WATER AND ITS PURIFICATION

S. RIDEAL, D.Sc.

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WATER AND ITS PURIFICATION

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A HANDBOOK FOR THE USE OF LOCAL AUTHORITIES SANITARY OFFICERS, AND OTHERS INTERESTED IN WATER SUPPLY

BY

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PREFACE TO THE SECOND EDITION.

In the present edition, additional matter dealing with recent water epidemics and with sand filtration has been included and I have had the advantage of having the proof sheets read by my friend Mr. H. Howard Humphreys, A.M.I.C.E., who has given me some useful suggestions. Several alterations in the body of the book have been made in order to bring the subject up to date, and to correct a few errors which crept into the first edition. Chapter I. has been almost entirely re-written.

SAMUEL RIDEAL.

28, Victoria Street, Westminster.
September, 1901.

PREFACE.

The purity of water supplies has always been a subject of importance, and every year it receives more and more attention. Not only in London—where the present public supply has been recently discussed by a Royal Commission and by various other bodies—but also in several provincial towns, the desirability of a public supply of greater purity and larger quantity is now under consideration; while in the rural districts outbreaks of disease have now so frequently been traced directly to polluted wells, that it can safely be said that at the present time the question of universal pure drinking water is one of primary importance to all classes of the community. The closing of polluted wells, and decisions on new supplies, are now, however, in the hands of the general public, who, and their elected representatives, thus need to become acquainted with the results of the progress made during the last few years in bacteriology and knowledge of the causation of disease.

To all who are interested in the subject of Water Supply this book is meant to appeal, and it is hoped that by its perusal some insight into the methods of research and the interpretation of results will be attained.

Reports of the results of water analysis are too often regarded as being of too technical a nature to be practically useful; whereas, on the contrary, such reports should at least indicate to the reader in what direction alterations, if necessary, in the present conditions of supply should proceed.

With this object in view, I have endeavoured to include in the scope of the book the more recent conclusions which have been arrived at by workers in different branches of the subject, and have as far as possible refrained from details. Whilst it is necessary that the results of a chemical or bacteriological analysis of a sample of water should be intelligible to a non-professional reader, it need hardly be pointed out that it is impossible for any but those who have been trained in the methods of analysis to arrive at results which are worthy of confidence. This little book will have achieved an important result if it tends to make more generally known the fact how valueless—and, moreover, how dangerous—it is to rely upon so-called rough-and-ready tests for forming an opinion upon the purity of a doubtful water.

In preparing the volume, I have had the advantage of several important suggestions from my friend Mr. Henry Law, M.Inst.C.E., who also was good enough to read the proof-sheets as they were passing through the press. My thanks are also due to my assistant Mr. C. G. Stewart, A.R.C.S.I., for his valuable help, and to those publishers, manufacturers, and others, who have kindly lent blocks for illustration.

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WATER PURIFICATION

CHAPTER I.

CHARACTERS OF NATURAL WATERS.

The word "pure," as applied to water for human use, bears a meaning different from the strict scientific sense. Chemically pure water is only to be obtained by laboratory processes and with great difficulty, and as it dissolves and absorbs a varying quantity of most matters with which it comes in contact, its preservation in the pure state presents an equal difficulty. For drinking, cleansing, and manufacturing purposes it is not necessary, nor is it always advisable, that it should be pure to this extent; it is sufficient that it should be as far as possible devoid of matters prejudicial to health or to commercial objects. Such water has in most inhabited countries been plentifully furnished by nature, and the first care must be to select the best, most constant, and copious of the supplies by studying the character of the substances that are usually found naturally admixed in more or less quantity with all waters; secondly, to secure that a good water shall be transmitted to the consumer without any diminution of its purity.

