CO_3$ | 13. $K_2SO_4$ |
| 2. $CaSO_4$ | 6. $MgSO_4$ | 10. $Na_2SO_4$ | 14. KCl |
| 3. $CaCl_2$ | 7. $MgCl_2$ | 11. NaCl | 15. $KNO_3$ |
| 4. $Ca2(NO_3)$ | 8. $Mg2(NO_3)$ | 12. $NaNO_3$ | 16. $K_2CO_3$ |

This is not exactly in the order of insolubility, but in practice it works out more in accordance with the order of probability, and its simplicity appeals to me. As long as the actual determinations are given, other chemists may combine them as they please.

FACTORS FOR USE IN WATER ANALYSES

| Cations | | Anions | Salt formed |
|---|---|---|---|
| 1 part Ca | combines with . . . | 1·5 $CO_3$ | 2·5 $CaCO_3$ |
| 1 „ Mg | „ . . . | 2·46 $CO_3$ | 3·46 $MgCO_3$ |
| 1 „ Na | „ . . . | 1·3 $CO_3$ | 2·3 $Na_2CO_3$ |
| 1 „ Ca | „ . . . | 1·772 Cl | 2·772 $CaCl_2$ |
| 1 „ Mg | „ . . . | 2·91 Cl | 3·91 $MgCl_2$ |
| 1 „ K | „ . . . | ·907 Cl | 1·907 KCl |
| 1 „ Na | „ . . . | 1·54 Cl | 2·54 NaCl |
| 1 „ Ca | „ . . . | 2·4 $SO_4$ | 3·4 $CaSO_4$ |
| 1 „ Mg | „ . . . | 3·94 $SO_4$ | 4·94 $MgSO_4$ |
| 1 „ K | „ . . . | 1·228 $SO_4$ | 2·228 $K_2SO_4$ |
| 1 „ Na | „ . . . | 2·083 $SO_4$ | 3·083 $Na_2SO_4$ |
| 1 „ Ca | „ . . . | 3·1 $NO_3$ | 4·1 $Ca2NO_3$ |
| 1 „ Mg | „ . . . | 5·1 $NO_3$ | 6·1 $Mg2NO_3$ |
| 1 „ K | „ . . . | 1·586 $NO_3$ | 2·586 $KNO_3$ |
| 1 „ Na | „ . . . | 2·69 $NO_3$ | 3·69 $NaNO_3$ |

Cl in $K_2PtCl_6$ × ·368 = K contained in the double salt

Cl in $K_2PtCl_6$ × ·701 = KCl contained in the double salt

The following examples will illustrate the mode of calculating the different constituents, and of recording the results.

No. 1. Chalk Well in South Essex, free from all possibility of contamination

Ions in Parts per 100,000

| Cations | | Anions | |
|---|---|---|---|
| Ca | 7·5 | $CO_3$ | 12·0 |
| Mg | 1·2 | $SO_4$ | 3·4 |
| Na | 1·65 | Cl | 3·0 |
| K | ·55 | $NO_3$ | ·13 |

The 7·5 of Ca would combine with $7·5 \times 1·5 = 11·25$ $CO_3$, forming 18·75 $CaCO_3$.

The remaining $CO_3$, $12 - 11·25 = ·75$, would combine with

$$\frac{·75}{2·46} = ·3 \text{ Mg, forming } 1·05 \text{ Mg,}CO_3.$$

The remainder of the Mg $1·2 - ·3 = ·9$, would combine with

$$·9 \times 3·94 = 3·546 \; SO_4, \text{ forming } 4·446 \; MgSO_4$$

or 3·4 $SO_4$ would combine with

$$\frac{3·4}{3·94} \text{ Mg.} = ·86, \text{ forming } 4·26 \; MgSO_4.$$

The latter leaves ·04 Mg uncombined, whilst the former shows that, to combine with the ·9 Mg, the $SO_4$ required is ·146 more than the $SO_4$ found in the water. With such trifling differences I give the mean of the two determinations,

$$(4·446 + 4·26) \div 2 = 4·35.$$

This brings the determination within ·1 mlgr. per 100 c.c. of either result.

The Na would combine with $1·65 \times 1·54 = 2·54$ Cl, forming 4·19 NaCl.

The K would combine with the remaining Cl and the $NO_3$.

The water contained also ·8 mlgr. $Fe_2O_3$ in suspension.

The total solids determined after evaporation, and drying at 180° C., weighed 31·7 mlgr., leaving 1·45 for silica, trace of organic matter, and errors.

The results are duly entered as shown on the following form.

SALINE CONSTITUENTS OF A SAMPLE OF WATER FROM CHALK WELL IN SOUTH ESSEX

EXPRESSED IN PARTS PER 100,000

| Ca 7·5 | Mg 1·2 | Na 1·65 | K ·55 | $CO_3$ 12·0 | $SO_4$ 3·4 | Cl 3·0 | $NO_3$ ·13 | Probable combinations | |
|---|---|---|---|---|---|---|---|---|---|
| 7·5 | — | — | — | 11·25 | — | — | — | Calcium carbonate . . | 18·75 |
| — | ·3 | — | — | ·75 | — | — | — | Magnesium carbonate . | 1·05 |
| — | ·9 | — | — | — | 3·45 | — | — | „ sulphate . | 4·35 |
| — | — | 1·65 | — | — | — | 2·55 | — | Sodium chloride . . | 4·20 |
| — | — | — | ·5 | — | — | ·45 | — | Potassium chloride . | ·95 |
| — | — | — | ·05 | — | — | — | ·10 | „ nitrate . . | ·15 |
| — | — | — | — | — | — | — | — | Ferric oxide . . . | ·80 |
| — | — | — | — | — | — | — | — | Traces ammonia &c. . | 1·45 |
| | | | | | | | | Total solid constituents dried at 180° C. . . . | 31·7 |

No. 2. The second example is an analysis of water from a chalk well, but in this case the well was sunk in a garden, and the effects of the manurial matter are shown by the presence of a large amount of nitrates.

WATER FROM CHALK WELL, SWANSCOMBE, KENT

IONS IN PARTS PER 100,000

| Cations | | Anions | |
|---|---|---|---|
| Ca | 14·05 | $CO_3$ | 16·5 |
| Mg | ·7 | $SO_4$ | 3·35 |
| K | ·6 | Cl | 5·0 |
| Na | 2·5 | $NO_3$ | 7·9 |
| | | $PO_4$ | traces. |

The Ca here is obviously in excess of that required to combine with all the $CO_3$. The 16·5 parts of the latter would combine with $\frac{16·5}{1·5}=11$ parts of Ca, forming 27·5 $CaCO_3$.

The remainder of the Ca is more than is required to combine with the whole of the $SO_4$.

The $SO_4$ will unite with $\frac{3·35}{2·4}=1·4$ of Ca, forming 4·75 $CaSO_4$.

The remaining Ca is not sufficient to take up all the Cl; it will combine with $[14{\cdot}05-(11{\cdot}0+1{\cdot}4)]\times 1{\cdot}772=2{\cdot}9$ of Cl, forming 4·55 $CaCl_2$.

The Mg would combine with $\cdot 7\times 2{\cdot}91=2{\cdot}04$ Cl, forming 2·74 $MgCl_2$.

This leaves only $5-2{\cdot}9-2{\cdot}04=\cdot 06$ mlgr. of Cl unaccounted for, a quantity so small as to be negligible.

The K will combine with $\cdot 6\times 1{\cdot}586=\cdot 95$ $NO_3$, forming 1·55 $KNO_3$, and the Na with $2{\cdot}5\times 2{\cdot}69=6{\cdot}7$ $NO_3$, forming 9·2 $NaNO_3$.

This accounts for $\cdot 95+6{\cdot}7=7{\cdot}65$ $NO_3$, but as the Na is more likely to be underestimated than the $NO_3$ overestimated, it may be taken that the remainder of the $NO_2$ is combined with Na. Therefore, $7{\cdot}9-\cdot 95$ of $NO_3$ combines with

$$\frac{7{\cdot}9-\cdot 95}{2{\cdot}69}=2{\cdot}6 \text{ Na, forming } 9{\cdot}55 \text{ } NaNO_3.$$

The results are given on the Form below.

SALINE CONSTITUENTS OF A SAMPLE OF WATER FROM SHALLOW WELL IN CHALK, SWANSCOMBE, KENT

EXPRESSED IN PARTS PER 100,000

| Ca 14·05 | Mg ·7 | Na 2·5 | K ·6 | $CO_3$ 16·5 | $SO_4$ 3·35 | Cl 5·0 | $NO_3$ 7·9 | $PO_4$ *t* | Probable combinations | |
|---|---|---|---|---|---|---|---|---|---|---|
| 11·0 | — | — | — | 16·5 | — | — | — | — | Calcium carbonate . | 27·50 |
| 1·4 | — | — | — | — | 3·35 | — | — | — | „ sulphate . | 4·75 |
| 1·65 | — | — | — | — | — | 2·9 | — | — | „ chloride . | 4·55 |
| — | ·7 | — | — | — | — | 2·05 | — | — | Magnesium chloride . | 2·75 |
| — | — | 2·6 | — | — | — | — | 6·95 | — | Sodium nitrate . . | 9·55 |
| — | — | — | ·6 | — | — | — | ·95 | — | Potassium nitrate . | 1·55 |
| — | — | — | — | — | — | — | — | — | Traces of phosphates, organic matter, &c. . | 3·25 |
| | | | | | | | | | Total solid constituents dried at 180° C. . . . . | 53·9 |

No. 3. The third example is that of a typical water from the Thanet sands and chalk in central Essex. These waters contain the merest trace of potassium salts, and where the total saline constituents come within 2 mlgr. of the total solids

I do not find it necessary to determine the potassium and sodium. The ammonium often reaches ·1 part per 100,000, and the silica 1 part.

SALINE CONSTITUENTS OF A SAMPLE OF WATER FROM CHALK UNDERLYING LONDON CLAY IN CENTRAL ESSEX

EXPRESSED IN PARTS PER 100,000

| Ca 1·4 | Mg ·5 | Na — | K *t* | $CO_3$ 24·0 | $SO_4$ 10·5 | Cl 42·4 | $NO_3$ ·2 | Probable combinations | |
|---|---|---|---|---|---|---|---|---|---|
| 1·4 | — | — | — | 2·1 | — | — | — | Calcium carbonate . | 3·50 |
| — | ·5 | — | — | 1·25 | — | — | — | Magnesium carbonate . | 1·75 |
| — | — | 15·9 | — | 20·65 | — | — | — | Sodium carbonate . | 36·55 |
| — | — | 5·05 | — | — | 10·5 | — | — | ,, sulphate . | 15·55 |
| — | — | 27·55 | — | — | — | 42·4 | — | ,, chloride . . | 69·95 |
| — | — | — | — | — | — | — | — | Traces nitrates, silica, ammonia, &c. . . | 1·20 |
| | | | | | | | | Total solid constituents dried at 180° C. . . . . | 128·5 |

No. 4. The last example is that of a water from a shallow well forming the chief supply to a small town. The subsoil is

SALINE CONSTITUENTS OF A SAMPLE OF WATER FROM PUBLIC WELL IN HIGH STREET

EXPRESSED IN PARTS PER 100,000

| Ca 14·8 | Mg 3·0 | Na 12·0 | K 8·8 | $CO_3$ 8·4 | $SO_4$ 26·5 | Cl 16·2 | $NO_3$ 26·4 | $PO_4$ *t.* | Probable combinations | |
|---|---|---|---|---|---|---|---|---|---|---|
| 5·6 | — | — | — | 8·4 | — | — | — | — | Calcium carbonate . | 14·0 |
| 9·2 | — | — | — | — | 22·1 | — | — | — | ,, sulphate . | 31·3 |
| — | 1·1 | — | — | — | 4·4 | — | — | — | Magnesium sulphate . | 5·5 |
| — | 1·9 | — | — | — | — | 5·5 | — | — | ,, chloride . | 7·4 |
| — | — | 7·0 | — | — | — | 10·7 | — | — | Sodium chloride . . | 17·7 |
| — | — | 5·0 | — | — | — | — | 13·45 | — | ,, nitrate . . | 18·45 |
| — | — | — | 8·2 | — | — | — | 12·95 | — | Potassium nitrate . | 21·15 |
| — | — | — | — | — | — | — | — | — | Phosphate, organic matter, errors . . | 4·8 |
| | | | | | | | | | Total solid constituents dried at 180° C. . . . . | 120·3 |

highly polluted, and the water is loaded with nitrates, and contains large quantities of potassium salts. The amount of organic matter is very small, and there are large traces of phosphates. In such waters the total saline constituents, as directly determined, rarely come within 3 mlgr. of the total solids obtained by evaporation. The reason for this I have not yet ascertained.

At the end of this section I have recorded the results of a considerable number of analyses of waters from various sources made by the methods just described. Their study may possibly throw some light on geological problems, and stimulate enquiry for the purpose of ascertaining the causes of the difference in the character of underground waters. For example, the waters No. 98–108 are from the Lincolnshire limestone, and referring to these Mr. H. Preston, F.G.S., in 'Notes on the Geology and Underground Water Supply of South Lincolnshire'[1] says 'that the series of analyses prepared by Dr. Thresh are of extreme interest, as they represent samples obtained from typical wells in the Lincolnshire limestone, from its normal condition on the west to its heavily charged condition on the east (as at Crowland) where the rock has thinned out. . . . One result deserves particular attention. The amount of dissolved calcium carbonate decreases from west to east, notwithstanding the longer travel of the water through the limestone rock, whilst the amount of sodium carbonate held in solution increases from east to west. This is shown in graphic form by the diagram.'

'Now, bearing in mind that the limestone decreases in thickness and becomes more argillaceous as it extends eastward, and that the upper and lower Esturine beds are coming closer together, and would probably meet at no great distance east of Crowland, the conclusions forced upon us are that, (1) the water contained in these beds is practically in a dormant condition, and as a consequence has been able to take

[1] Paper read before the Annual Meeting of the Association of Waterworks Engineers, 1903.

up from the clay and adjoining beds increasing proportions of sodium carbonate, together with other soluble substances, and (2) that the sodium carbonate has precipitated corresponding amounts of calcium carbonate.'

I do not agree with Mr. Preston as to the source of the sodium carbonate. This salt occurs in waters from many different sources. I have found it in water from the Hastings beds at a depth of over 800 feet (*vide* analysis No. 88), and it is a characteristic constituent of waters from the Thanet sands and chalk in Essex where these beds lie deep beneath the London clay. In my report on the 'Water Supply of Essex,' I have shown that there is a fairly clear line of demarcation between the districts where the chalk yields water containing sodium carbonate and little calcium carbonate, and those where the chalk water contains much calcium carbonate and no sodium carbonate. Whether this demarcation is due to some undiscovered fault or to some other cause geologists doubtless will some day ascertain. In Essex, where the chalk lies at some depth, it yields the very soft alkaline water. In the north-east portion of the county the chalk yields a water which is probably a mixture of sea water with the alkaline water, due to the infiltration

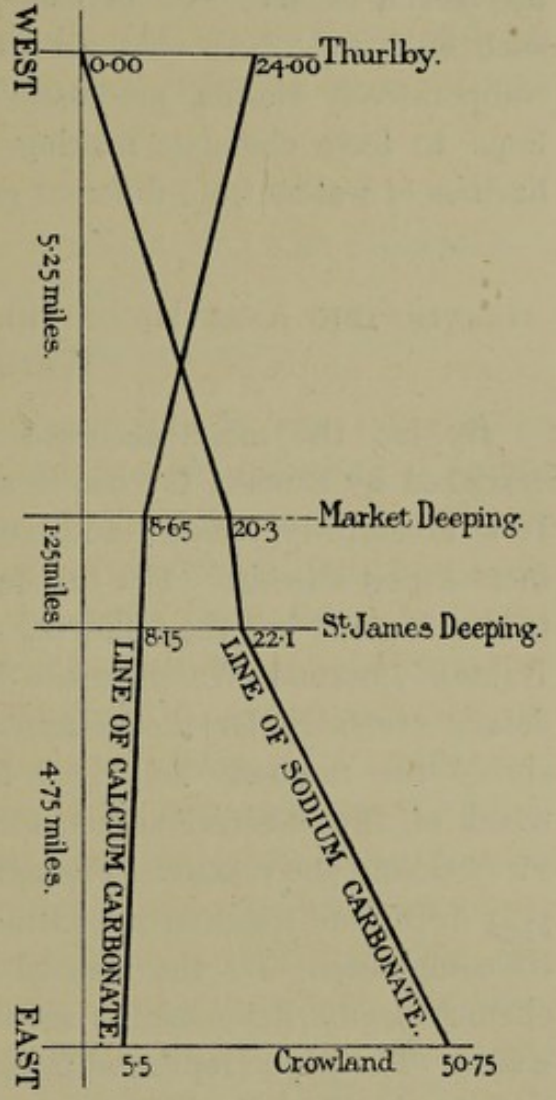



FIG. 8

of tidal or sea water, though at what point or points such infiltration occurs is not known. But wherever this alkaline water is found, there is evidence tending to prove that it comes from a practically stagnant source, and that it is not affected by the rainfall in the chalk outcrop.

Hitherto the estimation of the saline constituents of a water has been a difficult and tedious process, hence the paucity of such analyses. Now that sufficiently accurate, yet rapid and comparatively simple, processes have been devised, we may hope to have chemists making special studies of the peculiarities of waters from different geological sources.

## Gravimetric Analysis of the Saline Constituents of Water

By far the most accurate system of analysis is that described by Bunsen for use in examining the Baden waters. It is excessively tedious, and could only be undertaken by a most expert chemist. For full details I must refer the reader to the original, but the following account of an analysis of the Buxton Thermal Water, made by his method, gives all the details necessary for the examination of waters generally, and shows the methods employed for calculating the probable errors of the determinations, for eliminating the errors, and for checking the results. The analysis was made by me in the year 1881, and required an extraordinary amount of time for its completion. By the methods used, however, the skilled chemist could undertake a similar analysis of any mineral water. The paper, reprinted from the Journal of the Chemical Society, incidentally illustrates certain other determinations which may add to its interest.

Without going into all the elaborate details described by Bunsen, and without examining separately the soluble and insoluble portions, the various ions can be determined gravimetrically and the results tabulated either by Bunsen's method or by the simpler one to which reference has already been

made. In most cases the results, though taking much more time to obtain, will not be more valuable than those obtainable by the methods I have adopted and which have just been described.

The complete examination of a mineral spring includes the analyses of the water, the gases evolved from and dissolved in the water, and of the sinter (if any) deposited by the water.

The results of the examination of the Buxton water are recorded here, the analyses of the gases &c. are given in later chapters.

## CHEMICAL EXAMINATION OF THE BUXTON THERMAL WATER

(*Communicated to the Chemical Society January* 17, 1882)

During the autumn of 1881 advantage was taken of an opportunity for determining the flow of water, the reservoirs having been emptied to allow of the baths &c. being cleaned. By careful measurement the total capacity of the three reservoirs and bath was found to be 2,838 cubic feet. From the time when the outlet leading to the drains was closed to the time when the water reached the overflow level was 2 hrs. 55 min. Hence the flow per minute is 16·1 cubic feet, or 101 gallons. This, however, does not represent the whole of the flow from the thermal springs, as the water from all the springs does not flow into these tanks, the water supplying the Pump-room being derived from a spring flowing into a distinct reservoir. Some, also, appears to run to waste, but there is little doubt that the total outflow does not greatly exceed the amount stated.

**Density of the Water.**—On account of the small amount of saline matter present in this mineral water, it was necessary to collect and evaporate large quantities of it. The water was collected in stoppered Winchesters, and, as it was found impossible to fill these at the mouth of the springs when the tanks were emptied, they were filled in the large bath immediately over the spring yielding the largest proportion of gas. At the time

of filling, the water had been flowing through the bath fully twelve hours, without being disturbed by bathers. The capacity of the bottles at a known temperature having been ascertained, it was only requisite to determine the density of the water to find the weight of water employed.

A 50 c.c. specific gravity flask, filled with well-boiled distilled water, held, at 15° C., 49·9870 grams, and at 14° C. 49·9954 grams.

From equation—

$$C = \frac{w}{d}(1-ta)$$

we have in both cases C = 50·029 cubic centimetres at 0° C.

The flask filled with the spring water at 25·8° C. held in one experiment (1) 49·8890 grams, in another (2) 49·8874 grams.

| | | |
|---|---|---|
| Density at 25·8°C. | (1) | ·99688 |
| | (2) | ·99684 |
| | Mean | ·99686 |

The density of pure water at this temperature being ·99695 (Rossetti), we have ·99992 as the density of the thermal water, compared with that of pure water at the same temperature. As both the carbon dioxide and saline constituents tend to increase the density of a water, the presence of nitrogen in solution would appear to have a directly opposite effect.

The mode of procedure adopted in this investigation is that recommended by Bunsen in his 'Instruction für die Ausführung der vom Grossherzogl. Bad. Ministerium des Innern angeordneten chemischen Untersuchung der badischen Mineralwasser,' the processes in nearly all cases being those recommended therein.

21480·4 grams of the water were evaporated in a platinum dish on the water bath to dryness, care being taken to avoid loss by spirting, access of dust, &c. The residue was kept for several hours on the water bath, and then treated with successive small quantities of cold water. The aqueous solution was passed through a filter into a stoppered Schuster's burette,

avoiding splashing, and the insoluble portion finally transferred to the filter washed to 1/10000, and dried at 100° C.

**Analysis of the Soluble Portion.**—(A) The fluid in the burette was divided into 5 accurately weighed portions.

(1) The sulphuric acid was estimated by precipitation with barium chloride, &c., the resulting barium sulphate being digested repeatedly with water acidulated with hydrochloric acid, until a constant weight was attained.

(2) In another portion the calcium and magnesium were determined—the magnesium in the ammonium oxalate precipitate, and the calcium in the precipitate produced by ammonium phosphate being ascertained.

(3) In estimating the chlorine, the silver chloride was collected in a porcelain crucible, the filter paper through which the wash water was passed being burnt in a tared coil of platinum wire.

(4) In the fourth portion the sodium and potassium were determined. The boiling solution was precipitated with baryta water, evaporated to dryness in a platinum dish on the water bath, the residue exhausted with a small quantity of water and filtered. The excess of baryta was removed by repeated treatment with ammonia and ammonium carbonate, evaporation and ignition. The ammonia-free solution was next concentrated and digested for two hours on the water bath with a little freshly precipitated mercuric oxide, evaporated to dryness, gently ignited, the residue exhausted with water, and the solution evaporated to dryness in a small platinum crucible, gently ignited and weighed.

The fused mass was next moistened with hydrochloric acid, dried and weighed. The weight was unaffected by this treatment.

The residue was dissolved in water, and the solution divided into three accurately weighed portions. In one the chlorine was estimated, in another the potassium

and magnesium (after removal of the excess of platinum by hydrogen), and the third kept as a reserve.

(5) The fifth portion was reserved.

**Analysis of the Insoluble Portion.**—(B) In this portion the carbon dioxide, silica, sulphuric acid, barium sulphate, calcium, magnesium, iron and manganese, were estimated.

The Winchesters in which the water had been collected were rinsed with dilute hydrochloric acid, the rinsings transferred to the platinum dish in which the water had been evaporated, and evaporated to perfect dryness. In this residue the trace of silica was estimated, and the acid solution precipitated boiling by sodium carbonate, the ppt., after washing and drying, being added to the insoluble water residue. In the filtrate, the sulphuric acid and magnesia were determined. The carbon dioxide equivalent to the sulphuric acid was deducted from the amount of that substance found in (B), whilst the equivalent to the magnesia was added thereto.

**Estimation of the Carbon Dioxide.**—The dried residue (B) was transferred to a small flask fitted with bulb acid tube and a long calcium chloride tube, and the whole weighed. After all the gas had been liberated, the acid fluid was raised to the boiling-point, then allowed to become perfectly cold, and a very slow current of dry air, free from carbonic acid, aspirated through the apparatus, for about an hour. The heating and aspirating were repeated until a constant weight was attained.

**Silicic Acid, Barium Sulphate, and Organic Matter.**—The fluid remaining in the flask was evaporated to dryness, treated with acid passed through a filter, the impure silica exhausted with alcohol and ether, and the organic matter thus removed and estimated. The ignited silica was treated with warm, moderately concentrated solution of soda, when a residue consisting of barium sulphate remained, the weight and purity of which were duly ascertained. The filtrate from the silica was transferred to a weight-burette and divided into three portions.

In (1) the sulphuric acid was determined.

In (2) the iron, manganese, calcium, and magnesium were estimated. After oxidation by boiling with a little bromine water, the iron (with trace of calcium phosphate, and possibly of alumina) was precipitated by ammonia, redissolved and re-precipitated. The impure $Fe_2O_3$ thus obtained was dissolved in acid, and upon addition of ammonium molybdate, gave a very slight ppt., indicating the presence of a trace of phosphate too minute for estimation.

The acidified filtrate, after concentration, was treated with ammonia and ammonium sulphide, and the precipitated manganese determined as $Mn_3O_4$.

The filtrate from the manganese precipitate was acidified, concentrated on water bath, the sulphur filtered out, and the calcium and magnesium determined as in the soluble portion.

### Total Estimation

10740·1 grams of water were evaporated to dryness, and the residue treated at once with hydrochloric acid to separate *silica* and *barium sulphate*. The acid filtrate was divided into three portions, *a*, *b*, and *c* :—

(*a*) In this portion the sulphuric acid was determined.

(*b*) Used for estimating the *iron*, *manganese*, *calcium*, and *magnesium*. The impure ferric oxide here obtained was dissolved in acid, the iron reduced to the ferrous state, and determined volumetrically by aid of a very dilute solution of permanganate of potassium.

In the ammonium oxalate precipitate traces of barium and strontium were found. The ignited oxide was treated with nitric acid, the dry nitrate digested with absolute alcohol, the solution filtered off, the minute residue washed with water, and the fluid evaporated to dryness. The barely perceptible residue was taken up on a strip of moist filter paper, and after burning the paper the ash was examined for barium and strontium by the spectroscope. Momentary indications

were obtained of strontium, but the spectrum of barium was very distinct.

(*c*) Reserve.

For the estimation of the total *chlorine*, 3169·7 grams were evaporated to dryness, and the solution obtained by exhausting the residue with water, precipitated with silver nitrate.

The total *alkalies* were determined in the residue, resulting from the evaporation of 8013·9 grams of the water, the results being checked as in the former case by the estimation of the chlorine in the aliquot part of the mixed chlorides.

**Total Carbon Dioxide.**—The water used for this determination was collected in two flasks, each containing 50 c.c. of a solution of one part of crystallised chloride of calcium in five parts of distilled water and ten parts of ammonia solution.—Sp. gr. ·96. This mixture had been made over two months, and was carefully filtered immediately before use. The flasks were fitted with doubly perforated stoppers. Through one opening was passed a short piece of glass tube, whilst the other was connected with a long tube, kept closed with the thumb whilst the flasks were being sunk. Upon removing the thumb the water flowed into the flasks, and when the latter were full up to the bottom of the neck the thumb was again pressed on the end of the glass tube, and the flask withdrawn. A mark being made on the necks of the flasks at the level of the liquid, the quantity used for the analysis was readily ascertained.

The flasks were kept on the water bath for several hours, then kept for more than an hour immersed in boiling water, and the clear fluid rapidly filtered off by aid of the filter pump. As much as possible of the precipitate was transferred to a small flask of about 150 c.c. capacity. The crystalline matter on the sides of the flasks was dissolved in dilute hydrochloric acid, reprecipitated boiling with slight excess of sodium carbonate, and the supernatant fluid filtered off. The precipitate was well washed, collected on the filter, and the latter with its contents transferred to the flask containing the remaining portion of the carbonates. The carbon dioxide was then

liberated by hydrochloric acid, and after passing over calcium chloride and pumice with sulphate of copper, was absorbed in Geissler's bulbs containing solution of caustic soda, and attached to a soda lime tube.

In the filtrate from the sodium carbonate precipitate, the sulphuric acid and magnesia were estimated, and the requisite corrections afterwards made.

To detect, and, if possible, estimate the fluorine, boracic acid, iodine, bromine, lithium, and other rare metals, 42,687 grams of the water were evaporated to dryness, with addition of a little sodium carbonate. The residue was exhausted with hot water, and then with cold dilute hydrochloric acid, there being thus obtained (C) an aqueous solution, (D) an acid solution, and (E) a residue insoluble in dilute hydrochloric acid.

**Examination of** (C).—This measured 220 c.c., and was divided into three portions of 50, 50, and 120 c.c. respectively.

**Bromine and Iodine.**—50 c.c. were placed in a small stoppered bottle, and a little chloroform added after acidifying the fluid with hydrochloric acid. Standardised chlorine water was now dropped in, but not the slightest coloration was perceptible. For still greater certainty the solution was rendered alkaline with sodium carbonate, evaporated to dryness, gently ignited, and the residue dissolved in a small quantity of water, acidified, and filtered into a white dish. The chlorine water was now dropped into the heated fluid, but no indication of presence of either iodine or bromine was observable.

**Boracic Acid.**—To the second 50 c.c. were added magnesium chloride, ammonium chloride, and excess of ammonium carbonate, the mixture being evaporated to dryness, and the residue ignited. This was exhausted with hot water, and the filtrate submitted to a repetition of the above treatment. The two residues thus obtained were examined before the spectroscope for boracic acid, but with negative results.

**Cæsium, Rubidium, and Thallium.**—The filtrates from the residues obtained in searching for boracic acid, and the solution used in the examination for iodine and bromine, were evaporated

to a small bulk, and precipitated with excess of platinic chloride. After twenty-four hours the clear fluid was poured off, and the residue boiled repeatedly with just sufficient water to cover it, the hot supernatant fluid being each time decanted. The whole of the ppt. ultimately dissolved, but from time to time portions were examined before the spectroscope, but no trace of these metals was found.

**Lithium.**—The remaining 122 c.c. were treated with excess of baryta water, then with ammonium carbonate, filtered, evaporated to dryness, and ignited. The residue was moistened with hydrochloric acid, dried, and exhausted with alcohol. The filtrate, upon evaporation, left a residue in which the spectroscope showed traces of lithium, but evidently the quantity was too small for estimation.

**Examination of** (D).—This solution, saturated with sulphuretted hydrogen, and kept in the hot-water oven for several weeks, deposited a fawn-coloured precipitate. This, when digested with ammonium sulphide, left a black-brown insoluble sulphide, and yielded a brown solution. The fluid was acidified with hydrochloric acid, and the precipitate fused with sodium carbonate and potassium nitrate, and examined for molybdenum, but with no decisive result. The insoluble sulphide proved to be lead, and was estimated as sulphate.

The filtrate from the hydric sulphide precipitate contained traces of iron, manganese, and calcium phosphate.

**Examination of** (E).—This residue was examined for fluorine, by fusion with four times its weight of sodium carbonate, exhausting the smelt with water, and freeing the solution from silica by digestion with ammonium carbonate. The filtrate was nearly neutralised with hydrochloric acid, calcium chloride added, and evaporated to dryness. The residue was washed with water after gentle ignition, dried, ignited, and weighed. After treatment with strong sulphuric acid and ignition, the fluoride of calcium was estimated from the increase in weight. The escaping vapour etched glass.

**Estimation of Ammonia and Nitric Acid.**—Upon attempt-

ing to estimate these substances by Bunsen's method, it was found that they were present in too small proportions for accurate measurement by his process. Half a litre of the water, therefore, was rendered slightly alkaline with sodium carbonate, and the ammonia in the distillate estimated with Nessler's solution in the usual way. After concentrating the water in the retort by evaporation to about 25 c.c., 15 grains of recently ignited pure caustic potash were introduced, together with six zinc-iron spirals. The tubulure of the retort was filled up to the contracted portion in its middle with moistened fragments of glass, and a glass tube, bent at right angles, and closed with a caoutchouc valve dipping into a little water, fitted to the end. After standing twenty hours, the retort was placed on the water bath for two hours, then 150 c.c. of water poured into it, and the ammonia distilled over and estimated.

Nitrous acid had previously been sought for, but not a trace could be detected.

## TABLE A

### TOTAL ESTIMATION IN GRAMS

| Quantity of Water employed | Product (with Impurities) | Weight of Solution | Portion of Solution weighed off | Precipitate obtained | Impurities in the Precipitate | *Calculated for 10,000 parts of Water* Impure Products | Impurities |
|---|---|---|---|---|---|---|---|
| | | | $SiO_2$, MgO, | CaO, $H_2SO_4$ | | | |
| 10740·1 | ·1508 $SiO_2$ | 81·522 | 14·854 | ·0760 $BaSO_4$ | ·0064 $BaSO_4$ | ·14041 $SiO_2$<br>·38836 $BaSO_4$ | ·00596 $BaSO_4$ |
| | | | 18·3597 | ·1932 CaO<br>·2137 $Mg_2P_2O_7$ | ·0060 $Mg_2P_2O_7$<br>·0009 CaO | ·79873 CaO<br>·883497 $Mg_2P_2O_7$ | ·02478 $Mg_2P_2O_7$<br>·00372 CaO |
| | | | KCl and | NaCl | | | |
| 8013·9 | ·4969 KCl + NaCl | 17·7770 | 6·6318 | ·0737 $PtCl_4$2KCl<br>·0012 $Mg_2P_2O_7$ | | ·24718 $PtCl_4$2KCl | ·00401 $Mg_2P_2O_7$ |
| | | | 6·5376 | ·4384 AgCl | | 1·5109 AgCl | |
| 3169·7 | | | | NaCl estimated (by diff.) | | | |
| | | | Cl. | ·4789 AgCl | | 1·5109 AgCl | |
| 1526· | ·3197 $CO_2$ | | $CO_2$ | Filtrate from $Na_2CO_3$ ppt. gave | ·0015 $BaSO_4$<br>·0022 $Mg_2P_2O_7$ | 2·0950 $CO_2$ | 0·0098 $BaSO_4$<br>0·0144 $Mg_2P_2O_7$ |
| 996·9 | ·000011 $NH_3$<br>·000274 $HNO_3$ | | | | | ·00011 $NH_3$<br>·00275 $HNO_3$ | |
| 42687· | ·0121 $CaFl_2$<br>·0027 $PbSO_4$ | | | | | ·00283 $CaFl_2$<br>·00063 $PbSO_4$ | |

## TABLE B

### SOLUBLE AND INSOLUBLE PORTIONS

**A. PORTION SOLUBLE IN WATER**

| | PORTION WEIGHED OFF | PRODUCT WITH IMPURITIES | IMPURITIES | IMPURE PRODUCTS CALCULATED TO 10,000 PARTS OF WATER | IMPURITIES CALCULATED TO 10,000 PARTS OF WATER |
|---|---|---|---|---|---|
| Weight of Solution 109·1364 from 21480·4 grams water | 15·1814 | ·1078 $BaSO_4$ | | ·36078 $BaSO_4$ | |
| | 12·8082 | ·3772 AgCl | | 1·49629 AgCl | |
| | 28·9045 | ·0045 CaO | | ·00798 CaO | |
| | | ·0933 $Mg_2P_2O_7$ | ·0018 CaO | ·16400 $Mg_2P_2O_7$ | ·003192 CaO |
| | | | Portion of solution employed = 27690 gr. water | | |
| | 35·3020 | ·4356 KCl + NaCl | ·0682 $PtCl_4$2KCl | ·62693 KCl + NaCl | ·2463 $PtCl_4$2KCl |
| | | | ·0047 $Mg_2P_2O_7$ | | ·01697 $Mg_2P_2O_7$ |

**B. PORTION INSOLUBLE IN WATER**

| | | | | | |
|---|---|---|---|---|---|
| By action of hydrochloric acid . | | ·3103 $SiO_2$ | | ·14446 $SiO_2$ | ·00778 $BaSO_4$ |
| | | 1·9460 $CO_2$ | | ·90593 $CO_2$ | |
| Substance attached to dish and flasks | By action of HCl . | ·0003 $SiO_2$ | | ·00015 $SiO_2$ | |
| | Filtrate from $Na_2CO_3$ precipitate . . | ·0014 $BaSO_4$ | | ·00065 $BaSO_4$ | |
| | | ·0012 $Mg_2P_2O_7$ | | ·00055 $Mg_2P_2O_7$ | |
| Solution in acid, 102·1610 . . | 32·9924 | ·0113 $BaSO_4$ | | ·01629 $BaSO_4$ | |
| | | ·0016 $Fe_2O_3$ | | | |
| | | ·0013 $Mn_3O_4$ | | | |
| | 34·4675 | ·5796 CaO | ·0386 $Mg_2P_3O_7$ | ·79987 CaO | ·05326 |
| | | ·5048 $Mg_2P_2O_7$ | ·0017 CaO | ·69655 $Mg_2P_2O_7$ | ·00235 |

## Table C

### PRODUCTS FREE FROM IMPURITIES

Calculated as obtained from 10,000 Grams of Water

| | A Soluble Portion | B Insoluble Portion | A + B Total | Total Estimation | Mean |
|---|---|---|---|---|---|
| $SiO_2$ | | ·13668 | | ·13445 | ·13556 |
| $CO_2$ | | ·90593 | | 2·0990 | |
| $BaSO_4$ | ·36078 | ·01694 | ·37772 | ·38836 | ·38304 |
| AgCl | 1·49629 | | | 1·51090 | 1·50360 |
| $HNO_3$ | | | | ·00275 | |
| $CaFl_2$ | | | | ·00283 | |
| CaO | ·01117 | ·78303 | ·79420 | ·79352 | ·79386 |
| $Mg_2P_2O_7$ | ·15811 | ·74547 | ·90358 | ·90142 | ·90250 |
| NaCl | ·53708 | | | ·54092 | ·53900 |
| $(KCl)_2PtCl_4$ | ·24630 | | | ·24718 | ·24674 |
| $NH_3$ | | | | ·00011 | |
| $Fe_2O_3$ | | ·00221 | | ·00218 | ·00219 |
| $Mn_3O_4$ | | ·00179 | | ·00198 | ·00189 |
| $BaSO_4$ | | ·00778 | | ·00596 | ·00687 |
| $PbSO_4$ | | | | ·000633 | |
| $Al_2O_3$ | | | | ·000683 | |
| $Ca_3(PO_4)_2$ | | | | | |
| Organic matter | | ·00275 | | ·00379 | |
| Lithium | | | | Trace | |
| Strontium | | Trace | | | |

## Table D

| I | II | III | IV | V | VI |
|---|---|---|---|---|---|
| **Soluble Portion** | | | | | |
| (1) *Estimation of Acids* | | | | | |
| $\frac{1}{2}$ $BaSO_4$ | ·36586 | ·0031367 | | ·003114 | |
| AgCl | 1·50360 | ·0104883 | ·0136686 | ·010413 | ·013570 |
| $HNO_3$ | ·00275 | ·0000436 | = s. | ·000043 | |
| (2) *Estimation of Bases* | | | | | |
| NaCl | ·53900 | ·0092121 | | ·009278 | |
| $\frac{1}{2}$ $PtCl_4$, 2KCl | ·24674 | ·0010111 | | ·001018 | |
| $\frac{1}{2}$ CaO | ·01115 | ·0003986 | ·0134740 | ·000401 | ·013570 |
| $\frac{1}{4}$ $Mg_2P_2O_7$ | ·15793 | ·0028457 | = $s_1$ | ·002867 | |
| $NH_3$ | ·00011 | ·0000065 | | ·000006 | |
| **Insoluble Portion** | | | | | |
| (1) *Estimation of Acids* | | | | | |
| $\frac{1}{2}$ $BaSO_4$ | ·01718 | ·0001473 | | ·000147 | |
| $\frac{1}{2}$ $SiO_2$ | ·13556 | ·0044887 | | | |
| $\frac{1}{2}$ $CO_2$ | ·90593 | ·0411790 | ·0458878 | ·041249 | ·041469 |
| $\frac{1}{2}$ $CaFl_2$ | ·00284 | ·0000728 | | ·000073 | |
| (2) *Estimation of Bases* | | | | | |
| $\frac{1}{2}$ CaO | ·78271 | ·0279437 | | 027944 | |
| $\frac{1}{4}$ $Mg_2P_2O_7$ | ·74457 | ·0134158 | | ·013416 | |
| $\frac{1}{2}$ $Fe_2O_3$ | ·00219 | ·0000547 | ·0414679 | ·000055 | ·041469 |
| $\frac{1}{3}$ $Mn_3O_4$ | ·00189 | ·0000495 | | ·000050 | |
| $\frac{1}{2}$ $PbSO_4$ | ·00063 | ·0000042 | | ·000004 | |

From the mean values obtained as shown in Table C from the results of the 'total examination,' and of the analyses of the 'soluble' and 'insoluble' portions are calculated the most probable values of the products obtained in the latter. Let A be the weight of any precipitate obtained in analysis of the portion soluble in water, calculated to parts in 10,000, and B that of the precipitate from the insoluble portion, and M the mean value of A + B obtained as above. The portions $A_1$ and $B_1$ corresponding to this mean value are readily found from the equations:—

$$A_1 = \frac{A}{A+B} M \qquad B_1 = \frac{B}{A+B} M$$

The values thus found are placed in the second column of Table D.

As a further control each of these numbers is divided by the *equivalent* weight of the substance as deduced from its chemical formula, and the product placed in column III. In the soluble portion the sum of the numbers so obtained from the weights of the precipitates produced in estimating the acidulous radicals, should correspond within the limits of experimental error with the sum of the numbers similarly calculated from the determination of the bases.

This concordance is not to be expected in the results from the insoluble portion, inasmuch as the silica exists in the water uncombined with any base. As also by continued evaporation the silicic acid may decompose a portion of the carbonates, the above method of control is not applicable. The sum total obtained by division of the quantities found in estimating the acids should, however, exceed that of the bases by a number somewhat less than that calculated for the silicic acid.

In calculating out the results of the analysis of the insoluble portion a number is substituted in the fourth column for that of the carbonic acid in the third column of such magnitude as to render the sum of the values corresponding to the acids less that of the silicic acid, equal to the sum found for the bases.

For calculating the results of the analysis of the soluble portion, let A B C . . . be the equivalents of acid, column III., Table D, and $A_1$ $B_1$ $C_1$ . . . the equivalents of base in the same column, S the sum of the former, and $S_1$ of the latter, then if $\frac{e}{a}$ be the probable error of such determination, we have

$$a\,(1+\tfrac{e}{a}) + b\,(1+\tfrac{e}{a}) + c\,(1+\tfrac{e}{a}) + \ldots\ldots$$

$$= a_1\,(1-\tfrac{e}{a}) + b_1\,(1-\tfrac{e}{a}) + c_1\,(1-\tfrac{e}{a}) + \ldots\ldots$$

consequently

$$\frac{e}{a} = \frac{S_1 - S}{S_1 + S}$$

By aid of the value of $\frac{e}{a}$ so obtained, are found the numbers in column IV. of the Table D, which numbers are employed for calculating the quantities of the various salts present in the water.

In a table given by Bunsen, in the pamphlet previously mentioned, all the various salts found in mineral waters are arranged in the order of their decreasing solubility, and consequently in the order in which they would be deposited upon evaporation of a water holding all in solution.

In the soluble portion of the mineral water, the acids and bases are grouped in all the possible combinations, and the most difficultly soluble salt thus found is first estimated. In the present instance there are 3 acids and 5 bases, theoretically capable of combining to form 15 different salts. Of these the least soluble is calcium sulphate, and

$$\cdot 000401 \times 68\cdot 04\ (\tfrac{1}{2}CaSO_4) = \cdot 027284 \text{ gram},$$

represents the amount of this salt in 10,000 parts of the water.

The next in order of solubility is potassium sulphate :—

$$\cdot 001018 \times 87\cdot 19\ (\tfrac{1}{2}K_2SO_4) = \cdot 088759 \text{ gram},$$

and, therefore, is the amount of this salt present.

The equivalent of sulphuric acid still available

$$\cdot 003114 - (\cdot 000401 + \cdot 001018) = \cdot 001695$$

is not sufficient to unite with the whole of the sodium to form the salt next in order of solubility, hence

$$\cdot 001695 \times 71 \cdot 09 \ (\tfrac{1}{2}Na_2SO_4) = \cdot 1205 \text{ grams}$$

represents the amount of sodium sulphate.

In a similar manner the remainder of the constituents are calculated.

The composition of the dissolved gases being, according to the mean of the result, given in a later section,

N 59·78 per cent. by volume
$CO_2$ 40·22 „ „

the amount of nitrogen present has been calculated from that of the free carbonic acid, found in this analysis, by aid of this proportion.

The final result is tabulated in the usual form.

| | Parts in 10,000 of water |
|---|---|
| Calcium bicarbonate | 2·0014 |
| Magnesium „ | ·8587 |
| Ferrous „ | ·0044 |
| Manganous „ | ·0040 |
| Barium sulphate | ·0069 |
| Calcium „ | ·0273 |
| Potassium „ | ·0888 |
| Sodium „ | ·1205 |
| Lead „ | ·0006 |
| Sodium nitrate | ·0037 |
| Calcium fluoride | ·0028 |
| Sodium chloride | ·4412 |
| Ammonium „ | ·0003 |
| Magnesium „ | ·1361 |
| Silicic acid | ·1356 |
| Lithium | trace |
| Strontium | trace |
| Phosphoric acid | trace |
| Organic matter | ·0033 |
| Free carbon dioxide | ·0287 |
| Nitrogen | ·0272 |
| | 3·8915 |

## CHAPTER XIV

### DETERMINATION OF THE GASES DISSOLVED IN WATER AND EVOLVED THEREFROM

In examining samples of water taken from different points along the course of a river, it is sometimes desirable to estimate the gases dissolved therein, more especially the dissolved oxygen. The more nearly the water is saturated with oxygen the better is supposed to be its quality and the more efficient the process of 'self-purification.' Recently the estimation of the dissolved oxygen has assumed greater importance as a test of the efficiency of the so-called bacteria beds in the purification of sewage. In this case the object is to produce a well-oxygenated effluent, such being found generally to be more satisfactory with regard both to the degree of purification and to its keeping properties, i.e. its non-liability to putrefactive change. At one time it was thought that the test might prove of service in differentiating between polluted and non-polluted waters, since a pure water kept in a full sealed flask retains its oxygen in a free state for an indefinite period, whereas a polluted water gradually loses its free oxygen, the gas being taken up by bacteria, or being otherwise used up in the oxidation of the organic matter. I made a large number of experiments in connection with this subject, simply to confirm the experience of others that the results were far from reliable and that the desired information could be more definitely obtained by the ordinary methods of chemical and bacteriological examination. The three gases which it may on occasions be desirable to estimate are oxygen, carbon dioxide, and nitrogen. The two former can be estimated

volumetrically by the methods about to be described, and if the total amount of dissolved gases be ascertained the difference may be ascribed to nitrogen without any serious risk of error.

## THE GASES DISSOLVED IN WATER

### (*a*) Estimation of the Carbon Dioxide

The total carbon dioxide, combined and free, can be estimated as described in the analysis of the gases in the Buxton water, and the combined acid having also been determined, the difference gives the free $CO_2$. Few will care, however, to adopt this process.

The method I adopt was described by Trillick, and gives very satisfactory results. Moreover, it requires no special apparatus and no special reagents. It depends on the fact that when a solution of barium hydrate is added to the water the free and the so-called semi-combined $CO_2$ combine with the barium hydrate, the insoluble barium carbonate being precipitated. Calcium carbonate being practically insoluble in water is precipitated when the $CO_2$ is removed, but magnesium carbonate not being so insoluble is converted into magnesium hydrate, and the other magnesium salts will also be decomposed in a similar manner. Sodium carbonate also precipitates with the barium hydrate, but insomuch as an equivalent of sodium hydrate is formed this does not interfere with the reaction. From the total $CO_2$ calculated from the loss of alkalinity, it is only necessary to subtract any due to the presence of magnesium salts, and the remainder represents the free and semi-combined $CO_2$ in the amount of water examined. It is assumed, therefore, that the Mg will have been determined.