The physical or "organoleptic" characters of a water are by no means a safe guide as to its wholesomeness. Brightness may be due to a filtration through porous soil which is quite inadequate to remove danger, a sparkling quality to dissolved gases produced by decomposition of organic matter, and a piquant taste to nitrates and chlorides of animal origin. Yet water from shallow wells in towns has frequently been preferred by residents to a purer public supply, and considerable opposition has often been encountered to the closing of such sources. The London Broad Street pump is a notable instance. During the cholera outbreak in 1854, this infected source, bright and sparkling as it was, carried the disease to over one hundred cases, while others in the locality who made use of a different supply were not attacked. Moreover, a lady who formerly lived in the district, through preference for the brilliant character of the water, had it conveyed in bottles to her house at Hampstead for her own consumption, and an isolated outbreak occurred in her establishment with fatal results. Favourite drinking waters of this kind have often been directly traced to springs originating from graveyards. Both by chemical and biological examination, and by the results in spreading disease, the most serious pollution by decaying animal matters has frequently been demonstrated. On the other hand, flat, insipid, and even cloudy waters have caused no injury in use, their faults having been due to causes which had no hygienic importance. Physical characters, however, are of great value in conjunction with the subsequent analytical results. It is difficult to make them exactly comparable, and much work has been directed to establishing standards and degrees of colour, transparency, odour, and taste.

TRANSPARENCY

involves freedom from suspended particles, and in a less degree absence of colour. The difference between the two effects can be obtained by examination before and after careful filtration, which removes the first, but little affects the second. Transparency or turbidity is measured by the length of column through which an object can be seen when gradually lowered from the top, and afterwards approached from the bottom, the mean being taken as the measurement. It is best ascertained on the spot in large bodies of water, as it is rarely in the laboratory that a sufficient column of water is available, and it is usually only requisite to record the sample as turbid, very turbid, nearly clear, or clear. On the large scale various methods have been employed, by "diaphanometers." Secchi, in 1865, used in the Mediterranean a white disc, twenty centimetres in diameter; later, by the Geneva Commission, an incandescent light was lowered, noting the limits of "clear vision" and of "diffused light." This method would be specially adapted for wells. The intensity of light at different depths was also measured by sensitised photographic plates, but in this way colour considerably interfered. To obtain observations with less quantities of liquid, Hazen, at Lawrence, Mass., attached a bright platinum wire, one millimetre in diameter, at right angles to the end of a graduated rod, recording the turbidity in degrees; invisibility at one inch being taken as unity, other degrees were fractional, inversely as the depth at which the wire was obscured. If the turbidity was more than one, the sample was proportionally diluted; if less than 0·02 (50 in.), the turbidity was ascertained in another water, and this diluted to imitate the sample as nearly as possible. The jars or bottles were cased in black cloth and illuminated from below (*Filtration of Water Supplies*, by Allen Hazen, Wiley, New York, 1900). Whipple and Jackson have introduced silica standards for turbidity, made by finely grinding the silicious frustules of diatoms obtained from certain deposits, suspending in water, and diluting definitely. They seem to have many advantages over kaolin or chemical precipitates (*Eng. Record*, N.Y., Jan. 27th, 1900).

Waters which appear limpid to the eye may yet contain an appreciable amount of solid matter in suspension, consisting of substances and organisms so transparent that their presence can only be proved by filtration. Comparison should always be made with a pure water.

Colour

is observed by looking at an illuminated white surface through a two feet column of the water contained in a horizontal cylinder closed by glass plates; also with less distinctness through a column in a vertical jar. For ordinary purposes a thin tumbler of the water may be set on a sheet of white paper in a good light. Pure water has naturally a blue tint. A greenish tinge is communicated by algæ, a brown by peaty and sometimes by animal matter, a reddish by iron, while a yellowish tint points to the possible presence of urine. Various colours may be also communicated by manufactures.

Many conventional standards have been proposed for obtaining figures of comparison between waters by means of coloured solutions on the same principle as Nesslerizing. Formerly, as the yellow and brown tints were considered the most important, the Nessler test alone was used, recording the result in amounts of ammonia required to produce the same colour. The method, however, had many faults. Crookes, Odling and Tidy, for the London reports, employed hollow glass wedges containing solutions of copper sulphate, cobalt chloride, and ferric chloride, sliding over one another in front of a circular hole. The figures were stated in millimetres thick of blue and brown. Hazen employs standard mixtures of solutions of platinum and cobalt, the unit of colour being one of platinum in 10,000 of water (*American Chemical Journal*, xiv., 300). The London County Council measure the colours in terms of red, blue and yellow, by comparing the sample with an equal column of distilled water, before which graduated coloured glasses are interposed in Lovibond's Tintometer. The types chosen are somewhat unnatural, but in a clear water deviation from the usual tints follows the lines of contamination indicated above.