The reagents required are—the standard solution of sulphuric acid, 1 c.c. = 2 mlgr. $CO_3$, a freshly titrated baryta water, and solution of barium chloride.

Into a flask capable of holding a little over 250 c.c. place 200 c.c. of the water to be examined, add 10 c.c. of the barium

chloride solution, gently rotate, and after a few seconds add 40 c.c. of the baryta water. Close with a well-fitting stopper and again gently agitate until the mixture is uniform. Set aside all night or until the supernatant liquid is quite clear.

Remove with a pipette 100 c.c. of the clear liquid, add a little dilute phenolphthalein, and titrate with the standard acid (1 c.c.=2 mlgr. $CO_3$). The amount of acid which would be required to neutralise the whole of the liquid is then calculated, and this, deducted from the amount required to neutralise 40 c.c. of the baryta water used, gives the loss due to the carbon dioxide and magnesium salts.

1 c.c. of the standard acid=2 mlgr. $CO_3$=1·47 mlgr. $CO_2$.

1 mlgr. Mg corresponds to 1·83 mlgr. $CO_2$.

Let $x$=the amount of free and semi-combined $CO_2$ in 100 c.c. of the water.

$a$=the amount of Mg in 100 c.c. of the water.

$b$=the no. of c.c. of acid required to neutralise 40 c.c. of the baryta water.

$c$=the no. of c.c. required to neutralise the excess of baryta in the 200 c.c. of water,

then $1{\cdot}47\,\frac{b-c}{2}=x+1{\cdot}83a$, whence

$$x=\cdot 735\,(b-c)-1{\cdot}83a.$$

The following is an example of such an analysis.

The baryta water employed was of such strength that 40 c.c. required 98 c.c. of the standard sulphuric acid for neutralisation. 200 c.c. of the water were taken and 100 c.c. of the clear supernatant mixture removed for titration. This required 30·4 c.c. of acid to neutralise the excess of barium hydrate. The water plus reagents amounting to 250 c.c. and 100 c.c. being taken for the analysis, the excess of alkali in the 100 c.c. multiplied by 2·5 gives the excess in the 200 c.c. of the water used. This gives $30{\cdot}4\times 2{\cdot}5=76{\cdot}0$ as the amount of acid necessary to neutralise the total excess of barium hydrate.

The water contained 2·1 mlgr. Mg in 100 c.c.

$$\therefore x - \cdot 735\ (98-76) - (2\cdot1 \times 1\cdot83) = 12\cdot33.$$

The $CO_3$ in this water amounted to 14·8 mlgr. per 100 c.c., equivalent to 10·8 mlgr. $CO_2$. The $CO_2$ necessary to form bicarbonates would, of course, be the same, hence the water contained,

| | Mlgr. |
|---|---|
| $CO_2$ free and semi-combined in the bicarbonates . . . | 12·33 |
| $CO_2$ in bicarbonates . . . . . | 10·8 |
| Free $CO_2$ . . . . . | 1·53 |

Upon continued boiling both the free $CO_2$ and the semi-combined $CO_2$ in the bicarbonates would be evolved, and as 1 c.c. of $CO_2$ at N.P.T. (normal pressure and temperature) weighs 1·96 mlgr., the amount of $CO_2$ evolved from 100 c.c. of this water would be $\frac{12\cdot33}{1\cdot96} = 6\cdot27$ c.c.

### (*b*) Estimation of the Dissolved Oxygen

The following method, devised by me in 1890 and first described in a communication to the Chemical Society in the following year, has been widely adopted, and as no other method known to me approaches it in simplicity and accuracy, it continues to be the only one used in my laboratories.

It is based on the fact that a mere trace of nitrous acid will continue to liberate iodine in a solution of hydrogen iodide so long as air or oxygen has access to the solution.

The reaction is represented by the following equation :—

$$2HI + 2HNO_2 = I_2 + 2H_2O + 2NO.$$

The liberated NO then acts as a carrier, more HI being decomposed, $2HI + O = H_2O + I_2$.

When the reaction takes place in a closed vessel it continues until all the free oxygen has been used up, and the amount of iodine set free corresponds to the amount of nitrous acid used, plus the amount of oxygen present. It is only necessary

therefore to add a known quantity of sodium nitrite together with a little acid and potassium iodide to a definite volume of water, avoiding the presence of air, and to determine the amount of iodine liberated, in order to ascertain the amount of free oxygen in the water.

The reagents required are:

1. Solution of sodic nitrite and potassium iodide.
2. Dilute sulphuric acid (1 in 4).
3. Solution of starch.
4. Standard solution of sodium thiosulphate 1 c.c.= ·25 mlgr. O.

The apparatus required is shown in the accompanying figure.

A is a white glass bottle capable of holding about 500 c.c. closed by a caoutchouc stopper having four perforations. Through one passes the nozzle of a burette, C, through each of two others passes a short length of glass tubing bent at a right angle, and through the fourth the nozzle of a separating tube, D, which holds when completely full 252 c.c.[1] and has a mark on the neck at 250 c.c.

The bottle A having been carefully cleaned and dried, the tube D is filled carefully with the water to be examined up to the 250 mark, 1 c.c. of the nitrate solution is measured in by means of a pipette, and then 1 c.c. of the dilute acid. The stopper is then inserted, taking care not to include any bubble of gas. By gentle agitation mixture is effected, and after pushing the nozzle of the tube through the caoutchouc stopper it is allowed to remain at rest for 15 minutes. The solutions of acid and nitrite should be delivered with the pipette held vertically with its end under the surface of the water.

The burette filled with the thiosulphate solution is next placed in position (care must be taken to have the nozzle also filled), and one of the bent tubes having been connected with the gas supply, a current of gas is passed rapidly through the

[1] The apparatus can be had from Gallenkamp & Co., Cross Street, Finsbury Square, and other instrument makers.

bottle until all the air has been expelled and the gas burns at B with a full luminous flame. The gas is then turned low, but a constant stream is kept up until the conclusion of the experiment.

The stopper of D is now removed and the cork B inserted. Upon turning the tap the liquid in D flows into the bottle.

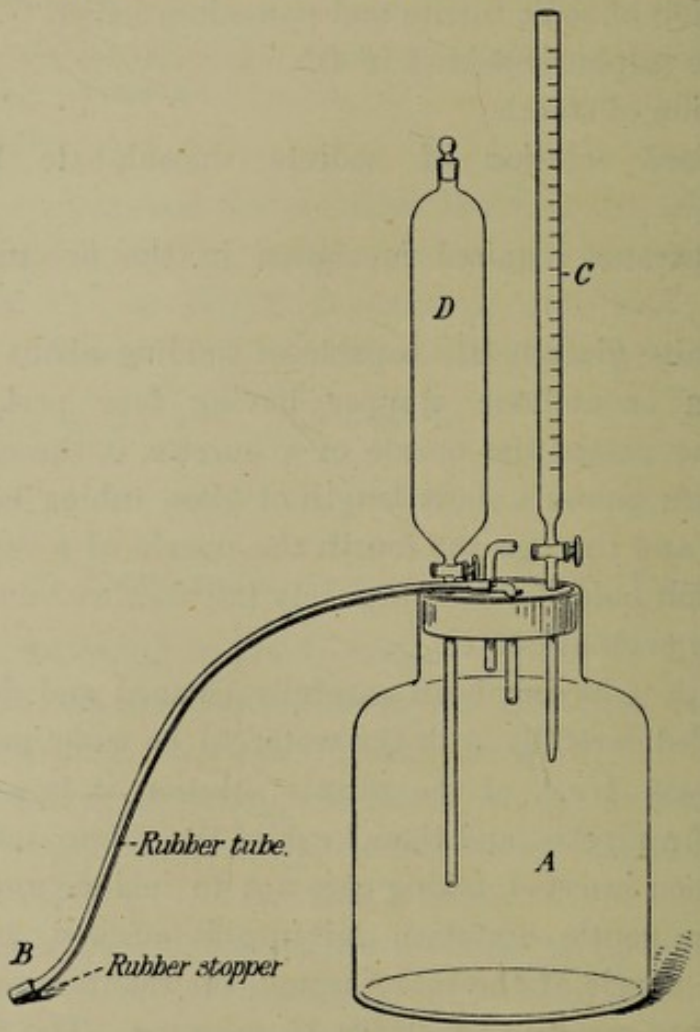



FIG. 9

When D is empty the cock is turned and the stopper reinserted. Thiosulphate is now run in until the colour of the iodine is nearly discharged. The stopper of D is again removed, 2 c.c. of starch solution poured in, and the tap turned to allow of this flowing into the bottle without the introduction of any air. The thiosulphate is again added until the blue colour disappears. The amount of thiosulphate used is then recorded.

After the above determination is concluded, introduce into the bottle in succession 5 c.c. of nitrite solution, 5 c.c. of the acid and 10 c.c. of starch solution, and again run in the thiosulphate. One fifth of the amount of thiosulphate thus used will correspond to the reagents used in the oxygen determination.

The thiosulphate should be well shaken before use, and it can then be regarded without appreciable error as being saturated with air, each c.c. containing oxygen equivalent to ·031 c.c. of thiosulphate used.

Let $a$ = the amount of thiosulphate used by the water and reagents.

$b$ = the amount of thiosulphate corresponding to the reagents only.

$x$ = the amount of oxygen in one litre of the water.

then $x = 4 \times \cdot 25\,[a - (b + \cdot 031a)]$.

$\therefore x = a - (b + \cdot 031a)$.

$\therefore x = \cdot 969a - b$.

For example, 250 c.c. of spring water gave the following results (temperature 14° C.) :—

$a = 9 \cdot 4$ c.c.

$b = 2 \cdot 1$ c.c.

$\therefore x = 9 \cdot 108 - 2 \cdot 1 = 7 \cdot 008$ mlgr. oxygen per litre, or ·701 mlgr. per 100 c.c.

As 1 c.c. of oxygen at normal pressure and temperature weighs 1·42 mlgr., 100 c.c. of the water at 14° C. contained ·494 c.c. of dissolved oxygen, measured at N.P.T.

At 15° C., 100 c.c. of water saturated with air contains 1·003 mlgr. oxygen, equal to ·702 c.c. at N.P.T.

The above process is applicable to all potable waters. The very trifling amount of nitrites occasionally found has no appreciable effect. If desired, any nitrite present can be estimated, and the oxygen equivalent having been calculated, the correction may be made.

From the table in the Appendix the percentage saturation can be calculated. Thus in the example above given, 100 c.c.

of the water at 14° C. contained only ·494 c.c. of oxygen, whereas had it been saturated, it would have contained ·712 c.c., consequently the percentage saturation was $100 \times \frac{\cdot 494}{\cdot 712} = 69 \cdot 3$.

### (*c*) Estimation of the Total Gases

The water to be used for the estimation of the dissolved gases should be collected in boiling flasks of from half to one litre capacity. These are suitably weighted and sunk, and the water which at first enters, and has therefore been in contact with more or less compressed air, is withdrawn by means of a small pump or exhausting syringe connected with the flask by a length of rubber tube, weighted at the end if necessary by a piece of lead or tin pipe. The piston should be worked until the water removed measures four or five times the amount which the flask will contain. The flask is then withdrawn and a rubber stopper, perforated, inserted. Finally the perforation is closed by means of a short piece of glass rod, and the flask taken to the laboratory.

The apparatus employed in my laboratory for determining the amount of gases dissolved in water is illustrated in fig. 10; *a* is the flask containing the water, *b* a piece of narrow bore tubing, connected by a short length of stout caoutchouc tubing carrying a pinchcock, with the tubulure *b'* projecting from the glass collecting vessel *c*. The second tubulure *d* is similarly connected by means of a caoutchouc tube, carrying a pinch-cock, with a length of thermometer tubing, by means of which gas collected in *c* can be transferred to the eudiometer, or absorption tube, *g*. The open vessel, *e*, containing mercury, is connected with *c* by a length of stout rubber tubing.

When a determination is to be made, the flask filled with water is placed upon the stand, the vessel *e* lowered and filled with mercury. The pinchcocks on *b b'* and *d d'* are released, and *e* raised gradually until *c* and the tubes connected therewith are filled with mercury, care being taken to leave no air bubbles in the rubber tubing under the pinchcocks. The

pinchcocks are then closed, and *e* lowered as far as possible and left in this position for some time, when, if no air bubbles have made their appearance, the experiment can be proceeded with. The free end of *b* is now inserted into the orifice in the stopper of the flask containing the water (care having been taken previously to replace any air or water in the cavity by mercury, and to see that the tube *b* is quite full of that metal), and gently pushed down so as to force the plug into the bottle, and until the end of the tube can just be seen below the stopper.

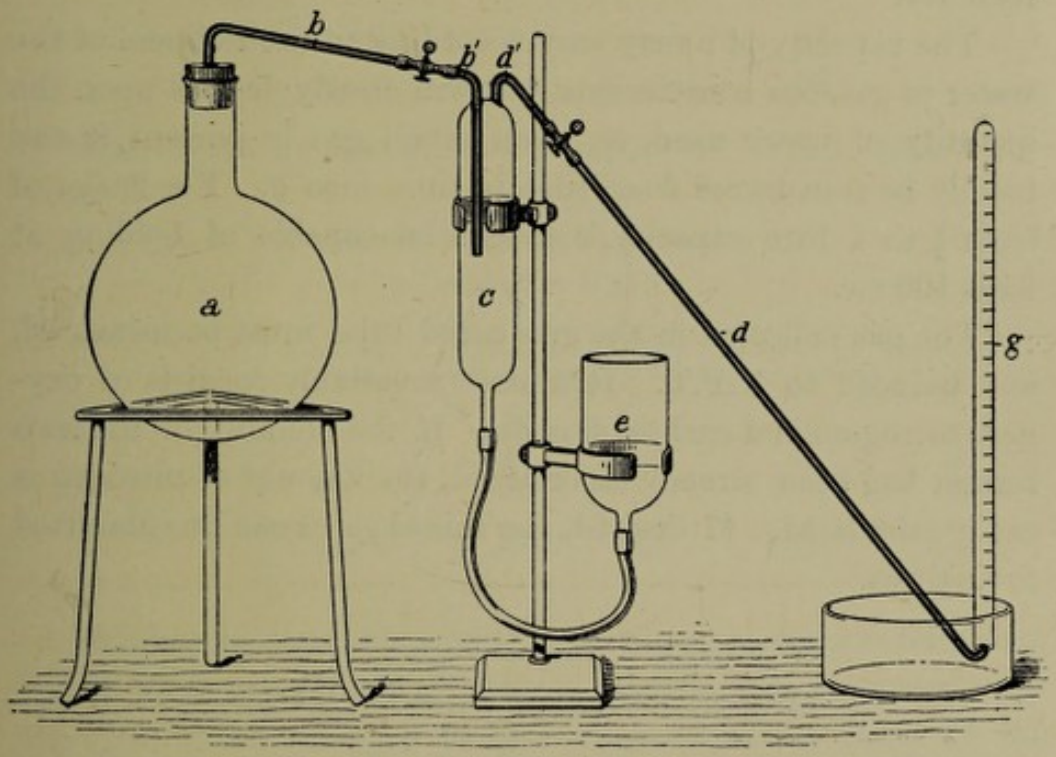



FIG. 10

On now releasing the clamp upon *b b'*, lowering *e* and applying heat to the flask, the heat and diminished pressure cause the gas to be readily given off, and the water will boil at a temperature below 100°, depending of course upon the difference between the levels of the mercury in *c* and *e*. The expansion of the water causes a portion to pass into *c*, above which the evolved gas collects, and when the latter nearly half fills the tube, *e* is raised after opening the pinchcock on *d d'*, and most of the gas thus forced into the absorption-tube. This process

can be repeated as often as necessary, care being taken not to force any mercury into the water flask, nor any water into the tube $d\,d_1$, and to keep the end of the tube $b_1$ always under the surface of the fluid in $c$. Finally, by keeping $e$ raised until the water is nearly at 100°, and then lowering, the water in $c$ may be made to boil and give up almost the last trace of gas. On again raising $e$, &c., the whole of the evolved gas is collected in $g$, saturated with moisture, but, due precaution having been taken, without any trace of water on the surface of the mercury.

The capacity of $c$ may vary according to the richness of the water in gaseous constituents, but will chiefly depend upon the quantity of water used, as when much gas is present it can readily be transferred from time to time into $g$. For flasks of from $\frac{1}{2}$ to 1 litre capacity, $c$ should be capable of holding at least 100 c.c.

The gas collected in the graduated tube must be measured, and reduced to N.P.T. It almost invariably consists of oxygen, nitrogen, and carbon dioxide. If the amount of the two former has been already ascertained, the amount of nitrogen is easily calculated. If desired, the mixed gases can be submitted to analysis.

### (*d*) Estimation of the Nitrogen

The free and semi-combined $CO_2$ and the free O having been determined, and the total volume of gas liberated by boiling ascertained, the difference between the sum of the two former and of the latter may be taken as the amount of N present.

For example, in 100 c.c. of a given sample of water the free and semi-combined $CO_2$ amounted to 6·3 c.c. at N.P.T. and the O present was ·5 c.c. The total amount of gas evolved from 490 c.c. of the water was 54·2 c.c. measured at 14° C. The barometer reading was 758 m.m. and the mercury in the measuring tube was 175 m.m. above the level of that in the

trough. The tension of aqueous vapour at 14° C. being 11·9 m.m., the pressure of the gas was 758−175−11·9= 571·1 m.m.

Corrected to N.P.T., the volume of the gas evolved from 100 c.c. of water would be

$$54{\cdot}2 \times \frac{571{\cdot}1}{760} \times \frac{273}{273+14} \times \frac{100}{490} = 7{\cdot}9.$$

The water therefore contained

| | |
|---|---|
| Oxygen . . . . . | ·5 c.c. |
| Nitrogen . . . . . | 1·1 „ |
| Carbon dioxide . . . . | 6·3 „ |
| | 7·9 |

The following are a few examples of actual determinations:—

GASEOUS CONSTITUENTS OF WATERS

BY VOLUME IN 100 C.C.

| — | Fresh rain-water | Limestone spring, Buxton | A pure river water | River water. Sewage-polluted | Essex deep chalk |
|---|---|---|---|---|---|
| $CO_2$ . . . | ·14 | 1·46 | 3·00 | 5·60 | 1·42 [1] |
| O . . . | ·64 | ·00 | ·75 | ·025 | ·61 |
| N . . . | 1·30 | 2·21 | 1·50 | 1·51 | 1·29 |
| | 2·08 | 3·67 | 5·25 | 7·135 | 3·32 |

Whilst the free $CO_2$ and O are still frequently determined, the N is rarely estimated. At one time it was suggested that the ratio of the nitrogen to the oxygen was an index of the quality of the water, a pure water containing at least half as much oxygen as nitrogen, impure waters containing a smaller proportion of oxygen. This may be true of most river waters, but there are certainly numerous exceptions among spring waters, and consequently the determinations are but rarely made.

The gases evolved from water on boiling, and collected in the way above described, may be submitted to any of the ordinary processes of gas analysis for the determination of the

[1] The whole existed in $CaCO_3CO_2$ and $MgCO_3CO_2$.

constituents. The following is an example of such an analysis, and includes a description of the method adopted in examining the gases evolved from a spring.

### Gases dissolved in the Buxton Thermal Water

The flasks employed for collecting the water varied in capacity from 300 to 700 c.c. After being rinsed with the thermal water, a flask was weighted and sunk. A long piece of glass tube was attached at its upper end to a small pump or exhaust syringe, its lower end being inserted into the flask, and the water which had first entered the flask was displaced by the action of the pump. In this way samples of the water which had not been in contact with air and from the very bottom of the spring were collected. The above-mentioned tube was then withdrawn, and a rubber stopper inserted by aid of a long rod. The flask was then drawn to the surface. Great care had to be taken in these operations, as the slightest movement in the water caused a disengagement of gas bubbles.

The gas contained in the water was driven off in the apparatus already described, the boiling under diminished pressure being continued from 1½ to 2 hours. After collecting the evolved gas in an absorption tube, a bullet of fused KHO was inserted until all $CO_2$ and moisture had been removed. When the gas was afterwards treated with alkaline pyrogallate, a trace of oxygen was found, but from its small proportion and from considerations derived from the composition of the sinter, there could be no doubt that its presence was due to traces of air entering the apparatus during the analysis. The residual nitrogen was then measured. The carbon dioxide was determined in 100 c.c. and in 250 c.c. of the water in the following manner. The water was collected in pipettes of the above capacity by aid of a syringe, the pipettes being sunk as deeply as possible in the spring. The water was transferred to a flask containing (when 100 c.c. were used) 10 c.c. of a solution of ammo-

nium chloride and calcium chloride (to precipitate the carbonates and to prevent the precipitation of magnesia) and 50 c.c. of lime-water of known strength added. After standing for twenty-four hours, 100 c.c. of the clear liquid were withdrawn and titrated with dilute nitric acid of such strength that 1 c.c.=1 mlgr. $CO_2$. The precipitate of $CaCO_3$ was as far as possible collected on a filter, washed, and the filter and contents returned to the carefully rinsed flask. After treatment with a measured excess of dilute acid and gentle ebullition, the acid solution was titrated back with lime water. This method answers very well when very little magnesium salt is present, but as a rule I now prefer the process previously described for determining the carbon dioxide. The above results enable us to estimate the nitrogen and the carbon dioxide, free and as bicarbonate.

The following is a typical result :—

Estimation of the Nitrogen

Water taken 707 c.c., Temperature 81·7° F.

| — | Volume | Pressure | Temperature | Volume at N.T.P. per litre of water |
|---|---|---|---|---|
| Residual gas after absorption of $CO_2$ . . . | 19·05 | 614·5 | 5° C. | — |
| After absorption of O . | 18·80 | 614·9 | 2·9° | 21·3 |

Estimation of the total $CO_2$ in 100 c.c. This was found to be 0·1901 gram.

The free and semi-combined $CO_2$ in 100 c.c. was 0·1096 gram, and the difference between this and the total $CO_2$ gives the combined $CO_2$ = ·0805. Then 0·1901 − 2(·0805) = 0·0291 the free $CO_2$ corresponding to 14·72 c.c. per litre at N.P.T.

One litre of water therefore would contain

| | | |
|---|---|---|
| N . . . . . | 21·30 c.c. | = 59·13 per cent. |
| $CO_2$ . . . . . | 14·72 „ | = 40·87 „ |
| O . . . . . | trace | |
| | 36·02 | |

The mean of several determinations gave N 59·78 per cent.,

$CO_2$ 40·22 per cent. The composition of the gas which should be evolved from such a water is given by the equation—

$$\frac{100 \quad \times 0{\cdot}01392 \times x}{0{\cdot}01392x + 0{\cdot}9054(100-x)} = 59{\cdot}78$$

where $x$=per cent. of nitrogen and $100-x$ the per cent. of carbon dioxide in the gas evolved, ·01392 the solubility of nitrogen in water and ·9054 the solubility of carbon dioxide.

The theoretical and calculated compositions of the evolved gas are as under :—

| | Theory | Found |
|---|---|---|
| N . . . . . | 98·98 | 99·12 |
| $CO_2$ . . . . . | 1·02 | ·88 |

To charge pure water with the amount of gas found in the Buxton thermal spring would require a pressure of 1·64 atmosphere, the temperature of the water being 81·7° F. The origin of this nitrogen and the absence of oxygen have been the subject of much speculation, but the constitution of the sinter or deposit formed by the water explains both phenomena. The water at its source becomes charged with air under some little pressure, and afterwards traverses a bed of manganese ore capable of taking up oxygen ; the whole of this gas is absorbed, the nitrogen alone remaining. The fact that the moist deposit from the water when exposed to air does take up oxygen, is a proof of the absence of free oxygen in the water.

The gas evolved from the water at the springs was examined as described below.

## GASES EVOLVED FROM WATERS

### Analysis of the Gases evolved from the Buxton Thermal Spring

The gases were collected in flasks of about 100 c.c. capacity by means of a funnel inserted in the mouth. The flask was filled with the water of the spring, the funnel inserted, and the whole

sunk and inverted in the spring. The bubbles of gas evolved ascended through the funnel, displacing the water in the flask. When full the mouth of each flask was closed with a caoutchouc stopper fitted with tubes, as figured in Bunsen's and Roscoe's 'Gasometry,' and then inverted in a glass cylinder containing sufficient water to cover the necks.

Arrived at the laboratory the gas was transferred as required to the absorption tube, and the $CO_2$ determined by absorption with balls of fused potash. The residual gas was inappreciably affected in volume by treatment with a papier-mâché ball impregnated with alkaline pyrogallate; it contained no combustible gas, and, in fact, comported itself in every way as pure nitrogen. (It has since been found to contain argon.) The analyses 1 and 2 were made from the same sample of gas. The pressures and volumes given refer to the dry gas. All readings were taken by aid of a telescope sliding on a vertical support.

| — | Volume | Pressure | Temperature |
|---|---|---|---|
| ANALYSIS 1 | | | |
| Gas taken | 43·01 | 693·9 | 8° C. |
| After absorption of $CO_2$ | 42·08 | 696·7 | 5·0° C. |
| Giving N | 99·161 p.c. | — | — |
| „ $CO_2$ | ·839 p.c. | — | — |
| ANALYSIS 2 | | | |
| Gas taken | 42·28 | 687·8 | 5·9° C. |
| After absorption of $CO_2$ | 41·28 | 696·5 | 5·3° C. |
| Giving N | 99·083 p.c. | — | — |
| „ $CO_2$ | ·917 p.c. | — | — |

The gas, if allowed to stand in contact with a little of the water, becomes richer in carbon dioxide, since the nitrogen and carbon dioxide dissolved in the water correspond to a pressure of 1·6 atmosphere and the proportion of carbon dioxide present is considerable; hence upon the removal of the pressure the evolved gas will become richer in carbon dioxide, and the greater the depth in the spring, the greater the pressure at which the gas is collected, and the less carbon dioxide will it contain. Analyses 3 and 4 are of gases which

had stood for a time in a flask, in which by accident a little of the water had been left.

| — | Volume | Pressure | Temperature |
|---|---|---|---|
| **Analysis 3** | | | |
| Gas taken . . . . . | 42·73 | 709·7 | 5·3° |
| After removal of $CO_2$ . . . . | 41·96 | 711·7 | 4·8° |
| **Analysis 4** | | | |
| Gas taken . . . . . | 31·40 | 653·2 | 12·5° |
| After removal of $CO_2$ . . . . | 30·12 | 668·4 | 11·2° |
| Giving (3) Nitrogen 98·65 per cent. and (4) 98·61 per cent. | | | |
| „ $CO_2$ 1·35 „ | | 1·39 „ | |

The above-recorded experiments incidentally illustrate the precautions which have to be taken to obtain concordant results, and explain why different results may be obtained from the same water.

Had the water contained any free oxygen, this would have been found in the evolved gases, and estimated from the loss in volume when treated with alkaline pyrogallate.

In making any future analysis of this character I should collect the gases in flasks, as above described, and transfer to a Hempel's gas burette, and absorb, first the carbon dioxide, and afterwards the oxygen in absorption pipettes. This method is more simple and, I think, less liable to error than Bunsen's method used by me in examining the gases of the Buxton water.

## CHAPTER XV

### ANALYSIS OF THE SINTER DEPOSITED BY WATER

THE rocks through the fissures of which the Buxton thermal water issues are coated with a dark brown mud. This mud or sinter has also been submitted to analysis to complete the examination of this spring. The analysis may be given as a sample of such an examination, but probably few sinters would be found of such a complex character.

This mud was collected by carefully scraping the slabs with a large knife. About as much as filled a 2–3 litre jar was obtained. Upon attempting to collect some from the bottom of the reservoir, the agitation caused it almost instantly to be diffused through the water, and carried away by the current.

A preliminary examination showed that this mud consisted chiefly of hydrated manganese dioxide, with small quantities of iron, zinc, cobalt, calcium, barium, and magnesium, and carbonic acid, together with traces of molybdenum, lead, copper, aluminium, strontium, and phosphoric, silicic, and sulphuric acids. After washing with distilled water, and drying in a water oven, it shrank up very considerably, leaving an exceedingly light purple-brown powder, which stained the skin when rubbed between the fingers. Instead of about a kilogram of dry residue being obtained, as expected, the weight of the whole when dry did not exceed 50 grams.

Bunsen's, Marsh's, and other tests were applied for detection of arsenic and antimony, but no decided indication of the presence of either could be obtained.

As molybdenum, so far as I am aware, has never before

been found in any mineral water, the proofs of its presence in this spring are given in detail.

For the qualitative examination a portion of the sinter was evaporated to dryness with hydrochloric acid and the residue treated with acid and water; a very small portion remained undissolved. The acid solution when heated to 70° C., and perseveringly treated with hydrogen sulphide, yielded a red-brown finely pulverulent precipitate, which required about thirty-six hours to settle.

This precipitate, when treated with potassium sulphide, partially dissolved, forming a reddish solution, which, upon addition of dilute hydrochloric acid, yielded a red-brown flocculent precipitate. Portions of this, exposed on a thread of asbestos to the reducing flame of a Bunsen's lamp, gave a slight brown stain on the bottom of a porcelain dish held immediately over it, which stain was insoluble in ammonium hydrosulphide and sodium hypochlorite, but soluble in nitric acid. The remainder of the dry precipitate and the filter paper, mixed with a little sodium carbonate and nitrate, was added by degrees to fused sodium nitrate, and the melt treated first with water, then with alcohol. A trace only remained undissolved. The solution acidulated with hydrochloric acid gave with stannous chloride a brown coloration, and with potassium thiocyanate and zinc a rich crimson colour, unaffected by phosphoric acid, but taken up entirely by agitation with ether.

Another portion of the mud was exhausted with dilute nitric acid, and the acid solution was boiled with slight excess of sodium carbonate, and filtered. The concentrated filtrate gave with hydrochloric acid and stannous chloride, and with hydrochloric acid potassium thiocyanate and zinc, the reactions of molybdic acid. After addition of ammonium hydrosulphide to this solution, excess of hydrochloric acid gave in a few minutes a distinct red-brown precipitate.

To render if possible the evidence still more complete, at the request of Professor Roscoe, to whom I was indebted for

many valuable suggestions in the course of this investigation, an attempt was made to obtain the very characteristic compound of phosphoric and molybdic acids with ammonia, from the molybdic acid obtained in the quantitative analysis. This attempt was successful, for upon dissolving the oxide in nitric acid, adding a little ammonia, then again nitric acid in excess, the yellow precipitate referred to was produced in a few minutes upon adding a minute trace of sodium phosphate, and warming the solution.

In the ammonium hydrosulphide precipitate, insoluble in dilute hydrochloric acid, nickel was sought for, but not detected. The barium chloride obtained gave up to absolute alcohol a very minute portion, in which strontium could be detected by the spectroscope.

Hydrofluoric, tungstic, titanic, and boracic acids were specially tested for, but with negative results.

### Quantitative Analysis of Mud dried at 120° C.

Loss on Ignition.– By ignition in a small table furnace, 0·7065 gram lost 0·1143 gram or 16·18 per cent.

0·5854 ignited over a blowpipe lost 0·097 gram, or 16·57 per cent. Mean loss 16·38 per cent.

$CO_2$.—Estimated by aid of the apparatus used for a similar purpose and referred to in the analysis of the saline constituents of the water.

3·8955 gram lost 0·1275 gram of $CO_2$ or 3·27 per cent.

1·0631 gram lost 0·0339 gram of $CO_2$ or 3·20 per cent.

Mean 3·235 per cent.

$MnO_2$.—The oxide was determined indirectly by ebullition with strong hydrochloric acid, the evolved chlorine being caused to liberate its equivalent of iodine, which was estimated volumetrically with standard solution of sodium thiosulphate.

0·3388 gram = 0·2587 gram $MnO_2$, or 76·36 per cent.

0·3160 gram = 0·2415 gram $MnO_2$, or 76·42 per cent.

Mean 76·39 per cent.

Portion insoluble in hydrochloric acid. 20·1411 grams, when treated with excess of hydrochloric acid, evaporated to perfect dryness on the water bath, then moistened with acid and treated with water, left a residue which after ignition weighed 0·2180 gram=1·08 per cent. This residue was not quantitatively examined, but consisted of barium sulphate, fine sandy particles, &c. ($SiO_2$, $Fe_2O_3$, $Al_2O_3$, $BaSO_4$).

PbO.—In the hydrogen sulphide precipitate, after treatment with potassium hydrosulphide until it was no longer coloured, the lead was estimated as sulphate by dissolving the residue in nitric acid, evaporating with sulphuric acid, washing with acidulated water, then with alcohol, drying, &c.

The lead sulphate weighed 0·0402 gram, corresponding to 0·147 per cent. PbO, and, after treatment with potassium chromate, was entirely soluble in caustic potash.

CuO.—From the concentrated filtrate from the lead precipitate the copper was deposited on a platinum dish by the action of pure zinc. The copper obtained weighed 0·011 gram, corresponding to 0·068 per cent. cupric oxide.

$MoO_3$.—Upon adding dilute hydrochloric acid to the potassium hydrosulphide solution, a reddish precipitate fell which was dried upon a small filter. The paper was cut up and mixed with sodium carbonate and nitrate, and gradually added to fused sodium nitrate. The filtered aqueous solution of the smelt, after being neutralised with nitric acid, the carbon dioxide having been allowed to escape, was precipitated by mercurous nitrate, and the precipitate after some hours was collected, washed with solution of mercurous nitrate, dried, and ignited in a porcelain boat in a current of hydrogen.

The resulting $MoO_2$ weighed 0·003 gram=0·016 per cent. $MoO_3$.

$P_2O_5$.—After removal of hydrogen sulphide by evaporation from a portion of the solution which had been treated with that reagent, and corresponding to 1·7 gram deposit, excess of ammonia was added, then nitric acid in excess and some ammonium molybdate. The resulting precipitate, after many

hours, was collected and treated with ammonia and magnesium mixture in the usual manner. The magnesium pyrophosphate obtained only weighed 0·0026 gram. = 0·01 per cent.

CoO.—To a portion of solution corresponding to 3·247 grams of dry mud, ammonium chloride, ammonia, and slightly yellow ammonium hydrosulphide were added in sufficient excess. After standing for twenty-four hours, the clear yellowish fluid was filtered off, and the precipitate rapidly washed with water containing a little ammonium hydrosulphide. In this precipitate the iron, aluminium, cobalt, and zinc were determined.

To isolate the cobalt, the precipitate was diffused through very dilute hydrochloric acid, and the mixture saturated with hydrogen sulphide. After filtering out the cobalt sulphide, the solution was reprecipitated by ammonia and ammonium hydrosulphide, and the precipitate again treated with dilute acid. The insoluble residue was digested with aqua regia (a minute portion, 0·002 gram, of barium sulphate was found here and estimated), evaporated to dryness in a porcelain dish, then boiled with slight excess of potash in a platinum vessel, and the well-washed precipitate was strongly ignited. Its weight was 0·0103 gram, corresponding to 0·30 per cent. CoO. The traces of $Fe_2O_3$ and alkali in this precipitate were not determined.

$Fe_2O_3$ and $Al_2O_3$.—The filtrate from the cobalt sulphide was boiled with a little nitric acid, filtered, nearly neutralised with sodium carbonate, and the mixed ferric oxide and alumina were thrown down by ebullition with excess of $NaC_2H_3O_2$ solution. The slightly washed precipitate was redissolved, reprecipitated, ignited, and weighed. The oxides, of which only a trace consisted of alumina, weighed 0·0440 gram = 1·36 per cent.

ZnO.—The filtrates from the iron precipitate, acidulated further with acetic acid and saturated with hydrogen sulphide, gave a nearly white precipitate of ZnS, which was collected, and dissolved in dilute hydrochloric acid; the solution was

mixed with a slight excess first of sodium carbonate, then of acetic acid, and the zinc sulphide was reprecipitated. When converted into zinc oxide by strong ignition in an open crucible, it weighed 0·0150 gram=0·462 per cent.

MnO.—On account of accidental loss of some of the solution, the manganous oxide had to be determined from a fresh portion of the deposit, after removal of the oxides of lead, copper, cobalt, and zinc, and of the ferric oxide, alumina, baryta, lime, and magnesia. The manganese was precipitated by ammonia and ammonium hydrosulphide, washed, dried, and ignited in a current of hydrogen. From 0·9061 gram deposit, 0·7316 gram manganous sulphide was obtained, corresponding to 66·19 per cent. MnO, or 71·11 per cent. $Mn_3O_4$. From estimation of $MnO_2$ the amount of oxygen united with the manganese over and above that required to form MnO is found to be 14·13 per cent., or 9·21 per cent. more than would convert the whole into $Mn_3O_4$.

Water of Hydration.—Found by deducting from the total loss upon ignition, the amount of $CO_2$ and O which would be driven off—

$$16{\cdot}38-(9{\cdot}21+3{\cdot}24)=3{\cdot}93 \text{ per cent.}$$

BaO.—The solution obtained by filtering off the precipitate produced by the addition of ammonium sulphide to the original solution was boiled with hydrochloric acid, filtered, rendered slightly alkaline with ammonia, and the calcium, barium, and trace of strontium thrown down by addition of ammonium oxalate to the hot solution. After reprecipitation and intense ignition, the mixed oxides weighed 0·1969 gram.

This residue, after treatment with nitric acid and evaporation to dryness, was digested with absolute alcohol. After twenty-four hours, the thick liquid was filtered off and the residue washed with more alcohol, then dissolved in water, evaporated to dryness in a platinum dish, and weighed. Its weight was 0·0416 gram, corresponding to 0·788 per cent. BaO (corrected for $BaSO_4$ found in CoS precipitate).

CaO.—Deducting the amount of BaO corresponding to 0·416 gram $Ba(NO_3)_2$, we have 0·1725 gram. CaO=5·31 per cent.

MgO.—The filtrate from the calcium and barium precipitates was evaporated to dryness, gently ignited, and the magnesia determined after reprecipitation as $Mg_2P_2O_7$. This salt weighed 0·2864 gram=3·178 per cent. MgO.

The results of the analysis are tabulated below, expressed to the nearest second decimal :—

| | |
|---|---|
| $Mn_3O_4$ | 71·11 |
| O | 9·21 |
| $BaSO_4$ and other matters insoluble in HCl | 1·08 |
| PbO | 0·15 |
| CuO | 0·07 |
| $MoO_3$ | 0·02 |
| CoO | 0·30 |
| $Fe_2O_3 + Al_2O_3$ | 1·36 |
| ZnO | 0·46 |
| BaO | 0·79 |
| CaO | 5·31 |
| SrO | a trace |
| MgO | 3·18 |
| $CO_2$ | 3·23 |
| $P_2O_5$ | 0·01 |
| $H_2O$ | 3·93 |
| | 100·21 |

It will be noticed that this deposit corresponds closely in composition with that of many samples of psilomelane, and wad or bog manganese.

# CHAPTER XVI

## TABLES OF ANALYSES OF WATERS FROM VARIOUS GEOLOGICAL SOURCES

As I have previously stated, the ordinary sanitary analyses give very little information of value with reference to the saline constituents of waters from different sources. The more complete analysis, which includes the estimation of the more important acids and bases, or anions and cations, not only is of value for sanitary purposes and for determining whether waters are suitable for special manufacturing purposes, but must ultimately assist in the elucidation of many problems of considerable geological importance, especially those connected with the flow and distribution of underground waters.

A discussion of these questions is beyond the scope of this volume, but a few examples of analyses of waters from the most important water-bearing strata are given here, as they will probably be useful, and may lead to others recording analyses from other strata. I have had some difficulty in their selection, but the following notes will in most cases suffice to explain why each was selected.

Unless otherwise stated, the waters were hygienically of good quality. Most of them, in fact, are either public supplies or used in large establishments. With reference to nearly all I have reliable information concerning the geological source, the depth of well, water level, &c. &c., which it is unnecessary to reproduce here.

Nos. 1–15.—These are typical of the waters from the deep chalk in the London Basin. They are distinctly alkaline,

i.e. when evaporated to a low bulk in a platinum dish they turn litmus paper blue, and phenol-phthalein red, and a very small quantity of insoluble carbonate is deposited in the dish. The chlorine variation is very great, but the figure is almost invariably high. Low chlorides are often associated with low sulphates, but a large amount of chloride does not necessarily imply an excess of sulphates. In some there is a suspicion of an admixture of sea water—in No. 1 for example—yet this well is miles from the sea, and if there is any connection it must be due to the chalk outcropping under the sea. No. 8 is from a well still further from the sea, and the water level in the well being far above the sea level, the direction of flow should be from the well towards the sea.

I have recently found similar waters in the Lincolnshire limestone and elsewhere (*vide* Nos. 88, 98, 99, and 105).

Analyses Nos. 16 to 30 are of waters derived from the chalk where it is either exposed or only covered with permeable deposits. None of these are of an alkaline character. As a rule the amount of magnesium present is very trifling; in the only instance in which it exceeds ·5 the excess of chlorine leads to a suspicion of the presence of sea water, and the analysis No. 22, Table D, corresponds to that of a mixture of chalk water with tidal water. The variation in the amount of nitrates present is very considerable. Two of them contained sufficient potassium to be worth estimating. Tables E and F include 15 samples of chalk water, most of which show some peculiarity. They are introduced to show to what extent chalk waters vary.

Nos. 31 and 32 are from the deep chalk at Romford. Although these waters are derived from the deep chalk in the London Basin, they are not alkaline, but they contain a considerable quantity of magnesium salts.

No. 33.—The well yielding this water is about one mile from the Thames. Twenty or thirty years ago the water only contained about 2 parts of chlorine per 100,000. The infiltration of Thames water has entirely altered its character. The

nitrates are derived from the well-manured land in the vicinity.

No. 34.—This is a water of curious character derived from the chalk near its outcrop. It is probably a mixture of chalk water with some magnesia water derived from the beds just overlying the chalk. *Vide* analyses 55, 58, and 59. 35 and 37 are chiefly of interest on account of the iron they contain. When freshly drawn the water is quite clear, but after standing a very short time an oxycarbonate of iron is deposited. Such waters are not uncommon from the Greensand formation.

Nos. 36 and 38 are chalk waters from the Lea valley. They bear a superficial resemblance to the water from the deep chalk at Romford, and it has been suggested that the deep chalk may be fed from the Lea valley. If so, the quantity must be very small. A careful study of the saline constituents does not support this view.

No. 37.—Compare with No. 10. The wells are within a short distance of one another, yet the types are totally different.

Nos. 39 and 40.—From the same well at different periods.

The increase in the chlorine and magnesium shows that tidal water is reaching this well. This was due to continuous pumping lowering the water level.

No. 41.—This water from Berkshire resembles the Lea valley water.

No. 42.—The well yielding this water was bored to a depth of 1,000 feet into the greensand underlying the chalk. The yield was not increased thereby. The source is undoubtedly superficial, as indicated by the large quantity of nitrates.

No. 43.—A recently sunk well yielding a water containing much sulphates in proportion to the chlorides.

No. 44.—Though this source is near a tidal river, the chalk is covered with London clay, and water was not obtained until the chalk had been penetrated to a considerable depth below the river level. It is certainly impregnated with sea water, but where or how it gains access is not known.

No. 45.—The well yielding this water is only 250 yards from a

tidal river, and it may be affected thereby, but such an effect was not anticipated when the boring was recently made.

Nos. 46, 47, 48, 49, 51, 53, 54.—These are typical of the waters obtained from the Thanet sands, and are identical with the water found in the chalk beneath. There is no impermeable stratum between the sands and chalk. Compare with analyses 2, 3, 6, &c.

No. 50.—The well yielding this water is near the outcrop of the sands and chalk. The sands here are very ferruginous.

No. 52.—The boring is said to be 100 feet deep, and many such wells still overflow supplying cisterns 3 or 4 feet above the ground. Other borings on the same fen yield a water of an entirely different character (*vide* 59), and do not overflow.

Nos. 55, 57, 58, 59.—These waters are probably derived from the Woolwich and Reading beds or in part from the London clay. This clay near the surface is often found to contain numerous laminæ of crystals of calcium sulphate, and probably at a greater depth magnesium sulphate may be associated therewith. Such waters are obtained from beneath the London clay in many parts of Essex and occasionally in somewhat large quantities. The Hockley Spa water is of this character.

In well-sinking the water from these beds is usually shut out.

The residues from these waters dried at 180° C. still retain much water.

No. 56.—From the examination of this water I certified that subsoil water must be gaining access to the well. When opened it was found that such water was entering freely at a depth of about 14 feet. There was a churchyard on the other side of the road.

No. 59.—*Vide* 52. Bulphan Fen is 4 or 5 miles north of the Thames. The chalk outcrops just beyond at Grays, and river water undoubtedly gains access to the chalk there. This, however, does not explain the composition of the saline constituents.

No. 60.—From the same well as sample 47. Here, again,

my opinion that the well was being affected by subsoil water proved to be correct.

No. 61.—This surface water contained much peaty matter.

No. 62.—This water contained a little vegetable matter, but was not discoloured.

No. 63.—Water from shallow well in river gravel.

Nos. 64, 69.—Two very hard gravel waters which markedly attacked the zinc lining of galvanised iron pipes and cisterns.

Both were piped from springs through such pipes to houses some distance away.

Nos. 65, 66.—Gravel waters of good quality.

Nos. 67, 68.—Note the enormous quantity of nitrates in these waters. No. 67 is from a public pump in the village street and supplies many houses. No. 68 is from a well in a garden. No illness has been attributed to the use of either, yet they are concentrated sewage effluents.

No. 70.—A very pure water from a ferruginous gravel.

No. 71.—Note the high chlorides. Well on very elevated ground, many miles from the sea.

No. 72.—Many boulder clay waters in Essex contain sulphuretted hydrogen, some in very appreciable quantity. This is a typical sample.

Nos. 73, 74.—From wells sunk in the Thames Marshes. Water useless for any purpose.

No. 75.—Water from Coralline Crag near the sea.

No. 76.—Spring at base of Barton beds, on the shore near Bournemouth.

No. 77.—From the Ashdown sands where overlaid by about 50 feet of Wadhurst clay.

No. 78.—In boring the well this water entered from the base of the Hythe beds at a depth of 168 feet from the ground surface.

No. 79.—River Lea water as taken by the East London Water Company.

No. 80.—From a stream in a magnesian limestone district.

No. 81.—River Dee, near intake of Chester Water Company.

No. 82.—This river flows through an agricultural district and is fed chiefly by surface water from cultivated lands.

No. 83.—Thames water as supplied by a London company.

No. 84.—Thames water taken near Windsor.

No. 85.—Lincolnshire limestone area. River Welland.

No. 86.—Thames water. Some miles below the outfall from the London sewage works. Contains about 50 per cent. of sea water.

This analysis was made in connection with an investigation on the effect of pumping from the chalk wells near the river.

No. 87.—From the open sea opposite Clacton. For the analyses of Nos. 86, 87, 100 c.c. of each water were diluted to 1 litre.

No. 88.—This is an alkaline water resembling those from the deep chalk in the London basin. Bored through the Weald clay into the Hastings bed.

No. 89.—Water from between the London clay and chalk.

No. 90.—Lower Greensand water. Clear when first drawn. Rapidly became turbid from deposition of oxycarbonate of iron.

No. 91.—Water from same well as 90, but oxidised and filtered to remove the iron.

No. 92.—From a Kent water company's well.

No. 93.—An overflowing well bored to Lower Greensand.

No. 94.—Spring water from Lower Greensand on north side of Hog's Back.

No. 95.—From one of the Kent company's wells.

No. 96.—From the Folkestone beds of Lower Greensand.

No. 97.—From the Hythe beds of Lower Greensand. Ferruginous.

No. 98.—Alkaline water from Lincolnshire limestone. Ferruginous.

No. 99.—Alkaline water from Lincolnshire limestone. Ferruginous.

No. 100.—Lincolnshire limestone. Calcareous.

No. 101.—Lincolnshire limestone. Spring. Calcareous.

No. 102.—Lincolnshire limestone. Alkaline.

No. 103.—Lincolnshire limestone. Peterborough water supply. Alkaline.

No. 104.—Lincolnshire limestone. Calcareous.

No. 105.—Lincolnshire limestone. Alkaline.

No. 106.—Said to come from Great Oolite, but well is sunk into Lincolnshire limestone.

No. 107.—Lincolnshire marlstone.

No. 108.—From Northampton sands below Lincolnshire limestone.

No. 109.—Deep well in new Red Sandstone.

No. 110.—From headings driven in marl and sandstone (Permian marl) lying on magnesian limestone.

No. 111.—Deep well in Keuper sandstone, near Bristol.

No. 112.—From a colliery near Bury.

No. 113.—From a colliery near Wolverhampton, yielding 2,000,000 gallons per day.

No. 114.—Deep well in millstone grit.

No. 115.—Boring passed through three beds of coal and three of fireclay. Water struck at 870 feet. Boring continued to 1,800 feet, but no increase in yield of water.

No. 116.—'Grand' Spring, Malvern. In this water the total saline constituents amount to 27·55 per 100,000, whilst the total solids only weighed 27·1.

No. 117.—A public supply in Aberdeenshire, from primary rocks. Acts powerfully on iron pipes, boilers, &c.

A further series of partial or sanitary analyses are given, taken from Professor Thorpe's report to the Water Examiner for the Metropolis, for the year 1902. These show the nature of the examination to which the waters supplying London are submitted, the extent to which they vary according to the sources from which they are derived, the season, &c. The relation of the organic carbon to the organic nitrogen, and of both to the albuminoid ammonia, and the oxygen absorbed, shows that when the two latter estimations are made the two former are quite unnecessary.

## SPECIMEN OF THE FORM USED BY THE AUTHOR IN RECORDING THE RESULTS OF THE ANALYSIS OF A POTABLE WATER

### Data

Respecting a sample of Water from .....

Labelled : .....

Particulars of Source : .....

### PHYSICAL EXAMINATION

Turbidity : .....

Colour : ..... Odour : .....

### CHEMICAL EXAMINATION

| Determinations | Results in | |
|---|---|---|
| | Grains per Gallon | Parts per 100,000 |
| Total Solid Matter dried at ..... | ..... | ..... |
| Chlorine ..... | ..... | ..... |
| Equivalent to Chlorides (60 p.c. Cl.) : ..... | ..... | ..... |
| Nitric Nitrogen : ..... | ..... | ..... |
| Equivalent to Nitrates (17 p.c. N.) : ..... | ..... | ..... |
| Nitrites ..... | ..... | ..... |
| Hardness<br>Permanent ..... ; Temporary ..... ; Total ..... | ..... | ..... |
| Lead, Copper, Zinc, Iron : ..... | ..... | ..... |
| Free Ammonia ..... | ..... | ..... |
| Organic Ammonia : ..... | ..... | ..... |
| Oxygen absorbed at ..... in ..... hours ..... | ..... | ..... |

.....

.....

## TABLE A

## WATER FROM DEEP WELLS IN THE CHALK

THE CHALK BEING COVERED BY THE THANET SANDS, WOOLWICH AND READING BEDS AND LONDON CLAY

| No. | Source | Depth of well in feet | Ions estimated. All in parts per 100,000. | | | | | | | | | Total solids, dried at 180° C. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | K | Na | $NH_4$ | $CO_3$ | $SO_4$ | Cl | $NO_3$ | |
| 1 | Thorpe, Essex . . | 440 | 3·8 | 1·2 | — | — | ·1 | 18·0 | 19·9 | 76·6 | ·3 | 187·0 |
| 2 | Near Southend ,, . . | 650 | ·75 | ·4 | — | — | ·05 | 15·3 | 5·8 | 32·1 | ·2 | 90·0 |
| 3 | Chelmsford ,, . . | 568 | ·6 | ·5 | — | — | ·0 | 20·6 | 8·4 | 32·8 | ·1 | 102·0 |
| 4 | Colchester ,, . . | 379 | 2·7 | 1·7 | — | — | ·1 | 17·8 | 7·5 | 31·4 | ·05 | 93·0 |
| 5 | Near Colchester ,, . . | 410 | 1·0 | 1·3 | — | — | ·1 | 21·0 | 9·8 | 41.6 | ·4 | 119·0 |
| 6 | Vange ,, . . | 793 | ·8 | ·36 | — | — | ·05 | 16·5 | 7·2 | 18·6 | ·2 | 72·0 |
| 7 | Barking ,, . . | 320 | 2·2 | ·8 | — | — | ·0 | 15·0 | 6·2 | 5·45 | ·75 | 48·2 |
| 8 | Tiptree ,, . . | 601 | ·925 | ·8 | — | — | ·0 | 26·6 | 17·8 | 58·9 | ·3 | 171·0 |
| 9 | Brentwood ,, . . | 709 | ·6 | ·3 | — | — | ·0 | 17·6 | 9·2 | 12·3 | ·2 | 65·5 |
| 10 | Braintree ,, . . | 331 | 1·9 | 1·45 | — | — | ·08 | 17·2 | 7·8 | 41·8 | ·1 | 109·5 |
| 11 | Burnham ,, . . | abt. 300 | ·6 | ·4 | — | — | ·0 | 22·3 | 8·5 | 38·6 | ·15 | 116·5 |
| 12 | Lambeth . . . . | 410 | 5·1 | 2·25 | — | — | ·06 | 17·4 | 7·5 | 8·7 | ·2 | 54·0 |
| 13 | Shepherd's Bush . . . | ? | 2·0 | 1·0 | — | — | ·00 | 17·7 | 16·3 | 13·7 | ·05 | 77·4 |
| 14 | Bunhill Row . . . . | 250 | 1·75 | 1·0 | — | — | ·04 | 15·3 | 13·6 | 9·7 | ·2 | 63·0 |
| 15 | Herne Bay . . . . | — | 1·35 | 1·0 | 5·4 | 35·4 | ·0 | 17·5 | 28·25 | 23·3 | ·1 | 114·0 |

## Table B

### CHALK WELLS REFERRED TO IN TABLE A

Saline Constituents in Parts per 100,000

| — | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . | 9·5 | 1·9 | 1·5 | 6·75 | 2·5 | 2·0 | 5·5 | 2·3 | 1·5 | 4·75 | 1·5 | 12·75 | 5·0 | 4·35 | 3·35 |
| Magnesium „ . | 4·2 | 1·4 | 1·75 | 5·95 | 4·55 | 1·25 | 2·7 | 2·8 | 1·05 | 5·1 | 1·4 | 7·85 | 3·5 | 3·5 | 3·5 |
| Sodium „ . | 16·4 | 23·3 | 32·6 | 16·8 | 28·7 | 25·4 | 17·3 | 40·95 | 28·15 | 18·9 | 36·1 | 6·9 | 21·6 | 18·0 | 23·0 |
| „ Sulphate . . | 29·45 | 8·6 | 12·45 | 11·1 | 14·5 | 10·65 | 11·8 | 26·35 | 13·6 | 11·5 | 12·6 | 11·1 | 24·1 | 20·1 | 41·75 |
| „ Chloride . | 126·4 | 52·95 | 54·1 | 51·8 | 68·65 | 30·7 | 9·0 | 97·2 | 20·3 | 68·3 | 63·7 | 14·35 | 22·6 | 16·0 | 30·2 |
| „ Nitrate . | ·4 | ·25 | — | — | ·55 | ·25 | 1·0 | ·4 | ·3 | ·15 | ·2 | ·3 | — | ·25 | KCl10·3 |
| Silica, &c. . . . | ·65 | 1·60 | — | ·6 | ·55 | 1·75 | ·9 | 1·0 | ·6 | ·8 | 1·0 | ·75 | ·6 | ·80 | 1·9 |
| Total Solids | 187·0 | 90·0 | 102· | 93· | 120· | 72·0 | 48·2 | 171· | 65·5 | 109·5 | 116·5 | 54·0 | 77·4 | 63·0 | 114·0 |

## Table C

## WATER FROM WELLS IN SUPERFICIAL CHALK OR CHALK COVERED WITH PERMEABLE DEPOSITS

| No. | Source | Depth of well in feet | Ions estimated in parts per 100,000 | | | | | | | | | Total solids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | K | Na | $NH_4$ | $CO_3$ | $SO_4$ | Cl | $NO_3$ | |
| 16 | Rochester | 130 | 10·7 | ·4 | — | — | ·0 | 15·0 | 3·2 | 3·8 | 2·2 | 42·5 |
| 17 | Ely | 74 | 9 75 | ·15 | — | — | ·0 | 11·2 | 1·5 | 2·1 | 2·1 | 30·0 |
| 18 | Linton | 120 | 11·6 | ·5 | — | — | ·0 | 16·6 | 3·3 | 1·9 | 1·5 | 39·0 |
| 19 | Warminster | 250 | 9·2 | ·0 | — | — | ·0 | 11·4 | ·8 | 1·0 | 2·2 | 26·5 |
| 20 | Eye | 156 | 15·4 | ·4 | — | — | ·0 | 19·2 | 6·7 | 3·6 | ·5 | 50·5 |
| 21 | Norwich | 90 | 8·35 | ·25 | — | — | ·0 | 8·6 | 3·0 | 2·8 | 4·4 | 31·0 |
| 22 | Ramsgate | 120+ | 13·3 | 1·25 | — | — | ·0 | 14·8 | 3·3 | 17·4 | 4·2 | 63·5 |
| 23 | Luton | 340 | 10·0 | ·15 | — | — | ·0 | 12·2 | 1·3 | 1·3 | 3·1 | 30·0 |
| 24 | Eastbourne | 100+ | 8·6 | ·3 | — | — | ·0 | 11·3 | ·4 | 3·8 | 1·8 | 29·0 |
| 25 | Portsmouth | Springs | 9·45 | ·2 | — | — | ·0 | 12·5 | ·5 | 1·55 | 1·95 | 27·5 |
| 26 | Brighton | 60+ | 7·8 | ·15 | — | — | ·0 | 9·6 | 1·7 | 2·0 | 1·65 | 25·0 |
| 27 | Dover | 194+ | 9·7 | ·2 | — | — | ·0 | 12·3 | ·8 | 2·4 | 2·0 | 30·5 |
| 28 | Winchester | 156+ | 9·5 | ·3 | — | — | ·0 | 11·7 | ·65 | 1·7 | 4·45 | 29·5 |
| 29 | Sutton | 200 | 12·4 | ·45 | ·9 | 1·1 | ·0 | 14·3 | 2·2 | 2·75 | 8·0 | 44·5 |
| 30 | Watford | 150 | 12·5 | ·3 | ·1 | ·9 | ·0 | 15·2 | 2·4 | 2·3 | 4·4 | 39·5 |

## TABLE D

## WATERS FROM WELLS IN SUPERFICIAL CHALK, OR CHALK COVERED WITH PERMEABLE DEPOSITS

PROBABLE SALINE CONSTITUENTS

| — | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium carbonate . . | 25·0 | 18·7 | 27·7 | 19·0 | 32·0 | 14·3 | 24·7 | 20·3 | 18·8 | 20·8 | 16·0 | 20·5 | 19·5 | 23·7 | 25·3 |
| „ sulphate . . | 2·4 | 2·1 | 1·8 | 1·1 | 8·85 | 4·25 | 4·7 | 1·85 | ·55 | ·7 | 2·4 | 1·15 | ·9 | 3·1 | 3·4 |
| „ chloride . . | — | 2·6 | — | 1·6 | — | — | 1·80 | ·95 | ·9 | ·85 | ·55 | 1·4 | — | — | — |
| „ nitrate . . | — | 2·8 | — | 2·9 | — | 5·8 | 5·55 | 4·1 | 2·4 | 2·55 | 2·15 | 2·65 | 5·9 | 8·2 | 5·8 |
| Magnesium sulphate . | 1·9 | — | 2·5 | — | ·55 | — | — | — | — | — | — | — | — | — | — |
| „ chloride . | — | ·6 | — | — | 1·2 | 1·0 | 4·95 | — | 1·2 | ·8 | ·6 | ·8 | 1·2 | 1·8 | 1·2 |
| Sodium chloride . . | 6·3 | — | 3·1 | — | 4·45 | 3·4 | 20·7 | 1·15 | 3·85 | ·75 | 2·0 | 1·5 | 1·3 | 2·25 | 2·3 |
| „ nitrate . . | 3·0 | — | 2·0 | — | ·7 | — | — | — | — | — | — | — | — | $KNO_3$ 2·9 | — |
| Silica, &c. . . . | 3·9 | 3·2 | 1·5 | 1·9 | 2·75 | 2·25 | 1·1 | 1·65 | 1·3 | 1·05 | 1·3 | 2·5 | ·7 | 2·55 | 1·5 |
| Total solids . . | 42·5 | 30·0 | 39·0 | 26·5 | 50·5 | 31·0 | 63·5 | 30·0 | 29·0 | 27·5 | 25·0 | 30·5 | 29·5 | 44·5 | 39·5 |

## TABLE E

## CHALK WATERS OF VARIOUS CHARACTERS

| No. | Source | Depth of well in feet | Ions per 100,000 parts | | | | | | | | | | Total solids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | K | Na | — | $CO_3$ | $SO_4$ | Cl | $NO_3$ | — | |
| 31 | Romford | 266 | 5·8 | 4·1 | — | — | — | 16·8 | 8·5 | 6·1 | ·0 | — | 47·6 |
| 32 | „ | 450 | 6·25 | 3·5 | — | — | — | 17·2 | 10·9 | 8·2 | ·3 | — | 57·0 |
| 33 | Grays | 30 | 16·3 | 2·9 | 7·2 | 18·7 | — | 14·3 | 9·7 | 42·3 | 11·3 | $PO_4$ trace | 124·0 |
| 34 | Orsett | 84 | 9·1 | 3·7 | — | — | — | 10·8 | 31·3 | 3·9 | 7·8 | — | 81·0 |
| 35 | Newport | 132 | 13·1 | ·6 | — | — | $Fe_2O_3$ 1·3 | 18·75 | 2·7 | 1·5 | ·25 | $SiO_2$ ·8 | 42·0 |
| 36 | Lea Valley | 206 | 5·05 | 1·3 | — | — | — | 10·8 | 3·5 | 2·3 | ·0 | — | 26·0 |
| 37 | Bocking | 271 | 8·1 | 3·6 | — | — | $Al_2O_3$ 1·3<br>$Fe_2O_3$ ·25 | 19·2 | 7·8 | 12·0 | ·10 | — | 63·0 |
| 38 | Lea Valley | 451 | 6·4 | 1·6 | — | — | — | 11·8 | 2·9 | 2·2 | ·08 | — | 27·0 |
| 39 | Near Portsmouth | 300 | 6·6 | 1·3 | — | — | — | 12·4 | 7·4 | 32·0 | ·3 | — | 87·0 |
| 40 | „ | 300 | 7·8 | 3·7 | — | — | — | 14·8 | 7·6 | 42·4 | ·3 | — | 105·0 |
| 41 | Aldermaston | 193 | 8·7 | 1·15 | — | — | $Al_2O_3$ 1·5 | 15·6 | 1·6 | 1·7 | ·15 | — | 32·5 |
| 42 | S. Walden | 160 | 14·7 | ·6 | — | — | — | 15·6 | 5·4 | 3·9 | 9·7 | — | 53·3 |
| 43 | Stoke | 140 | 15·15 | 2·3 | — | — | — | 16·9 | 15·5 | 1·85 | 2·0 | — | 57·0 |
| 44 | Shotley | 148 | 24·9 | 16·5 | — | — | $Fe_2O_3$ t. | 15·2 | 25·0 | 293·0 | ·35 | — | 530·0 |
| 45 | Woodbridge | 250 | 20·75 | 1·7 | — | — | — | 17·8 | 16·55 | 11·2 | 10·5 | — | 87·1 |

## TABLE F

## CHALK WATERS OF VARIOUS CHARACTERS

PROBABLE SALINE CONSTITUENTS IN PARTS PER 100,000

| — | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium carbonate . . | 14·5 | 15 65 | 23·8 | 18·0 | 31·25 | 12·65 | 20·25 | 16·0 | 16·5 | 19·5 | 21·75 | 26·0 | 28·2 | 25·3 | 29·7 |
| „ sulphate . . | — | — | 13·75 | 6·45 | 2·05 | — | — | — | — | — | — | 7·65 | 13·1 | 35·4 | 23·45 |
| „ chloride . . | — | — | — | — | — | — | — | — | — | — | — | 5·65 | — | 12·2 | 5·4 |
| „ nitrate . . | — | — | 11·25 | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium carbonate . | 11·3 | 10·9 | — | — | — | 4·5 | 9·65 | 3·1 | 3·5 | 4·35 | 3·7 | — | — | — | — |
| „ sulphate . | 4·5 | 2·0 | — | 18·5 | 1·55 | — | 4·25 | 2·5 | 1·5 | 9·5 | — | — | 7·8 | — | — |
| „ chloride . | — | — | 11·45 | — | 1·2 | — | — | — | — | 2·15 | — | ·4 | 2·5 | 65·2 | 6·7 |
| Potassium chloride . | — | — | 10·55 | — | — | — | — | — | — | — | — | — | — | — | — |
| „ nitrate . . | — | — | 4·55 | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium sulphate . . | 7·25 | 13·75 | — | 17·7 | — | 5·2 | 6·5 | — | 9·2 | — | 2·4 | — | — | — | — |
| „ chloride . . | 10·05 | 13·5 | 47·3 | 6·45 | 1·0 | 3·65 | 19·8 | 3·6 | 52·8 | 67·3 | 2·8 | — | — | 390·2 | 4·55 |
| „ nitrate . . | — | ·4 | — | 10·7 | ·3 | — | — | — | ·4 | ·4 | ·2 | Mg / Na 12·8 | 2·7 | ·5 | 15·5 |
| Silica, &c. . . . | — | ·80 | 1·35 | 3·2 | 4·65 | — | 2·55 | 1·8 | 3·1 | 1·8 | 1·65 | ·8 | 2·7 | 1·2 | 1·8 |
| | 47·6 | 57· | 124·0 | 81· | 42·0 | 26·0 | 63·0 | 27·0 | 87·0 | 105·0 | 32·5 | 53·3 | 57·0 | 530·0 | 87·1 |

## TABLE G

### WATERS FROM TERTIARY BEDS BETWEEN THE LONDON CLAY AND CHALK

| No. | Source | Depth of well in feet | Ions in parts per 100,000 | | | | | | | | | Total solids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | K | Na | — | $CO_3$ | $SO_4$ | Cl | $NO_3$ | |
| 46 | Steeple | 300? | 1·8 | ·7 | — | — | $Al_2O_3$ 1·0 | 21·6 | 6·5 | 51·9 | ·4 | 136·0 |
| 47 | Maldon | 234 | ·7 | ·6 | — | — | — | 23·7 | 10·2 | 36·4 | ·3 | 119·0 |
| 48 | Chelmsford | 340 | ·15 | ·1 | — | — | — | 20·7 | 9·2 | 34·1 | ·0 | 107·5 |
| 49 | Laindon Hill | 336 | ·8 | ·45 | — | — | — | 18·0 | 12·4 | 15·5 | ·1 | 77·0 |
| 50 | Stanford-le-Hope | ? | 6·25 | 2·2 | — | — | Fe 1·26 | 11·2 | 11·1 | 4·0 | ·04 | 43·5 |
| 51 | Shoeburyness | 475 | 1·6 | ·25 | — | — | „ t. | 16·6 | 7·0 | 33·5 | ·0 | 95·0 |
| 52 | Bulphan Fen | Overflows | 1·7 | ·9 | — | — | — | 15·8 | 9·6 | 4·9 | ·27 | 50·0 |
| 53 | Fambridge | 319 | ·65 | ·35 | — | — | — | 21·5 | 7·0 | 32·4 | ·5 | 102·5 |
| 54 | Margaretting | 451 | ·9 | ·1 | — | — | — | 20·4 | 13·6 | 23·8 | ·8 | 96·0 |
| 55 | Althorne | 300? | 36·2 | 24·4 | — | — | — | 13·8 | 161·0 | 54·7 | ·4 | 328·0 |
| 56 | Goldhanger | 120 | 3·6 | 1·3 | — | — | — | 21·0 | 6·3 | 57·2 | 4·3 | 147·0 |
| 57 | Mersea Island | 92 | 15·6 | 7·7 | — | — | — | 26·6 | 36·2 | 33·3 | ·15 | 157·3 |
| 58 | Margaretting | 214 | 27·6 | 16·3 | — | — | — | 22·6 | 102·2 | 46·8 | 6·5 | 262·0 |
| 59 | Bulphan Fen | 105 | 45·5 | 84·0 | — | — | — | 17·6 | 371·0 | 174·0 | 1·1 | 818·0 |
| 60 | Maldon | 234 | 6·1 | 1·8 | — | — | — | 20·3 | 12·8 | 43·3 | 3·5 | 130·5 |

## Table H

### WATERS FROM THE TERTIARY BEDS BETWEEN THE LONDON CLAY AND CHALK

Probable Saline Constituents in Parts per 100,000

| — | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium carbonate . . | 4·5 | 1·75 | ·35 | 2·0 | 15·65 | 4·0 | 4·25 | 1·65 | 2·25 | 23·0 | 9·0 | 39·0 | 37·7 | 29·3 | 15·25 |
| Magnesium „ . . | 2·45 | 2·1 | ·35 | 1·55 | ·75 | ·85 | 3·15 | 1·25 | ·35 | — | 4·5 | 4·55 | — | — | 6·3 |
| Sodium „ . . | 30·3 | 37·4 | 35·85 | 28·0 | — | 24·05 | 19·4 | 34·7 | 33·3 | — | 21·9 | — | — | — | 11·75 |
| „ sulphate . . | 9·6 | 15·0 | 13·6 | 18·35 | 4·6 | 10·35 | 14·2 | 10·35 | 20·1 | — | 9·3 | 15·7 | 10·5 | — | 18·95 |
| „ chloride . . | 85·6 | 60·0 | 56·6 | 25·6 | 6·6 | 55·3 | 8·1 | 53·45 | 39·3 | 90·1 | 94·4 | 54·9 | 68·2 | 231·0 | 71·45 |
| „ nitrate . . | ·55 | ·4 | ·00 | ·1 | ·1 | ·0 | ·4 | ·7 | ·7 | ·55 | 5·9 | ·2 | 8·6 | 1·5 | 4·8 |
| Magnesium sulphate . | — | — | — | — | 10·0 | — | — | — | — | 120·6 | — | 32·0 | 81·5 | 362·5 | — |
| Calcium „ . | — | — | — | — | — | — | — | — | — | 92·0 | — | — | 42·5 | 114·9 | — |
| Magnesium chloride . | — | — | — | — | — | — | — | — | — | — | — | — | — | 45·5 | — |
| Ferrous carbonate . . | — | — | — | — | 2·6 | — | — | — | — | — | — | — | — | — | — |
| Silica &c. . . . | 3·0 | 2·35 | ·75 | 1·4 | 3·2 | ·45 | ·5 | ·4 | — | 1·75 | 2·0 | 9·95 | 13·0 | 33·3 | 2·0 |
| Total solids . . | 136·0 | 119·0 | 107·5 | 77·0 | 43·5 | 95·0 | 50·0 | 102·5 | 96·0 | 328·0 | 147·0 | 157·3 | 262·0 | 818·0 | 130·5 |

## TABLE I

## SURFACE AND SHALLOW WELL WATERS

IONS IN PARTS PER 100,000

| No. | Source | Ca | Mg | Na | K | — | $CO_3$ | $SO_4$ | Cl | $NO_3$ | — | Total solids dried at 180°C. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 61 | Bury | 1·25 | ·55 | — | — | Fe *m.t.* | ·5 | 4·5 | 1·1 | ·25 | — | 12·4 | *Surface water* Millstone grit |
| 62 | Lancaster | ·55 | ·13 | — | — | — | ·3 | ·8 | ·8 | ·15 | — | 4·2 | ,, |
| 63 | Tonbridge | 8·7 | ·8 | — | — | — | 10·3 | 7·3 | 3·7 | 1·3 | — | 37·0 | Well in gravel |
| 64 | Copford | 12·3 | ·7 | — | — | Zn 1·1 | 18·3 | 4·6 | 3·2 | 1·0 | — | 45·7 | ,, |
| 65 | Clacton | 4·2 | 1·3 | — | — | — | 3·9 | 10·8 | 7·6 | 3·3 | — | 42·0 | ,, |
| 66 | Coggeshall | 12·3 | ·65 | — | — | — | 17·6 | 7·4 | 3·1 | 4·1 | — | 49·5 | ,, |
| 67 | Tollesbury | 14·8 | 3·0 | 12·0 | 8·8 | — | 8·4 | 26·5 | 16·2 | 26·4 | $PO_4$ trace | 120·3 | ,, |
| 68 | Broomfield | 35·5 | 3·0 | 12·3 | 2·25 | — | 12·3 | 38·5 | 15·4 | 56·0 | $PO_4$ trace | 180·0 | ,, |
| 69 | Wiggin | 16·65 | ·65 | — | — | Zn 2·2 | 26·7 | 4·8 | 7·4 | tr. | — | 66·0 | ,, |
| 70 | Somerset | 14·0 | ·6 | — | — | Fe tr. | 19·55 | 5·3 | 3·0 | tr. | — | 45·2 | ,, |
| 71 | South Hanningfield | 19·6 | 2·9 | — | — | — | 14·1 | 12·4 | 32·5 | 2·26 | — | 98·0 | London clay & sand |
| 72 | Gt. Waltham | 13·8 | 1·9 | — | — | — | 21·3 | 11·7 | 2·2 | ·9 | $H_2S$ tr. | 58·0 | Boulder clay |
| 73 | Yarrow | 30·6 | 16·8 | — | — | Fe 6·3 | 23·8 | 34·6 | 253· | tr. | — | 510·0 | Alluvium |
| 74 | East Ham | 35·4 | 11·0 | — | — | — | 42·0 | 39·0 | 112·0 | — | — | 326·0 | ,, |
| 75 | Aldeburgh | 12·3 | ·8 | — | 3·1 | — | 14·0 | 10·5 | 25·6 | 4·9 | — | 89·7 | Coralline crag |

## TABLE K

## SURFACE AND SHALLOW WELL WATERS

### PROBABLE SALINE CONSTITUENTS

| — | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium carbonate . . | ·8 | ·5 | 17·2 | 28·8 | 6·5 | 29·3 | 14·0 | 20·5 | 41·4 | 38·0 | 23·4 | 34·5 | 39·7 | 70·0 | 23·3 |
| „ sulphate . . | 3·2 | 1·15 | 5·8 | 2·6 | 5·4 | 2·05 | 31·3 | 54·5 | — | — | 17·6 | — | 49·0 | 25·2 | 10·2 |
| „ chloride . . | — | — | — | — | — | — | — | 24·1 | — | — | 14·1 | — | ·8 | — | — |
| „ nitrate . . . | — | — | — | — | — | — | — | 4·9 | — | — | — | — | — | — | — |
| Magnesium carbonate . | — | — | — | — | — | — | — | — | ·5 | 12·25 | — | ·85 | — | — | — |
| „ sulphate . . | 2·8 | — | 4·0 | 3·5 | 6·5 | 3·25 | 5·5 | — | 2·5 | — | — | 8·25 | — | 26·5 | 4·0 |
| „ chloride . . | — | ·51 | — | — | — | — | 7·5 | — | — | — | 11·5 | — | 66·5 | 22·7 | — |
| nitrate . . | — | — | — | — | — | — | — | 18·5 | — | — | — | — | — | — | — |
| Sodium sulphate . . | — | — | — | — | 2·7 | 5·0 | — | — | 5·1 | 79·9 | — | 7·55 | — | — | — |
| „ chloride . . | 1·8 | ·69 | 6·1 | 5·3 | 12·5 | 5·1 | 17·5 | — | 12·2 | 17·5 | 24·6 | 3·65 | 334·6 | 181·5 | 42·2 |
| „ nitrate . . . | ·35 | — | 1·7 | — | 5·4 | 5·6 | 17·0 | 45·5 | — | — | — | 1·25 | — | — | — |
| „ carbonate . . | — | — | — | — | — | — | — | — | — | 9·45 | — | — | — | — | — |
| Potassium nitrate . . | — | ·25 | — | 1·65 | — | — | 22·8 | 5·85 | — | — | 3·7 | — | — | — | 8·0 |
| | | | | $ZnCO_3$ 2·1 | | | | | $ZnCO_3$ 3·8 | | | | $FeCO_3$ 13·1 | | |
| &c. | 3·45 | 1·1 | 2·2 | 1·75 | 3·0 | — | 4·7 | 6·15 | ·5 | ·9 | 3·1 | 1·95 | 6·3 | ·5 | 2·0 |
| Total solids . . . | 12·4 | 4·2 | 37·0 | 45·7 | 42·0 | 49·5 | 120·3 | 180·0 | 66·0 | 158·0 | 98·0 | 58·0 | 510·0 | 326·4 | 89·7 |

## TABLE L

## WATERS FROM VARIOUS SOURCES

IONS IN PARTS PER 100,000

| No. | Source | Ca | Mg | Na | K | — | $CO_3$ | $SO_4$ | Cl | $NO_3$ | — | Total solids dried at 180° C. | Depth of well in feet | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 76 | Barton | 6·6 | ·4 | — | — | — | 9·5 | 3·1 | 3·9 | 1·0 | — | 29·5 | — | Spring in Barton sands |
| 77 | Etchingham | 3·15 | ·6 | — | — | Fe ·2 | 6·45 | 3·3 | 3·7 | ·6 | — | 22·1 | — | Hastings sands |
| 78 | Rogate | 1·0 | tr. | — | — | Fe min.tr. | ·5 | 1·5 | 1·5 | ·75 | — | 7·4 | — | ,, |
| 79 | Lee R. | 10·0 | ·45 | — | — | — | 12·9 | 5·1 | 2·1 | 1·65 | $PO_4$ tr. | 34·5 | — | Non-tidal river |
| 80 | Cheesden Brook | ·65 | ·30 | — | — | — | ·0 | 2·75 | 1·5 | ·7 | — | 8·0 | — | ,, |
| 81 | Dee R. | 3·4 | ·8 | — | — | — | 5·4 | 3·8 | 2·2 | ·07 | — | 18·5 | — | ,, |
| 82 | Blackwater R. | 10·7 | ·65 | — | — | — | 14·75 | 5·0 | 4·2 | 1·6 | — | 41·0 | — | ,, |
| 83 | Thames R. | 6·1 | ·4 | — | — | — | 9·2 | 1·8 | 1·8 | ·5 | — | 21·6 | — | ,, |
| 84 | Thames R. | 9·4 | ·4 | — | — | — | 11·9 | 2·8 | 4·7 | 3·8 | — | 38·0 | — | Near Windsor sewage works |
| 85 | Welland R. | 10·3 | 1·0 | — | — | — | 11·9 | 8·2 | 2·8 | ·9 | — | 37·0 | — | |
| 86 | Grays (Thames Estuary) | 27·5 | 65·0 | — | 21·5 | — | 9·8 | 154·0 | 978·0 | 1·8 | — | 1854·0 | — | *Tidal river* |
| 87 | Clacton | 42·5 | 136·5 | — | 41·0 | — | 5·0 | 269·0 | 1885·0 | — | — | 3570·0 | — | *Sea* |
| 88 | Stye Place | ·16 | ·04 | — | — | — | 37·2 | — | 15·1 | ·18 | — | 93·0 | 830 | *Hastings sands* |
| 89 | Southend | 4·7 | 3·5 | — | ·9 | — | 16·8 | 19·8 | 26 6 | ·5 | — | 102·0 | 500 | *Mixed Lower Tertiary and chalk* |
| 90 | Linslade | 10·35 | ·7 | ·55 | — | Fe min.tr. | 14·05 | 4·8 | 1·0 | ·3 | — | 34·0 | 148 | *Lower Greensand* |

## Table M

### PROBABLE SALINE CONSTITUENTS OF WATERS INCLUDED IN TABLE L

| — | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium carbonate . . | 15·8 | 7·9 | ·85 | 21·5 | — | 8·5 | 24·55 | 15·3 | 19·8 | 19·8 | 16·3 | 8·3 | ·4 | 11·75 | 23·4 |
| „ sulphate . . | 1·0 | — | 2·2 | 4·75 | 2·2 | — | 3·1 | — | 4·0 | 8·15 | 71·4 | 133·4 | — | — | 3·4 |
| „ chloride . . | — | — | — | — | — | — | — | — | ·8 | — | — | — | — | — | — |
| Magnesium carbonate . | — | 2·1 | — | — | — | ·42 | — | — | — | — | — | — | ·14 | 12·25 | — |
| „ sulphate . | 2·0 | — | — | 2·2 | 1·5 | 3·4 | 3·15 | 2·0 | — | 3·05 | 129·5 | 218·5 | — | — | 3·0 |
| „ chloride . | — | — | — | — | — | — | — | — | 1·6 | 1·6 | 154·8 | 366·6 | — | — | ·4 |
| Sodium carbonate . . | — | — | — | — | — | — | — | — | — | — | — | — | 65·2 | 1·75 | — |
| „ sulphate . . | 1·2 | 4·85 | — | — | — | 1·6 | ·45 | — | — | — | — | — | — | 27·7 | — |
| „ chloride . . | 6·45 | 6·1 | 2·5 | 3·45 | 2·5 | 3·6 | 6·9 | 3·0 | 4·95 | 2·65 | 1390·6 | 2597·1 | 24·9 | 43·9 | 1·15 |
| „ nitrate . . | 1·4 | ·8 | 1·0 | 2·1 | ·95 | — | 2·3 | ·7 | 5·3 | — | 2·5 | — | ·28 | ·7 | ·4 |
| Potassium sulphate . | — | — | — | — | — | — | — | — | — | — | — | — | — | 2·0 | — |
| „ chloride . | — | $FeCO_3$ ·4 | — | — | — | — | — | — | — | — | 41·0 | 78·2 | — | — | — |
| &c. . . . . | 1·65 | — | ·85 | ·5 | ·85 | 1·0 | ·55 | ·6 | 1·55 | 1·75 | 47·9 | 169·7 | 2·08 | 1·95 | 2·25 |
| Total solids . . | 29·5 | 22·1 | 7·4 | 34·5 | 8·0 | 18·5 | 41·0 | 21·6 | 38·0 | 37·0 | 1854·0 | 3570·0 | 93·0 | 102·0 | 34·0 |

## Table N

## WATERS FROM VARIOUS SOURCES

Ions in Parts per 100,000

| No. | Source | Ca | Mg | Na | K | — | $CO_3$ | $SO_4$ | Cl | $NO_3$ | Total solids dried at 180° C. | Depth of well in feet | — |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91 | Linslade (filtered) . | 10·1 | ·75 | — | — | Fe nil | 11·3 | 15·0 | 1·7 | ·25 | 43·5 | 148 | *Lower Greensand* |
| 92 | Mid-Kent . . . | 5·6 | ·5 | — | — | — | 9·6 | ·5 | 1·9 | ·25 | 21·5 | — | ,, |
| 93 | Shere . . . . | 4·2 | ·25 | — | — | — | 5·6 | 1·15 | 1·2 | ·9 | 15·5 | 75 | ,, |
| 94 | Wanboro . . . | 10·05 | ·2 | — | — | — | 12·6 | 1·7 | 2·2 | 5·9 | 34·8 | — | ,, |
| 95 | Kent Water Co. . . | 9·65 | ·2 | — | — | — | 13·5 | ·8 | 1·4 | 2·2 | 29·0 | — | ,, |
| 96 | Saltwood . . . | 4·95 | ·3 | — | — | Fe trace | 4·5 | 3·7 | 2·65 | 4·3 | 25·1 | 45 | ,, |
| 97 | Petersfield . . . | 5·6 | ·7 | — | — | Fe ·2 | 10·2 | 3·0 | 1·6 | ·09 | 24·0 | 736 | ,, |
| 98 | Crowland . . . | 2·2 | ·9 | — | — | Fe ·15 | 34·5 | 11·0 | 148·0 | ·45 | 323·5 | 603½ | *Lincs. Limestone* |
| 99 | Market Deeping . . | 3·45 | 1·0 | — | — | Fe nil | 19·2 | 5·9 | 13·6 | ·25 | 64·0 | 130 | ,, |
| 100 | Bourne . . . | 12·1 | 1·05 | — | — | — | 13·7 | 10·5 | 2·2 | ·34 | 41·5 | — | ,, |
| 101 | Stoke Park . . . | 9·2 | ·5 | — | — | — | 11·2 | 4·5 | 1·8 | 2·2 | 31·0 | — | ,, |
| 102 | Elton, Peterbro' . . | 8·1 | 1·0 | — | — | — | 17·5 | 7·0 | 5·4 | ·25 | 50·9 | 143 | ,, |
| 103 | Peterborough . . | 7·7 | ·495 | 1·32 | ·3 | — | 9·75 | 5·94 | 1·5 | ·06 | 27·68 | — | ,, |
| 104 | Thurlby . . . | 11·5 | ·7 | — | — | Fe less than ·1 | 14·4 | 8·5 | 2·4 | ·25 | 41·0 | 100·6 | ,, |
| 105 | St. James Deeping . | 3·25 | 1·05 | 25·5 | ·52 | — | 20·0 | 6·2 | 20·2 | ·25 | 78·5 | 120·0 | ,, |

## TABLE O

### PROBABLE SALINE CONSTITUENTS OF WATERS INCLUDED IN TABLE N

| | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium carbonate . | 18·8 | 14·0 | 9·3 | 21·0 | 22·5 | 7·5 | 14·0 | 5·5 | 8·65 | 22·8 | 18·7 | 20·25 | 13·087 | 24·0 | 8·15 |
| „ sulphate . | 8·85 | — | 1·65 | 2·4 | 1·15 | 5·25 | — | — | — | 10·2 | 5·8 | — | 8·42 | 6·45 | — |
| „ chloride . | — | — | — | 2·65 | ·8 | 1·1 | — | — | — | — | — | — | — | — | — |
| Magnesium carbonate | — | 1·7 | — | — | — | — | 2·4 | 3·15 | 3·5 | — | — | 3·5 | 1·73 | — | 3·65 |
| „ sulphate | 3·75 | — | — | — | — | — | — | — | — | 4·12 | ·5 | — | — | 3·5 | — |
| „ chloride | — | — | 1·0 | ·7 | ·8 | 1·2 | — | — | — | ·91 | 1·55 | — | — | — | — |
| Sodium carbonate . | — | — | — | — | — | — | — | 50·75 | 20·3 | — | — | 5·05 | ·746 | — | 22·1 |
| „ sulphate . | 8·5 | ·75 | — | — | — | — | 4·45 | 16·3 | 8·7 | — | — | 10·35 | — | 1·65 | 8·2 |
| „ chloride . | 2·8 | 3·15 | ·75 | — | ·5 | 1·75 | 2·65 | 244·2 | 22·45 | 2·49 | 1·05 | 8·9 | 2·47 | 3·95 | 33·3 |
| „ nitrate . | — | ·35 | 1·25 | 8·05 | 3·0 | 6·4 | — | — | — | — | 3·0 | ·35 | — | — | — |
| Potassium carbonate | — | — | — | — | — | — | — | — | — | — | — | — | ·54 | — | — |
| „ sulphate . | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 1·1 |
| — | — | — | — | — | — | — | $FeCO_3$ ·4 | $FeCO_3$ ·35 | — | — | — | — | $Fe_2O_3$ ·077 | — | — |
| &c. | ·8 | 1·55 | 1·55 | — | ·25 | 1·9 | ·1 | 3·25 | ·4 | ·98 | ·4 | 2·5 | ·518 | 1·45 | 2·0 |
| — | 43·5 | 21·5 | 15·5 | 34·8 | 29·0 | 25·1 | 24·0 | 323·5 | 64·0 | 41·5 | 31·0 | 50·9 | 27·588 | 41·0 | 78·5 |

## Table P

## WATERS FROM VARIOUS SOURCES

Ions in Parts per 100,000

| No. | Source | Ca | Mg | Na | K | — | $CO_3$ | $SO_4$ | Cl | $NO_3$ | Total solids dried at 180° C. | Depth of well in feet | — |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | *Lincs. Limestone* |
| 106 | Thurlby . . . | 10·5 | ·75 | — | — | — | 14·2 | 8·5 | 2·4 | ·12 | 40·5 | 100·6 | Oolite and cornbrash |
| 107 | Caythorpe Court . | 13·9 | 1·5 | — | — | Fe $O_3$ 1·5 | 21·3 | 22·4 | 4·0 | ·17 | 76·5 | 231·5 | Marlstone |
| 108 | „ „ . . | 13·2 | ·5 | ·9 | ·35 | — | 12·0 | 11·5 | 2·2 | 3·1 | 44·5 | 40·5 | Ironstone |
| 109 | Southport . . . | 7·0 | 2·45 | — | — | — | 15·8 | 3·6 | 2·8 | ·25 | 35·2 | — | *New Red Sandstone* |
| 110 | Kirkby . . . | 2·6 | 1·05 | — | — | — | 4·0 | 2·4 | 1·35 | 2·9 | 16·5 | 143·7 | Bunter beds |
| 111 | Avonmouth . . | 35·55 | 38·6 | — | — | — | 35·7 | 91·2 | 716·0 | ·4 | 1350·0 | 73·0 | Keuper |
| 112 | Gambleside . . | 8·6 | ·8 | — | — | Fe ·56 | 5·1 | 28·8 | 1·0 | ·0 | 56·0 | — | *Coal Measures* |
| 113 | Wolverhampton . . | 15·2 | 3·5 | — | — | Fe ·4 | 36·9 | 54·0 | 10·7 | ·4 | 158·0 | — | |
| 114 | Lancaster . . . | 5·6 | ·3 | — | — | — | 10·2 | 1·9 | 2·3 | ·14 | 25·5 | 265·5 | *Millstone Grit* |
| 115 | Ilkestone . . . | 1·2 | 2·0 | — | — | Ba ·7 | 14·7 | ·0 | 6·4 | ·0 | 36·0 | 1800·0 | Lower Carboniferous |
| 116 | Malvern . . . | 3·65 | 2·5 | — | — | — | 6·55 | 3·2 | 8·0 | ·8 | 27·55 | — | *Old Red Sandstone* |
| 117 | Aberdeenshire . . | 1·2 | ·4 | — | — | — | 1·35 | 1·5 | 2·0 | 2·2 | 11·5 | — | Primary rocks |

## TABLE Q

### PROBABLE SALINE CONSTITUENTS OF WATERS INCLUDED IN TABLE P

| -- | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium carbonate . . . | 23·7 | 34·75 | 20·0 | 17·5 | 6·6 | 59·15 | 7·5 | 38·0 | 14·0 | 3·0 | 9·15 | 2·25 |
| „ sulphate . . . . | 3·4 | — | 16·3 | — | — | 41·15 | 19·05 | — | — | — | — | 1·0 |
| „ chloride . . . . | — | — | 1·1 | — | — | — | — | — | — | — | — | — |
| Magnesium carbonate . . . | — | ·65 | — | 7·4 | — | — | — | 12·25 | 1·05 | 7·0 | 1·45 | — |
| „ sulphate . . . | 3·75 | 6·5 | — | 1·75 | 3·0 | 77·7 | 4·0 | — | — | — | 4·0 | 1·0 |
| „ chloride . . . | — | — | 2·0 | — | 1·8 | 90·95 | — | — | — | — | 5·15 | ·8 |
| Sodium carbonate . . . | — | — | — | — | — | — | — | 9·45 | 1·85 | 13·6 | — | — |
| „ sulphate . . . . | 4·6 | 25·45 | — | 3·25 | — | — | 17·95 | 79·9 | 2·8 | — | — | — |
| „ chloride . . . . | 3·95 | 6·6 | — | 4·6 | — | 1069·4 | 1·65 | 17·5 | 3·8 | 10·5 | 6·8 | 2·3 |
| „ nitrate . . . . | — | — | 3·4 | ·35 | 3·95 | ·5 | — | — | — | — | 1·0 | 3·0 |
| Potassium „ . . . . | — | — | ·95 | — | — | — | — | — | ·2 | — | — | — |
| — | — | — | — | — | — | — | $FeCO_3$ 1·2 | — | — | $BaCO_3$ 1·0 | — | — |
| — | — | Ferric oxide 1·5 | — | — | — | — | — | — | — | — | — | — |
| &c. | 1·1 | 1·05 | ·75 | ·35 | 1·15 | 11·15 | 4·65 | ·9 | 1·8 | ·9 | — | 1·15 |
| — | 40·5 | 76·5 | 44·5 | 35·2 | 16·5 | 1350·0 | 56·0 | 158·0 | 25·5 | 36·0 | 27·5 | 11·5 |

## London Water Supplies, 1902

### DERIVED FROM THE THAMES.—(1) CHELSEA

Results in Parts per 100,000

| Monthly samples | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 5·7 | 2·6 | 7·1 | 8·0 | 10·8 | 15·3 | 19·8 | 17·2 | 16·6 | 12·6 | 10·0 | 6·4 | 11·0 |
| Chlorine | 2·0 | 1·9 | 1·9 | 1·9 | 1·8 | 1·85 | 1·8 | 1·9 | 1·85 | 1·95 | 1·95 | 1·9 | 1·9 |
| Hardness | 22·7 | 22·4 | 21·8 | 20·3 | 19·1 | 18·6 | 18·9 | 18·1 | 17·7 | 19·6 | 19·7 | 20·9 | 20·0 |
| N. as nitrates | ·321 | ·307 | ·270 | ·197 | ·154 | ·156 | ·135 | ·113 | ·121 | ·169 | ·186 | ·208 | ·195 |
| Total solids | 32·06 | 32·24 | 31·50 | 29·76 | 27·20 | 25·72 | 26·72 | 24·80 | 23·72 | 26·72 | 26·50 | 30·65 | 28·18 |
| Organic carbon | ·279 | ·183 | ·203 | ·217 | ·126 | ·129 | ·216 | ·137 | ·151 | ·135 | ·142 | ·209 | ·177 |
| „ nitrogen | ·035 | ·017 | ·017 | ·018 | ·017 | ·017 | ·025 | ·018 | ·016 | ·017 | ·018 | ·022 | ·020 |
| O. absorbed in 4 hours at 26–7 C. | ·112 | ·081 | ·087 | ·092 | ·080 | ·069 | ·096 | ·069 | ·065 | ·061 | ·063 | ·100 | ·081 |
| O. „ 1 hour at 50 C. | ·121 | ·089 | ·097 | ·102 | ·089 | ·077 | ·109 | ·077 | ·073 | ·068 | ·070 | ·113 | ·090 |
| Alb. ammonia | ·011 | ·008 | ·0085 | ·009 | ·008 | ·007 | ·009 | ·008 | ·007 | ·0075 | ·007 | ·010 | ·0083 |
| Free „ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## London Water Supplies

### DERIVED FROM THE THAMES.—(2) WEST MIDDLESEX

Results in Parts per 100,000

| Monthly samples | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 5·2 | 2·7 | 7·0 | 8·3 | 11·5 | 14·8 | 18·0 | 18·6 | 15·6 | 12·7 | 10·1 | 6·5 | 10·9 |
| Chlorine | 2·0 | 1·9 | 1·8 | 1·9 | 1·8 | 1·8 | 1·9 | 1·8 | 1·8 | 1·9 | 2·0 | 1·95 | 1·9 |
| Hardness | 21·8 | 23·0 | 22·1 | 20·0 | 18·3 | 18·3 | 18·3 | 17·9 | 17·7 | 18·0 | 19·1 | 19·7 | 19·5 |
| N. as nitrates | ·302 | ·312 | ·260 | ·195 | ·125 | ·137 | ·121 | ·109 | ·134 | ·152 | ·170 | ·206 | ·185 |
| Total solids | 31·82 | 32·68 | 31·00 | 28·40 | 26·60 | 24·92 | 25·54 | 24·44 | 24·44 | 25·16 | 26·28 | 29·61 | 27·57 |
| Organic carbon | ·244 | ·201 | ·205 | ·225 | ·168 | ·138 | ·199 | ·152 | ·159 | ·136 | ·137 | ·219 | ·182 |
| „ nitrogen | ·023 | ·019 | ·018 | ·018 | ·016 | ·014 | ·025 | ·017 | ·017 | ·013 | ·015 | ·023 | ·018 |
| O. absorbed in 4 hours at 26–7 C. | ·112 | ·095 | ·094 | ·092 | ·082 | ·082 | ·104 | ·075 | ·072 | ·065 | ·072 | ·107 | ·088 |
| O. „ 1 hour at 50 C. | ·117 | ·101 | ·103 | ·101 | ·090 | ·088 | ·114 | ·084 | ·080 | ·071 | ·082 | ·124 | ·096 |
| Alb. ammonia | ·009 | ·009 | ·009 | ·009 | ·008 | ·007 | ·0095 | ·008 | ·008 | ·0075 | ·008 | ·010 | ·0085 |
| Free „ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## London Water Supplies

## DERIVED FROM THE THAMES.—(3) SOUTHWARK

Results in Parts per 100,000

| Monthly samples | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 6·0 | 3·1 | 9·1 | 8·8 | 12·2 | 14·0 | 20·5 | 19·2 | 16·0 | 13·0 | 10·8 | 5·0 | 11·5 |
| Chlorine | 1·9 | 1·85 | 1·85 | 1·95 | 1·8 | 1·8 | 1·8 | 1·85 | 1·8 | 1·9 | 1·95 | 1·95 | 1·9 |
| Hardness | 23·0 | 23·0 | 21·9 | 20·1 | 18·3 | 18·3 | 20·0 | 18·1 | 18·0 | 19·4 | 19·9 | 20·0 | 20·0 |
| N. as nitrates | ·318 | ·314 | ·228 | ·189 | ·161 | ·133 | ·117 | ·140 | ·154 | ·193 | ·209 | ·229 | ·199 |
| Total solids | 33·40 | 32·64 | 32·04 | 29·04 | 26·96 | 24·78 | 27·72 | 25·36 | 23·48 | 27·44 | 27·64 | 31·00 | 28·51 |
| Organic carbon | ·192 | ·148 | ·184 | ·182 | ·151 | ·151 | ·204 | ·095 | ·174 | ·112 | ·157 | ·250 | ·167 |
| „ nitrogen | ·022 | ·015 | ·020 | ·015 | ·016 | ·017 | ·021 | ·014 | ·018 | ·014 | ·015 | ·026 | ·018 |
| O. absorbed in 4 hours at 26–7 C. | ·109 | ·069 | ·117 | ·088 | ·080 | ·078 | ·095 | ·073 | ·077 | ·066 | ·079 | ·129 | ·088 |
| O. „ 1 hour at 50 C. | ·116 | ·074 | ·129 | ·096 | ·085 | ·089 | ·103 | ·080 | ·085 | ·074 | ·089 | ·142 | ·097 |
| Alb. ammonia | ·009 | ·0075 | ·011 | ·009 | ·009 | ·008 | ·008 | ·007 | ·0075 | ·0075 | ·008 | ·012 | ·0086 |
| Free „ | 0 | trace | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ·007 | ·001 |

## London Water Supplies

## DERIVED FROM THE THAMES.—(4) GRAND JUNCTION

Results in Parts per 100,000

| Monthly samples | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 5·4 | 3·6 | 8·2 | 8·0 | 11·5 | 15·2 | 20·7 | 18·0 | 16·4 | 12·6 | 10·2 | 4·8 | 11·2 |
| Chlorine | 1·8 | 1·8 | 1·9 | 1·85 | 1·8 | 1·8 | 1·95 | 1·85 | 1·85 | 1·9 | 1·9 | 1·95 | 1·9 |
| Hardness | 23·6 | 22·4 | 21·5 | 19·7 | 18·3 | 18·5 | 18·9 | 18·1 | 18·0 | 18·6 | 19·9 | 19·7 | 19·8 |
| N. as nitrates | ·337 | ·309 | ·259 | ·187 | ·170 | ·171 | ·154 | ·157 | ·180 | ·212 | ·213 | ·252 | ·217 |
| Total solids | 33·50 | 31·98 | 30·04 | 28·46 | 26·52 | 24·97 | 26·76 | 25·44 | 25·32 | 27·08 | 27·34 | 31·02 | 28·20 |
| Organic carbon | ·229 | ·179 | ·246 | ·189 | ·157 | ·214 | ·209 | ·122 | ·139 | ·114 | ·141 | ·285 | ·185 |
| „ nitrogen | ·025 | ·016 | ·023 | ·014 | ·016 | ·020 | ·026 | ·013 | ·014 | ·012 | ·013 | ·028 | ·018 |
| O. absorbed in 4 hours at 26–7 C. | ·117 | ·074 | ·110 | ·089 | ·083 | ·096 | ·097 | ·066 | ·070 | ·062 | ·076 | ·129 | ·089 |
| O. „ 1 hour at 50 C. | ·124 | ·081 | ·122 | ·097 | ·084 | ·111 | ·111 | ·080 | ·085 | ·068 | ·087 | ·146 | ·100 |
| Alb. ammonia | ·012 | ·008 | ·010 | ·009 | ·008 | ·0085 | ·009 | ·007 | ·007 | ·007 | ·0075 | ·011 | ·0087 |
| Free „ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## London Water Supplies

## DERIVED FROM THE THAMES.—(5) LAMBETH

Results in Parts per 100,000

| Monthly samples | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 5·4 | 4·0 | 8·3 | 7·7 | 10·9 | 14·9 | 19·7 | 17·6 | 15·6 | 12·0 | 10·2 | 4·8 | 10·9 |
| Chlorine | 1·8 | 1·9 | 1·9 | 1·9 | 1·8 | 1·85 | 1·95 | 1·9 | 1·85 | 1·9 | 1·95 | 2·0 | 1·9 |
| Hardness | 23·9 | 22·7 | 22·1 | 20·0 | 18·6 | 19·0 | 19·9 | 18·4 | 18·7 | 20·3 | 20·0 | 20·3 | 20·3 |
| N. as nitrates | ·336 | ·300 | ·271 | ·206 | ·187 | ·179 | ·145 | ·145 | ·176 | ·160 | ·213 | ·251 | ·214 |
| Total solids | 33·66 | 32·24 | 31·68 | 29·60 | 26·44 | 26·64 | 27·32 | 25·64 | 26·56 | 27·52 | 27·90 | 31·46 | 28·89 |
| Organic carbon | ·182 | ·162 | ·249 | ·176 | ·147 | ·273 | ·214 | ·135 | ·201 | ·105 | ·148 | ·318 | ·192 |
| „ nitrogen | ·019 | ·014 | ·021 | ·015 | ·015 | ·024 | ·023 | ·015 | ·019 | ·013 | ·013 | ·026 | ·018 |
| O. absorbed in 4 hours at 26–7 C. | ·133 | ·074 | ·129 | ·099 | ·086 | ·125 | ·101 | ·074 | ·080 | ·068 | ·079 | ·132 | ·098 |
| O. „ 1 hour at 50 C. | ·143 | ·079 | ·144 | ·107 | ·093 | ·134 | ·113 | ·084 | ·090 | ·076 | ·089 | ·151 | ·109 |
| Alb. ammonia | ·013 | ·0075 | ·012 | ·009 | ·0085 | ·011 | ·009 | ·007 | ·0075 | ·0075 | ·008 | ·012 | ·0093 |
| Free „ | ·001 | trace | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ·008 | ·001 |

## London Water Supplies

## DERIVED FROM THE LEA AND WELLS.—(6) NEW RIVER

Results in Parts per 100,000

| Monthly samples | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 5·3 | 3·3 | 8·7 | 8·8 | 10·4 | 15·1 | 18·0 | 17·0 | 15·4 | 12·3 | 9·7 | 5·5 | 10·8 |
| Chlorine | 1·8 | 1·75 | 1·6 | 1·55 | 1·75 | 1·7 | 1·7 | 1·9 | 1·95 | 1·9 | 1·95 | 1·95 | 1·8 |
| Hardness | 24·2 | 22·7 | 21·8 | 20·6 | 19·4 | 18·4 | 22·7 | 21·5 | 21·2 | 23·0 | 22·8 | 21·7 | 21·7 |
| N. as nitrates | ·287 | ·275 | ·222 | ·194 | ·187 | ·159 | ·168 | ·168 | ·178 | ·216 | ·217 | ·232 | ·209 |
| Total solids | 34·64 | 33·46 | 31·06 | 28·40 | 28·46 | 29·60 | 30·80 | 31·24 | 33·40 | 31·92 | 34·24 | 32·96 | 31·68 |
| Organic carbon | ·077 | ·062 | ·082 | ·070 | ·062 | ·060 | ·067 | ·065 | ·073 | ·054 | ·062 | ·112 | ·070 |
| „ nitrogen | ·008 | ·005 | ·008 | ·009 | ·008 | ·006 | ·013 | ·008 | ·007 | ·006 | ·006 | ·012 | ·008 |
| O. absorbed in 4 hours at 26–7 C. | ·045 | ·019 | ·039 | ·027 | ·023 | ·036 | ·029 | ·027 | ·022 | 022 | ·023 | ·044 | ·030 |
| O. „ 1 hour at 50 C. | ·018 | ·021 | ·044 | ·031 | ·024 | ·037 | ·032 | ·028 | ·024 | ·025 | ·026 | ·050 | ·033 |
| Alb. ammonia | ·005 | ·003 | ·004 | ·003 | ·0025 | ·003 | ·003 | ·003 | ·0025 | ·003 | ·0025 | ·004 | ·0032 |
| Free „ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## London Water Supplies

### DERIVED FROM THE LEA AND WELLS.—(7) EAST LONDON

Results in Parts per 100,000

| Monthly samples | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 4·4 | 3·6 | 9·1 | 8·0 | 12·5 | 15·5 | 20·3 | 17·0 | 16·3 | 13·6 | 10·3 | 5 ·0 | 11·3 |
| Chlorine | 2·5 | 2·0 | 2·05 | 2·5 | 2·0 | 2·3 | 2·1 | 2·2 | 1·85 | 2·0 | 2·4 | 2·3 | 2·1 |
| Hardness | 28·4 | 22·7 | 23·3 | 22·7 | 19·7 | 21·2 | 21·0 | 18·0 | 20·6 | 20·0 | 21·5 | 18·9 | 21·5 |
| N. as nitrates | ·530 | ·460 | ·445 | ·206 | ·354 | ·182 | ·329 | ·108 | ·172 | ·356 | ·163 | ·166 | ·289 |
| Total solids | 45·30 | 33·80 | 34·10 | 38·52 | 29·16 | 36·36 | 30·24 | 30·42 | 27·20 | 29·36 | 38·44 | 37·60 | 34·21 |
| Organic carbon | ·269 | ·164 | ·236 | ·182 | ·148 | ·267 | ·208 | ·138 | ·183 | ·124 | ·098 | ·083 | ·175 |
| „ nitrogen | ·026 | ·015 | ·019 | ·016 | ·015 | ·025 | ·025 | ·014 | ·018 | ·010 | ·010 | ·008 | ·017 |
| O. absorbed in 4 hours at 26–7 C. | ·125 | ·074 | ·127 | ·092 | ·079 | ·103 | ·101 | ·069 | ·070 | ·063 | ·061 | ·093 | ·088 |
| O. „ 1 hour at 50 C. | ·136 | ·080 | ·138 | ·100 | ·087 | ·115 | ·112 | ·078 | ·080 | ·070 | ·067 | ·107 | ·097 |
| Alb. ammonia | ·013 | ·008 | ·011 | ·0085 | ·009 | ·0115 | ·009 | ·007 | ·007 | ·007 | ·006 | ·007 | ·0087 |
| Free „ | ·001 | trace | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## London Water Supplies

## DERIVED FROM DEEP WELLS.—(8) KENT

Results in Parts per 100,000

| Monthly samples | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | — | 10·0 | 11·0 | 11·0 | 10·0 | 12·0 | 13·0 | 13·0 | 13·0 | 12·5 | 11·5 | 11·0 | 11·6 |
| Chlorine | 3·8 | 2·3 | 2·15 | 2·0 | 4·35 | 2·15 | 2·25 | 2·2 | 4·3 | 2·3 | 2·05 | 2·1 | 2·7 |
| Hardness | 31·3 | 28·1 | 27·8 | 26·3 | 31·3 | 27·5 | 28·9 | 27·5 | 32·4 | 27·8 | 27·5 | 27·2 | 28·8 |
| N. as nitrates | ·664 | ·454 | ·466 | ·476 | ·668 | ·362 | ·482 | ·436 | ·611 | ·461 | ·468 | ·503 | ·504 |
| Total solids | 49·88 | 40·72 | 39·66 | 37·20 | 52·20 | 38·26 | 39·14 | 38·0 | 50·68 | 41·44 | 39·22 | 39·84 | 42·19 |
| Organic carbon | ·059 | ·054 | ·041 | ·040 | ·061 | ·032 | ·038 | ·030 | ·068 | ·049 | ·049 | ·037 | ·046 |
| „ nitrogen | ·006 | ·005 | ·006 | ·003 | ·008 | ·006 | ·007 | ·006 | ·007 | ·006 | ·006 | ·005 | ·006 |
| O. absorbed in 4 hours at 26–7 C. | ·003 | ·005 | ·006 | ·006 | ·005 | ·008 | ·007 | ·007 | ·007 | ·006 | ·005 | ·005 | ·006 |
| O. „ 1 hour at 50 C. | ·004 | ·007 | ·009 | ·008 | ·007 | ·008 | ·009 | ·009 | ·008 | ·008 | ·006 | ·006 | ·007 |
| Alb. ammonia | ·0015 | ·002 | ·001 | ·0015 | ·0015 | ·0015 | ·0015 | ·0015 | ·0015 | ·0015 | ·0015 | ·0015 | ·0015 |
| Free „ | 0 | ·001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## CHAPTER XVII

### THE BACTERIOLOGICAL EXAMINATION OF WATER

THE media referred to in this section should be prepared according to the formulæ given in the appendix. No uniformity is attainable without the use of standard media, and as my results are based upon experiments in which the solid and liquid media described there were employed, it cannot be taken for granted that results obtained by other methods or with other media will admit of similar interpretation.

It is also assumed that no one will attempt the bacteriological examination of waters who has not previously acquired experience in technique in a properly equipped laboratory and under the guidance of a competent instructor. For this reason, it is unnecessary to describe the apparatus found in every laboratory, or to give all the details of the comparatively simple processes used in the routine method of water examination.

Bacteriological examinations are in the great majority of cases undertaken either for the purpose of ascertaining the efficiency of some filtering arrangement, or for the detection of pollution derived from sewage or of manurial origin. For both these purposes it is desirable to ascertain approximately the number of bacteria present in the sample of water under examination, and to make a search for certain organisms the presence of which, either alone or in association in the water, would imply that it was more or less contaminated. The smaller the amount of water in which such organisms can be detected the greater the pollution, and *vice versa*.

With reference to the enumeration of the bacteria present in a given quantity of a water (1 c.c. is the amount universally adopted) I have already stated that it does not, in itself, furnish

information of any great importance, and this was on the assumption that the number could be ascertained with a fair degree of accuracy, and that the results obtained by different bacteriologists would be fairly comparable. Notwithstanding all that has been written about the precautions to be taken to obtain comparable results, those obtained by different bacteriologists examining the same waters vary considerably. As an illustration of this discrepancy I may compare the results obtained in my own laboratory with those from another well-known London laboratory where the same series of carefully collected samples were being examined at the same time. It will be seen that there is no kind of agreement between them.

Number of Organisms per c.c.

| | Lab. A | Lab. B | | Lab. A | Lab. B |
|---|---|---|---|---|---|
| No. 1. | 12 | 152 | No. 4. | 25 | 250 |
| No. 2. | 13 | 48 | No. 5. | 95 | 164 |
| No. 3. | 15 | 260 | No. 6. | 108 | 240 |

I could quote many such instances, some exhibiting even greater discrepancies. It is not surprising therefore that sanitary authorities doubt the infallibility of bacteriologists when such discrepancies occur in their results. The variations which occur in chemical analyses made in different laboratories are usually very slight, and not at all comparable with those found in bacteriological work.

It is a well-known fact that the nature of the medium, its reaction, the duration of incubation, and the temperature, are all important factors in the development of water bacteria, yet no standard is generally adopted. There is no standard medium, reaction, period of incubation, &c. Some count only colonies visible on the third day, others those visible on the fourth or even the fifth day, some again use a lens or the low power of a microscope for counting purposes, others enumerate only those visible to the naked eye. It is probable that this difference in the mode of counting is the chief cause of the discrepancy so often observed.

In some cases the colonies develop so slowly that few are

visible to the naked eye on the third day. I have just examined a plate which has been incubated for three days, and only about a dozen small colonies are visible. By aid of a lens, however, hundreds of minute colonies can be counted. It is very easy to understand how in such a case different observers would record different results.

It is desirable to avoid stating that a given water contains a certain number of organisms per c.c., since such a determination is practically impossible. There may be many bacteria present which refuse to grow in or on the particular media employed; hence it is more accurate and scientific to state the number of colonies which grow from 1 c.c. of the water on alkaline nutrient jelly after so many days incubation at a given temperature, and to avoid misconception it would be well to add whether the colonies included only those visible to the naked eye, or all visible under a certain magnifying power.

### A. Determination of the number of Organisms present in one cubic centimetre of Water which are capable of growing at 20 C. in four days, upon nutrient jelly having a reaction Alkaline to Litmus but neutral to Phenol-Phthalein.

Ten c.c. of the nutrient jelly recommended (Formula 1) is used for each plate or petri dish. To one tube of jelly ·5 c.c. of the water is added, to another 1 c.c. The water should be well agitated before taking out the sample, as the bacteria may be adherent or even in zooglea masses. It does not appear to be either necessary or desirable to use larger or smaller quantities of water. If the colonies which grow on the ·5 c.c. plate are exceedingly numerous, their exact enumeration would be a mere waste of time; and on the other hand, however few bacteria may be present 1 c.c. will suffice for their enumeration, and the results obtained with ·5 and 1 c.c. are more comparable than those obtained when smaller quantities are used. The petri dishes used should be placed within a large dish the

bottom of which is covered with thick blotting-paper well moistened with ·1 per cent. solution of mercuric chloride. This prevents any excessive evaporation and the consequent drying of the thin plate of jelly. Incubate at 20° C. and count the number of colonies at the end of the fourth day by aid of a pocket lens having a focal length of 1½ in. Should many liquefying colonies be present, the counting may take place earlier, but if so the fact should be stated. Such a necessity rarely arises save when the water is of doubtful quality.

When every care is taken cases occur in which different observers examining the same plate obtain markedly different results. Many colonies are so minute and transparent that they can only be discovered when the light falls upon them at a special angle. If the jelly is not perfectly bright, the suspended particles will increase the difficulty of making an accurate count.

In some laboratories the water is mixed with agar instead of with nutrient jelly, and the plates incubated at 36°–37° C. The growth of the colonies is more rapid, but only a small proportion of the organisms present are capable of development at this temperature. As a rule, the number of colonies growing on agar at 36°–37° C. from a given quantity of water is only about one-tenth the number which will grow on nutrient jelly at 20° C. In polluted waters it is said that the proportion of organisms growing at 36°–37° will exceed this, but my experience does not lead me to place any confidence in conclusions drawn from such comparisons.

### B. Detection of Organisms indicative of Sewage Pollution

Whenever fairly recent sewage has been added to a water from a satisfactory source, in the proportion of one part of crude sewage to one million parts of the water, I have found it possible, in practically all cases, to obtain from the water so polluted organisms which gave all the reactions of the bacillus

coli communis and of the bacillus enteritidis sporogenes of Klein, suitable quantities of the water being used for the experiment. These were undoubtedly associated with a larger number of other organisms of the intestinal type. In waters to which a similar proportion of sewage effluent or old sewage has been added the B. coli communis and the B. enteritidis sporogenes cannot always be discovered, though in such cases the water still shows the presence of organisms of intestinal type. This may be due to the B. coli communis having died out, or to its having undergone some variation in character.

The sewage used in these experiments has usually been derived from the works of a small urban district in Essex, where the Surveyor has had collected for me hourly samples through the day and night. These were mixed in proportion to the flow at the time of taking, so as to produce as true a sample of the whole day's flow as possible. The sewage effluents used were from divers sources.

My experiments have led me to the following conclusions:

1. That in a water recently polluted by sewage there will always be found, if suitable quantities of water are used for the purpose, the bacillus enteritidis sporogenes of Klein, the bacillus coli communis, and other organisms of the intestinal type. Such a water must be considered as especially dangerous.

2. That in a water polluted by sewage or by matter of manurial origin, but in which the pollution is not of such a recent character, the bacillus enteritidis sporogenes, or the bacillus coli communis, or both may be absent, but organisms of the intestinal type and belonging to the B. coli groups 'B' and 'C' (*vide* page 353) will be present.

3. That the presence in a water of microbes of an intestinal type not associated with members of the coli groups has at present no known significance.

4. That the danger, if any, to be apprehended from using such waters as are referred to in (2) and (3) can only be ascer-

tained by an inspection of the source of the water and a knowledge of its history.

5. That a bacteriological examination, if properly conducted, may be relied upon to detect pollution in water even where such pollution does not correspond to more than 1 part of recent sewage in 1 million parts of water. In other words the bacterial method of examination is about 1,000 times more delicate than the chemical method.

6. When the pollution is smaller in amount than 1 in 1 million, the bacteriological results may suffice to raise a suspicion of pollution, but will rarely justify any definite opinion being given.

In the above paragraphs, microbes which are capable of producing acid in glucose broth in the presence of bile salts (MacConkey's fluid) are those referred to as being of the intestinal type. These organisms are so abundant in all sewages and manurial matter that if their absence in a given quantity of water is determined, it may be affirmed that no polluting matter derived from such sources is present, or that the amount of pollution is so small as to be incapable of being detected by bacteriological methods.

In examining a water, therefore, the search should first be directed towards the detection of the presence of organisms of the intestinal type. If these are absent the examination need not proceed further. If present, pollution is indicated, but it must be remembered that there are organisms capable of fermenting glucose and even lactose which are in no way characteristic of sewage or excremental matter, and that these may occur in waters free from admixture therewith; hence the investigation must be carried further before an opinion can be expressed with reference to the absence or presence of polluting matter derived from such sources.

Several tests have been proposed for obtaining an indication of the presence or absence of groups of organisms which are rarely found in waters of known purity, but which invari-

ably are present in sewage-polluted waters. In all such tests varying quantities of the water, or of the bacterially concentrated water, are added to some special medium and the effects produced during incubation noted. The tests chiefly used are:

MacConkey's, using bile salt litmus glucose broth.
Parietti's, using phenolated broth.
Houston's, or the shake gelatine test.
The neutral red test.

My experience tends to prove that the bile salt test is the most useful; it may therefore be considered first.

(1) **MacConkey's Test.**—This was first suggested by Drs. MacConkey and Hill, the Assistant Bacteriologists to the Royal Commission on Sewage Pollution, and consists in adding, to varying quantities of the water, bile salt glucose peptone litmus solution, and incubating at 36°–37° C. or preferably at 42° C. for twenty-four hours.

The organisms which can grow in this medium may be divided into three classes:

1. Those producing acid and gas.
2. Those producing acid but no gas.
3. Those producing a turbidity merely.

If the microbes present, as is very frequently the case with pure waters, are not capable of growing in this solution, of course the broth remains clear after incubation. Interest chiefly centres in the first group, as this includes all the more important organisms found in sewage. Those included in the second group are also organisms of intestinal type, but inasmuch as, if present, they would be associated with others belonging to group 1, it is not necessary to examine any water further if it does not contain organisms capable of producing acid and gas in this medium. Group 3 includes few, if any, organisms which can be said to be of intestinal origin. This group therefore is not considered as belonging to the intestinal type.

The known organisms which produce acid or acid and gas in bile salt glucose broth are given in the following Table :

| Group 1<br>Producing acid and gas | Group 2<br>Producing acid, but no gas |
|---|---|
| Bacillus coli communis. | Bacillus typhosus. |
| ,, enteritidis (Gaertner). | ,, pyogenes fœtidus. |
| ,, acidi lactici. | ,, dysenteriæ. |
| ,, cavicida. | ,, choleræ. |
| ,, neapolitanus. | ,, prodigiosus. |
| ,, capsulatus. | Proteus vulgaris. |
| ,, lactis aerogenes. | Staphylococcus aureus. |
| ,, icteroides. | ,, albus. |
| ,, paracolon. | ,, citreus. |
| ,, pneumoniæ. | |
| ,, cloacæ. | |

MacConkey and Hill appeared to think that the reaction of group 1 alone was sufficient to prove the absence or presence of sewage contamination, and they quote the following experiments in proof thereof. Waters from different sources were examined by this test, and afterwards those which gave a positive reaction were further investigated to ascertain if the bacillus coli communis could be detected. In each case 1 c.c. of the water was added to each of three separate tubes of solution. Dilutions of sewage varying from 1 in 10 to 1 in 1,000,000 were similarly treated. The tubes were incubated at 42° C. for forty-eight hours.

The results obtained were as follows :

A. Drinking Waters

| — | Moorland filtered water | Filtered rain water | River water |
|---|---|---|---|
| No. of samples examined . . . | 118 | 169 | 41 |
| No. giving reaction . . . . . | 5 | 16 | 41 |
| No. found to contain the B. coli communis | 5 | 16 | 41 |

B. Sample of Sewage

Positive result in every instance.

In every case in which a positive reaction was obtained the water was subsequently found to contain the bacillus coli communis (?). Dr. MacConkey has recently informed me that the test is not so conclusive as he at first believed.

I have not been able to confirm the above results, as in several instances the reaction has been observed with waters in which the B. coli could not be detected, although 36 c.c. were used for the purpose. This is apparently the experience of other observers, since it has been recommended to substitute lactose for the glucose in the original medium in order to effect a more definite differentiation. I prefer to use the solution originally recommended, and to effect the further differentiation at a later stage. The test as applied in my laboratory is carried out in the following manner :

Four test-tubes of suitable dimensions, each containing 10 c.c. of bile salt fluid of requisite strength (*vide* Formulæ A, B, C and D), are taken. To the weakest 1 c.c. of the water is added, to the next 5 c.c., to the third 10 c.c., and to the fourth and strongest 20 c.c. The resulting solutions are approximately of the same strength.

The tubes are placed in the incubator at 36°–37° C., and those which show the presence of acid and gas at the end of twenty-four hours are removed for further examination. If all the results are negative it is obvious that the water in the quantities examined contained no organisms of an intestinal type, and there is no necessity to carry the examination further. If, on the other hand, acid and gas have been produced in any of the tubes, there is reason to suspect the possible presence of organisms derived from sewage or manurial matter. The production of acid without gas is without significance in connection with this investigation, since, had any of the organisms producing the acid been derived from excremental matter, organisms belonging to the first group would also have been present.

The presence of organisms capable of producing acid and gas in a glucose solution containing bile salt cannot at present be regarded as conclusive proof of dangerous contamination. Water supplies, regularly examined by me, which are efficiently filtered and which have never been suspected of causing disease, frequently give this reaction when 5 or 10 c.c. of the

water are employed, and further examination has failed in these cases to prove the presence of the B. coli communis or of the spores of the B. enteritidis of Klein. In other cases also I have obtained similar results; hence it is imperative to continue the investigation before deciding that the water is polluted.

(2) **Parietti's Test.**—Parietti showed that the B. coli and B. typhosus would grow freely in a broth containing ·05 to ·1 per cent. of phenol, whilst the growth of nearly all other microbes is inhibited. Polluted waters, bacterially concentrated if necessary, when mixed with phenolated broth and incubated for twenty-four hours, produce a very visible and uniform turbidity, whilst many pure waters treated in the same way produce no change or a turbidity which is not uniform.

I have, however, discarded the use of the phenolated media, and commence the bacteriological examination with the bile salt broth, the result of a series of experiments having convinced me that the latter method is the more useful and reliable. The following experiments showing that this is the case are given as typical of many others recently made in my laboratory:

1. Water from a Deep Well in the Chalk

| | Results with ·05 per cent. phenolated broth | Resu'ts with bile salt broth |
|---|---|---|
| 1 c.c. of water . . . . | − | − |
| 2 „ . . . . | − | + |

The growth in the bile salt broth proved to be a motile bacillus which did not stain by Gram's method, but which coagulated milk, produced acid and gas in litmus lactose peptone solution, and gave gas bubbles in shake gelatine, indol in plain broth, and fluorescence in neutral red broth.

Here with the phenolated broth there was no indication of the presence of organisms of intestinal origin in 2 c.c. of the water, whereas with the bile salt broth their detection in this quantity of water was easy.

2. Water from another Deep Well in the Chalk

| | Phenolated broth | Bile salt broth |
|---|---|---|
| 1 c.c. of water used . . . | − | − |
| 2 „ „ . . . | − | − |
| 5 „ „ . . | − | + |

In this case also the bile salt broth proved the more reliable, as further tests showed that the organisms growing therein produced all the reactions recorded above. In practically all cases a growth occurs with a smaller quantity of water in the bile salt broth than in the phenolated broth. Probably the former fosters the growth of organisms of intestinal origin, whilst the latter merely retards the growth of other organisms, and possibly even of the intestinal forms if they are at all attenuated.

Using mixtures of sterile water with sewage from various sources, the following results were very uniformly obtained with the bile salt broth, whereas with the phenolated broth the results were far from uniform :

| | | | | |
|---|---|---|---|---|
| Dilution—sewage 1, | water | 10,000, | with 1 c.c., | acid and gas produced. |
| „ | „ | 100,000, | „ | „ „ |
| „ | „ | 1,000,000, | „ | results usually negative. |
| „ | „ | „ | with 5 c.c., | acid and gas produced. |

(3) **Houston's Shake Gelatine Test.**—Houston appears to lay much stress on the production of gas in gelatine 'shake' cultures, varying quantities of water being used and the incubation taking place at 20° C.

In his Report to the Medical Officer of the Local Government Board (Report 1899–1900, p. 487), he says :

'The gas-producing property of certain bacteria has been for long utilised as a test in one way or another by different bacteriologists. The sense in which I would here advocate this test may be briefly outlined as follows :

'From a long series of experiments I have found that in sewage B. coli (or closely allied forms) and a microbe, which I have described under the name of "sewage proteus," are present in crude sewage in numbers usually exceeding 100,000 per c.c. This "sewage proteus" (and its close allies), just like B. coli, produces "gas" in gelatine "shake" cultures in twenty-four hours at 20° C. It is evident, then, that it might be anticipated that the addition of sewage directly to gelatine would produce "gas" in "shake" culture, provided that these microbes were present in sufficient numbers. Such a biological test could

hardly be considered scientific in the absence of records to show (*a*) that the most numerous gas-forming bacteria in sewage belong to the objectionable coli and proteus class, and (*b*) that a parallelism exists between the numbers of B. coli and sewage proteus and the amount of liquid required to produce a gaseous change.

'In my experience both these things are true, although it is to be noted that a larger quantity of sewage is required to form "gas" when added directly to the gelatine than the actual number (as ascertained by plate culture) of B. coli and B. proteus would lead one to expect. As a matter of fact the test is about one hundred times less delicate (although still very delicate) than the enumeration of B. coli and B. proteus by plate culture. Usually about $\frac{1}{1000}$ c.c. of sewage is required to produce "gas" in gelatine "shake" culture in twenty-four hours at 20° C., whereas, as has been stated, gas-forming B. coli and B. proteus are commonly present in $\frac{1}{100000}$ c.c. of sewage. So that the absence of "gas" in twenty-four hours in gelatine (at 20° C.) to which, say, $\frac{1}{1000}$ c.c. of sewage had previously been added, would not imply the absence of the microbes from this amount of sewage, but only that they were not present in sufficient numbers to produce a visible development of "gas." The test may be rendered more delicate by extending the time up to forty-eight hours or even longer, but I have not, for various reasons, found this advisable unless when dealing with potable waters, and when the result is negative in twenty-four hours. Although unquestionably, in my experience, there is a broad parallelism between the number of B. coli and B. proteus in a substance, and the amount of that substance necessary to effect a gaseous change in gelatine, it must not be supposed that the agreement is an absolute one. Yet such discrepancies as do occur need not be regarded as so pronounced as to seriously impair the value of the test as a "rough and ready" biological method of comparing different substances in respect of these objectionable bacteria.

'It has been stated that $\frac{1}{1000}$ c.c. of sewage is usually

sufficient to produce "gas" in gelatine "shake" cultures in twenty-four hours at 20° C. As regards other substances, so far as my experience goes, comparatively large quantities of virgin soils do not produce this gaseous change, whereas a minimal quantity of a soil recently polluted yields a positive result. As regards waters, it may be said that 1 c.c. of a pure water never gives rise to "gas" formation under these conditions, and very frequently the bacterial contents of a much larger quantity (obtained by the "filter-brushing" method) also yield a negative result. In the case of polluted waters the results depend on the nature and degree of the pollution, and whether it is recent or remote in character. As a rapid and simple method of forming an opinion of the extent to which biological purification has been carried in the case of polluted rivers and sewage effluents the test is one of considerable value.

'There is some reason to suppose that B. coli and B. proteus, outside the animal body and under natural conditions, may in course of time lose their original gas-producing property or retain the ability in diminished degree. But if this be true is it not also probably the case that they and other correlated germs of excremental sort are the less to be thought of as noxious or dangerous in character, by reason of loss of their original properties as the result of a too long separation from their initial animal surroundings?'

To apply this test it is necessary to concentrate the bacterial contents of a considerable quantity of water, 100 c.c. or more, in the manner described in the section relating to the detection of the B. enteritidis sporogenes of Klein. The final 5 c.c. of water contained within the filter candle, after brushing, will contain all the organisms in the quantity of water originally taken.

Take 5 tubes of gelatine medium. To one add 1 c.c. of the original water, to a second ·25 c.c. of the filter brushing, to a third ·5 c.c., to a fourth 1 c.c., to a fifth 2 c.c. These tubes will contain the bacteria in 1, 5, 10 and 20 and 40 c.c. of water

respectively, and of 76 c.c. collectively, assuming 100 c.c. to have been used originally.

Place in the incubator at 20° C. for twenty-four hours and record the result. The smaller the quantity of water causing the production of gas bubbles in the jelly, the more likely is the water to prove to be polluted. This production of gas must not, by itself, be taken as proving that the water is dangerously contaminated, or even polluted at all with sewage matter, but merely as indicating that certain microbes are present which may have been derived from sewage or manure.

(4) **The Neutral Red Test.**—In 1898 Rothberger showed that if a little neutral red were added to tubes containing glucose media, and these were inoculated with the bacillus coli communis, after from twenty-four to thirty-six hours' incubation the colour became greenish-yellow and markedly fluorescent. As the bacillus typhosus produces no such change he recommended this process as a ready means of distinguishing between the two. Many observers have since endeavoured to make this test available in the examination of water for the detection of the B. coli, notwithstanding that it is known that other organisms found in soil and in potable waters possess the power of reducing neutral red with the production of fluorescence.

Dr. Makgill[1] found that, using bouillon, the reaction could be constantly obtained within twenty-four hours, even with dilutions corresponding to from 1 to 5 B. coli per c.c. As the result of his experience he concluded that a negative result justified the conclusion that the B. coli was absent, but he would not assert that a positive reaction always denoted the presence of that organism.

E. E. Irons, of the University of Chicago,[2] as the result of a considerable number of experiments, says: 'It is evident that organisms common in river water, other than the B. coli communis, give the neutral red reaction. . . . Although the neutral red gives approximately accurate determinations when only the B. coli is present, the results obtained in the examina-

[1] *Journal of Hygiene*, 1901, No. 3. [2] *Ibid.*, 1902, No. 2.

tion of a water for B. coli by the neutral red method alone are likely to be misleading, the tendency obviously being to give too high an estimate of the number of the organisms present. We merely conclude, therefore, that in the routine examination of water, the neutral red reaction when made alone cannot be depended upon for the diagnosis of the B. coli, since the reaction is given under the conditions of the test by a number of other common water organisms which no classification, however liberal, would place in the colon group.'

Dr. Savage, in discussing the use of neutral red in the routine examination of water,[1] lays stress on the strength of the neutral red media employed. If too much is used the organisms present may not be able to reduce it, and he recommends that to get the best results 0·1 c.c. of a 0·5 per cent. watery solution of neutral red (Grübler's) should be added to 10 c.c. of broth or agar. He examined 50 waters from different sources. Ten of these, which gave no reaction with the neutral red, on further examination appeared to be free from the B. coli. Of 39 samples giving a positive reaction, 34 were further examined and the bacilli found in 31. The results of 47 examinations are given in the following table:

| General character of water | No. of samples | Neutral red reaction | | B. coli looked for | | B. coli found | |
|---|---|---|---|---|---|---|---|
| | | + reaction | − reaction | with + reaction | with − reaction | with + reaction | with − reaction |
| Bad . . | 25 | 25 | 0 | 20 | 0 | 20 | 0 |
| Good . . | 19 | 9 | 10 | 9 | 9 | 7 | 0 |
| Suspicious . | 3 | 2 | 1 | 2 | 1 | 2 | 0 |
| Totals . | 47 | 36 | 11 | 31 | 10 | 29 | 0 |

In these experiments Dr. Savage used from 1 to 40 c.c. of water, and the conclusions he arrived at are as under:

'1. A positive neutral red reaction, obtained as above, whilst not absolutely diagnostic of the B. coli, yet in the vast majority of cases points to the presence of that organism.

[1] *Journal of Hygiene*, vol i. p. 437.

'2. A negative neutral red reaction obtained as above does not entirely exclude B. coli, but renders its presence highly improbable.

'3. The neutral red test is very readily applied, and with reasonable care fallacies in its employment can be avoided.

'4. It is a test which is of great value in the routine examination of a water.'

Reviewing the results obtained with the potable waters examined, he says: 'The results are somewhat surprising, and tend to make me reconsider the significance of the presence of the B. coli in water. The detection of the organism in all the obviously bad waters points strongly to its association with contamination.'

The method adopted by Dr. Savage was to add 10 c.c. or less of the water to 10 c.c. of the neutral red broth, and to add to 40 c.c. of the water 10 c.c. of the neutral red broth of four times the ordinary strength. If the B. coli be present the mixture of broth and neutral red becomes yellow and fluorescent after twenty-four to forty-eight hours' incubation at 36°–37° C. By using 1, 5, 10, 20, 40, &c., c.c. of water the smallest quantity of water capable of giving the reaction is determined. I have no confidence in this test, for I find it frequently fails to detect pollution when such is known to be present. When an inverted test-tube is placed in the neutral red broth, fluorescence often appears in the liquid within this smaller tube when that without the tube is unaffected, and a reaction is often obtained with an agar medium containing neutral red when no fluorescence is produced in a liquid medium. Samples of water to which small quantities of sewage or sewage effluent have been added have from time to time failed to give the neutral red reaction when both the bile salt broth and the shake gelatine test indicated the pollution, the same quantities of water being used in all the experiments. On several occasions organisms have been isolated from unpolluted waters which gave a brilliant fluorescence when growing in neutral red broth.

### C. Detection of the Bacillus Coli Communis

The preliminary test with MacConkey's fluid having given indications of the presence of organisms of an intestinal type, the fluid in the tube containing the smallest quantity of water which has given a rapid positive reaction is used for the isolation of individual bacteria in order to ascertain whether any of them are the B. coli communis. This may be effected by diluting a little of the solution and brushing it over the surface of some solid medium, and incubating until the separate colonies can be recognised. For this purpose I have used phenolated gelatine, bile salt agar medium (Formula F), and Drigalski and Conradi's medium (Formula M), but prefer the bile salt. On this medium the B. coli and a few other organisms which ferment lactose grow freely, the resulting colonies having a dull red colour, and being surrounded by a haze due to the precipitation of the bile acid. This haze, however, may not appear for forty-eight hours.

To isolate the organisms growing in the fluid medium, transfer a loopful to about 5 c.c. of sterile water, and after agitation diffuse a droplet of the mixture over a recently poured plate of neutral red agar (Formula F) by means of a platinum rubber or glass spreader. Incubate at 36-37° C. for twenty-four hours, and examine.

On rare occasions no growth whatever will be obvious, in which case the examination need not be carried further, as there are no organisms present which belong to the B. coli groups. Occasionally the growth may consist entirely of small white colonies; frequently there are both red and white colonies, the former predominating, but usually there are red colonies only. The red colonies alone need be considered, and of these only such as produce a haze in the medium around can be the B. coli communis. These vary somewhat in appearance, some being wholly red, others only red towards the centre, the peripheral portion being of a creamy white. The latter are generally found to give all the reactions of the coli groups, but

not necessarily of the B. coli communis; hence several colonies must be examined. If the colonies formed are not red, or being red do not produce a haze in the surrounding medium, the plate need not be examined further, as the special organism of which we are in search is absent.

Having selected three or more colonies for further examination, each one is used for inoculating a tube of lactose litmus broth, and these are incubated for twenty-four hours. Usually all produce acid and gas within this period: those which produce acid only can be rejected, whilst the others are used for the following experiments:

Examine in a hanging drop, and note whether the organism is motile or not.

Stain by Gram's method, and note whether the stain is retained or not. If the organism is motile and does not stain by Gram's method, it probably belongs to the coli group, but further investigation is necessary to ascertain whether it is the B. coli communis.

This further examination is made as follows:

From each selected colony—

1. Inoculate a tube of sterilised litmus milk. (For the production of acid, and curdling.)

2. Inoculate a tube of peptone solution. (For indol production.)

3. Make a streak culture on gelatine. (To ascertain the appearance of the growth and the non-production of liquefaction.) The above will suffice for the identification of the B. coli communis and other organisms of the coli group, but further tests may be applied if deemed necessary, such as—

4. Inoculation of a tube of neutral red agar. (For the production of fluorescence.)

5. Inoculation of sucrose broth.

6. Inoculation of mannite broth.

7. Inoculation of dulcite broth.

The latter tests may ultimately be found to differentiate various species of the B. coli communis, but in the present state

of our knowledge no information of importance to the water analyst is obtained by this attempt at differentiation.

Certain organisms giving all the essential reactions of the B. coli communis ferment one or other or all of these sugars.

All the preparations, save the gelatine streak, are kept in the incubator at 26–27° C., and the results recorded from day to day. The gelatine tube is placed in the cool incubator (at 20° C.) for at least a week.

The results obtained if the B. coli communis is the organism under observation are as under :

1. The milk will become acid within twenty-four hours and be curdled within three days.

2. Indol will be found in the peptone solution on or before the fifth day.

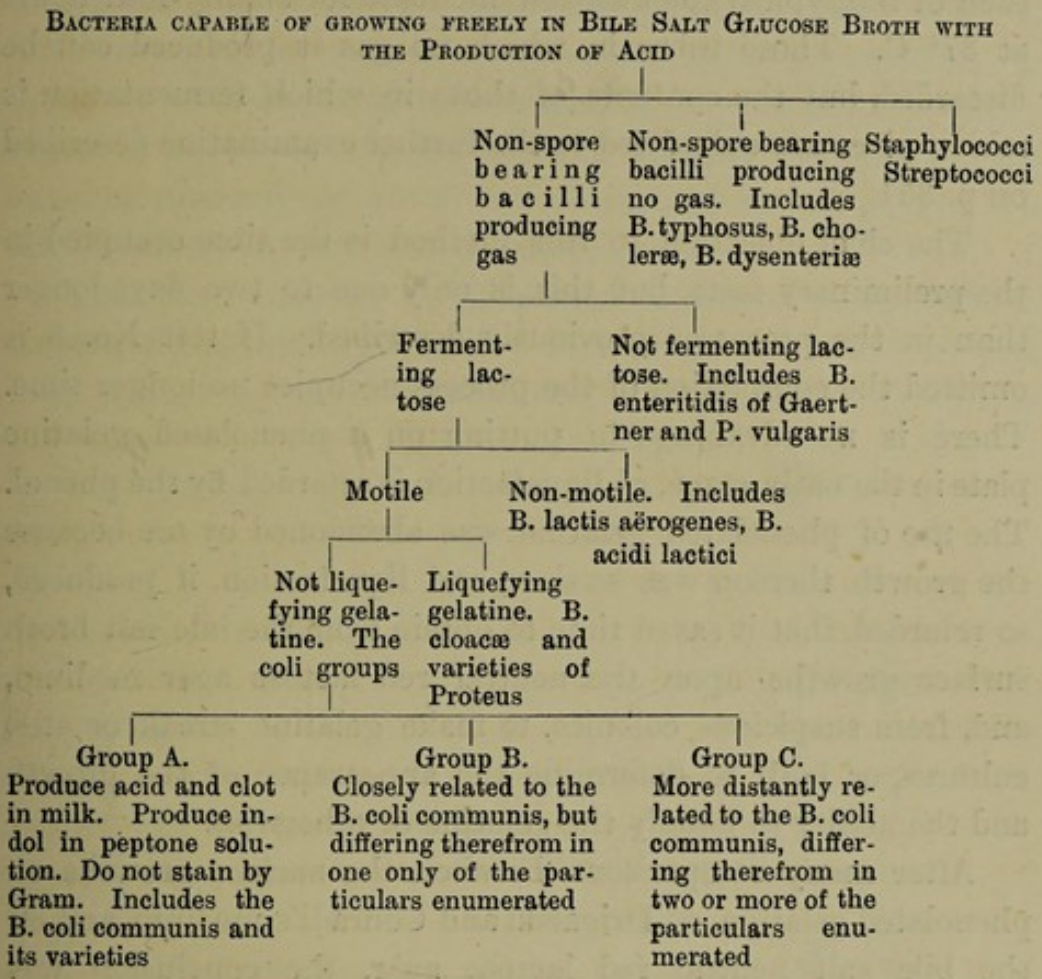
3. At the end of a week there should not be the slightest signs of liquefaction in the gelatine, and the growth should have the pearly appearance of the B. coli communis.

If all these reactions are obtained the B. coli communis may definitely be said to be present. Further tests with mannite, dulcite, and sucrose will show differences even in these organisms, but at present I regard all as varieties of the B. coli communis, or as belonging to group ' A ' of the annexed chart.

If the microbe under examination ferments both lactose and glucose, is motile, and does not liquefy gelatine yet corresponds to all the other reactions of the group ' A ' save in any one particular, I consider it to belong to group ' B,' and to be a near ally of the members of group 'A.' In the absence of members of the latter group the presence in association with the B. enteritidis sporogenes of Klein of members of group ' B ' possibly indicates contamination, but in the absence of the B. enteritidis sporogenes I should be guided in my opinion by an examination of the source of the water.

If the microbe belongs to the coli groups but differs from the B. coli communis in two or more particulars, it will be included in group ' C,' and if not associated with members of group ' A ' no definite significance can be attached to its presence.

## BACTERIA OF INTESTINAL TYPE




An alternative method for examining a sample of water for organisms of the coli group is as follows:

Add 1, 5, 10, and 20 c.c. respectively of the water to the proper quantity of phenolated bouillon, using a concentrated bouillon for the larger quantities, and incubate at 37° C. for twenty-four hours.

If a visible turbidity is produced, select the tube with turbid contents to which the smallest quantity of water has been added, and mix a loopful with 5 c.c of sterile water. With this dilution smear the surface of a plate of phenolated gelatine, and incubate at 20° C. for two or three days.

Examine the colonies produced, and select for further examination those which resemble the growths of the coli group.

Inoculate a tube of litmus lactose peptone solution from each of the typical colonies and incubate for twenty-four hours at 37° C. Those tubes in which no gas is produced can be discarded, but the contents of those in which fermentation is taking place are submitted to the further examination described on p. 351.

The chief objection to this method is the time occupied in the preliminary tests, but this is only one to two days longer than in the processes previously described. If test No. 3 is omitted the completion of the process occupies no longer time. There is no advantage in putting on a phenolated gelatine plate in the early stage, as liquefaction is retarded by the phenol. The use of phenolated gelatine was abandoned by me because the growth thereon was so slow, and liquefaction, if produced, so retarded, that it saved time to obtain from the bile salt broth surface growths upon the neutral red lactose agar medium, and, from suspicious colonies, to make gelatine streak or stab cultures, or both, to determine the appearance of the growth and the ability to liquefy the gelatine or otherwise.

After many comparisons between the surface growths on phenolated gelatine, on Drigalski and Conradi's medium, and on the bile salt neutral red lactose agar, the conclusion was arrived at that organisms of the coli group could more readily be picked out from the latter than from either of the former, and therefore that the bile salt medium was the better for this particular purpose.

### D. Detection of the Bacillus enteritidis sporogenes of Klein or its close allies

As these spore-bearing organisms rarely occur in large numbers in potable waters, the bacterial contents of a considerable volume of water must be used for their detection.

The apparatus used in my laboratories for the concentration of the bacteria in samples of water is figured on the next page.

A is a flask capable of holding 500 c.c., and drawn out at

the lower end so that it can be tightly fitted by means of a small perforated rubber stopper into the porcelain filter tube C. This tube should hold about 10 c.c. of water when filled. D is the usual filter pump flask containing a piece of glass tubing sealed at the upper end, and used for denoting the extent of the vacuum obtained by aid of the exhausting syringe F, which is fixed securely to the bench on a block of wood, G.

The filter candle C is passed through a caoutchouc stopper fitting tightly into the filter flask D. The filter and flask A having been duly sterilised, half a litre of the water

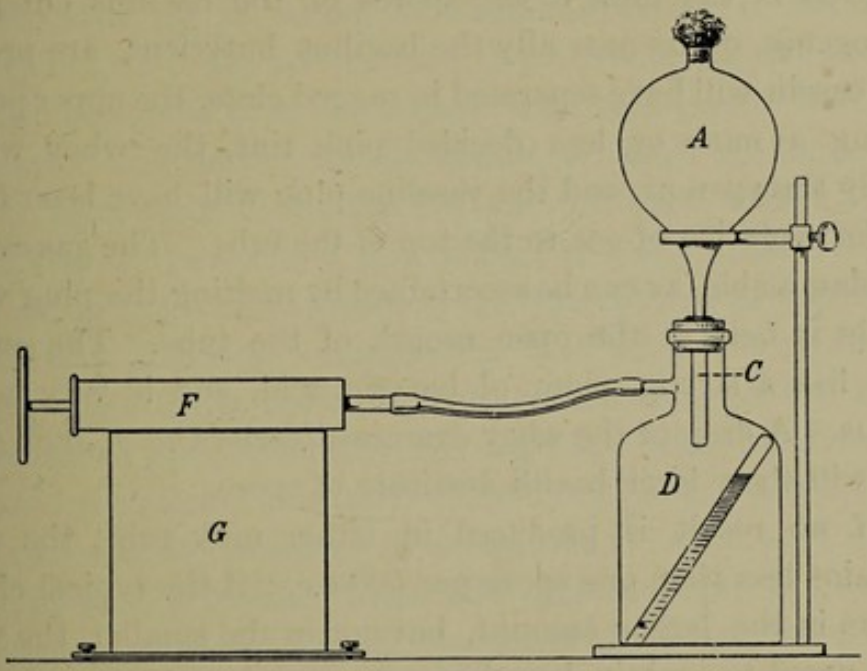



FIG. 11

is poured into A and the neck lightly plugged with cotton wool. Upon exhausting the air from the flask by means of the syringe, filtration commences, and should be so regulated that about an hour is occupied in passing through the 500 c.c. The filtration is stopped as soon as the water disappears from A, and the latter is then removed. The filtration is again proceeded with until only 4 c.c. remain in the tube. The capacity of the tube being known, the filtering process can be easily stopped at very near this point. By means of a sterile brush the organisms on the sides of the tube are brushed into

the water and portions of the latter are transferred to tubes of recently boiled sterile milk, the temperature of which has been reduced to below 80° C. One-fourth of the water residue is added to one tube and the remainder to a second. A little melted vaseline is then poured over the surface of the milk in order to form a covering about $\frac{1}{2}$ inch in depth. The tubes are next kept at 80° C. for fifteen minutes, placed in cold water until the vaseline has set, and finally transferred to the incubator at 37° C., where they are kept for one, two, or three days. Before the expiration of the third day certain changes will have occurred in the milk if the spores of the bacillus enteritidis sporogenes, or its near ally the bacillus butyricus, are present. The casein will have separated in ragged clots, the upper portion having a more or less decided pink tint, the whey will be nearly transparent, and the vaseline plug will have been forced by the evolution of gas to the top of the tube. The gas evolved is inflammable, as can be ascertained by melting the plug whilst a light is held at the open mouth of the tube. The curdled milk has a strong odour of butyric acid, and is very acid to litmus. A drop of the whey examined under the $\frac{1}{12}$-inch objective will show large bacilli destitute of spores.

If no result is produced in either milk tube, the water contains less than one spore per 500 c.c. : if the typical change occurs in the larger amount, but not in the smaller, the water is assumed to contain less than one spore per 125 c.c., but one or more in 375 c.c. If change occurs in both tubes, there is probably one or more spores in each 125 c.c. This information is all that is desired.

If from the atypical character of the reaction there is reason to believe that the organism present is not the B. enteritidis sporogenes, but one of its allies, it may be grown on other media as suggested by Klein, and its pathogenicity for rodents determined. The results obtained will probably lead to its identification. In several instances I have found spore-bearing organisms present in water which did not correspond to any of those described by Klein as occurring in the intestinal

contents, though they curdled milk and evolved gas when grown anaërobically. The curd, however, never bears any resemblance to that produced by the B. enteritidis sporogenes, and the presence of the organisms producing this atypical result appears to be devoid of significance.

### E. Examination for Streptococci

For this purpose the bacterial contents of a comparatively large amount of water must be used. 500 c.c. may be concentrated by filtration, as described under B. enteritidis sporogenes, to 5 c.c., and of this, ·1 c.c. (=10 c.c. of water) is brushed or spread over the surface of an agar plate. The plate is inverted and kept in the incubator at 36–37° C. for twenty-four to forty-eight hours, the surface examined with a lens or under the low power of a microscope, and any minute colonies resembling those of streptococci are subcultured in broth tubes at 37° C. Houston recommends that after twenty-four to twenty-eight hours the broth cultures showing growth should be examined microscopically, the organism being (*a*) unstained, (*b*) stained by Gram's method. Should this preliminary examination indicate the presence of streptococci, subcultures may be made in various media, litmus milk, gelatine, agar, &c., and the morphological and biological characters of the microbe carefully determined. By concentrating the bacterial contents of one or more litres of water to 5 c.c. (the smallest amount to which it is safe to concentrate) and using ·1 c.c. for brushing over the agar plates, the presence or absence of streptococci in much larger quantities of water may possibly be determined. The method of examination is so tedious and troublesome that few will be tempted to use it more than once. Moreover, as these microbes must, if derived from sewage, be associated with the B. coli and the B. enteritidis sporogenes of Klein, both of which are far more easily detected, I think that the cases in which it is desirable to search for streptococci will be very few indeed.

## F. Expression of the Results of the Bacteriological Examination

The following are examples of the results obtained by the methods recommended and of the way in which they may be recorded :

1. Water from a Deep Well in the Chalk. No known Source of Pollution

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| Bile salt glucose broth . . . . . | − | − | + | + |
| „ „ lactose agar . . . . . | | | − | |

(The growth was deep crimson rather than red in colour, and did not produce any haze in the medium. The organism proved to be allied to the B. prodigiosus, but I have not been able to identify it with any known bacillus.)

B. enteritidis sporogenes absent in 500 c.c.

*Report.*—The water is free from organisms of the coli type, and therefore is in my opinion free from dangerous sewage or manurial pollution.

2. Water from a Shallow Well in a Garden. Soil around heavily manured. Well Defective

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| Bile salt glucose broth . . . . | + | + | + | + |
| „ „ lactose agar . . . . | + | | | |
| Litmus lactose broth . . . . | + + | (Acid & gas) | | |
| Motility . . . . . | + | | | |
| Gram's stain . . . . . | − | | | |
| Milk . . . . . | + + | (Acid & curd) | | |
| Peptone solution . . . . | + | (Indol formed) | | |
| Neutral red agar . . . . | + | | | |
| Gelatine streak . . . . | − | | | |

Bacillus enteritidis sporogenes present in 100 c.c.

*Report.*—This water contains the B. coli communis in 1 c.c. and the B. enteritidis in 100 c.c. (possibly in less). It is undoubtedly contaminated with sewage or manurial matter, and quite unfit for domestic purposes.

3. Water from a Well at a Mineral Water Factory. No known Source of Pollution near

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms capable of growing on gelatine in four days at 20° C. | 1400 | | | |
| Bile salt glucose broth | + | + | + | + |
| „ „ lactose agar | + | | | |
| Litmus lactose broth | + | | | |
| Motility | + | | | |
| Gram's stain | − | | | |
| Milk | − | | | |
| Peptone solution | + | | | |
| Neutral red agar | − | | | |
| Gelatine streak | − | | | |

B. enteritidis sporogenes not found in 500 c.c.

*Report.*—Although this water does not contain in the quantity examined the B. coli communis or the B. enteritidis sporogenes, it is bacteriologically unsatisfactory, and the well should be carefully examined.

As the result of this report the well was opened, and at a point near the ground surface water was found trickling in. No doubt the organisms were derived from the soil of the surrounding pasture.

4. Water from the Mains of the East London Water Company

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms, &c. | 180 | | | |
| Bile salt glucose broth | + | + | + | + |
| „ „ lactose agar | − | (a few white colonies only) | | |

B. enteritidis sporogenes not found in 375 c.c.

*Report.*—Satisfactory. Contains no organisms suggestive of recent contamination by sewage or manure.

5. Water from the South Essex Water Company's Mains

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms, &c. | 178 | | | |
| Bile salt glucose broth | − | + | + | + |
| „ „ lactose agar | | − | | |

B. enteritidis sporogenes not found in 500 c.c.

*Report.*—Satisfactory.—No evidence of the presence of recent sewage or manurial pollution.

6. Spring Water from Plantation at —— Asylum

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms, &c. | 9500 | | | |
| Bile salt glucose broth | + | + | + | + |
| „ „ lactose agar | + | | | |
| Litmus lactose broth | + + | | | |
| Motility | — | | | |
| Gram's stain | — | | | |
| Milk | + + | | | |
| Peptone solution | — | | | |
| Neutral red agar | — | | | |
| Gelatine streak | — | | | |

B. enteritidis sporogenes.—After three days a little gas was produced and the milk was clotted, but the reaction was not at all characteristic of the B. enteritidis sporogenes.

*Report.*—This water appears to contain organisms of intestinal type, but there is no evidence of direct sewage pollution. It is far from satisfactory, and the source should be examined.

A week or two afterwards I examined the so-called spring, and found that water from swampy ground in a plantation collected in various rivulets which ultimately combined to form the 'spring.' One of these rivulets received the water from a road drain near a public-house where waggoners rested their horses. This was the only source of pollution discernible. Decaying leaves abounded in the streamlets. I sanctioned the use of the water for laundry and boiler purposes only.

7. Water derived from a Deep Well in the New Red Sandstone and supplied by a large Water Company

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms, &c. | 78 | | | |
| Bile salt glucose broth | — | + | — | — |
| „ „ lactose agar | | — | (white colonies only) | |

B. enteritidis sporogenes not detected in 500 c.c.

*Report.*—The bacteriological examination affords no evidence of pollution.

8. Tap Waters to which $\frac{1}{100000}$ Part of Sewage had been added

| — | 1 c.c. | 5 c.c. |
|---|---|---|
| No. of organisms, &c. . . . . | 2000–4000 | |
| Bile salt glucose broth . . . . . | + | + |
| ,, lactose agar . . . . . | + | |

Twelve different colonies were examined, three from each of four plates made from the polluted water. All were red in colour and surrounded by haze. The results of these examinations are recorded in the following table :

| No. | Litmus lactose broth | | Litmus dulcite broth | | Litmus mannite broth | | Litmus sucrose broth | | Milk | | Indol | Neutral red agar. Fluorescence | Motility | Gram | Gelatine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Acid | Gas | Acid | Gas | Acid | Gas | Acid | Gas | Acid | Clot | | | | | |
| 1 | + | + | + | + | + | + | − | − | + | + | + | + | + | − | − |
| 2 | + | + | − | − | + | + | − | − | + | + | + | − | − | | − |
| 3 | + | + | − | − | + | + | − | − | + | + | + | + | − | | − |
| 4 | + | + | − | − | + | + | − | − | + | + | + | − | − | | − |
| 5 | + | + | − | − | + | + | + | + | + | + | + | + | + | | − |
| 6 | + | + | + | + | + | + | + | + | + | + | + | + | + | | − |
| 7 | + | + | − | − | + | + | + | + | + | + | + | + | − | − | − |
| 8 | + | + | − | − | + | + | + | + | + | + | + | − | + | | − |
| 9 | + | + | − | − | + | + | − | − | + | + | + | + | − | − | |
| 10 | + | + | − | − | + | + | + | + | + | + | + | + | + | | + |
| 11 | + | + | | | | | + | + | + | + | + | − | + | | − |
| 12 | + | + | | | | | − | − | + | + | − | + | − | | − |

Nos. 1, 5, 6, 8, and 11, I regard as the true bacillus coli communis. Nos. 2, 3, 4, 7, 9, and 12 are non-motile, and belong to the bacillus lactis aërogenes group. No. 10 is probably a Proteus, differing only from the B. coli communis in liquefying gelatine. All, of course, are organisms of intestinal type.

It is obvious that several colonies must be selected from the lactose agar plate for the extended investigations. Where, as is often the case, the colonies are very similar in appearance, I have generally hitherto been content with at first examining a single colony, examining others later if the first did not prove to be the B. coli communis, but now I prefer to examine three or more in the first instance. Where the colonies are dissimilar one of each of those of a red colour and surrounded by haze is examined. The subjoined table, by Jordan, is taken

| GROUPS | SOURCE | MORPHOLOGY | | | | BIOLOGY | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cultural Features | | | | | | | | | | |
| | | | | | | Nutrient broth tube | | Nutrient agar tube | | Gelatin plate | Gelatin stab. | | | Potato tube | | Fermentation tube |
| | No. of cultures | Bacillus | Diameter greater than 1μ | Motile | Spores | Scum | Turbidity | Dull | Wrinkled | Characteristic appearance | Deep funnel | Surface growth | Needle growth | Visible | Luxuriant | Growth in closed arm |
| Group I. B. coli, var. (*a*) | 25 | + | − | + | − | ± | + | − | − | − | − | + | + | + | + | + |
| var. (*b*) | 21 | + | − | + | − | ± | + | − | − | − | − | + | + | + | + | + |
| Group II. B. lactis aërogenes, var. (*a*) | 16 | + | − | − | − | ± | + | − | − | − | − | + | + | + | + | + |
| var. (*b*) | 11 | + | − | − | − | ± | + | − | − | − | − | + | + | + | + | + |
| Groups I. and II. undifferentiated further | 29 | + | − | ± | − | ± | + | − | − | − | − | + | + | + | + | + |
| Group III. (1) Proteus vulgaris (type) | 23 | + | − | + | − | ± | + | − | − | ± | + | + | + | + | ± | + |
| (2) Proteus (varieties) | 17 | + | − | + | − | ± | + | − | − | ± | ± | + | + | + | ± | + |
| (3) B. cloacae | 21 | + | − | + | − | ± | + | − | − | ± | ± | + | + | + | ± | + |
| Group IV. B. enteritidis | 6 | + | − | + | − | ± | + | − | − | − | − | + | + | + | − | + |
| Group V. Fluorescens liquefaciens | 33 | + | − | + | − | + | + | − | − | − | + | + | + | + | + | + |
| Group VI. Fluorescens non-liquefaciens | 25 | + | − | + | − | + | + | − | − | − | + | + | + | + | + | − |
| Group VII. Subtilis | 26 | + | − | + | + | + | + | − | + | + | + | − | − | + | + | + |
| Mesentericus vulgatus | 8 | + | − | + | + | + | + | − | + | + | + | − | − | + | + | + |
| ,, fuscus | 3 | + | − | + | + | + | + | − | + | + | + | − | − | + | + | − |
| ,, ruber | 3 | + | − | + | + | + | + | − | + | + | + | − | − | + | + | + |
| Yellow Subtilis | 4 | + | + | + | + | + | + | − | − | − | + | − | − | + | + | + |
| Megatherium | 1 | + | − | + | + | + | + | − | − | − | + | − | − | + | + | + |
| Non-liquefying | 1 | + | − | + | + | + | + | − | − | − | − | + | + | + | + | + |
| Group VIII. Gel. liquef.-Milk acid | 74 | + | − | ± | − | + | + | − | − | − | + | + | + | + | ± | + |
| Group IX. Gel. liquef.-Milk alkaline | 30 | + | ± | ± | − | + | + | − | − | − | + | + | + | + | + | + |
| | | + | − | ± | − | + | + | − | − | − | + | + | + | ± | ± | + |
| Group X. Gel. not liquef.-Milk acid | 32 | + | − | ± | − | + | + | − | − | − | − | + | + | + | + | + |
| Group XI. Gel. not liquef.-Milk alkaline | 29 | + | − | ± | − | + | + | − | − | − | − | + | + | + | + | + |
| Group XII. Gel. not liq.-Milk amphoteric | 30 | + | − | ± | − | + | + | − | − | − | − | + | + | + | ± | + |
| Group XIII. Chromogenic Bacilli | | | | | | | | | | | | | | | | |
| Red | 1 | + | − | + | − | + | + | − | − | + | + | + | + | + | + | + |
| | 2 | + | − | − | − | + | + | − | − | + | − | + | + | + | + | − |
| | 2 | + | − | − | − | + | + | − | − | + | − | + | ± | − | − | − |
| Orange | 4 | + | − | + | − | + | + | − | − | − | + | + | − | + | + | + |
| | 3 | + | − | − | − | + | + | − | − | − | − | + | + | + | − | − |
| Yellow liquefying | 6 | + | − | ± | − | + | + | − | − | − | + | + | ± | ± | ± | ± |
| Lact. erythrogenes | 1 | + | − | − | − | + | + | − | − | − | + | + | + | + | + | + |
| Group XIV. Chromogenic Cocci | | | | | | | | | | | | | | | | |
| Yellow liquefying | 1 | − | − | − | − | − | + | − | − | − | + | + | + | + | + | − |
| | 5 | − | − | − | − | − | + | − | − | − | + | + | + | + | + | ± |
| Yellow non-liquefying | 3 | − | − | − | − | + | + | − | − | − | − | + | + | | | − |
| Pink | 5 | − | − | − | − | + | + | − | − | − | − | + | + | − | − | − |
| Group XV. Non-chromogenic Cocci | | | | | | | | | | | | | | | | |
| Liquefying | 8 | − | − | − | − | ± | + | − | − | − | + | ± | ± | + | ± | ± |
| Non-liquefying | 27 | − | − | − | − | ± | + | − | − | − | − | + | + | + | + | ± |
| Group XVI. Sarcinae | | | | | | | | | | | | | | | | |
| Yellow | 1 | − | − | − | − | + | + | − | − | − | − | + | + | + | − | − |
| White | 2 | − | − | − | − | − | + | − | − | − | − | + | + | + | + | + |
| Group XVII. Streptococci | | | | | | | | | | | | | | | | |
| Liquefying | 1 | − | − | − | − | − | − | − | − | − | − | + | + | | | |
| Non-liquefying | 3 | − | − | − | − | − | + | − | − | − | − | + | + | | | + |

| BIOLOGY | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biochemical Features | | | | | | | | | | | | | | | | | | |
| | | | Liquefaction | | | Gas production | | | | | Milk | | | | Nutrient agar tubes | |
| Grows at body temperature | Facultative anaërobe | Affected by range of reaction | Gelatin | Casein | Blood serum | Dextrose broth | Lactose broth | Saccharose broth | Nitrate reduced | Indol produced | Curdled | Acid | Alkaline | Fecal odour | Chromogenesis | Fluorescence |
| + | + | + | − | − | − | + | + | + | ± | ± | + | + | − | ± | − | − |
| + | + | + | − | − | − | + | + | − | ± | ± | + | + | − | ± | − | − |
| + | + | + | − | − | − | + | + | + | ± | + | + | + | − | ± | − | − |
| + | + | + | − | − | − | + | + | − | ± | ± | + | + | − | ± | − | − |
| + | + | + | − | − | − | + | + | ± | ± | ± | + | + | − | ± | − | − |
| + | + | + | + | + | + | + | − | + | ± | ± | + | + | − | ± | ± | − |
| + | + | + | ± | ± | ± | + | − | + | ± | ± | ± | + | − | ± | ± | − |
| + | + | + | ± | ± | ± | + | ± | + | ± | ± | + | + | − | ± | − | − |
| + | + | + | − | + | + | + | − | − | ± | ± | − | − | + | ± | − | − |
| + | ± | + | + | + | + | − | − | − | ± | ± | + | + | − | ± | − | + |
| ± | − | + | − | + | + | − | − | − | ± | ± | − | − | + | ± | − | + |
| + | − | + | + | + | ± | − | − | − | + | − | + | + | − | − | − | − |
| + | − | + | + | + | + | − | − | − | + | − | ± | + | − | − | − | − |
| + | − | + | + | + | + | − | − | − | + | − | + | + | − | − | brown | − |
| + | − | + | + | + | + | − | − | − | + | − | + | + | − | − | rose | − |
| + | − | + | + | + | + | − | − | − | − | − | + | − | + | − | yellow | − |
| + | | + | + | + | | − | − | − | + | − | − | − | + | − | − | − |
| + | | | − | − | | − | − | − | | − | − | − | + | − | − | − |
| + | + | − | + | + | + | − | − | − | ± | ± | ± | + | − | − | − | − |
| + | + | − | + | + | + | − | − | − | ± | ± | + | − | + | − | − | − |
| ± | + | − | + | + | + | − | − | − | ± | ± | − | − | + | − | − | − |
| + | + | − | − | − | − | − | − | − | ± | ± | ± | + | − | − | − | − |
| + | + | − | − | ± | − | − | − | − | ± | − | − | − | + | − | − | − |
| ± | + | − | − | − | − | − | − | − | − | − | − | − | − | − | − | − |
| + | + | + | + | + | − | − | − | − | + | − | + | + | − | − | red | − |
| + | − | + | + s | − | − | − | − | − | − | − | − | − | + | − | red | − |
| + | − | − | + | − | − | − | − | − | + | − | − | − | + | − | red | − |
| + | − | − | + | + | − | − | − | − | − | − | + | + | − | − | orange | − |
| + | − | | + | + | − | − | − | − | − | + | + | + | − | − | orange | − |
| + | + | + | ± s | + | − | − | − | − | ± | − | ± | − | ± | − | yellow | − |
| + | + | + | + | + | − | − | − | − | − | − | − | − | + | − | yellow | + red |
| + | | + | + r | − | − | − | − | − | − | − | − | − | + | − | bright yel. | − |
| + | − | + | + | + | − | − | − | − | + | ± | + | + | − | − | yellow | − |
| + | | | − | + | − | − | − | − | | | − | − | + | − | yellow | − |
| + | − | − | − | + | − | − | − | − | + | − | − | − | + | − | pink | − |
| + | ± | ± | + r | ± | − | − | − | − | − | − | + | + | − | − | − | − |
| + | ± | ± | − | ± | − | − | − | − | − | − | − | − | + | − | − | − |
| + | | − | + s | + | + | − | − | − | − | − | − | − | − | − | yellow | − |
| + | − | − | − | − | − | − | − | − | + | + | − | − | + | − | − | − |
| + | | | + | + | − | − | − | − | − | − | + | + | − | − | − | − |
| + | | | − | − | − | − | − | − | − | − | ± | + | − | − | − | − |

from the 'Journal of Hygiene,' vol. iii. part 1, and by its aid many of the organisms found in potable waters can be identified with sufficient accuracy to enable them to be referred to one or other of his groups. The first column gives the number of times organisms belonging to the various groups were found in 543 samples of river water collected in Illinois. Unfortunately he does not include several tests which we now regard as important, and includes several others which are of minor importance; but the table will probably serve a useful purpose, as other observers may compare their results with his and extend it either by the addition of new groups or by effecting subdivision in the present groups. It seems probable that Nos. 1, 5, 6, 8, and 11 in the table on page 361 would belong to his first group, and Nos. 2, 3, 4, 7, 9, and 12 to his second group, whilst No. 10 is probably the B. cloacæ of the third group.

ORGANISMS FERMENTING LACTOSE AND PRODUCING RED COLONIES ON BILE SALT, AGAR, NEUTRAL RED MEDIA

ISOLATED FROM 9 SEWAGES AND 36 WATERS

| Group to which organism belongs | No. of times found in sewage | Milk | | Glucose neutral red agar | | Gelatine. Liquefaction | Indol | Motility | No. of times found in water |
|---|---|---|---|---|---|---|---|---|---|
| | | Acid | Curd | Gas | Fluor. | | | | |
| The coli groups: | | | | | | | | | |
| A | 10 | + | + | + | + | − | + | + | 12 |
| A′ | 10 | + | + | + | − | − | + | + | 16 |
| B | 0 | + | + | + | − | − | − | + | 3 |
| B′ | 0 | + | − | + | + | − | + | + | 1 |
| B″ | 0 | + | − | + | − | − | + | + | 4 |
| C | 0 | + | − | + | − | − | − | + | 2 |
| B. lactis aërogenes group | 5 | + | + | + | + | − | + | − | 7 |
| „ „ | 5 | + | + | + | − | − | + | − | 7 |
| „ „ | 1 | + | + | + | + | − | − | − | 0 |
| „ „ | 0 | + | + | + | − | − | − | − | 1 |
| Liquefy gelatine. Proteus group | 0 | + | + | + | − | + | + | + | 0 |
| „ | 1 | + | + | + | + | + | − | + | 0 |
| „ | 1 | + | + | + | + | + | + | + | 0 |
| „ | 1 | + Digested | | + | + | + | + | + | 0 |
| „ | 1 | + | + | + | + | + | − | − | 1 |

None of the organisms retained Gram's stain.

The members of the bacillus coli group 'A' were alone found in every sample of sewage and of polluted water. The next in order of frequency were the members of the B. lactis aërogenes group, which corresponded with the B. coli group 'A' in all respects save that of motility. That organisms capable of liquefying gelatine should be so rarely found is probably due to the selective action of the bile salt medium.

In an extended series of examinations of nine samples of sewage and thirty-six samples of water, the organisms isolated which were capable of fermenting lactose gave the results which are tabulated on page 364. The fact that about half the bacilli which corresponded to the B. coli communis reduced neutral red, whilst the other half did not, led me to discard the use of the neutral red test in the routine examination just described.

## G. The Bacillus Typhosus

This organism is exceedingly difficult to detect in sewage-polluted waters; some assert that in the present state of our knowledge its isolation from such a water is impossible. The cases recorded in which it has been detected in water supplies are all open to doubt, since the characteristics given of the organism isolated would not now permit of the bacillus being definitely regarded as the true B. typhosus. In all fluid media as yet suggested other organisms of intestinal type appear to grow more luxuriantly than the typhoid bacillus. I am constantly examining waters believed to have conveyed the infection of typhoid fever, but have never succeeded in satisfying myself that the specific organism was present. When a little broth containing the B. typhosus has been added to a good potable water, there has been little difficulty in detecting the organism for days afterwards, but if added in small amount to a sewage-polluted water I have invariably failed to isolate it later.

In polluted waters the B. typhosus must always be associated with a relatively large number of organisms of the intestinal type, and with many belonging to the coli groups. It may possibly therefore be detected by the following methods:

1. Mix 50 or 100 c.c. of the water with the requisite quantity of the concentrated bile salt glucose broth, and incubate for 24 hours at 37° C.

2. If acid and gas are produced, make a series of the bile salt lactose agar plates, and upon each spread a little of the

highly diluted turbid liquid. Incubate at 37° C. for twenty-four hours, and search amongst the colonies for those which are colourless and around which the medium has an increased transparency and a pale orange tint.

3. Inoculate a tube of litmus lactose solution from each such colony, and after incubation at 37° C. for twenty-four hours reject all those showing signs of gas production. The growths in the other tubes may be submitted to the following further tests :

4. Examine in the hanging drop for motility, size, &c.

5. Stain by Gram's method. The organism should not retain the stain.

6. Incubate a tube of litmus glucose broth and keep for twenty-four hours at 37° C. Acid should be produced, but no gas.

7. Incubate a tube of litmus milk. After several days' incubation little acid should be produced, and the milk should not clot.

8. Inoculate a tube of neutral red agar. No fluorescence should be produced.

9. Inoculate a peptone solution. No indol should be formed.

10. Make a streak gelatine culture. The growth should have no tendency to liquefy the gelatine, but should be dry, translucent, and greyish yellow.

11. Make a potato streak culture. The growth should be delicate, creamy, forming an almost invisible layer.

12. Finally apply the agglutination test, using the anti-typhoid serum of an immunised animal. The growth used should be taken from an eighteen to twenty-four hours' culture on agar, and the reaction be observed with a serum dilution of at least 1 to 50. If a stronger serum is required to cause agglutination, the reaction has no value for diagnostic purposes.

### H. The Bacillus Enteritidis of Gaertner

This organism may be sought for by a method similar to that described for the detection of the B. typhosus.

1. Since it produces both acid and gas in the bile salt glucose broth, and always occurs associated with other organisms of this group, it will have to be differentiated from these latter by the character of the growth on the lactose agar plate, made from the fermenting glucose broth.

2. The enteritidis colonies will be colourless and free from haze in the surrounding medium. All such colonies must be submitted to the series of tests 3 to 11, described on the previous page. The results should be as follows:

3. Gas not produced in the litmus lactose solution. If gas is formed the examination need not be carried further.

4. The organism is motile and shows no signs of bearing spores.

5. It does not stain by Gram's method.

6. Fermentation takes place in the glucose broth with the production of acid and gas.

7. The milk will not be curdled, and though at first an acid reaction may be observed, on the second or third day the milk will become alkaline.

8. Fluorescence is produced in the neutral red medium.

9. No indol will be formed in the peptone solution.

10. The growth on gelatine will resemble that of the B. coli communis, and the medium will not be liquefied.

11. The growth on potato will be translucent and colourless.

12. To make the results absolutely conclusive, an agglutination test should be applied if a suitable serum is available.

This organism appears to have been met with by Jordan in the waters of the Illinois rivers. Compare group 4 in Jordan's table.

Drs. Grünbaum and Hume recommend a medium which may prove useful in searching for the B. typhosus and B. enteritidis Gaertner in the presence of organisms of the coli groups.

They find that a lactose agar to which both neutral red and 'Krystall-violett' (1–100000) have been added permits of a

striking double stain of the colonies. B. coli is red, but B. typhosus and the B. enteritidis Gaertner are blue to purple. This effect is better seen after forty-eight hours than after twenty-four. The most typical plates are, of course, obtained when a known mixture of two bacteria—for example, B. coli and B. typhosus—is used.

### I. The Bacillus Choleræ Asiaticæ

There is little difficulty in detecting this organism in water to which it has been added, provided the examination is not delayed more than two or three days, but it is very different when a sewage-polluted water is being examined, especially if the contamination has taken place several days before.

Various methods of examining water for the presence of the cholera vibrio have been described, the more important being those of Metschnikoff and Sanarelli. The vibrio if present in a water must be associated with the bacillus coli communis and other organisms of the intestinal type; hence it would be useless searching for it if the latter organism were shown to be absent, or not relatively abundant. In the routine process of examination described in this work, the cholera bacillus, if present, would be contained in the growth in the bile salt glucose broth associated with the organisms producing acid and gas, although the vibrio itself only produces acid in this medium. Upon the lactose agar medium the colonies would be white surrounded by a clear halo, since Hellin states that in contact with air in a lactose medium it produces alkali. Colonies could be selected and lactose litmus solutions inoculated therewith, and those rejected which showed gas production. The growth in the other tubes could be used for inoculating tubes of peptone solution. After incubation for twenty-four hours at 37° C. a little pure sulphuric acid should be added, and if a red colour is developed the examination may be carried further, but if no colour is produced the tube from which the cultivation was made can be discarded.

This so-called cholera-red reaction is by no means peculiar to the cholera vibrio. I have on several occasions obtained the reaction when testing for indol production in examining for the B. coli communis.

The red coloration being produced, and the organism when examined in the hanging drop showing a resemblance to the cholera vibrio, make

1. A gelatine plate or streak culture.
2. A gelatine stab culture.
3. An agar slope culture, and
4. Inoculate a tube of litmus milk,

and compare the results with those described on page 167.

Koch says that the organism has no particular effect upon milk, but according to Hellin, as quoted by Lehmann and Neumann ('Bacteriology,' p. 359), 'in 10 c.c. of litmus milk the cholera vibrio forms a blue pellicle on the top, the following layer is red, the deepest part is decolorised (reduction); thus the formation of alkali is favoured by the entrance of oxygen, and the fermentation of sugar and formation of acid by anaërobiosis.' The agar growth should be tested with Pfeiffer's cholera serum. A positive reaction with the serum diluted 100 times is said to be positive proof that the organism is the B. choleræ asiaticæ. If a stronger serum is required to produce the reaction, the evidence is inconclusive.

Metchnikoff and Sanarelli both employed strong peptone gelatine solutions which they added to certain quantities of the water to be examined. Sanarelli's medium contained potassium nitrate whilst Metchnikoff's did not. The former's solution contained 20 per cent. of gelatine, 10 per cent. of peptone, 10 per cent. of sodium chloride, and 1 per cent. of potassium nitrate. Quantities of water varying from 100 to 500 c.c. may be examined by adding one twenty-fifth the volume of the sterilised gelatine solution, and incubating the mixture at 37° C. for twelve hours. In the presence of the cholera organism a pellicle forms over the surface of the water within the time

specified, and a loopful of this is transferred to a proper dilution of the gelatine medium with sterilised water and incubated for six hours only. From this a loopful is withdrawn and another similar solution inoculated. Finally, a little of this solution may be spread on agar plates, and the colonies resulting from the incubation examined for the production of cholera red. Those which give the reaction may be further examined as detailed on the previous page.

### J. Other Special Examinations

Occasionally bacteriological examinations may be conducted for other purposes than the discovery of sewage pollution, as in the three following examples which have recently occurred in my practice:

1. Two samples of water were submitted to me for examination. One (No. 1) was from a well about 30 feet deep, in a stable yard, supplying a mansion with water; the other (No. 2) from a similar well which had been discovered in the basement, and which had evidently at one time supplied the house, as various pipes were connected with it. The second well was discovered when relaying the drains; a drain was found near it, but it was in good condition. The soil around the well was removed and replaced by clean gravel and sand, and the well itself pumped dry and the sides thoroughly scoured. It was proposed to use this well water as the supply to the house, on account chiefly of its more convenient position.

The physical and chemical examination of the two waters gave the following results:

| Turbidity | No. 1. Quite bright. No deposit | No. 2. Very dull. A little earthy deposit |
|---|---|---|
| Colour | Very faint yellow | Yellow tint |
| Odour | None | None |
| Chlorine | 3·7 | 3·4 |
| Hardness | 17·2 | 18·6 |
| Nitrites | None | Trace |
| Nitric nitrogen | 1·98 | ·20 |
| Free ammonia | ·003 | ·068 |
| Organic „ | ·006 | ·032 |
| Oxygen absorbed in 3 hours 98° F. | ·088 | ·200 |

The bacteriological examination showed that in 5 c.c. of each there were organisms present capable of fermenting glucose in the presence of bile salt. The contents of these broth tubes were used for making dilutions with which MacConkey's agar neutral red medium was smeared.

No. 1 gave red colonies in twenty-four hours, and some of these gave all the reactions of the B. coli communis group, except the formation of indol.

No. 2 gave after forty-eight hours a number of minute colourless colonies not at all resembling those of the coli groups.

The filter brushings from 350 c.c. of No. 1 gave with milk the characteristic reaction of the presence of the B. enteritidis sporogenes of Klein.

The filter brushings from 350 c.c. of No. 2 gave no such reaction.

There could be no doubt therefore that No. 1, notwithstanding its considerable organic purity, contained organisms indicative of sewage or manurial pollution, though possibly not of recent character. The chemical results obtained with No. 2 strongly indicated sewage pollution, but this I was assured was impossible. The bacteriological results also tended to negative the assumption that the organic matter was due to sewage. A further bacteriological examination was therefore made.

A tube of bouillon to which a little potassium nitrate had been added was inoculated from the fermenting glucose broth and kept at 37° C. for twenty-four hours. It was then tested for nitrites, and found to contain so large a quantity that when 1 or 2 drops were added to 50 c.c. of water the test for nitrite, with starch, iodide, and acid, gave a most marked and instant reaction. The same result was produced when a nitrated broth was infected with a little of the original water.

A litre of good tap water containing about 1 part of nitric nitrogen per 100,000 was infected with 1 c.c. of the water, and to a second litre similarly infected were added 5 c.c of bouillon, and 250 c.c. of each were examined on four successive days.

The water containing no added organic matter remained

practically unchanged, whilst nitrites and ammonia developed rapidly in the one containing the broth. Obviously therefore this sample contained an organism capable of rapidly reducing nitrates to nitrites, and ammonia in the presence of organic matter, thus accounting for the presence of these substances in the water.

Although this water was almost certainly free from sewage pollution, I could not approve of its use for domestic purposes whilst in this condition. It remains to be seen whether the water will improve in character if the well is repeatedly pumped out.

2. In this case a well water showed signs of turbidity, and deposited a little red flocculent matter, giving it an unsightly appearance. The cause of this was to be investigated. The water was satisfactory bacteriologically, showing no signs of sewage pollution, and the report on the well showed that any such pollution was practically impossible. The chemical analysis showed the presence of a trace of iron, nitrites were absent, and it contained practically no free ammonia. The organic ammonia, ·054 part per 100,000 of water, proved that the water contained a considerable amount of organic matter.

The microscopical examination showed the presence of myriads of micrococci or spores and many filaments, suggestive of crenothrix. A portion of the water containing some of the red deposit was centrifugalised. The clear water was then poured off and the residue mixed with more sterile water and again centrifugalised. This process was repeated several times. A little of the washed deposit was then spread on sterilised potato, which had been moistened with an exceedingly dilute solution of ferric chloride. In a few days the whole surface of the potato was covered with a wrinkled reddish growth, which later became chocolate-coloured. Under the microscope this consisted of a mass of spores and hyphæ. A trace was added to a little water containing ferrous carbonate and incubated. A flocculent growth occurred within a few days, resembling in all respects that found originally in the water.

There was no doubt the water, containing organic matter and a trace of iron, had become infected with a crenothrix, and to this the unsightly appearance was due.

3. In this case, which occurred recently, I had to examine a water with a decided odour of sulphuretted hydrogen, derived from a source apparently free from the possibility of sewage pollution, and which on chemical and bacteriological examination gave no indications of such contamination.

Two c.c. of this water were added to a tube of gelatine, containing a small quantity of solution of tartrated iron and incubated at 20° C. After several days the gelatine blackened from below upwards, indicating the presence of some organism capable of producing sulphuretted hydrogen. The bacillus isolated appeared to be the bacillus fluorescens.

## CHAPTER XVIII

### THE MICROSCOPICAL AND BIOLOGICAL EXAMINATION OF A POTABLE WATER

THE examination of the sample of the water in the long tube to ascertain its colour will almost certainly have shown whether it contained any suspended matter. Sometimes, however, the visible particles are so few that they can only be discovered by examining the water in bulk by bright transmitted light. This is a simple matter if the sample is contained in a large bottle of colourless or but slightly coloured glass. If the water has been delivered in a bottle of dark glass or of earthenware, it is desirable to transfer it to a white glass bottle for the purpose of examination. The following incident will show the importance of this procedure. A few years ago I examined a sample of deep well water and found in it a few algal filaments. I expressed the opinion that some surface water was trickling into the well, or that there was some defect in the service reservoir. A sample was sent to another analyst, who reported that the water was free from any vegetable growth. Chemically the water was of excellent quality. A little later the water became visibly affected by this algoid growth, which was found to be due to an imperfection in the roof of the reservoir, allowing light to gain access. Soon afterwards I received a letter from the other analyst saying that by accident the dark glass bottle which had contained the sample submitted to him had been broken, and that on examining it he had found the sides covered with a green confervoid growth.

A minute deposit may often be discovered by carefully examining the bottom of the containing vessel after it has

stood at rest all night. As a matter of routine, any deposit of this kind should be examined microscopically. Occasionally also a chemical or micro-chemical examination is indicated, as, for example, when the deposit resembles ferric hydrate.

In these cases the deposit may appear to be dissolved upon the addition of a little dilute acid, but such deposits, especially if flocculent in character, are very often associated with fungoid growths, and the latter may easily be overlooked if not carefully sought for.

As a rule, it suffices to fill a conical test glass with the water and set it aside for twenty-four hours, when the larger organisms and other matters in suspension will settle upon the sides and bottom of the glass. By carefully siphoning off the supernatant clear liquid the suspended matter is concentrated into a very small volume of water, and droplets can be removed for examination under a low power of the microscope. For this purpose hollow ground slides are very useful. When it is desired to preserve such deposits for future examination, they can be preserved in a solution of cupric chloride, &c., in camphor water. (*Vide* Formula No. 47.) To collect the organisms from water passing through mains, a small bag of fine linen may be tied over the mouth of a tap, which is then left running for a period. When the bag is removed it is turned inside out and gently immersed in a small quantity of water to remove all the organisms. Or a piece of fine linen may be tied over the small end of a funnel and a quantity of water passed through. The linen is then removed, and by blowing through it the deposit can be blown upon a slide and examined

The following is the method which I recommend for the collection of suspended matter in potable waters. It requires the use of 'hardened' filter paper in sheets about 3 inches in diameter. A piece of this paper is folded, fitted in a funnel, and the latter connected with a filter flask and exhausting arrangement. The water to be examined is measured in a flask with a long narrow neck. This is inverted with the neck within the cone

of filter paper, and filtration continued until all the water has passed through. By aid of a wash-bottle containing filtered water the deposit on the filter paper is washed into a small tube drawn out to a point at the end, and the tube introduced into a hand centrifuge. The deposit is thus obtained at the point of the tube, and an idea can be formed of its quantity; it can then be transferred to a slide for examination under the microscope.

Mr. Dibdin prefers to use a method of collecting the deposit formed on the sides of the filter paper which admits of the amount of sediment being expressed numerically. He draws out the end of a piece of combustion tubing until the capillary portion has an internal diameter of 2 mm. The end of this is plugged with a paste of clay and Kieselguhr, and heated to redness to 'set' the mixture. The filter deposit is washed into this tube, and filtered out by the Kieselguhr plug, the process being accelerated by the use of the filter pump. When only a drop of the water remains in the micro-filter the length of the deposit can be measured. The end of the capillary tube can be cut off, and the deposit blown out upon a slide for examination.

In any process of filtration the filter paper must be previously rinsed with filtered water, and be kept covered while the water is passing through. With very clear waters a litre or more may be required to furnish any visible deposit, but 250 to 500 c.c. suffice with most waters submitted to examination.

There is a difficulty sometimes in removing the deposited matter for examination without damaging many of the organisms so as to render their recognition impossible. Probably the best quantitative as well as qualitative method is that widely used in America and known as the Sedgwick-Rafter method. The following description is taken from Rafter's little work on 'The Microscopical Examination of Potable Water.'

The bottom of a funnel is plugged with wire cloth, and upon this is placed about half an inch of clean coarse sand. This is

lightly pressed with a glass rod, and from 20 to 40 c.c. of freshly filtered water allowed to run through, to ensure the settling of the sand. The amount of water to be filtered is gauged by the number of organisms which it contains, as ascertained by a preliminary inspection. Generally, however, as large a quantity should be used as can be conveniently filtered without clogging the sand so much as to render the completion of the process too prolonged. For all ordinary purposes 500 c.c. suffice. The first 100 or 150 c.c. passed through are returned to the funnel. After all the water has passed through, the wire cloth is removed, and the sand and contained organisms washed with 5 c.c. of freshly filtered water, run from a 5 c.c. pipette into a 5 or 6 inch test-tube. The test-tube is slightly shaken to wash all the organisms clear from the sand, the latter from its greater specific gravity sinking quickly to the bottom, leaving the organisms distributed through the water. At the instant of the completion of the settling of the sand the supernatant water is turned into another smaller test-tube, leaving the clean sand at the bottom of the first tube. The organisms from 500 c.c. of water are now concentrated in 5 c.c. After slight stirring to secure uniform distribution 1 c.c. is transferred by means of a pipette to a specially prepared cell of $50 \times 20$ mm. area and of exactly 1 mm. in depth. Such a cell of course just holds 1,000 cubic mm. or 1 c.c. The top of the cell (preferably the sides should be constructed of metal) is ground perfectly smooth, and a cover-glass, thoroughly cleaned and moistened, is placed over it, by sliding gently from one end. With a little practice this can be done without enclosing any air-bubbles or losing a drop of the liquid.

For the purpose of enumeration, an eye-piece micrometer is required, so ruled as to cover, with a given objective and fixed tube length, a square millimetre on the stage. The mechanical stage recommended has a precise millimetre movement, so that the position of the squares counted is definitely known. This movement is insisted upon as an integral part of

the method. Rafter recommends that about 50 squares should be counted. The working objective for these counts may be either a two-thirds or a one-half inch. In certain cases for identification purposes a higher power may be required.

The amorphous organic matter is estimated 'mentally,' a unit of area being 20 square microns.

The following table shows how the results are tabulated:

Number of Organisms per c.c.

| Source of sample | Spring | Lake waters of medium quality | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Sponge spicules | 0 | 0 | 1 | 1 |
| Rhizopods | 1 | 0 | 1 | 0 |
| Infusoria | 0 | 21 | 50 | 16 |
| Rotifera | 0 | 3 | 6 | 1 |
| Crustacea | 0 | 0 | 1 | 0 |
| Total animals | 1 | 24 | 59 | 18 |
| Desmidieæ | 0 | 3 | 4 | 5 |
| Diatomaceæ | 8 | 19 | 45 | 50 |
| Zoospores | 26 | 244 | 88 | 2400 |
| Chlorophyceæ | 0 | 55 | 13 | 1 |
| Cyanophyceæ | 0 | 157 | 110 | 0 |
| Fungi | 0 | 0 | 0 | 0 |
| Total plants | 34 | 478 | 260 | 2456 |
| Amorphous matter | 165 | 238 | 230 | 45 |

An expert biologist who has made a special study of organisms found in water may venture to name most of those found in potable waters, but it is impossible even for an expert to recognise all the forms. There is no doubt that many fresh-water algæ, for example, exhibit very different forms during their life-histories, and many forms now bearing distinct names are really the same organism at different stages of its existence.

Those who wish to make a special study of these low forms of vegetable and animal life must consult the most exhaustive treatises on this class of organism. The best probably are—

Cooke's 'British Freshwater Algæ, exclusive of the Desmidieæ and Diatomaceæ.'

Cooke's 'British Desmids.'

Smith's 'Synopsis of the British Diatomaceæ.'

De Barry's 'Comparative Morphology and Biology of the Fungi Mycetozoa and Bacteria.'

Baird's 'Natural History of the British Entomostraca.'

Hudson and Gosse's 'The Rotifera.'

Allman's 'Freshwater Polyzoa.'

Kent's 'Manual of the Infusoria.'

Whipple's 'The Microscopy of Drinking Water.'

The best single work covering the whole ground is undoubtedly the 'Anleitung zur Untersuchung des Wassers, mit besonderer Berücksichtigung von Trink- und Abwasser,' by Dr. C. Mez, Professor at the University of Breslau. A very useful work, with the advantage of being in English, is Dr. MacDonald's 'Guide to the Microscopical Examination of Drinking Water.'

The objects seen under the microscope can be divided into five groups :

1. Mineral matter.
2. Dead vegetable matter.
3. Dead animal matter.
4. Living vegetable organisms.
5. Living animal organisms.

The mineral matter as a rule admits of easy identification.

If the presence of chalk is suspected, a little dilute hydrochloric acid may be run under the cover-slip, when the particles of chalk will be seen to dissolve, giving off bubbles of gas. If oxide of iron is present, a droplet of solution of potassium ferrocyanide may be passed under the cover-slip after the acid, when the presence of iron will be revealed by the production of a blue colour. Particles of clay and sand will be unaffected by these tests.

Dead vegetable matter is often difficult to recognise, but usually some cell or fibre will have escaped complete disintegration and thus aid in its identification. Dead animal

matter is as a rule more readily recognised, as destruction by maceration is rarely so complete as to obscure the origin of the débris.

The differentiation of animals from plants is frequently exceedingly difficult, if not impossible, in the lower forms of life. The presence or absence of organs of locomotion is not always reliable for the differentiation, as many algæ in certain stages of their existence possess flagella, whilst other organisms, which on physiological grounds must be classed as animals, either are motionless or requires prolonged observation to detect their motility.

Search should be made for the animal and vegetable growths, the presence of which has special significance. The more important of these are described in Chapter IX. and are illustrated on one or more of the plates in this section.

A careful study of the following illustrations of deposits found in waters from various sources will, when taken in connection with the descriptions of the sources from which they were derived, suffice for most practical purposes to enable an observer to draw reliable conclusions as to the source of the suspended matter found in a water, and this is the utmost which can be attempted by anyone who has not made a prolonged and systematic study of the lower forms of animal and vegetable life.

# PLATES

## PLATE I

The forms shown on this plate were contained in a sample of water from a stream on Dartmoor which was used in its unfiltered condition for the supply of a small town. After heavy rains the town supply contained visible particles, sufficient in number to cause complaints to be received from the consumers. The nature and the source of the deposit found in the water were submitted to me for investigation. I examined a sample of the water from the stream feeding the reservoir supplying the town, and afterwards the water which came from the mains during a period of heavy rainfall.

The deposit from the brook water contained a number of organisms, vegetable débris, &c., characteristic of water from such sources.

1. Vegetable débris—remains of cells, fragments of diatoms.
2. Staurospermum viride. F.W.A.[1] N.O. Zygophyceæ.
3. Lemanea torulosa. F.W.A. N.O. Lemaneaceæ.
4. Desmid. F.W.A. Species of Penium.
5. Pleurococcus. F.W.A. N.O. Palmellaceæ.
6. Dead form of 3. Cells plasmolysed.
7. Ulothrix tenuis. F.W.A. N.O. Ulotricheæ.

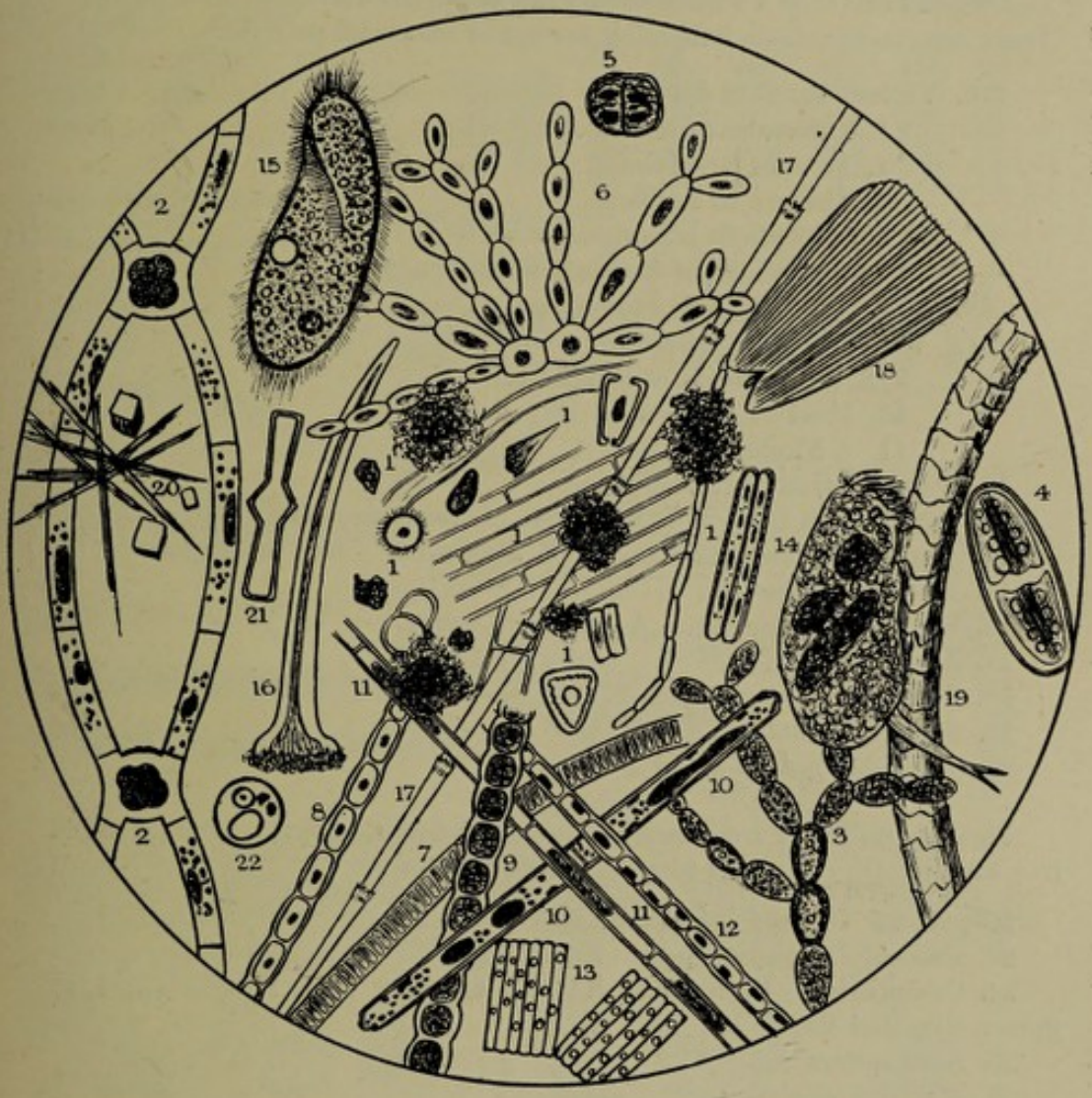
8–12. Various forms of algal filaments. 9 is evidently a species of Ulothrix. 10 was motile.

13. Diatom. F.W.A. Sub-family Fragilarieæ.
14. A rotifer or wheel animalcule. Animal of sub-kingdom Annuloida.
15. Paramœcium (Nassula?). S.K. Protozoa. Class Infusoria.
16. An animal spine.
17. Hair of insect.
18. Wing scale of insect.
19. Fibre of wool.
20. Crystal; probably calcium sulphate.
21. Skeleton of a diatom.
22. Not identified. Free swimming, but no visible cilia.

All magnified 500 diameters.

[1] F.W.A. = Freshwater Algæ.

PLATE I



## PLATE II

The first twenty organisms on this plate were found in the water from the mains supplied by the reservoir referred to in Plate I. It is obvious that water from such a source should not be supplied without prior filtration. There are no organisms indicating sewage or manurial pollution.

1–6. Various kinds of desmids:
- 1. Euastrum pinnatum.
- 2. Penium Brébissonii.
- 3. Closterium Leibleini.
- 3*a*. Docidium hirsutum.
- 4 & 6. Species of Staurastrum.
- 5. Arthrodesmus convergens.

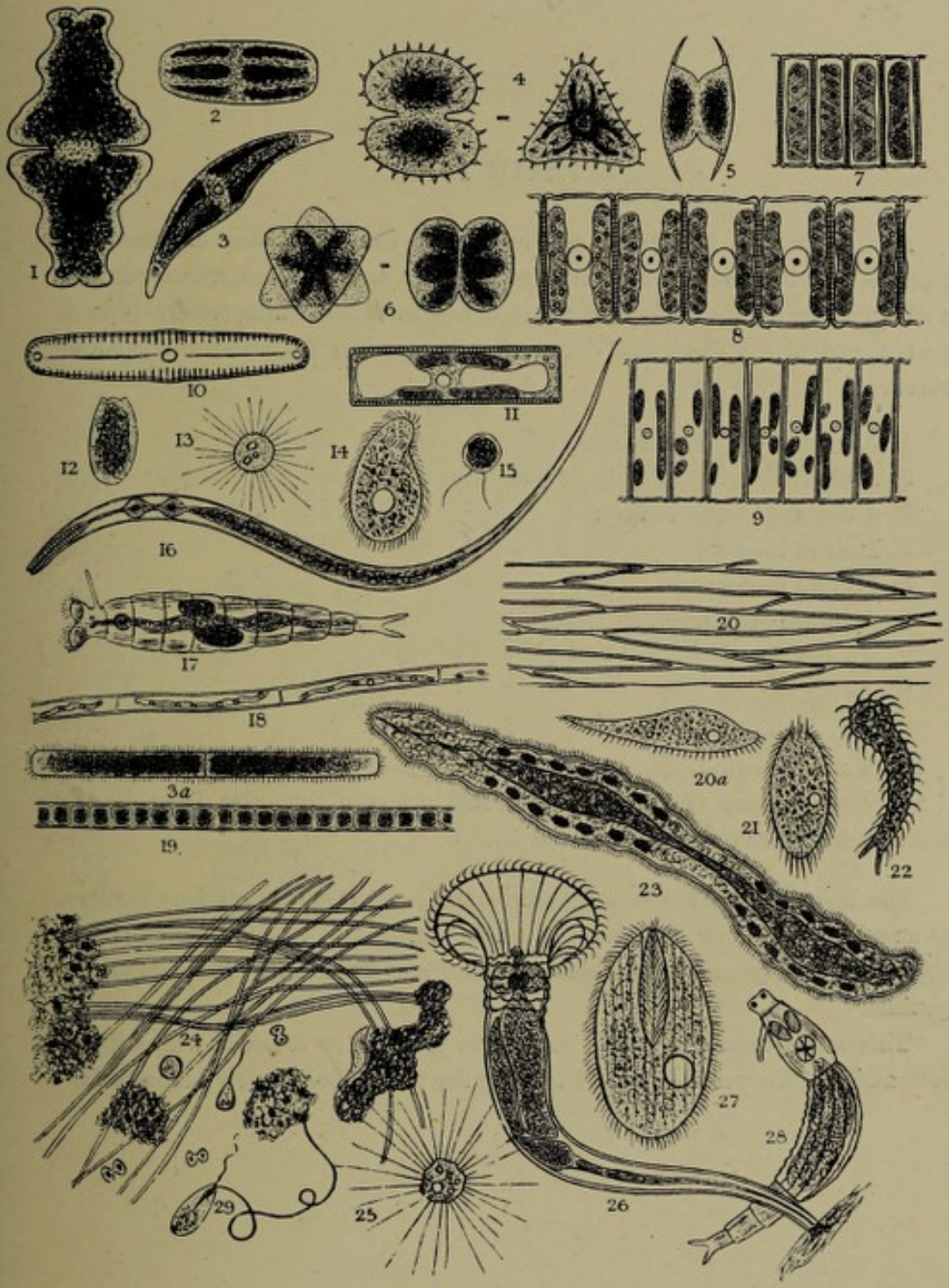
7–11. Various kinds of diatoms:
- 7, 8, & 9. Species of Fragilaria.
- 10. Dead Pinnularia.
- 11. A Pinnularia (?).

12. An infusorian in resting stage.
13. Actinophrys Sol. S.K. Protozoa. Class Rhizopoda.
14. A species of Paramœcium. S.K. Protozoa. Class Infusoria.
15. An algal zoospore.
16. Species of Anguillula. A nematode worm.
17. A rotifer.
18. Species of Mesocarpus. F.W.A.
19. Species of Ulothrix. F.W.A.
20. Vegetable tissue.

Figs. 20*a* to 29 are from another moorland water supply. All were found in a sample taken from the town mains (N. Wales).

20*a*, 21, 22. Ciliated animalcula.
23. Probably a spirostomum. N.O. Ciliata.
24. Crenothrix. (*Vide* Plate XVIII., Nos. 7*a*, 7*b*.) Fungus allied to Sphærotilus and Beggiatoa.
25. Actinophrys Sol.
26. A rotifer (Œcistes).
27. Large infusorian.
28. Rotifer with cilia withdrawn.
29. A small infusorian with long cilium, attached like a vorticella.

# PLATE II


1
2
3
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9
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12
13
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15
16
17
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3a
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20
20a
21
22
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24
25
26
27
28
29

## PLATE III

At a later date the water referred to in the description of Plate II., Nos. 20*a*–29, became quite green in appearance, and acquired, when warmed, a disagreeable odour. The water was found to be swarming with a pleurococcus, and to the death and decay of this organism I attributed the odour observed.

1. A desmid (Arthrodesmus).
2. Scale from wing of moth or butterfly.
3. A desmid (Ankistrodesmus).
4. Hair of insect.
5. Minute protozoon.
6. A ciliate infusorian.
7. An amœba.
8. As fig. 3.

9 & 11. Diatoms.

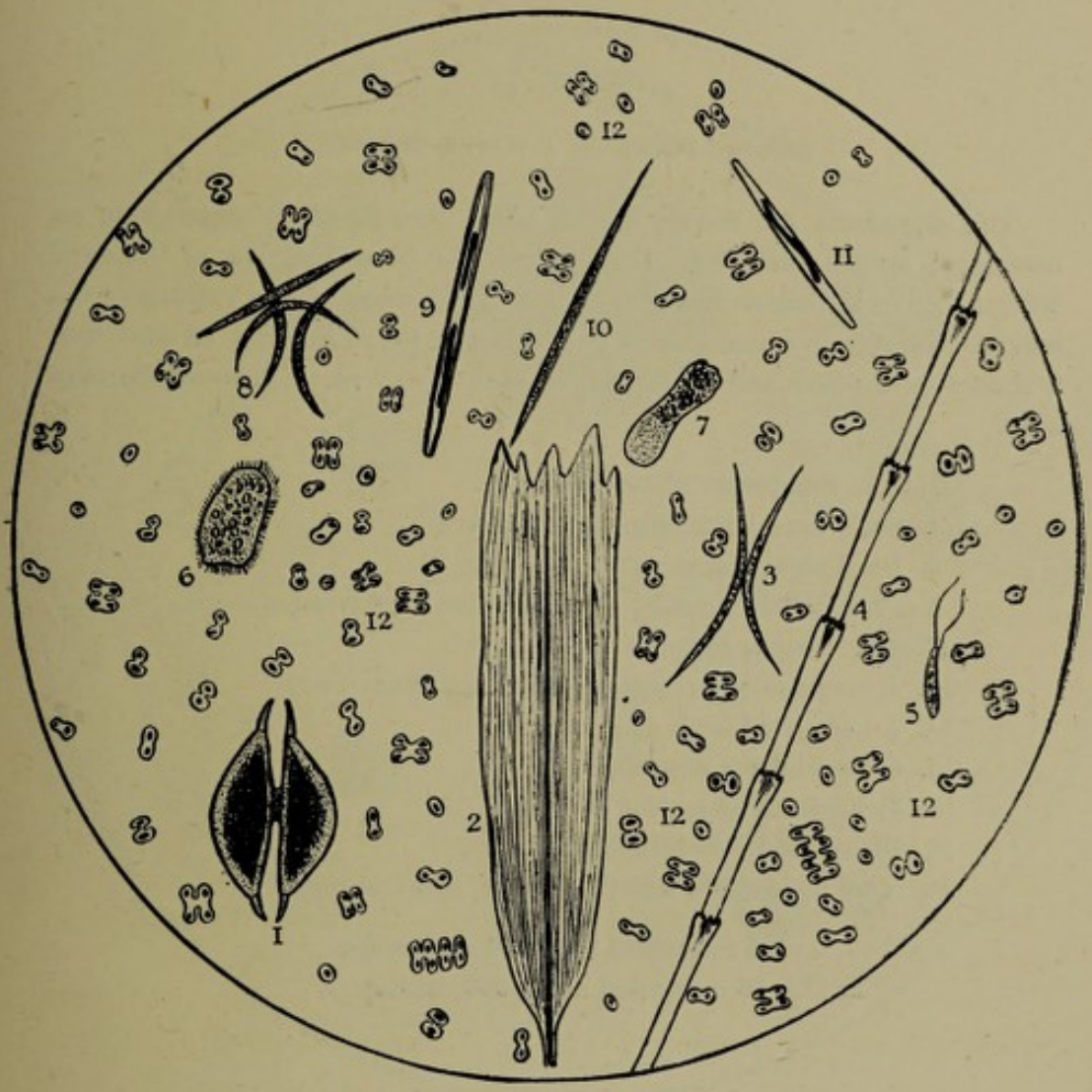
10. A small desmid.

12. Pleurococcus. The members of this genus of the order Palmellaceæ are very frequently met with in waters.

The description of the genus given by Cooke is: 'Cells gregarious, globose, or angular; single or associated in small families. Cell-contents green, or oily red. Multiplication by division in alternate directions. Propagation by gonidia.'

This water formed a green deposit in any jug or vessel in which it was left, and in glass vessels exposed to light the pleurococcus grew luxuriantly.

## PLATE III



## PLATE IV

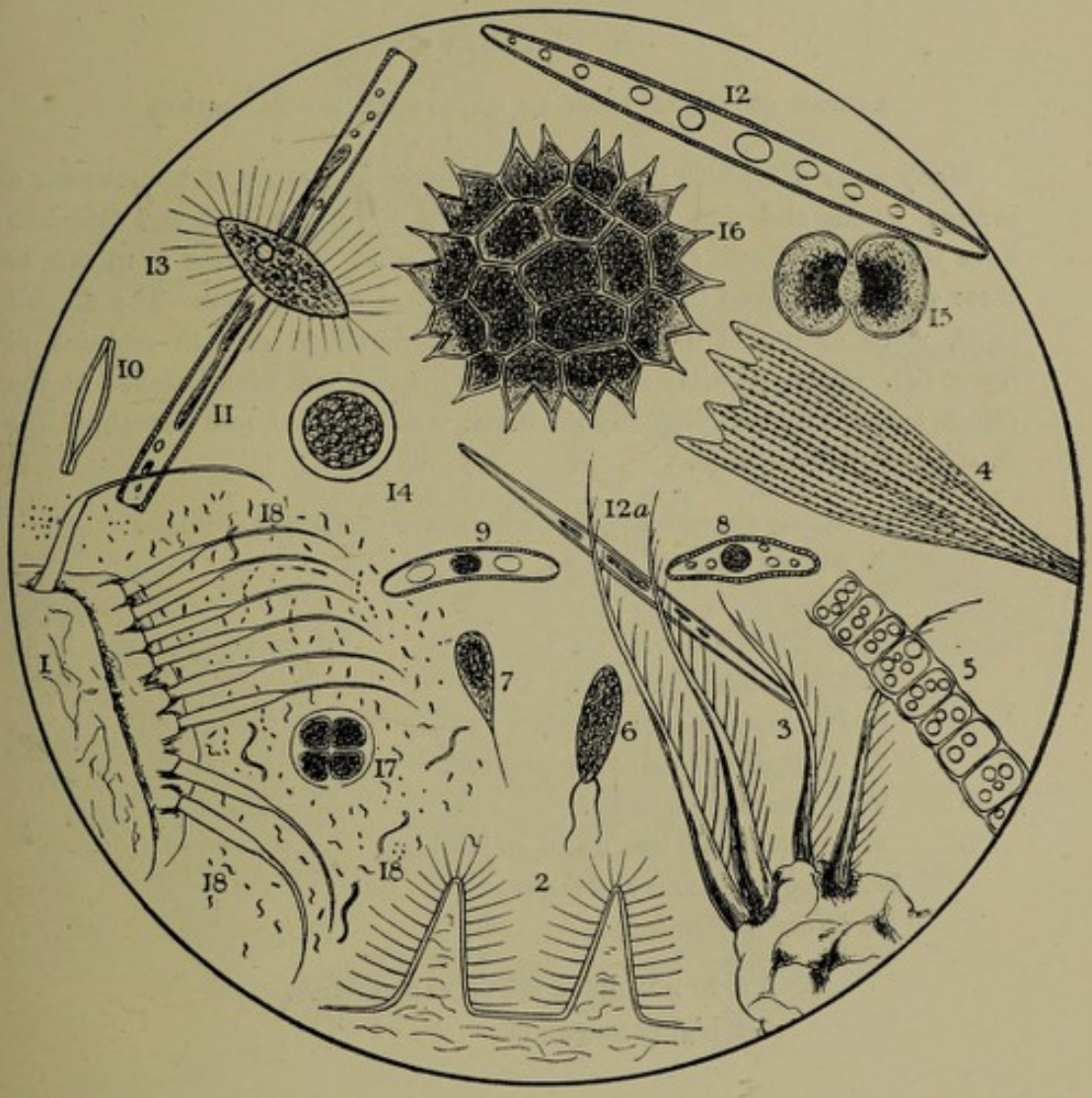
### DEPOSIT FOUND IN A WATER RESERVOIR

The organisms &c. shown in this plate were found in water from an uncovered service reservoir. Complaints had been received of 'insects' being found in the water drawn from the house taps. Upon examining the service reservoir an accumulation of débris was found in it. I advised that it should be covered and ventilated in such a way as to prevent access of light.

1, 2, 3. Fragments of animal tissue.
4. Scale from wing of moth or butterfly.
5. Dead algal filament.
6 & 7. Ciliated monads. S.K. Protozoa. Class Infusoria.
8–12*a*. Various diatoms.
13. A very active infusorian; probably Halteria.
14. An encysted form of infusorian.
15. Cosmarium (a desmid).
16. Pediastrum (discoidal desmid).
17. Pleurococcus undergoing division.
18. Various bacteria (spirilla, bacilli, and micrococci).

1–4 magnified about 50 diameters.
5–18 magnified about 500 diameters.

PLATE IV



## PLATE V

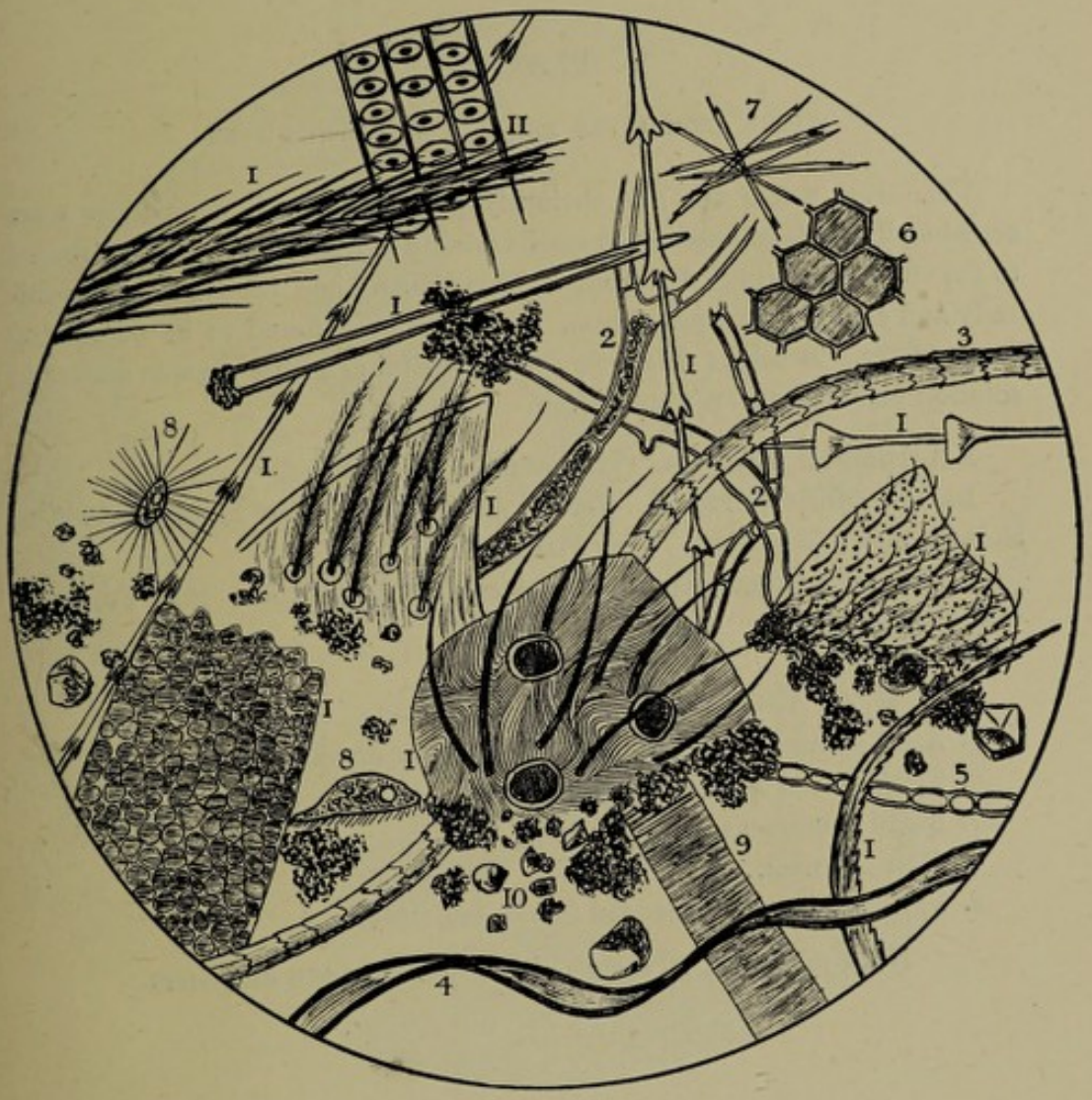
### SAMPLE OF WATER FROM AN UNCOVERED HOUSE CISTERN

Many cases of typhoid fever having occurred in a group of houses near a sewage works and dust shoot, the houses were examined and found to have small uncovered cisterns in the sculleries. The water from one of these cisterns was sent to me for bacteriological examination. The deposit in it, when examined microscopically, was found to contain remains of insect life. Quite possibly many of these insects had been hatched in the refuse heaps. Bacteriologically the water was very foul, and contained the B. coli in fair abundance.

1. Hairs, appendages, and wing-cases of various animals.
2. Fungal hyphæ.
3. Wool fibre.
4. Cotton fibre.
5. Dead algal filaments.
6. Portion of eye of insect.
7. Crystals of calcium sulphate.
8. A ciliate animalcule.
9. Probably the trachea of an insect.
10. Sand and mineral débris.
11. Wood of Conifer.

1 & 10 magnified about 50 diameters.
2–9 highly magnified.

PLATE V



## PLATE VI

### WATER FROM RIVER BELOW A SMALL DYE-WORKS

This river water was not obviously polluted, though complaints were occasionally made of unpleasant smells arising in the vicinity, and attributed to the effluent from the dye-works. This effluent had been treated chemically and contained a trace of iron. Crenothrix was found to be flourishing in the water. It occurs chiefly in water containing a little organic matter in solution together with a trace of iron.

1. Crenothrix polyspora. Tuft attached to dead leaf.

1*a*. Crenothrix polyspora. Portion of this fungus more highly magnified, showing spore formation. *Vide* Plate XVIII.

2. Probably an artodiscus without contractile vacuole. S.K. Protozoa. Class Rhizopoda.

3. An amœba.

4, 4*a*, 4*b*, 4*c*. Various diatoms.

5. Algal filament (Ulothrix). Cells in act of dividing.

6. Spiral vessel of flowering plant.

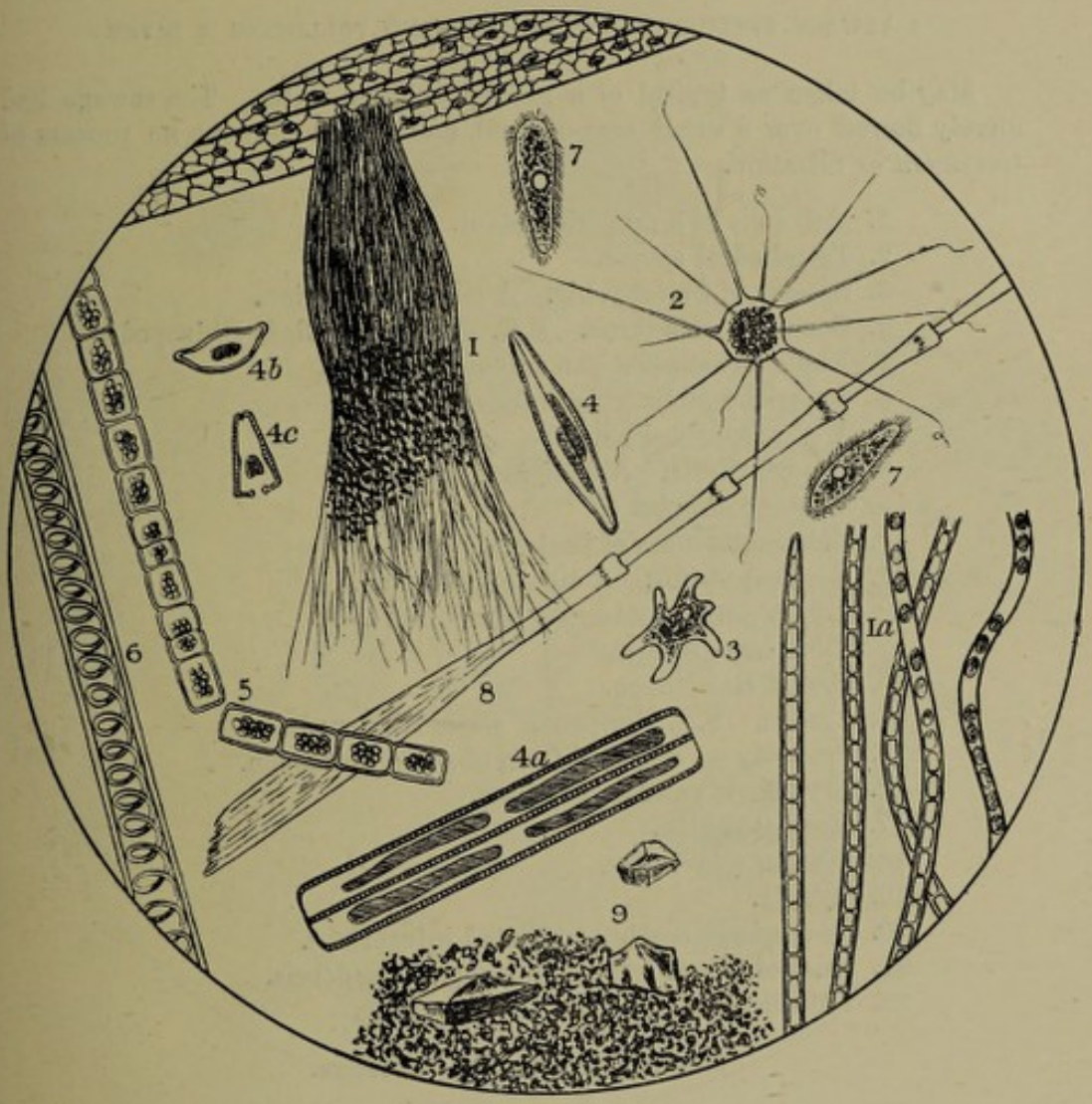
7. Small paramœcia.

8. Hair of insect.

9. Particles of sand embedded in vegetable débris.

No. 1 magnified 20 diameters, others about 500 diameters.

PLATE VI



## PLATE VII

### A SEWAGE EFFLUENT FLOWING INTO AND POLLUTING A RIVER

May be taken as typical of a grossly polluted water. The sewage had merely flowed over a small area of land, and had undergone no process of treatment or filtration.

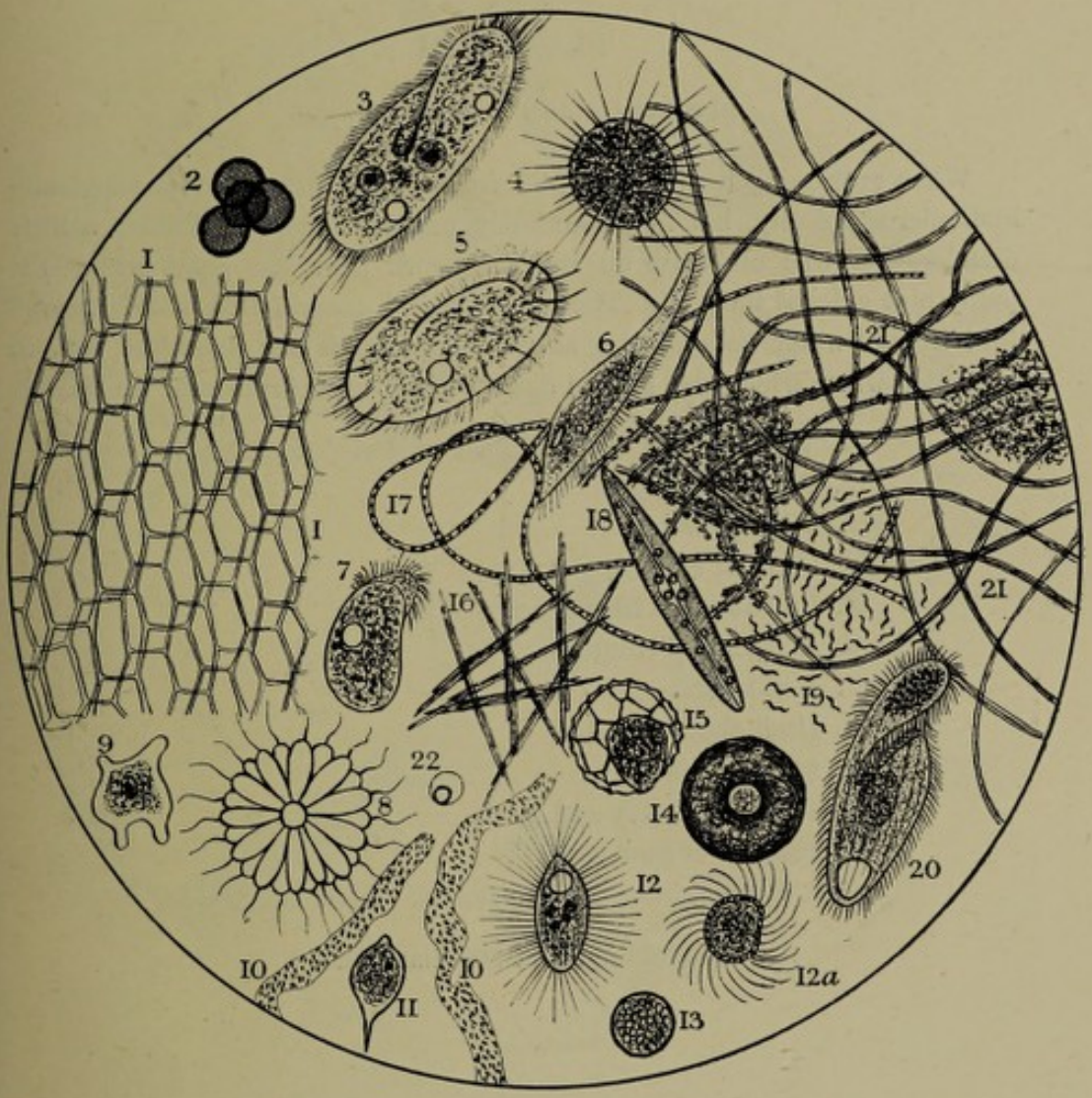
1. Pith cells of a flowering plant.
2. Tetrahedral spores.
3. Species of Stylonychia. A ciliate infusorian.
4. One of the Heliozoa. S.K. Protozoa. Class Rhizopoda.
5. Euplotes vannus. An infusorian.
6. Oxytricha gibba. An infusorian.
7. A ciliate infusorian.
8. Synura uvella. A confervoid alga.
9. A lobose amœba.
10. Gelatinous mass of bacteria.
11. Euglena viridis. A ciliate infusorian.
12. A very active infusorian (Halteria ?).

12*a*. The same at rest.

13. Egg of an entozoa.
14. Arcella. S.K. Protozoa. Class Rhizopoda.
15. Probably an encysted form of some protozoon.
16. Crystals of calcium sulphate.
17. Beggiatoa alba.
18. Diatom (Navicula).
19. Spirilla.
20. Leucophrys spathula (ciliated infusorian).
21. Mass of fungal hyphæ with vegetable débris.
22. ? Motile, with highly refractive spot.

Magnified about 500 diameters.

PLATE VII



## PLATE VIII

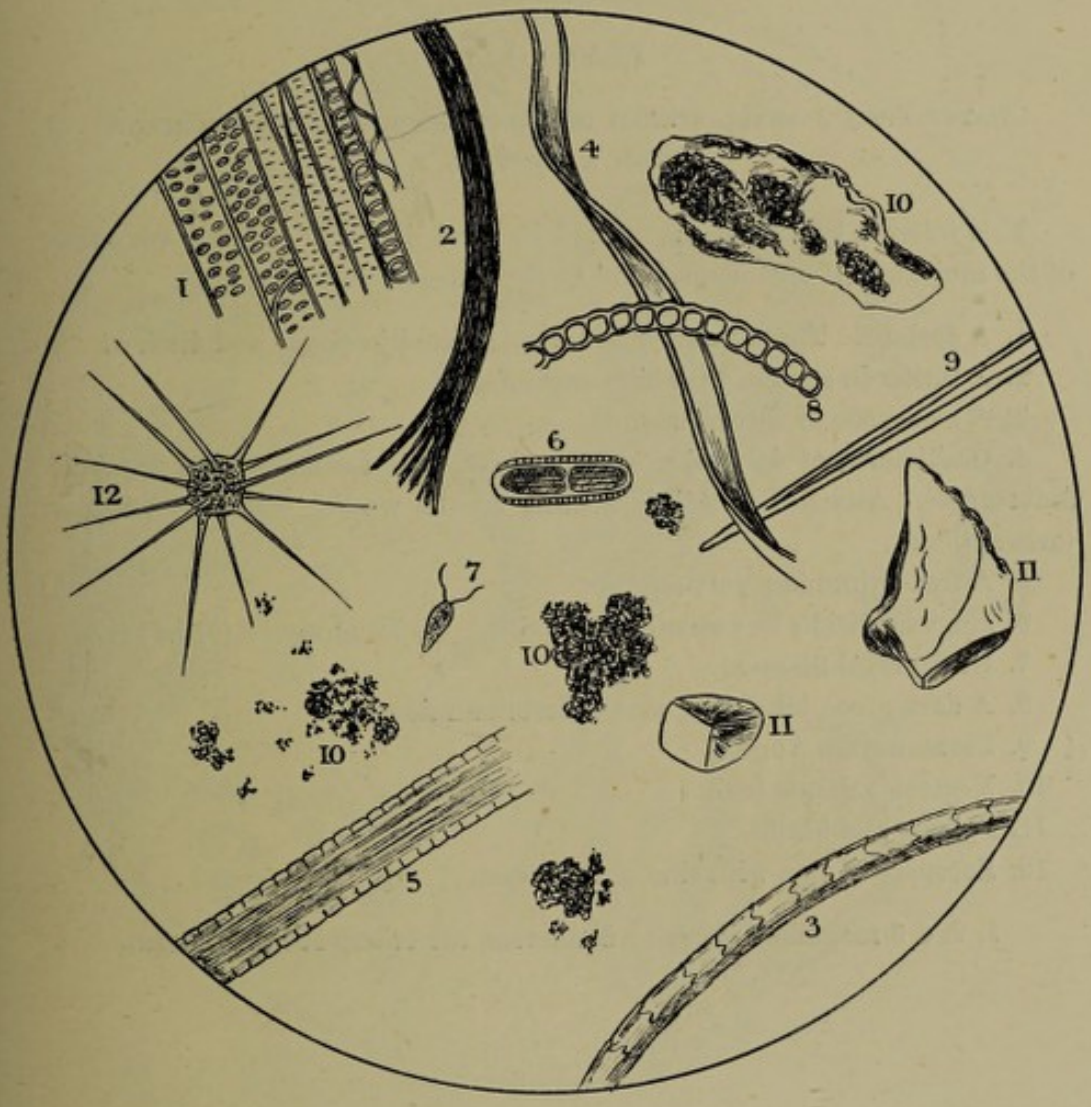
### DEPOSIT ON THE SIDE OF A WELL

When examining a well, the water from which showed bacteriologically and microscopically, but not chemically, certain signs of pollution, a little discoloration was observed on the brickwork near the point where the pump pipe entered the well. The microscopical examination of this proved that impure water was entering at this spot, and it was doubtless derived from slop water which was poured down the defective drain near the pump.

1. Various wood cells from some dicotyledon.
2. Fibre of hemp.
3. Fibre of wool.
4. Fibre of cotton.
5. Probably the hair of some animal.
6. A desmid (Penium).
7. A zoospore.
8. Dead algal filament.
9. Animal spine.
10. Particles of clay and brick.
11. Particle of sand.
12. A Radiolarian. S.K. Protozoa. Class Rhizopoda.

Magnified about 500 diameters.

PLATE VIII



## PLATE IX

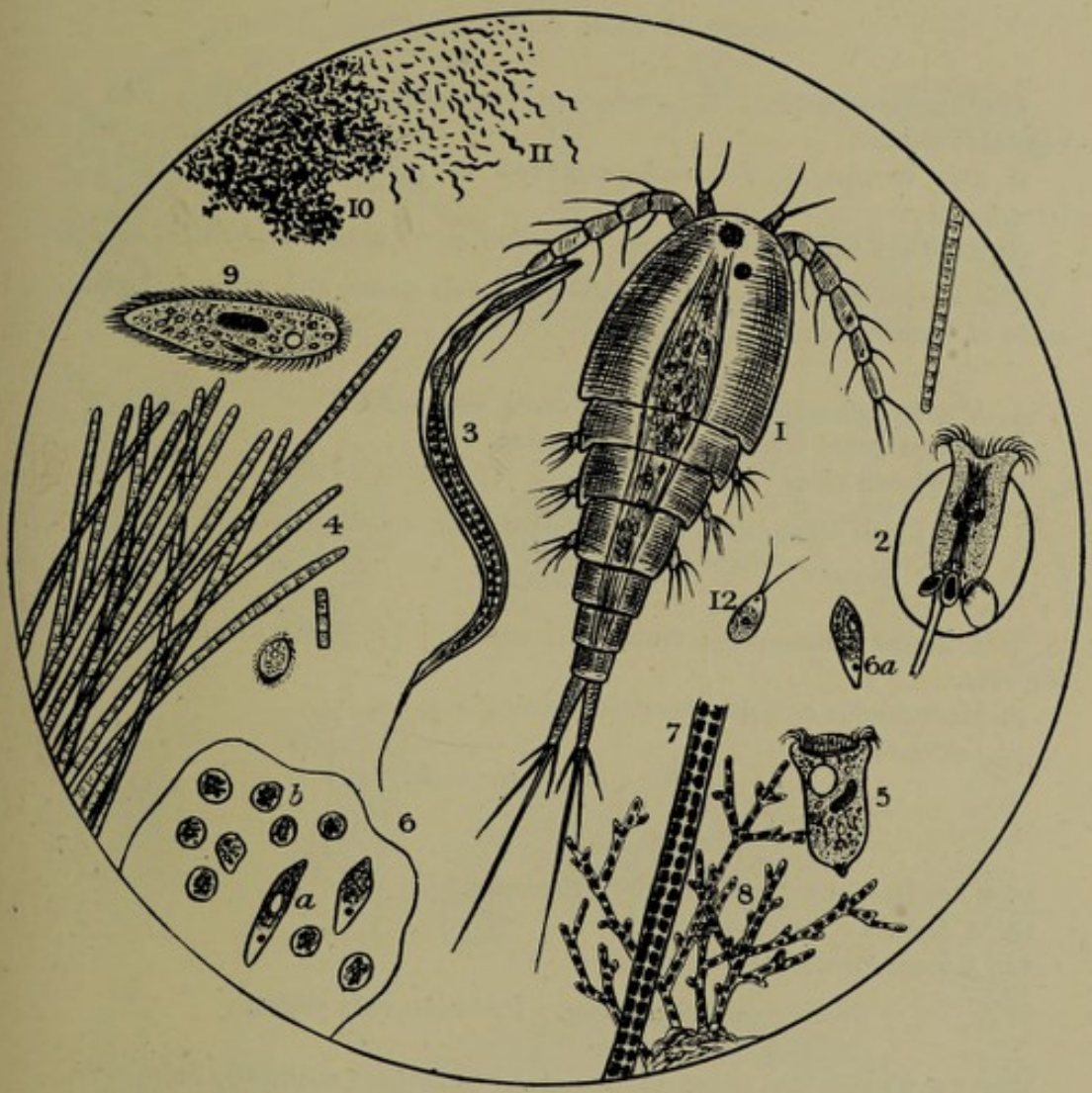
### WATER FROM A SMALL STREAM OR DITCH RECEIVING THE OVERFLOW FROM A CESSPOOL

This water is typical of many used in rural districts. Only a very few of the multitude of organisms found in the water are here depicted.

1. A cyclops. These small crustaceans abound in ponds and ditches.
2. A rotifer in sheath, with cilia expanded.
3. A nematode or thread-worm.
4. Oscillatoria of dark blue green colour, with oscillatory and sinuous movements. Attached to débris floating on the water. Probably Oscillatoria antliaria.
5. A free-swimming Vorticella.
6. Euglena viridis in a gelatinous sheath. (*a*) In motion ; (*b*) at rest.
7. Green algal filament.
8. A dark green branching alga (Microthamnion ?).
9. Paramœcium Aurelia.
10. Vegetable débris with
11. Spirilla and bacilli.
12. Zoospore of alga with cilia and eyespot.

1, 2, & 3 magnified about 50 diameters, the others 500 diameters.

PLATE IX



## PLATE X

### ORGANISMS FROM VARIOUS SOURCES

1. Gammarus pulex. A crustacean very prevalent in waters rich in vegetable matter.
2. Two species of Vorticella attached to portion of the body of a Gammarus.
3. Euplotes Charon, side view. 3*a*. The same organism, ventral aspect.

The above were found in a Chichester well water, and proved the presence of surface pollution.

---

4. A large infusorian. 4*a*. The same, contracted.
5. The encysted form of some infusorian.
6. Beggiatoa alba.

These were found in the effluent from a sewage works.

---

7. A rotifer (Floscularia ornata) in sheath. 7*a*. Some extended, showing cilia.
8. Macrobiotus or water bear, containing ova, 8*a*.
9. Larva of gnat.

From a rainwater tank.

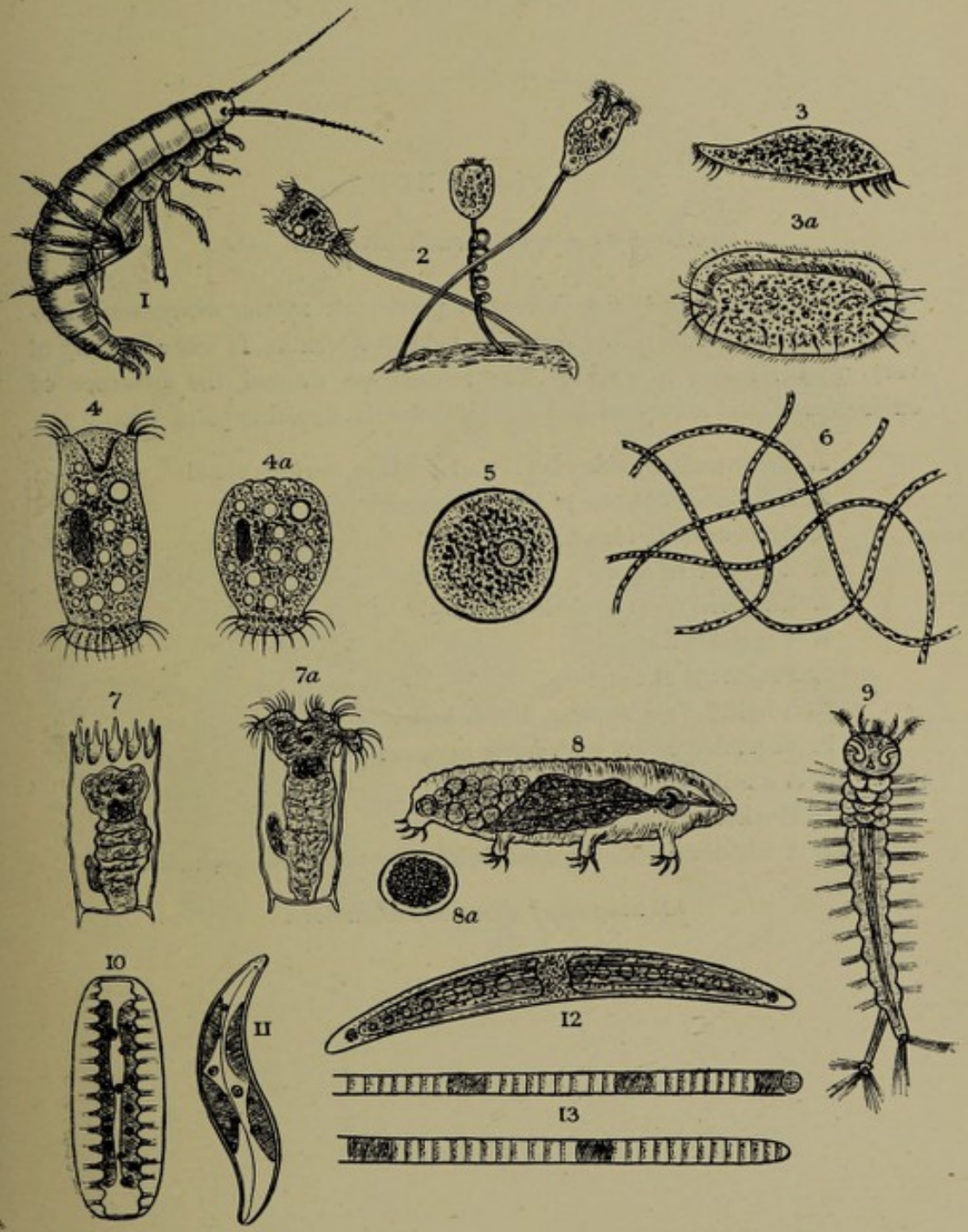
---

10 & 11. Diatoms (Surirella and Pleurosigma).
12. A desmid (Closterium).
13. A large form of Oscillatoria.

From river Blackwater. Pollution very slight.

Nos. 1 & 9 magnified about 15 diameters, the others about 500 diameters.

PLATE X



## PLATE XI

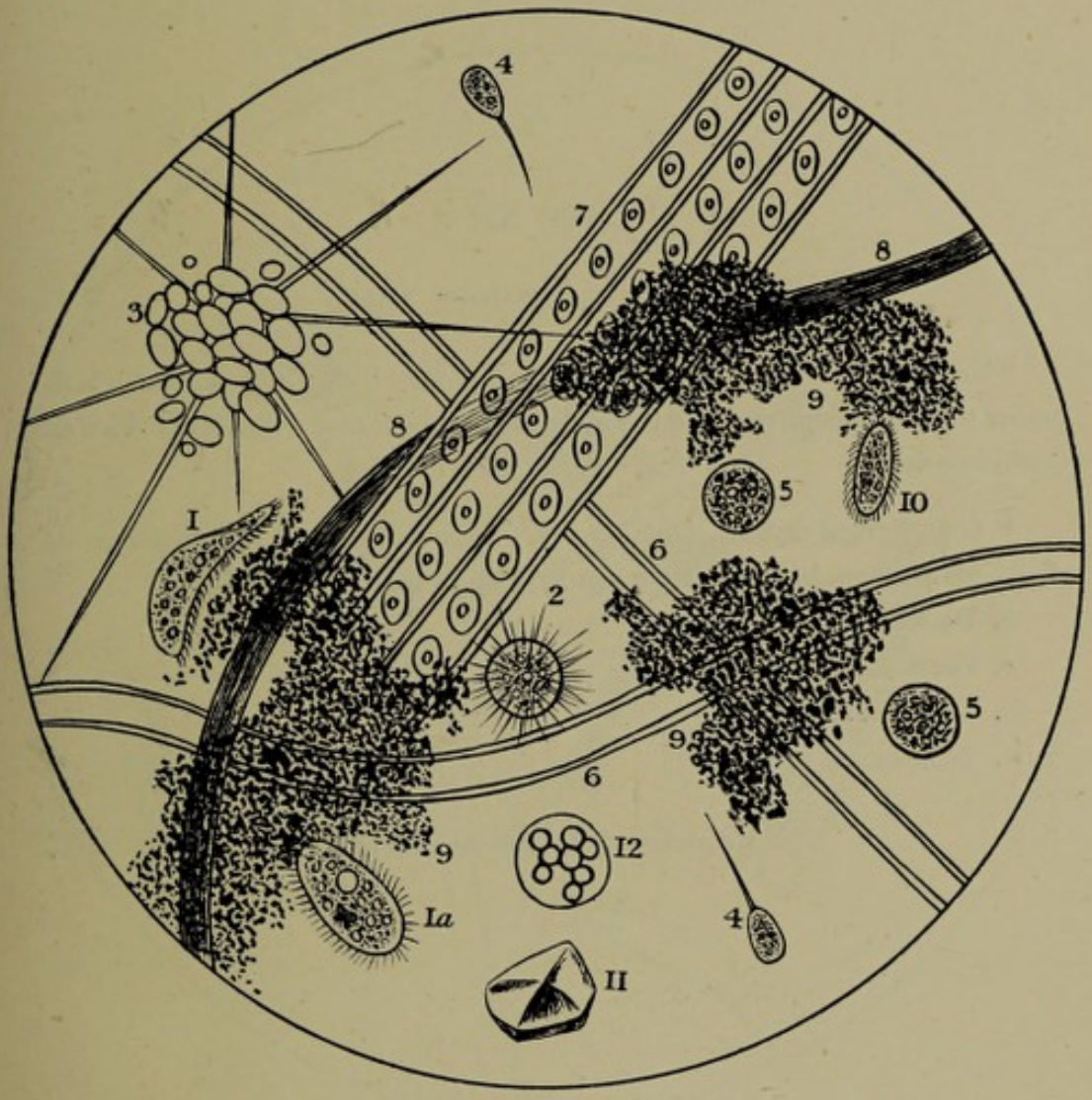
### SHALLOW WELL WATER FROM NEWPORT, SALOP

This water contained a good deal of particulate matter which settled to the bottom of the containing vessel in reddish flocculi. It was obviously of very unsatisfactory character. The microscope showed the presence of oxide of iron, and of animal and vegetable débris, denoting pollution.

1. Paramœcium, side view. 1*a*. Same, surface view.
2. Acanthocystis, one of the Heliozoa.
3. Aphanochæte (dead).
4. Zoospore of alga.
5. Encysted form of some protozoa.
6. Vegetable fibre.
7. Fragment of Conifer.
8. A hair. Very opaque, bluish tinge.
9. Vegetable débris with ferric hydrate.
10. A small paramœcium.
11. Particle of sand.
12. A slightly motile organism with very refractive granules.

All magnified about 500 diameters.

PLATE XI



## PLATE XII

### WATER FROM A SHALLOW WELL

This water, good chemically, contained a very little fluffy matter which under the microscope revealed the undermentioned forms. Obviously the well had some defect.

1 & 2. Fungal hyphæ, with spores. This constituted the particles of fluffy matter seen in the water when held up to the light.

3. Diatoms.

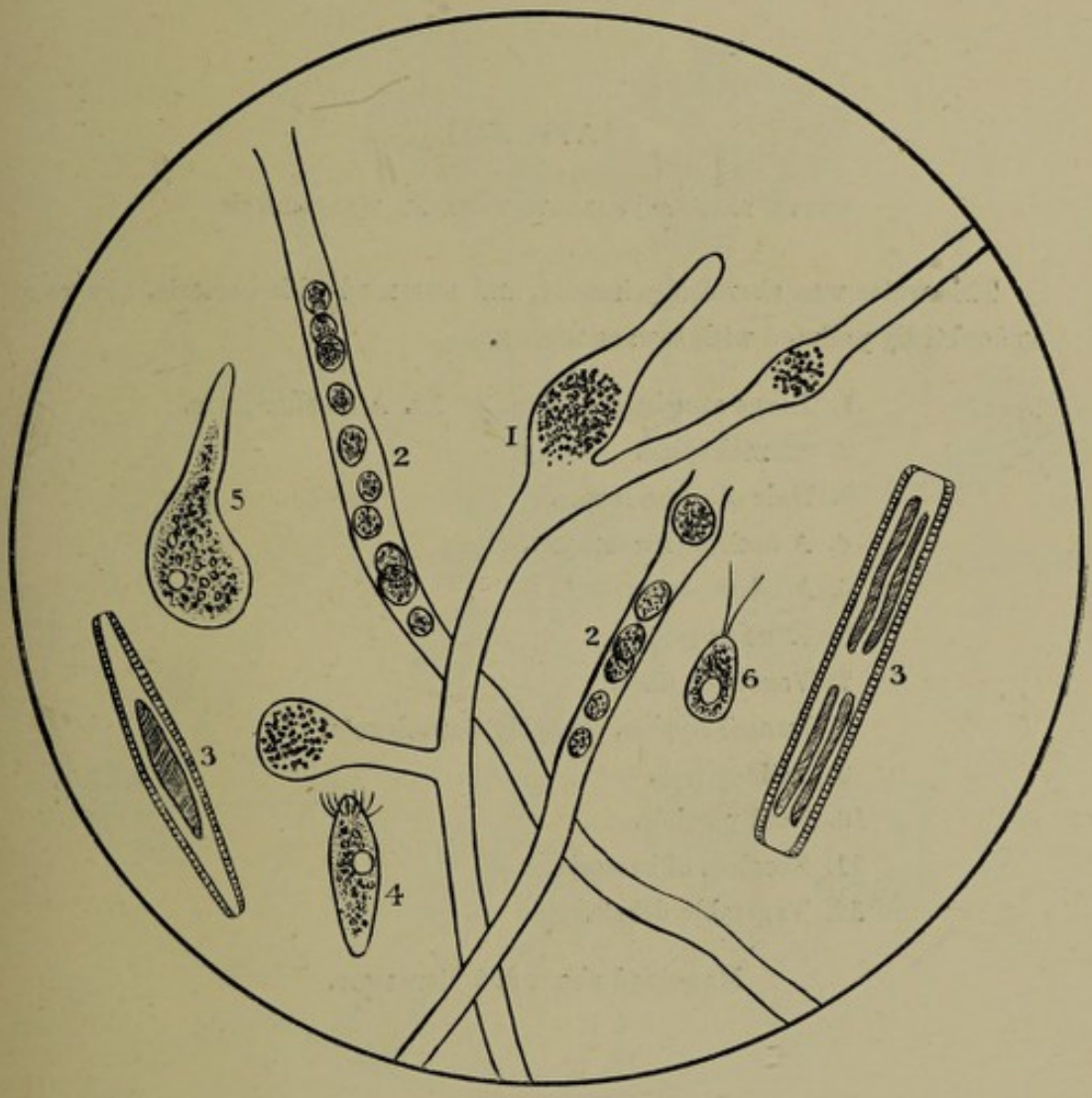
4. Species of infusorian.

5. An amœba (Lobosa).

6. Zoospore of alga.

Magnified about 500 diameters.

PLATE XII



## PLATE XIII

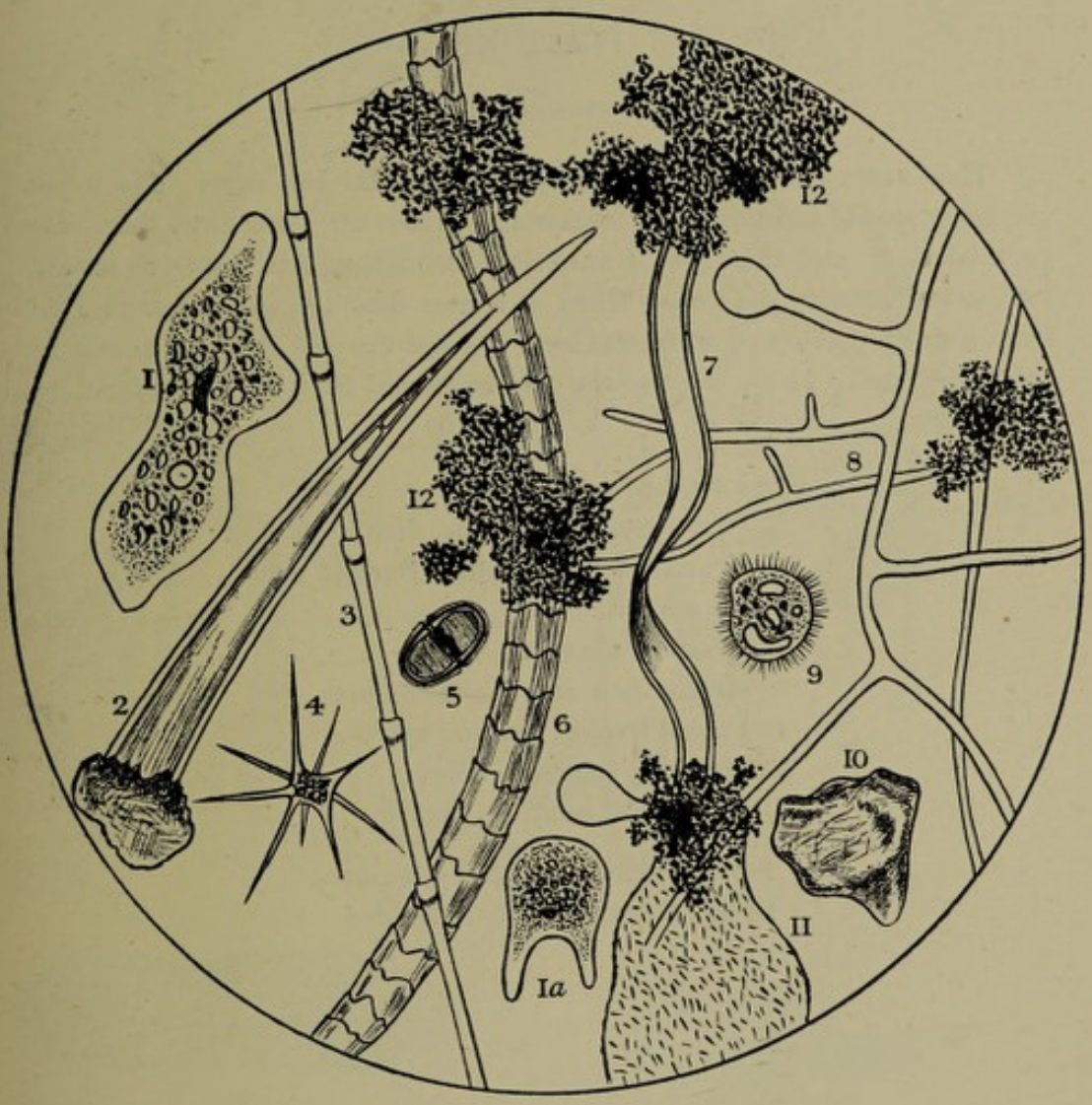
### WATER FROM A SHALLOW WELL AT WYMONDHAM

This water was chemically impure, and swarmed with bacteria. It was undoubtedly polluted with sewage matter.

1. Large amœba (Lobosa). 1*a*. A smaller form.
2. Animal spine.
3. Hair of some insect.
4. A form of Protomyxa.
5. A teleutospore.
6. Fibre of wool.
7. Vegetable fibre.
8. Fungal hyphæ, probably Saprolegnia.
9. Actinophrys.
10. Sand particle.
11. Zooglœa of bacteria.
12. Vegetable débris.

Magnified about 300 diameters.

PLATE XIII



## PLATE XIV

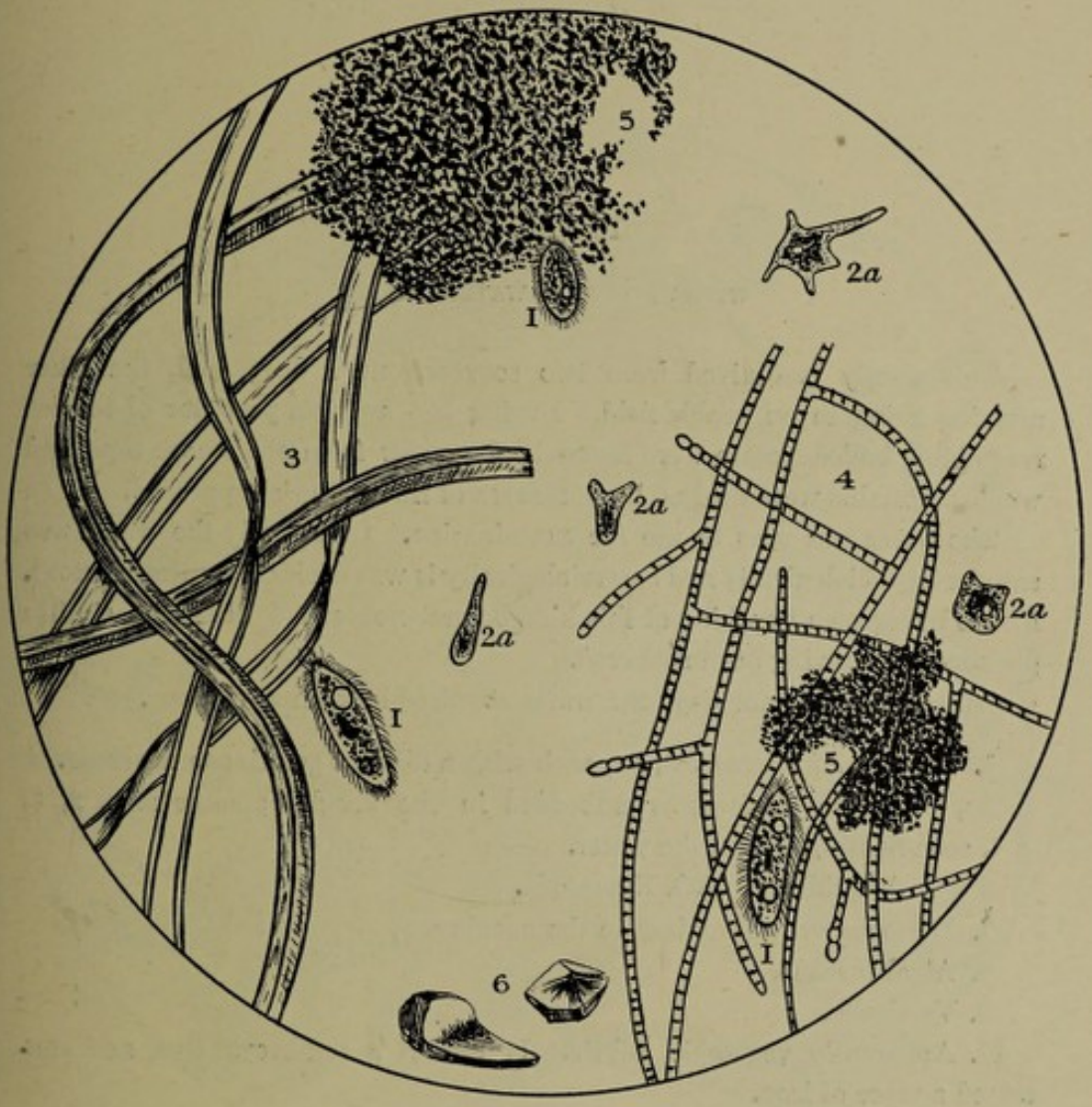
### WATER FROM A DEEP WELL

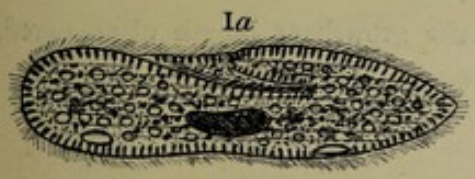
This water came from a bored well about 120 feet deep. The upper 20 feet was dug and lined with brickwork. About 20 yards away there was a tidal river, and there was a suspicion that either tidal water or subsoil water was entering the well. When, at a later date, the water was pumped out, a great quantity of water was seen to enter the well through defects in the brickwork. This confirmed the opinion formed from the examination of the water.

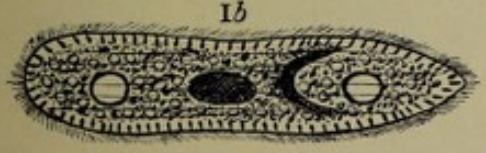
1. Paramœcia.
1*a*. Paramœcium Aurelia. Side view.
1*b*. Paramœcium Aurelia. Surface view.
2. An amœba.
2*a*. Various amœba.
3. Human hair and vegetable fibres.
4. Fungal hyphæ, forming spores.
5. Decaying vegetable débris.
6. Particles of sand.

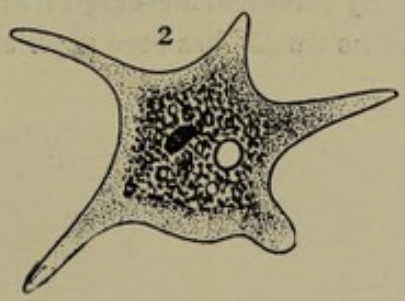
1–6 magnified about 500 diameters.
1*a* and 1*b* more highly magnified.

PLATE XIV



## PLATE XV

### WITHAM PUBLIC WATER SUPPLY

This supply is derived from two sources, one a deep well, the other a spring rising in an arable field. During last autumn particles of matter resembling boiled potato were found in the water from the house taps, and when the mains were flushed large masses of this material appeared.

The water was sent to me for examination. Chemically the water was satisfactory, biologically and bacteriologically it was decidedly unsatisfactory. I have never seen anything of this kind before, nor can I hear of a similar phenomenon having been observed.

After standing some days the water acquired an offensive odour.

1. Zooglœa of micrococci, 1*a*, each with a distinct gelatinous envelope.

2*a*, 3*a*, & 4*a*. Organisms embedded in the zooglœa; some also, 2, 3, & 4, seen floating free in the water.

5 & 6. Anguillulæ. N.O. Nematoda.

7. Diatoms, very abundant in the zooglœa.

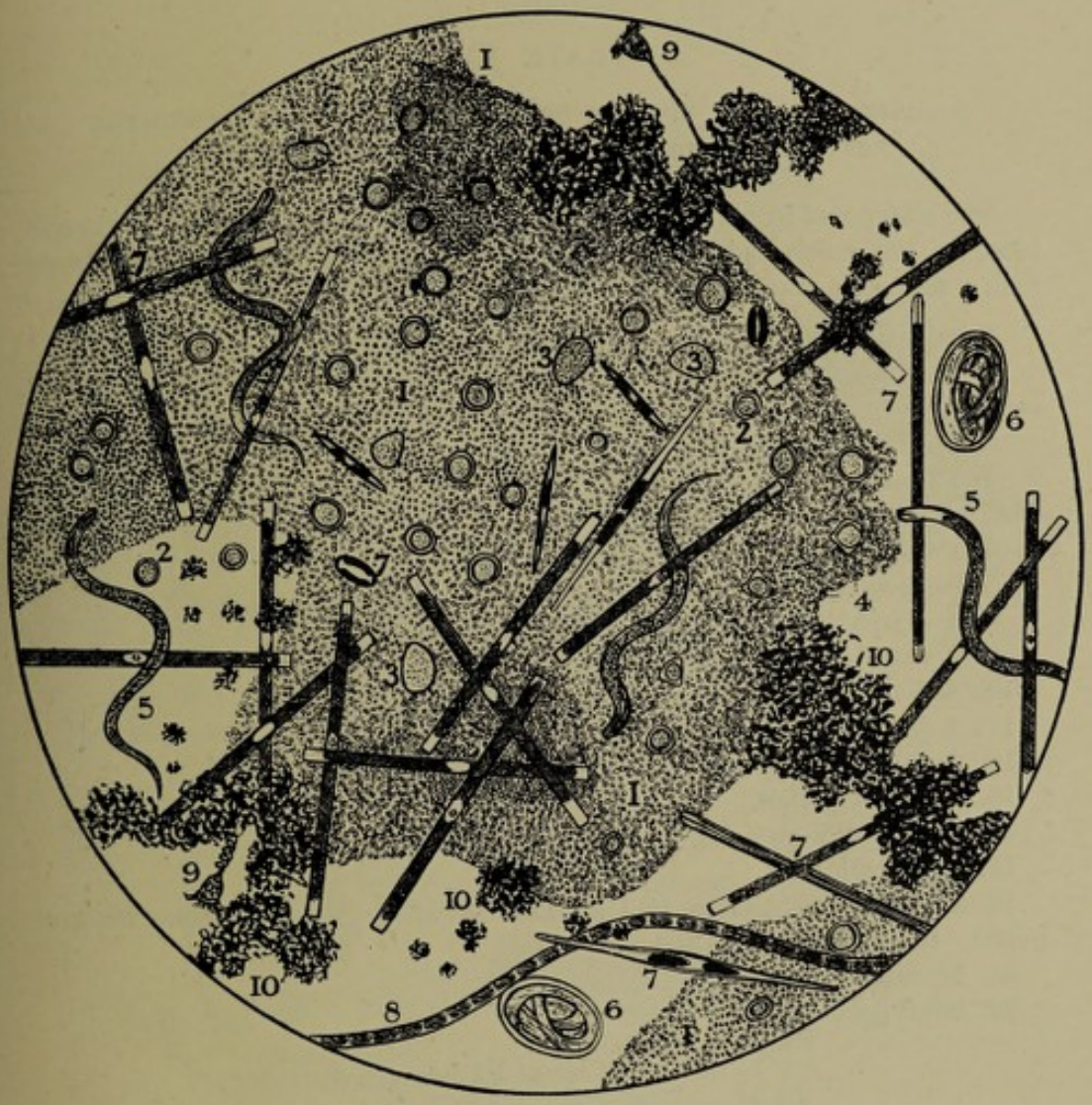
8. Algal threads.

9. Vorticella.

10. Apparently vegetable débris. It was of a red-brown tint, and contained a trace of iron.

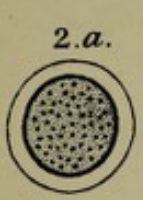
By persistent flushing of the mains the growth at length disappeared, and no trouble has been experienced since.

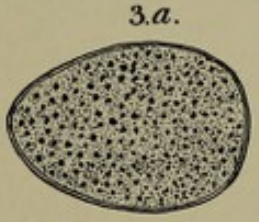
PLATE XV

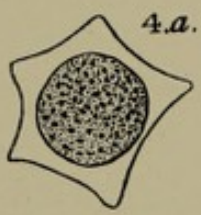




1.*a*.


2.*a*.


3.*a*.


4.*a*.

## PLATE XVI

SCRAPING FROM THE SURFACE OF A LARGE SAND FILTER USED FOR THE PURIFICATION OF THE SUPPLY TO A LARGE TOWN

The water was in part derived from springs and in part from surface of more or less cultivated land. The dried surface of the sand was covered with a thin semi-transparent film of a brownish-green colour.

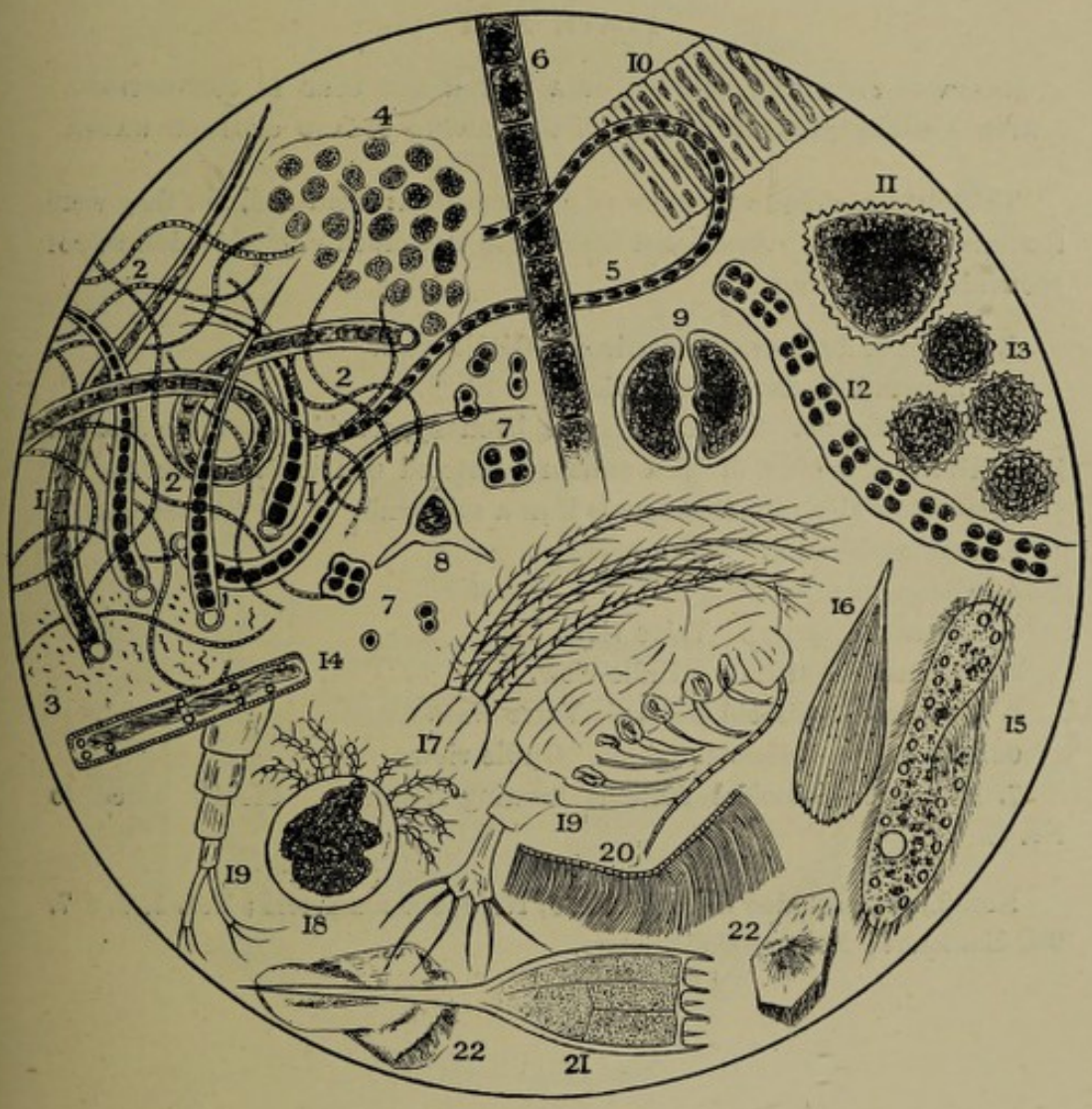
1. Rivularia and allied forms, which with
2. Beggiatoa formed the larger portion of the felted mass covering the sands.
3. Bacilli and spirilla.
4. Palmella embedded in jelly.
5. A conferva.
6. Probably a species of Zygnema.
7. Pleurococcus.
8. A desmid (Staurastrum).
9. A desmid (Cosmarium).
10. A diatom (Fragilarieæ).
11. A desmid.
12. An algal filament.
13. Probably pollen.
14. Diatom (Pinnularia).
15. Stylonychia.

16–20. Dead and disorganised animal remains. (16. Scale from wing of moth. 18. A mite. 19. Cyclops.)

21. Sheath of rotifer.
22. Sand particles.

1–15 magnified about 50 diameters.
16–21 magnified about 500 diameters.

PLATE XVI



## PLATE XVII

SCRAPINGS FROM THE SURFACE OF A FILTER BED USED IN CONNECTION WITH A LARGE STORAGE RESERVOIR COLLECTING UPLAND SURFACE WATER

This plate contains only a few of the organisms identified, but they were the most abundant. Associated with these was much vegetable débris, not shown in the drawing.

1. Bands of diatoms (Fragilarieæ). Girdle view.

1*a*. Separate diatom. Valve view.

2. Hydrodictyon. This organism is, by many, considered to be a desmid, in which the cells after division remain connected and form a network. It a freshwater alga. Cooke regards it as a sub-family of the Palmellaceæ.

3. Actinosphærium. A rhizopod.

4. Filaments of a Spirogyra.

5. Diatom (Synedra). Valve view.

5*a*. Diatom (Synedra). Girdle view.

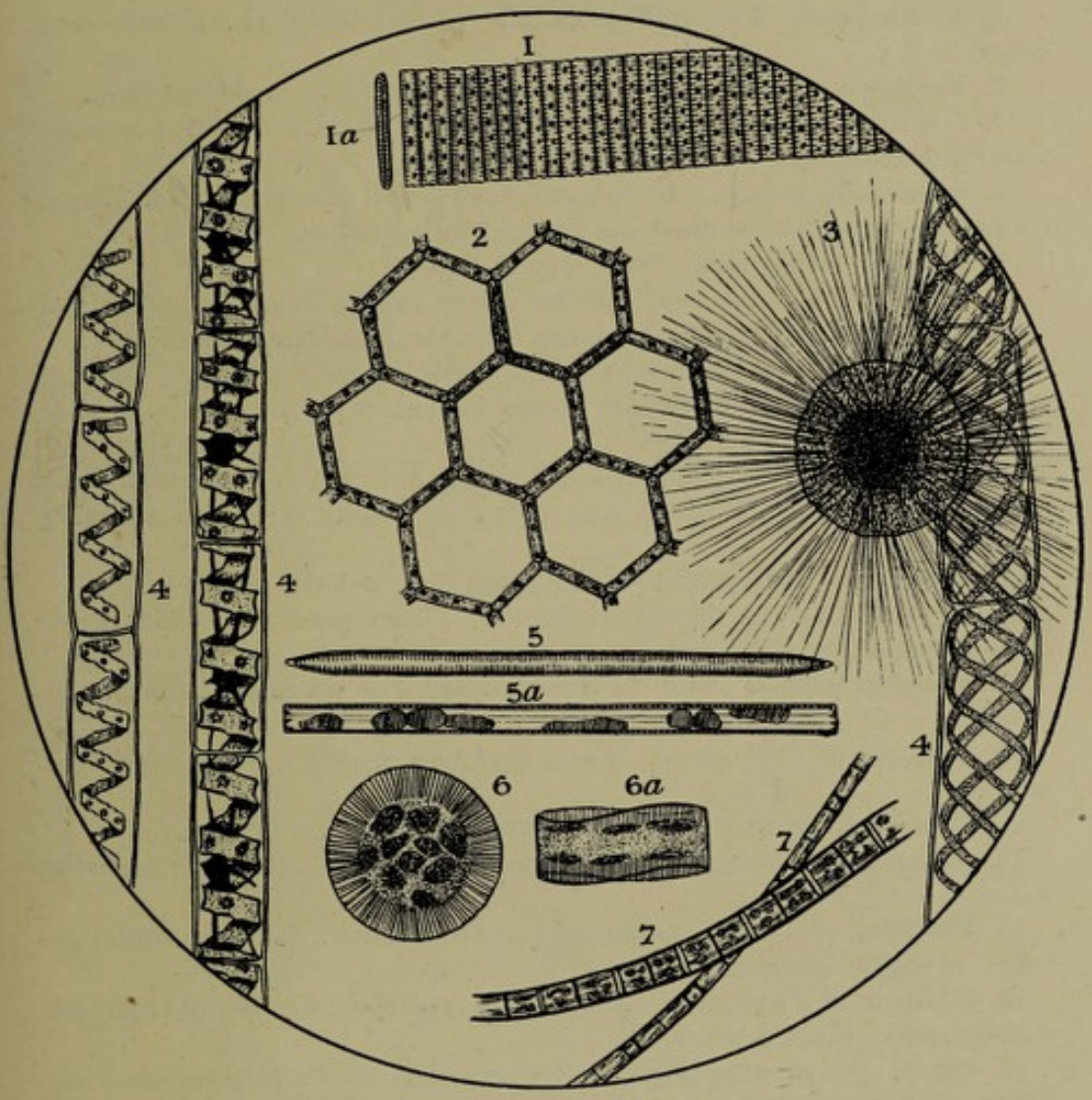
6. Cyclotella, a discoid diatom. Valve view.

6*a*. Cyclotella, a discoid diatom. Girdle view.

7. Melosira. Discoidal diatoms forming filaments. Closely allied to No. 6.

Nos. 2 & 3 magnified 100 diameters; No. 4, 200 diameters; Nos. 1, 5, & 7, 250 diameters; No. 6, 500 diameters.

PLATE XVII



## PLATE XVIII

### ORGANISMS FROM VARIOUS SOURCES

1. An Anabæna. Family Nostocaceæ. From a water with a horse-dung odour.

2. Beggiatoa alba. From outfall of a land drain from a sewage farm.

3. A species of Nostoc. From a ditch water. Said sometimes to cause water to become odorous.

4. Sphærotilus natans. (*a*) Natural size; (*b*) an enlarged thread. From a stream polluted with sewage and manufacturing refuse.

5. Conferva bombycina. Source, pond water.

6. Spongilla fluviatilis. (*a*) Natural size on twig; (*b*) spicules; (*c*) animal cells forming the sarcode of the sponge. Source, mountain stream.

7. (*a*) Macro- and micro-spores of Crenothrix polyspora; (*b*) tufts of thread formed by germination of spores in parent thread. (Zopf.) *Vide* Plate II, No. 24.

8. Volvox globator. This organism was found in myriads recently in a reservoir, the water of which had fallen very low. Odour on standing became fishy.

9. Leptomitus lacteus. From an impure river water.

10. Cryptomonas. A flagellate infusorian, from a pond water, said sometimes to impart a 'violet' odour to water.

11. Bursaria gastris. Said to have imparted a seaweed-like odour to water.

12. Carchesium Lachmanni. From luxuriant growth in sewage-polluted brook.

13. Tabellaria. A diatom found in waters with an 'aromatic' odour.

14. Asterionella formosa. A diatom said to give an 'aromatic' odour to water.

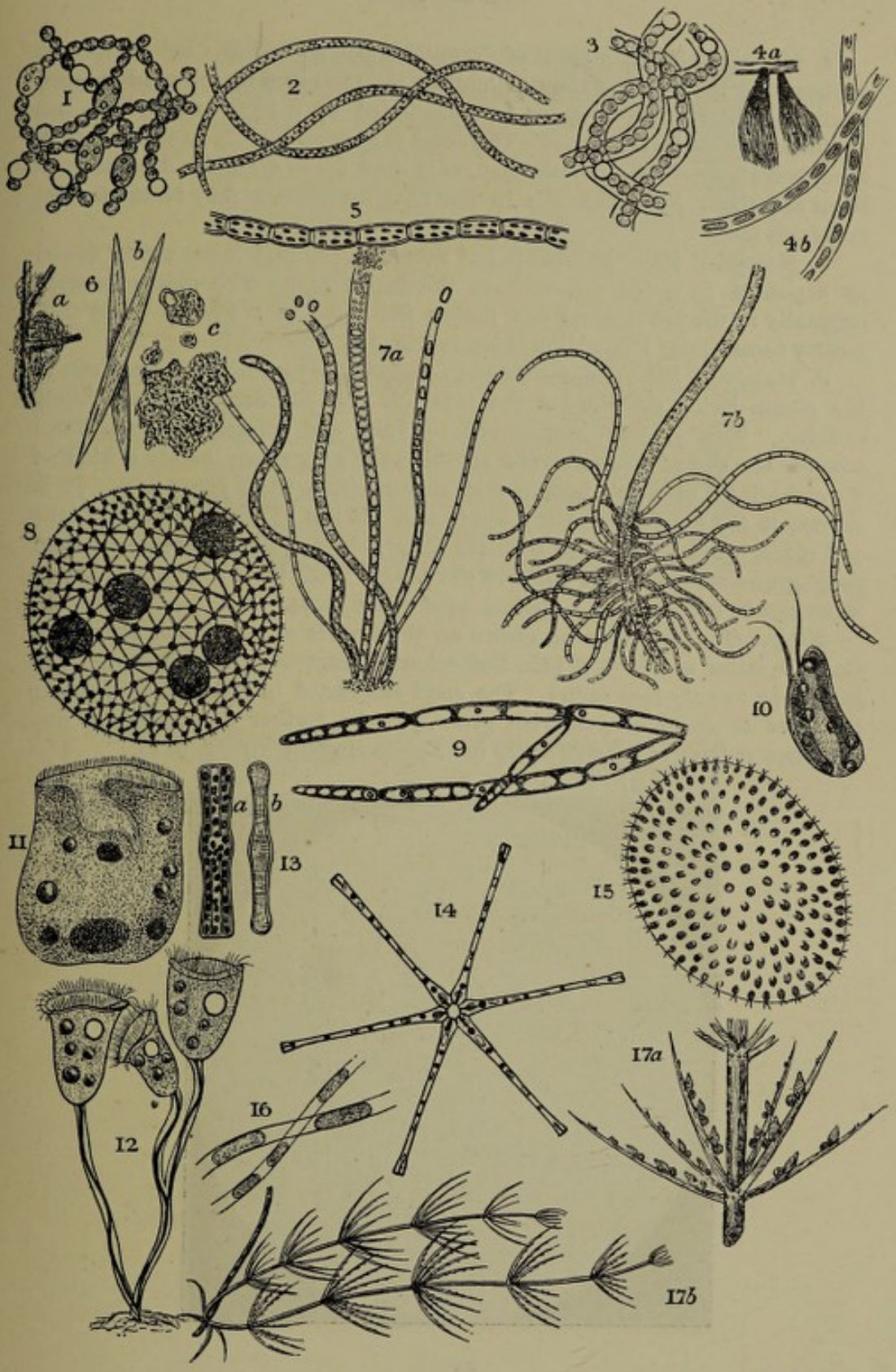
15. Uroglena, species of. Often mistaken for Volvox. Said to impart an 'oily' or 'fishy' odour to water.

16. Filament of a species of Lyngyba. A freshwater alga, said to impart a disagreeable odour to water.

17. Chara, (*a*) showing reproductive organs. (*b*) C. fragilis, showing fertile and barren branches. (After Oliver.)

Nos. 8, 11, & 16 magnified 100 diameters. 17*a* slightly enlarged, 4*a* & 6*a* natural size, 17*b* slightly reduced. All others magnified 250 diameters.

PLATE XVIII



## PLATE XIX

1. Magnified 1000. Spores of Crenothrix polyspora, var. Cheltonensis, as contained in the water of the Cheltenham reservoir and in the sand scraped from the filters. Each spore is surrounded by a hyaline envelope, not distinctly visible in the print. The cocci vary considerably in size, some of them being exceedingly minute, not more than 3 $\mu$ in diameter, but many of them are about 1 $\mu$. The cells in the zooglœa masses may be more than twice this size.

2. Magnified 500. Filaments and zooglœa cells (the latter not in focus) as deposited in water drawn from the house taps. The filaments were originally in the cell masses and taking the place of the cells. They ultimately form spores resembling those in Fig. 1.

3. Magnified 125. Filaments and zooglœa cells as developed upon one of the stones lining the sides of the reservoir; all the dark parts are finely cellular. This growth commenced in July, and reached its maximum towards the end of August. The growth was 'very short, merely a kind of "weathering" of a pale buff or drab colour with a little green in it. It is velvety to the touch when the stone is wet. It can be easily brushed off the wet stone, or even rubbed off with the finger. The filaments are larger than those grown artificially, or found in the deposit from the water, and many of them can be seen to have a distinct solid central axis.'

Note.—The cocci can be grown on the surface of gelatine or agar-agar. On the latter at 37° C. a pale buff-coloured rugose expansion covers the surface in twenty-four hours. The cocci suspended in water vary in colour from red to green, or yellowish green. For a further description of this organism *vide* Dr. Garrett's paper in 'Public Health,' vol. ix. p. 15.

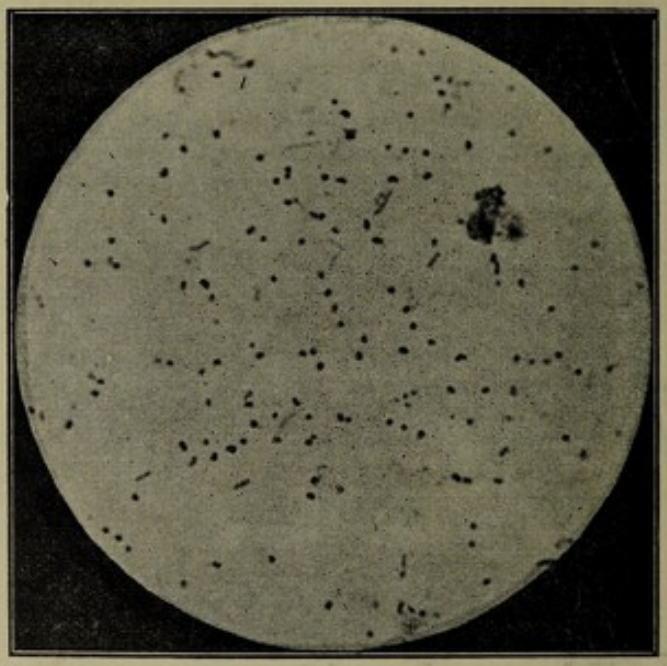


Fig. 1

FIG. 2

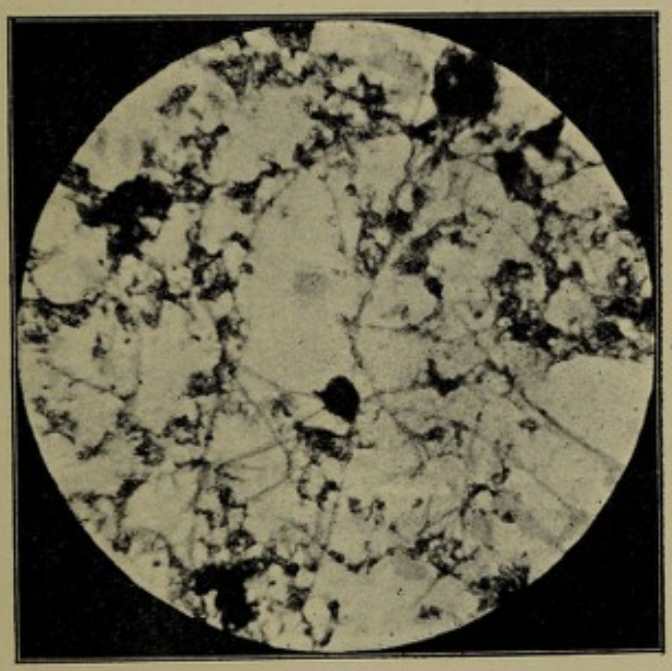


FIG. 3

# APPENDIX

## *PREPARATION OF REAGENTS AND MEDIA*

### Volumetric Solutions

**(1) Solution of Sodium Carbonate (Decinormal).**

| | |
|---|---|
| Pure sodium carbonate, recently ignited and cooled | 5·3 grammes |
| Distilled water . . . . . | to 1 litre |

Dissolve.

[1 c.c. = 5·3 mlgr. $Na_2CO_3$ = 4·8 mlgr. $SO_4$ = 3 mlgr. $CO_3$.]

**(2) Solution of Sulphuric Acid (Decinormal).**

| | |
|---|---|
| Strong pure sulphuric acid . . . . . | 3 c.c. |
| Distilled water . . . . . | a sufficiency |

Add the acid to 1 litre of water, and shake.

Take 20 c.c. of the decinormal solution of sodium carbonate in a beaker, dilute to 100 c.c. with distilled water, and add one or two drops of solution of methyl-orange. Run in the acid from a burette until the last drop produces a red colour, and note the amount used. Now add decinormal solution of sodium carbonate until the red colour disappears. Let $a$ = the number of c.c. of acid used and $b$ = the number of c.c. of alkali required to remove the red colour, then $a - \frac{b}{2}$ = the amount of acid required to exactly neutralise the 20 c.c. of sodium carbonate solution. Fifty times this quantity should then be taken and diluted with water to 1 litre. Confirm the result by another experiment made in exactly the same way.

**(3) Solution of Sulphuric Acid for estimating $CO_3$ in Water.**

| | |
|---|---|
| Decinormal sulphuric acid . . . . . | 100 c.c. |
| Distilled water . . . . . | 50 „ |

Mix.

[1 c.c. = 2 mlgr. $CO_3$ = 3·2 mlgr. $SO_4$.]

**(4) Solution of Barium Chloride.**

| | |
|---|---|
| Pure crystals barium chloride (dried by exposure over strong sulphuric acid in a desiccator for a few hours) . . . . . | 5·071 grammes |
| Distilled water . . . . . | 1 litre |

Dissolve.

[1 c.c. = 2 mlgr. $SO_4$.]

**(5) Solution of Potassium Chromate.**

| | |
|---|---|
| Pure crystals of potassium chromate (dried by exposure in an oven at 120° C.) | 4·05 grammes |
| Distilled water | 1 litre |

Dissolve.

[This solution is equivalent in strength to the barium chloride solution.]

**(6) Solution of Silver Nitrate.**

| | |
|---|---|
| Crushed crystals of pure silver nitrate (dried in an air oven at 105° C.) | 4·797 grammes |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = 1 mlgr. chlorine in chlorides.]

**(7) Solution of Indigo.**

| | |
|---|---|
| Indigo carmine | 2 grammes (approximately) |
| Fuming sulphuric acid | 6 c.c. |
| Sulphuric acid | 15 „ |
| Distilled water | to 1 litre |

Digest the indigo with the fuming acid for twenty-four hours, add the sulphuric acid, and dilute with distilled water to 1 litre. Filter. The standardisation is effected as follows:

A deep glass beaker, or, better still, a thin white earthenware cylinder, is fitted into a water-bath containing so much $CaCl_2$ solution at 120° C. that the lower half of the cylinder is immersed in the liquid.

To 98 c.c. of distilled water add 2 c.c. of the solution of potassium nitrate (8), and pour 25 c.c. of this dilution, by means of a rapidly discharging pipette, into 50 c.c. of strong pure sulphuric acid contained in the cold beaker. Stir briskly by means of a thermometer, and place the beaker in the bath. Run in the indigo solution from a graduated burette, at first at the rate of one drop per second, and afterwards a little faster until the blue colour is but slowly discharged. Then add the indigo again drop by drop, until a blue-green colour is produced which remains permanent for one minute. This is taken as the end of the reaction. The amount of indigo solution used is equivalent to ·5 mlgr. of nitric nitrogen, from which the equivalent to 1 c.c. of the indigo solution is calculated. Repeat this experiment, and make two other pairs of experiments, using (*a*) 25 c.c. of a nitrate solution half the above strength, and (*b*) 25 c.c. of solution one-fourth the strength of the original dilution.

The results are expressed as follows :

| Amount of solution taken | Strength of solution | Amount of indigo solution used | Value of 1 c.c. indigo solution |
|---|---|---|---|
| 25 c.c. . | 2 mlgr. N in 100 c.c. . | $a$ | $\left(\frac{\cdot5}{a} + \frac{\cdot5}{a'}\right) \div 2$ |
| 25 „ . | 2 „ „ 100 „ . | $a'$ | |
| 25 „ . | 1 „ „ 100 „ . | $b$ | $\left(\frac{\cdot25}{b} + \frac{\cdot25}{b'}\right) \div 2$ |
| 25 „ . | 1 „ „ 100 „ . | $b'$ | |
| 25 „ . | ·5 „ „ 100 „ . | $c$ | $\left(\frac{\cdot125}{c} + \frac{\cdot125}{c'}\right) \div 2$ |
| 25 „ . | ·5 „ „ 100 „ . | $c'$ | |

The values of 1 c.c. of indigo for varying quantities of nitrates are thus ascertained and recorded for use. If desired, the values for intermediate quantities can be intercalated.

**(8) Solution of Potassium Nitrate.**

| | |
|---|---|
| Powdered crystals of potassium nitrate (dried in an oven at about 110° C.) . . . . . | 7·214 grammes |
| Distilled water . . . . . | 1 litre |

Dissolve.

[1 c.c. = 1 mlgr. N.]

**(9) Solution of Sodium Nitrite.**

| | |
|---|---|
| Pure silver nitrite . . . . . | 1·1 gramme |
| Sodium chloride . . . . . | ·5 „ |
| Distilled water . . . . . | a sufficiency |

Dissolve the silver nitrite in about half a litre of the water by aid of heat. Add the sodium chloride, and when cold dilute to 1 litre. Allow to stand in the dark, and decant the supernatant clear fluid. Keep in a dark place.

[1 c.c. = ·1 mlgr. N.]

**(10) Solution of Sodium Phosphate.**

| | |
|---|---|
| Pure sodium phosphate ($HNa_2PO_4,12H_2O$) . . | ·377 gramme |
| Distilled water . . . . . | 100 c.c. |

Dissolve.

[1 c.c. = 1 mlgr. $PO_4$.]

**(11) Solution of Iodine.**

| | |
|---|---|
| Freshly sublimed iodine . . . . . | 1·265 gramme |
| Pure potassium iodide . . . . . | 2 grammes (about) |
| Distilled water . . . . . | to 100 c.c. |

Dissolve. This forms a decinormal solution. For use in estimating $H_2S$ in water it can be diluted with nine volumes of water to form the centinormal solution.

(12) **Solution of Ammonium Chloride.**

| | |
|---|---|
| Fine crystals of pure ammonium chloride (dried in an oven at 105° C.) | 3·15 grammes |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = 1 mlgr. $NH_3$.]

(13) **Dilute Solution of Ammonium Chloride.**

| | |
|---|---|
| Solution of ammonium chloride | 10 c.c. |
| Distilled water | 990 „ |

Mix.

[1 c.c. = ·01 mlgr. $NH_3$.]

(14) **Solution of Sodium Thiosulphate.**

| | |
|---|---|
| Sodium thiosulphate | 25 grammes |
| Distilled water | to 250 c.c. |

Dissolve.

(15) **Dilute Solution of Thiosulphate.**

| | |
|---|---|
| Solution of thiosulphate | 10 c.c. |
| Distilled water | 90 „ |

Mix.

To be made as required, and standardised immediately before use. (*Vide* page 221.)

(16) **Solution of Potassium Permanganate.**

| | |
|---|---|
| Crystals of potassium permanganate (dried at 100° C. in a platinum or glass dish in an air oven) | 3·950 grammes |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = 1 mlgr. available oxygen.]

(17) **Dilute Solution of Potassium Permanganate.**

| | |
|---|---|
| Solution of potassium permanganate | 10 c.c. |
| Distilled water | 90 „ |

Mix.

The strong solution, in an amber bottle in a dark place, keeps very well. The dilute solution should be freshly prepared every few days.

The solution of potassium permanganate may be standardised with ammonio-ferrous sulphate. Forty-nine parts of this salt require one part of oxygen for the conversion of the ferrous into ferric sulphate. An accurately known quantity (about half a gramme) of the pure crystals is dissolved in about 100 c.c. of freshly boiled distilled

water, 5 c.c. of dilute sulphuric acid (No. 44) added, and the permanganate run in until the last drop produces a faint but distinct pink tint. If the permanganate solution is not absolutely accurate in strength, the factor obtained from the test should be marked on the label.

**(18) Solution of Calcium Chloride.**

| | |
|---|---|
| Powdered calc spar which has been dried by heating in the air oven to 120° C. for about half an hour | 2 grammes |
| Hydrochloric acid | a sufficiency |
| Water | to 1 litre |

Place the calc spar in a shallow beaker, add about 50 c.c. of the water, and heat on the water-bath. Drop in a little hydrochloric acid from time to time until the spar is dissolved. To avoid loss by spurting, cover the beaker with a watch-glass. When solution has taken place rinse the watch-glass with a little distilled water, and evaporate to dryness. Add a few c.c. more water and again evaporate. Repeat this a third time. Finally dissolve the residue in 1 litre of freshly boiled distilled water.

[1 c.c. contains calcium equivalent to 2 mlgr. of $CaCO_3$.]

**(19) Solution of Soap.**

| | | |
|---|---|---|
| White Castile soap in fine shreds | | 12 grammes |
| Methylated spirit free from petroleum<br>Distilled water | equal parts | a sufficiency |

Dissolve the soap in 1 litre of the mixture of spirit and water. Set aside in a very cool place (an ice chest preferred) for twenty-four hours. Filter. Standardise the solution in the following way:

Take 5 c.c. of the calcium chloride solution and dilute with 90 c.c. of distilled water in a bottle capable of holding about 200 c.c. Run in the soap solution until a permanent lather is produced. Note the amount required, and dilute 950 c.c. of the remaining solution with dilute spirit to

$$\frac{10 + 1}{a} \times 950 \text{ c.c.}$$

where $a$ = number of c.c. of the soap solution used.

Repeat the experiment with the calcium solution; and if the soap solution used for producing a lather is not exactly 11 c.c., add more dilute spirit or stronger soap solution until a final experiment shows that the soap solution is of the required strength.

If, upon keeping, the solution becomes turbid, the standardisation must be repeated. As the strength may be found to be slightly reduced, the excess of strong soap solution should be preserved for bringing the solution again to the required strength.

(20) **Solution of Ferric Chloride.**

| | |
|---|---|
| Pure iron wire | ·1 gramme |
| Dilute hydrochloric acid | 5 c.c. |

Dissolve by aid of heat in a small flask, then add

| | |
|---|---|
| Potassium chlorate | ·25 gramme |

and boil until free from the odour of chlorine. Dilute with distilled water to 1 litre.

[1 c.c. = ·1 mlgr. Fe.]

(21) **Solution of Lead Acetate.**

| | |
|---|---|
| Pure lead acetate in crystals | ·183 gramme |
| Acetic acid | a sufficiency |
| Distilled water | 1 litre |

Dissolve the lead acetate in about 100 c.c. of water, and add sufficient acetic acid to render the solution distinctly acid; then dilute to 1 litre.

[1 c.c. = ·1 mlgr. Pb.]

(22) **Solution of Zinc Sulphate.**

| | |
|---|---|
| Pure zinc sulphate | ·442 gramme |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = ·1 mlgr. Zn.]

(23) **Solution of Magnesium Chloride.**

| | |
|---|---|
| Pure magnesium wire | ·250 gramme |
| Dilute hydrochloric acid | 20 c.c. |
| Distilled water | to 1 litre |

Dissolve the magnesium in the acid in a large flask, and dilute with water to 1 litre.

[1 c.c. = ·25 mlgr. Mg.]

## Reagents required for estimating Dissolved Oxygen

(24) **Solution of Sodium Nitrite and Potassium Iodide.**

| | |
|---|---|
| Sodium nitrite | ·5 gramme |
| Potassium iodide | 20 grammes |
| Solution of sodium hydrate | 1 c.c. |
| Distilled water | 100 „ |

Dissolve.

(25) **Solution of Sodium Thiosulphate.**

| | |
|---|---|
| Pure dry crystals of sodium thiosulphate | 7·75 grammes |
| Distilled water | to 1 litre |

Dissolve.

[1 c.c. = ·25 mlgr. of oxygen.]

### Reagents for Estimation of Dissolved $CO_2$ in Water

**(26) Solution of Barium Hydrate.**

| | |
|---|---|
| Barium hydrate crystals | 10 grammes |
| Barium chloride | ·2 gramme |
| Distilled water | 1 litre |

Dissolve and filter. This solution must be standardised immediately before use.

**(27) Solution of Barium Chloride.**

| | |
|---|---|
| Barium chloride crystals | 10 grammes |
| Distilled water | 100 c.c. |

Dissolve and filter.

---

## *FORMULÆ FOR REAGENTS*

### Reagents

**(28) Solution of Ammonium Carbonate.**

| | |
|---|---|
| Ammonium carbonate | 5 grammes |
| Solution of ammonia (sp. gr. ·890) | 5 c.c. |
| Distilled water | 95 ,, |

Dissolve and filter.

**(29) Solution of Ammonium Molybdate.**

| | |
|---|---|
| 1. Ammonium molybdate | 10 grammes |
| Distilled water | 30 c.c. |
| Solution of ammonia (sp. gr. ·89) | 10 ,, |

Dissolve.

| | |
|---|---|
| 2. Nitric acid (sp. gr. 1·42) | 60 c.c. |
| Distilled water | 60 ,, |

Mix, and pour into the molybdate solution with constant stirring. Allow to stand for several days, and decant the clear solution.

**(30) Solution of Ammonium Phosphate.**

| | |
|---|---|
| Ammonium phosphate | 10 grammes |
| Distilled water | 100 c.c. |

Dissolve, and add solution of ammonia (sp. gr. ·89) until a permanent turbidity is produced. Filter.

**(31) Solution of Ammonium Oxalate.**

| | |
|---|---|
| Ammonium oxalate | 4 grammes |
| Distilled water | 100 c.c. |

Dissolve. Filter if necessary.

**(32) Acid Solution of Barium Chloride.**

| | |
|---|---|
| Barium chloride | 10 grammes |
| Hydrochloric acid | 20 c.c. |
| Distilled water | 80 „ |

Dissolve the chloride in the water, and add the acid.

**(33) Solution of Calcium Sulphide.**

| | |
|---|---|
| Sulphur, in fine powder | 20 grammes |
| Slaked lime | 20 „ |
| Distilled water | 500 c.c. |

Boil until about 400 c.c. remain. Filter.

The solution should have a rich orange-red colour. When, by keeping, this colour has faded, the solution has become useless.

**(34) Solution of Calcium Hydrate.**

| | |
|---|---|
| Pure calcium hydrate | 20 grammes |
| Distilled water | 100 c.c. |

Shake together at frequent intervals for a few hours, then allow to stand, and pour away the supernatant liquid. Repeat this operation. Finally add 250 c.c. distilled water to the residue; shake at intervals for twenty-four hours. Allow to settle, and draw off the lime water as required. The bottle can be refilled with distilled water many times.

**(35) Solution of Copper Sulphate.**

| | |
|---|---|
| Copper sulphate | 10 grammes |
| Distilled water | 100 c.c. |

Dissolve and filter.

**(36) Dilute Hydrochloric Acid.**

| | |
|---|---|
| Hydrochloric acid (sp. gr. 1·16) | 40 c.c. |
| Distilled water | 200 „ |

Mix.

**(37) Solution of Metaphenylenediamine (Griess's Solution).**

| | |
|---|---|
| Metaphenylenediamine | ·5 gramme |
| Distilled water | 100 c.c. |

Dissolve, and add dilute sulphuric acid until the reaction is very faintly acid. Keep in a dark place.

**(38) Ilosvay's Solutions.**

| | |
|---|---|
| 1. Sulphanilic acid | ·5 gramme |
| Glacial acetic acid | 30 c.c. |
| Distilled water | 120 „ |

Dissolve.

| | |
|---|---|
| 2. Naphthylamine | ·1 gramme |
| Glacial acetic acid | 30 c.c. |
| Distilled water | 120 „ |

Dissolve the naphthylamine in the water at a boiling temperature. Cool, and add the acetic acid. Filter. Mix the two solutions, and keep in an accurately stoppered bottle. If the liquid becomes coloured by keeping, shake with a little zinc dust, and filter.

**(39) Solution of Potassium Chromate.**

| | |
|---|---|
| Potassium chromate | 10 c.c. |
| Distilled water | 100 „ |

Add a few drops of volumetric solution of silver nitrate until a permanent red precipitate is produced. Filter.

**(40) Alkaline Solution of Potassium Permanganate.**

| | |
|---|---|
| 1. Potassium permanganate | 8 grammes |
| Distilled water | 1 litre |

Dissolve by the aid of heat.

| | |
|---|---|
| 2. Potassium or sodium hydrate | 200 grammes |
| Distilled water | 500 c.c. |

Mix 1 and 2, and boil down to 1000 c.c.

An enamelled iron kettle answers well for this purpose. During the evaporation the lid is left off. When the flame is removed the cover is put on, and finally, when the liquid is cool, it can be easily poured into the stock-bottle. The kettle should be used for no other purpose.

**(41) Solution of Platinic Chloride.**

| | |
|---|---|
| Platinum foil | 10 grammes |
| Hydrochloric acid (sp. gr. 1·16) | 60 c.c. |
| Nitric acid (sp. gr. 1·42) | 10 „ |
| Distilled water, to produce | 200 „ |

Warm the hydrochloric acid to 80° C., add the platinum, pour in the nitric acid very gradually, and evaporate the solution to dryness on the water-bath. Moisten the residue with a few drops of hydrochloric acid; again evaporate to dryness. Finally dissolve the residue in sufficient water to make 200 c.c.

(42) **Phenolsulphonic Acid.**

| | |
|---|---|
| Sulphuric acid (sp. gr. 1·843) | 25 c.c. |
| Phenol | 3 „ |
| Distilled water | 75 „ |

Mix the phenol with the acid in a beaker. Place on the water-bath for an hour, then allow to cool, and pour into the distilled water.

(43) **Alkaline Solution of Mercuric Iodide (Nessler's Solution).**

1. Prepare a cold saturated solution of mercuric chloride.

2. Dissolve 35 grammes of potassium iodide in 100 c.c. of distilled water, and pour 1 into 2 until, after thorough agitation, a slight red precipitate remains permanent.

Now add 120 grammes of sodium or potassium hydrate, and, when dissolved, dilute to 1 litre. Finally add a little more of the mercuric chloride solution to produce a red colour. Set aside to clear.

Decant off the clear liquid as required into a smaller bottle. The delicacy of the reagent is said to be increased by keeping for a few weeks before use.

(44) **Dilute Sulphuric Acid.**

| | |
|---|---|
| Sulphuric acid (sp. gr. 1·843) | 100 c.c. |
| Distilled water | 300 „ |

Pour the acid gradually into the water with constant stirring. Allow to get quite cold, and drop in volumetric solution of potassium permanganate until the faint pink tint remains permanent for four hours.

(45) **Solution of Sodium Hydrate (free from Ammonia and Nitrites and Nitrates).**

| | |
|---|---|
| Sodium hydrate prepared from sodium | 10 grammes |
| Distilled water | 110 c.c. |

Dissolve, and boil down to 100 c.c.

(46) **Solution of Starch.**

| | |
|---|---|
| Starch | 4 grammes |
| Zinc chloride | 20 „ |
| Water | 1 litre |

Dissolve the zinc chloride in about 100 c.c. of water, and filter. Mix the starch with a few c.c. of cold water into a thin paste, and pour into the boiling solution of zinc chloride with constant stirring. Dilute to a litre. Allow the flocculent matter to settle, and filter the supernatant fluid through a small jelly-bag.

**(47) King's Fluid for preserving Algæ &c.**

| | |
|---|---|
| Copper chloride | ·20 gramme |
| Copper nitrate | ·20 „ |
| Glacial acetic acid | ·5 c.c. |
| Camphor water | 100 „ |

Make a solution, and filter.

---

## *MEDIA FOR BACTERIOLOGICAL WORK*

**(A) Bile Salt Glucose Peptone Litmus Solution.**

This solution has to be used for mixing with various quantities of water; consequently, in order that each dilution may contain approximately the same proportion of bile salt &c., a concentrated solution must be prepared and be diluted as required. This stock solution is made as follows:

| | |
|---|---|
| Peptone | 60 grammes |
| Glucose | 15 „ |
| Sodium taurocholate | 15 „ |
| Litmus solution | a sufficiency |
| Water, distilled | 1 litre |

The litmus used must give a decided purple colour, distinctly visible when the liquid is diluted with 2 volumes of water.

Boil and filter.

Thoroughly cleanse a number of test-tubes 6 inches long and 1 inch in diameter, and place in each a small inverted test-tube (about $1\frac{1}{2}$ inch $\times \frac{1}{2}$ inch). Run into each 10 c.c. of this concentrated solution, plug with cotton wool, and sterilise for fifteen minutes at 100° C. on three successive days. These tubes are for use with 20 c.c. of the water to be examined.

The dilutions required are as under:

**(B) For 10 c.c. of water.**

| | |
|---|---|
| Concentrated solution (A) | 200 c.c. |
| Distilled water | 100 „ |

Mix. Cleanse a number of test-tubes about 6 inches long and $\frac{3}{4}$ inch wide, and insert in each a small inverted test-tube ($1\frac{1}{2}$ inch $\times \frac{1}{4}$ inch), and run into each 10 c.c. of this solution.

Plug and sterilise as before.

**(C) For 5 c.c. of water.**

| | |
|---|---|
| Concentrated solution (A) | 150 c.c. |
| Distilled water | 150 „ |

Mix. Prepare tubes as before, each containing 10 c.c. of the solution.

**(D) For 2 c.c. and smaller quantities of water.**

| | |
|---|---|
| Concentrated solution (A) | 100 c.c. |
| Distilled water | 200 „ |

Mix. Prepare tubes as before, each containing 10 c.c. of the solution.

**(E) Bile Salt Lactose Peptone Litmus Solution.**

Take of

| | |
|---|---|
| Peptone | 20 grammes |
| Sodium taurocholate | 5 „ |
| Water | 1 litre |

Dissolve and boil. Then add

| | |
|---|---|
| Lactose | 10 grammes |
| Litmus solution | a sufficiency to give a distinct purple tint |

Prepare a number of tubes containing smaller inverted tubes, and place in each 10 c.c. of the solution. Plug with cotton wool, and sterilise at 100° C. for fifteen minutes on three successive days.

**(F) Bile Salt Lactose Peptone Agar Medium, with Neutral Red.**

Take of

| | |
|---|---|
| Agar | 20 grammes |
| Peptone | 20 „ |
| Distilled water | 1 litre |

Digest the agar overnight in the distilled water, then dissolve by aid of heat in a Koch's steriliser. Add the peptone, and when dissolved drop in normal solution of sodium hydrate until the reaction is neutral to litmus, then add a further 4 c.c. of the alkaline solution. Filter, and add

| | |
|---|---|
| Sodium taurocholate | 5 grammes |
| Lactose | 10 „ |
| ·5 per cent. solution neutral red | 10 c.c. |

Heat the whole in a steam steriliser to 100° C. for fifteen minutes. As this medium is used for plating, the whole, or a portion, may be

poured into cleaned test-tubes, 10 c.c. in each, before the final sterilisation. From each tube a plate can be made a few minutes before required, by placing the tube in a water-bath until the agar is melted, and then pouring into the petri dish.

**(G) Litmus Milk.**

Fill a separating funnel with fresh milk (free from any preservative), and place in the steam steriliser for half an hour. Allow to stand twenty-four hours, draw off the separated milk, and colour deeply with neutral litmus. If the milk has an acid reaction, add solution of sodium carbonate until an alkaline reaction is obtained.

Fill into test-tubes, 10 c.c. in each, and sterilise by heating to 100° C. for fifteen minutes on three successive days.

**(H) Peptone Solution.**

Take of

| | |
|---|---|
| Peptone | 1 gramme |
| Sodium chloride | ·5 ,, |
| Distilled water | 100 c.c. |

Dissolve, boil for ten minutes, and filter. Pour into tubes, each to contain 5 c.c. Sterilise at 100° C. for fifteen minutes on three successive days.

**(I) Nutrient Gelatine.**

Take of

| | |
|---|---|
| Sheet gelatine | 120 grammes |
| Liebig Company's extract of meat | 5 ,, |
| Witte's peptone | 10 ,, |
| Sodium chloride | 5 ,, |
| Distilled water | 1 litre |

Dissolve with the aid of heat. Raise to the boiling point, drop in solution of sodium hydrate until the liquid has a neutral reaction to litmus, then add 4 c.c. of normal solution of sodium hydrate. Pour about 100 c.c. of the liquid into a beaker, and when cool add the white of an egg. Beat up thoroughly, and pour slowly into the remainder of the liquid jelly, with constant agitation.

Place in the steam chamber for half an hour, and filter. Pour into test-tubes, 10 c.c. in each, and sterilise by heating to 100° for fifteen minutes on three successive days. 5 c.c. tubes may be made for the 'shake' gelatine test and slope cultures.

**(K) Neutral Red Broth.**

| | |
|---|---|
| Take of Liebig's extract of meat | 5 grammes |
| Witte's peptone | 10 „ |
| Sodium chloride | „ |
| Glucose | 5 |
| ·5 per cent. solution of neutral red | 10 c.c. |
| Water | 1 litre |

Dissolve the solids by aid of heat. Boil for a few minutes, and add the solution of neutral red. Filter into test-tubes, 5 to 10 c.c. in each. Sterilise by heating to 100° C. for fifteen minutes on three successive days.

**(L) Neutral Solution of Litmus.**

Take of

| | |
|---|---|
| Litmus (pure) | 20 grammes |
| Distilled water | 500 c.c. |

Digest in a flask on water-bath, with frequent agitation, for one hour. Filter. Take out about 20 c.c. of the clear liquid, and add dilute sulphuric acid to the remainder until a port-wine tint is obtained, then add portions of the 20 c.c. which had been reserved, until the colour is again blue.

Sterilise by boiling for ten minutes.

**(M) Drigalski and Conradi's Medium (modified).**

Take of

| | |
|---|---|
| Liebig's extract of meat | 5 grammes |
| Peptone | 10 „ |
| Sodium chloride | 5 „ |
| Distilled water | 1 litre |

Dissolve, and add

| | |
|---|---|
| Agar (previously digested with acidulated water and washed) | 25 grammes |

Make faintly alkaline to phenol-phthalein paper by addition of solution of sodium hydrate. Add the white of an egg, and filter.

To the filtrate add neutral solution of litmus (L) until the solution is distinctly blue, and 15 grammes of lactose. Keep at 100° C. for fifteen minutes, then add

| | |
|---|---|
| 10 per cent. solution of sodium carbonate | 2 c.c. |
| ·1 „ „ kristall violet | 10 „ |

Pour into tubes, 8 to 10 c.c. in each, and sterilise by heating to 100° C. for fifteen minutes.

**(N) Gram's Method of Staining.**

*Requisites :*

1. A strong alcoholic solution of methyl-violet.
2. Anilin water.
3. Solution of iodine.

| | |
|---|---|
| Iodine | 1 gramme |
| Potassium iodide | 2 grammes |
| Distilled water | 300 c.c. |

Dissolve.

4. Absolute alcohol.

*Method of procedure adopted by the Author.*—Select four watch-glasses of suitable size, and into the first pour a mixture of one part of the methyl-violet solution and nine parts of anilin water, into the second pour the solution of iodine, and in the third and fourth pour absolute alcohol.

After making the coverslip preparation, float it upon the stain for three minutes. Remove, wash with water, and float on the iodine solution for one minute. Finally pass it successively through the two lots of alcohol, allowing it to stay about one minute in each, or until no more colour is removed. Then dry and mount.

---

*TABLE OF ATOMIC WEIGHTS*

| | Atomic weights according to the most recent research | Atomic weights usually employed |
|---|---|---|
| Aluminium | 26·9 | 27·3 |
| Barium | 136·4 | 136·8 |
| Bromine | 79·35 | 80·0 |
| Calcium | 39·71 | 40·0 |
| Carbon | 11·91 | 12·0 |
| Chlorine | 35·19 | 35·37 |
| Chromium | 52·0 | 52·4 |
| Copper | 63·12 | 63·0 |
| Hydrogen | 1·00 | 1·0 |
| Iodine | 125·9 | 126·5 |
| Iron | 55·6 | 56·0 |
| Lead | 205·35 | 206·4 |
| Magnesium | 24·18 | 24·0 |
| Manganese | 54·52 | 55·0 |
| Nitrogen | 13·94 | 14·0 |
| Oxygen | 15·88 | 16·0 |
| Phosphorus | 30·96 | 31·0 |
| Platinum | 193·3 | 194·3 |
| Potassium | 38·83 | 39·0 |
| Silver | 107·11 | 107·66 |
| Sodium | 22·88 | 23·0 |
| Sulphur | 31·82 | 32·0 |
| Zinc | 64·91 | 65·0 |

## *MOLECULAR WEIGHT OF VARIOUS SALTS*

| Formulæ of salts used in making reagents | Molecular weights according to the most recent research | Molecular weights usually employed |
|---|---|---|
| $Na_2CO_3$ | 105·31 | 106·0 |
| $BaCl_2.2H_2O$ | 206·78 | 207·64 |
| $K_2CrO_4$ | 193·18 | 194·4 |
| $AgNO_3$ | 168·69 | 169·66 |
| $KNO_3$ | 100·41 | 101·0 |
| $AgNO_2$ | 152·81 | 153·66 |
| $HNa_2PO_4,12H_2O$ | 355·8 | 358·0 |
| $NH_4Cl$ | 53·13 | 53·37 |
| $Na_2S_2O_3,5H_2O$ | 246·44 | 248·0 |
| $KMnO_4$ | 156·87 | 158·0 |
| $Pb_2(C_2H_3O_2),3H_2O$ | 376·16 | 378·4 |
| $ZnSO_4,7H_2O$ | 285·41 | 287·0 |

## *OXYGEN DISSOLVED BY DISTILLED WATER WHEN SATURATED WITH AIR AT DIFFERENT TEMPERATURES*

(Roscoe and Lunt.)

| Temperature C. | c.c. oxygen at N.P.T. | Mlgrs. of oxygen per litre of water |
|---|---|---|
| 5 ... ... | 8·68 | 12·3 |
| 6 ... ... | 8·49 | 12·05 |
| 7 ... ... | 8·31 | 11·80 |
| 8 ... ... | 8·13 | 11·55 |
| 9 ... ... | 7·95 | 11·29 |
| 10 ... ... | 7·77 | 11·03 |
| 11 ... ... | 7·60 | 10·79 |
| 12 ... ... | 7·44 | 10·56 |
| 13 ... ... | 7·28 | 10·34 |
| 14 ... ... | 7·12 | 10·11 |
| 15 ... ... | 6·96 | 9·88 |
| 16 ... ... | 6·82 | 9·68 |
| 17 ... ... | 6·68 | 9·48 |
| 18 ... ... | 6·54 | 9·28 |
| 19 ... ... | 6·40 | 9·08 |
| 20 ... ... | 6·28 | 8·92 |

## *WEIGHT OF 1 C.C. OF VARIOUS GASES AT N.P.T.*

| | |
|---|---|
| Hydrogen | 0·089 mlgr. |
| Oxygen | 1·430 „ |
| Nitrogen | 1·260 „ |
| Hydric sulphide | 1·635 „ |
| Carbon dioxide | 1·89 „ |

## *ESTIMATION OF IONS*

FACTORS FOR USE IN CALCULATING THE RESULTS OF ANALYSES

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ca | × | 1·5 | = $CO_3$ | $CO_3$ | × | ·6 | = Ca |
| Mg | × | 2·46 | = $CO_3$ | $CO_3$ | × | ·405 | = Mg |
| Na | × | 1·3 | = $CO_3$ | $CO_3$ | × | ·77 | = Na |
| K | × | ·765 | = $CO_3$ | $CO_3$ | × | 1·31 | = K |
| Ca | × | 2·4 | = $SO_4$ | $SO_4$ | × | ·417 | = Ca |
| Mg | × | 3·94 | = $SO_4$ | $SO_4$ | × | ·254 | = Mg |
| Na | × | 2·08 | = $SO_4$ | $SO_4$ | × | ·48 | = Na |
| K | × | 1·23 | = $SO_4$ | $SO_4$ | × | ·813 | = K |
| Ca | × | 1·77 | = Cl | Cl | × | ·565 | = Ca |
| Mg | × | 2·91 | = Cl | Cl | × | ·343 | = Mg |
| Na | × | 1·54 | = Cl | Cl | × | ·65 | = Na |
| K | × | ·907 | = Cl | Cl | × | 1·1 | = K |
| Ca | × | 3·1 | = $NO_3$ | $NO_3$ | × | ·323 | = Ca |
| Mg | × | 5·1 | = $NO_3$ | $NO_3$ | × | ·196 | = Mg |
| Na | × | 2·69 | = $NO_3$ | $NO_3$ | × | ·372 | = Na |
| K | × | 1·59 | = $NO_3$ | $NO_3$ | × | ·63 | = K |

Cl × ·368 = K in $K_2PtCl_6$
Cl × ·701 = KCl in $K_2PtCl_6$

The amount of any ion in the first column multiplied by the factor in the second column gives the amount of the ion in the third column with which it will combine.

## *SOLUBILITY OF VARIOUS SALTS IN WATER AT 16° C. IN PARTS PER 100*

| | | | |
|---|---|---|---|
| $BaSO_4$ | 0·005 | $SrCl_2$ | 40·0 |
| $SrSO_4$ | 0·018 | $LiNO_3$ | 40·4 |
| $CaSO_4$ | 0·205 | $CaCl_2$ | 40·6 |
| $Ba2NO_3$ | 7·6 | LiCl | 43·1 |
| $NaHCO_3$ | 8·6 | $NH_4Br$ | 44·7 |
| $K_2SO_4$ | 9·4 | NaBr | 46·1 |
| $Na_2SO_4$ | 11·9 | $SrBr_2$ | 49·9 |
| $KHCO_3$ | 18·3 | $Mg2NO_3$ | 50·0 |
| $KNO_3$ | 21·1 | $BaBr_2$ | 50·6 |
| $Na_2CO_3$ | 22·0 | $Ca2NO_3$ | 53·3 |
| KCl | 25·0 | $NH_4NO_3$ | 55·0 |
| BaCl | 25·8 | $CaBr_2$ | 58·0 |
| $NH_4Cl$ | 26·3 | KI | 58·1 |
| $NH_4I$ | 31·4 | $MgI_2$ | 59·8 |
| $(NH_4)_2SO_4$ | 33·0 | LiI | 61·1 |
| $MgSO_4$ | 33·7 | LiBr | 62·3 |
| $NaNO_3$ | 34·0 | NaI | 63·0 |
| $Li_2SO_4$ | 34·5 | $SrI_2$ | 63·6 |
| $Sr2NO_3$ | 34·8 | $BaI_2$ | 66·5 |
| NaCl | 35·9 | $MgCl_2$ | 66·6 |
| $MgBr_2$ | 36·0 | $CaI_2$ | 66·7 |
| KBr | 38·0 | $K_2CO_3$ | 100·0 |

# NOTES

## *DETECTION OF RADIUM IN WATERS*

Radium has recently been detected in the Bath springs, and in the sinter from the same springs and from the Buxton springs, by the Hon. R. J. Strutt, and it is quite possible that traces of radium salts may occur in other waters. The fact that radium sulphate is even more insoluble than barium sulphate, renders it impossible for any water containing sulphates in solution to contain more than an infinitesimal trace of radium; but the test applied by Mr. Strutt so far exceeds in delicacy any other known method of analysis that the presence of one ten-millionth part of a milligram of radium per 100 c.c. of water can easily be detected. He estimates that the whole of the radium in a year's flow from the Bath springs does not exceed one-third of a gramme, yet this was easily detected in the residue left upon the evaporation of 10 litres of the water. After the evaporation of the water the detection of the presence of a radio-active substance is the work of a few minutes only, and the proof that this substance is radium merely requires a second experiment after the lapse of a few days.

The process is based upon an examination for the characteristic emanation of radium as determined by its rate of decay. The emanation is given off in the cold, but more readily at a dull red heat.

The powdered water residue (or sinter) is placed in a hard combustion tube, drawn out, and sealed at one end and connected to a mercury gas-holder at the other. The tube is heated to redness, and the gas evolved collected in the gas-holder. When the evolution of gas has ceased, the point of the tube is broken off and air drawn into the gas-holder up to a standard volume.

For measuring the electrical effect an electroscope is used. This is exhausted, and the gas extracted from the residue, together with the air which has been used to make up its volume to a sufficient amount, is dried and admitted. After a few hours, enough for the deposited activity to attain its full value, the rate of leak is read. Any leakage above the normal indicates the presence of a radio-active body. Leakage being found, the amount and day and hour are noted, and the gas pumped out into a test-tube and stored over mercury. After a sufficient time has elapsed, three to seven or more days, it is again introduced into the apparatus by means of a siphon gas pipette, and the rate of leak again measured. The method of manipulation used in storing and transforming the gases is described in Dr. Travers's 'Study of Gases.'

In Mr. Strutt's experiments with air alone in the electroscope the rate of leak was 2·25 scale divisions per hour, and excess over this was due to the emanations from the ignited substance. With radium the rate of leak falls to one half in a little under four days. Mr. Strutt says: 'By measuring the rate of leak due to the accumulated emanation from a weighed amount of material, the proportion of radium present may be estimated. A comparison with the leak due to the emanation of a known weight of radium must of course be made. For this purpose it would be best to weigh out, say, a milligram of radium bromide, dissolve it in a litre of water, and evaporate a small measured quantity of the substance in a suitable tube. In this way the effect due to a standard quantity could be determined.' Mr. Strutt has examined the residues from several other waters, but with negative results. (*From a paper read before the Royal Society, March* 10, 1904. *Vide also Madame Curie's 'Thesis on Radio-active Substances,' published at the 'Chemical News' Office, E.C.*)

## *HELIUM IN SPRING WATERS*

Lord Rayleigh has examined the gases contained in many mineral waters, and discovered the presence of helium in the water from the warm springs at Bath. The method employed for obtaining the gases from a large quantity of water is described in Travers's 'Study of Gases,' p. 32. The amount of helium and other recently discovered gases in the atmosphere is said by Travers to be—

Helium, 1 to 2 parts per 1,000,000 of air.
Neon, 1 to 2 parts per 100,000 of air.
Argon, 0·937 parts per 100 of air.
Krypton, 1 part per 1,000,000 of air.
Xenon, 1 part per 20,000,000 of air.

It is probable, therefore, that all waters containing in solution gases derived from the air contain traces of these elements. Their detection, however, has at present no practical importance. Certain springs give off more helium than can apparently have been derived from the atmosphere. The gases evolved by the Bath spring, for example, contain about ·1 per cent. of helium. Travers says that 'the quantity of helium, which is constantly being given off by mineral springs, is, however, enormous, so that it is probable that the amount present in the atmosphere does not tend to diminish.' The source of this helium is conjectured to be the spontaneous dissociation of the element radium.

## *THE TEMPERATURE OF WATER*

Occasionally the thermometer is of use in tracing the source of a water; water ascending from a considerable depth being usually at a higher temperature than water from a more superficial source. A bath thermometer having the bulb at the bottom of a metallic cup is the most generally

useful, but occasionally it is desirable to use a maximum registering thermometer which must have been cooled before use to a temperature below that which it will have to register. An ordinary long thermometer with the scale etched on the glass is best for taking the temperature of the water entering from various fissures. In taking such readings recently in a chalk pit, the waters were found to vary considerably. At the side nearest the river the temperature was decidedly lower than at the opposite side, whilst at the third side the water flowing from the fissures was many degrees warmer than that from either of the others. It was significant that on this third side, not far away, was the cooling pond connected with a large manufactory.

### *THE NEW TURBIDIMETER*

Mr. C. Baker, scientific instrument manufacturer, 244 High Holborn, London, W.C., has made for me a modified form of Anthony's turbidimeter, and has kindly given me the following description of it:

'This new turbidimeter consists of two parallel tubes, one of which, of standard length, viz. 50 centimetres, closed at the ends by plates of glass, contains the water to be examined, and the other a Nicol prism.

'The ends of these tubes are covered with caps containing ground-glass screens of the same density. These two sources of light are examined through an eyepiece containing another Nicol prism, and by employing a rectangular prism between the eyepiece and the two tubes the field of view is seen neatly dechrotomised, one half being illuminated from light coming through the tube containing the water under examination, whilst the other half receives light from the tube containing the Nicol prism. By rotating the eyepiece the illumination of the latter half of the field, seeing that the light has already passed through a Nicol prism, can be varied until it matches the half receiving light through the standard thickness of water under examination. To the eyepiece a pointer is attached which rotates through 90° and indicates the amount of turbidity of the water to a rational scale, in which 0 represents perfect transparency and 1 total obscuration. When water of very great turbidity is to be examined the tubes can be unscrewed and the lengths reduced to 25 or 12½ centimetres, when the results read must be multiplied by 2 or 4 to bring them to the standard length of 50 centimetres.

'If the turbidity of the water is such that even with the 12½-centimetre tube length it is too opaque to permit of an accurate determination, recourse must be had to diluting it with an equal or double volume of distilled water, when the results must be still further multiplied by 2 or 3 to bring them into due relation with the standard tube length of 50 centimetres.

'The instrument can be used with practically any illumination, and is packed in a mahogany case, which also serves as a stand.'

So far I am very much pleased with the instrument, and it appears to be a distinct improvement on the original form described by Anthony.

*Turbidity of Water.*—Over a large portion of the American continent the only water available for public purposes is derived from the rivers, the

waters of which are turbid and which vary in turbidity from day to day. The clarification is effected by the use of coagulants, chiefly aluminic sulphate, and subsequent filtration. The amount of coagulant used depends upon the turbidity of the water. This is estimated by the aid of a graduated rod having a platinum wire 1 mm. in diameter projecting at right angles from its extremity. This end is plunged vertically into the water and gradually raised until the platinum wire just becomes visible; the distance of the wire from the surface of the water, in inches, is then read off, and the reciprocal gives the turbidity. Thus, if the wire becomes visible at a depth of 20 inches the turbidity is ·05; if it does not become visible until within 2 inches of the surface the turbidity is ·5, &c.

## *COPPER IN WATER*

While these pages have been passing through the press I have had submitted to me a sample of moorland water alleged to have an action on copper. A tooth-brush was sent with the water, the fibres of which had a grass-green colour, which proved to be due to copper. The water contained traces of both copper and lead. A sample of the water from the mains had an acid reaction (100 c.c. required 1·25 c.c. decinormal solution of sodium carbonate for neutralisation), but contained neither lead nor copper. It had both an erosive and solvent action on lead, and digested with clean copper wire, it dissolved an appreciable amount in twelve hours. The water is conveyed by a lead service pipe to the house, and is heated in a copper cylinder which supplies the bathroom. In passing through the pipe and cylinder it evidently takes up traces of both metals. The subject is being further investigated.

## *UNCERTAINTY OF DEEP WELL BORINGS*

A boring has recently been made into the calciferous sandstone of the Lower Carboniferous system in order to obtain a supply of water for a certain town. The result was successful so far as finding water was concerned, but unfortunately, as the subjoined analysis shows, the water is useless for any purpose.

The water contained in parts per 100,000:

| | |
|---|---|
| Calcium carbonate | 19·2 |
| Calcium sulphate | 39·7 |
| Calcium chloride | 142·9 |
| Magnesium chloride | 62·6 |
| Sodium chloride | 721·2 |
| Silica &c., and errors | 4·4 |
| Total solids | 990·0 |

The site is over twenty miles from the sea.

## *VALUE OF SYSTEMATIC EXAMINATIONS OF PUBLIC SUPPLIES*

An excellent example of the value of periodic examinations has occurred in my practice during the present year.

A certain supply derived from a deep well in the chalk occasionally gave, upon bacteriological examination, results indicating some contamination. The well had a long superficial adit for storage purposes, and I suggested that the water level should be kept down below this adit for a time and a sample of the water from the deep source collected for examination. This was done, and the water proved unexceptionable in character. At the top of the adit in one place water was seen to be entering, and a sample of this was examined. It had all the characteristics of an imperfectly purified sewage. There is no doubt that this is the source of the objectionable organisms which I had from time to time discovered. Needless to say, the cause of this pollution is being sought for with the object of removing it.

## *THE QUESTION OF STANDARDS*

I have carefully refrained from suggesting any standards in either the chemical or bacteriological sections of this work; and it is gratifying to find that Dr. Houston, in his most recent report to the Royal Commission on the Disposal of Sewage (March 1904), is also of opinion that 'to lay down absolute standards is not justifiable.' He however suggests the subdivision of waters into classes for practical purposes, and the drawing of a definite line, objection being taken to all waters giving results above, and to pass all waters giving results below, this arbitrary standard. This is apparently illogical, especially as in the same paragraph he says (page 103): 'It ought to be understood that, whenever possible, multiple analyses should be made, and the results interpreted by aid of local conditions.' I do not find where he would draw this line, but he divides waters into classes according to the number of coli-like (*sic*) organisms they contain.

'In the first class of waters are placed all those containing no coli-like microbes in 100 c.c.

'In the second class are waters giving a positive result with 100 c.c. but a negative result with 10 c.c.

'In the third class are waters giving a positive result with 10 c.c. but a negative result with 1 c.c.

'In the fourth class are waters giving a positive result with 1 c.c. but a negative result with 0·1 c.c., and so on.'

At the commencement of the report above referred to, Houston gives reasons for not using the term 'communis' with reference to the B. coli, and adds: 'Throughout this division the term B. coli has been used to indicate all gas forming coli-like microbes.' No doubt, therefore, the term 'coli-like' in the above divisions includes any organism which in pure culture produces gas in a gelatine 'shake' culture, without subsequently causing liquefaction.

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