TASTE,

though often deceptive as to composition, is of great importance from the engineer's and consumer's point of view. Some of the London official reports speak of an "evanescent smoky taste." This, though certainly possible in a smoky town, does not seem to be elsewhere recorded. But tastes and odours due to algæ and animal * growths in reservoirs and pipes have frequently occasioned serious trouble, as many of these organisms cause peculiarly unpleasant flavours, while earthy and vegetable or marshy ones are sometimes communicated by larger aquatic plants and mouldy tastes and smells by fungi (p. 284). Custom may render such waters comparatively innocuous, but nausea, diarrhœa, and other ill effects

* A "bitter and cucumber taste" in the Boston (Mass.) water supply caused trouble in 1881 and 1892. It was traced to the protozoon Synura (Whipple).

have been traced to their use. Waters astringent from tanninoid substances, acid or alkaline from chemicals, brackish from sodium chloride, bitter from magnesium salts, inky from ferrous compounds, or in some districts sulphuretted (H_2S) or sulphurous (SO_2), are readily appreciated by taste, and are obviously unsuited for ordinary drinking.

Odour

is often a valuable indication. It may be earthy from clay, peaty from upland sources, marshy (there is a distinct difference) from rivers, swamps, and ponds, sulphuretted or even urinous from recent sewage contamination. The odour is best observed by half filling a stoppered bottle (a cork is inadmissible, as by itself it imparts some odour) with the water, warming to blood heat (about 100° F.), shaking vigorously with the stopper slightly loosened to relieve the pressure of the gas, and smelling carefully, preferably in comparison with a pure water warmed to the same degree. The natural odour of pure warmed water is very slight. A mere trace of urine could at once be detected by this test, and would, of course, condemn the water and render necessary a rigorous investigation as to its source.

In special cases a large volume of the water may be extracted with pure ether (p. 276), or a litre distilled and the first portions collected. Distillates from all waters have a "boiled" odour, due probably to an alteration of the organic matter by the heat: in pollution with sewage a peculiar camphoraceous smell is often observed, derived from a neutral substance which I have isolated from sewage distillates in white volatile crystals almost insoluble in water, therefore collecting as a white scum when present in some quantity; it is frequently more strongly evident in the albuminoid ammonia distillates (p. 279).

No exact measurement of odour has yet been attained, and the nomenclature has no precision. A fishy taste and odour, due probably to trimethylamine, attends some bacteria of putrefaction which may invade water, such as *B. fluorescens putridus*; others, as *B. sulphureum*, yield sulphuretted hydrogen. Apart from the smell produced by decay, many odours affecting large bodies of water are due to oils secreted by algæ and protozoa. Anabæna, Scenedesmus, and Asterionella among the algæ, and some flagellate infusoria, such as Uroglena and Synura, have given great annoyance from this cause. Several public water supplies in England have at times been suddenly invaded by fishy odours and tastes, attributed to Volvox, Nostoc, and other organisms. At Cheltenham, in 1891, the fault was traced to *Chara fœtida* or some of its parasites. The fishy odours are generally produced by animal, the aromatic by vegetable, organisms. It is found that these difficulties are avoided by adopting covered or dark reservoirs. Boiling the water in many cases removes the odour.

Thresh states that in some parts of Essex the water derived from veins of sand beneath the boulder clay has a faint but decided odour of sulphuretted hydrogen; the smell entirely disappears upon leaving the water exposed to the air for a short time in a bucket or tank. "In these districts, however, the inhabitants will drink any kind of ditch or pond water rather than this."

Temperature.

This should always be observed at the time of taking the sample. The preference for deep supplies depends to a certain extent on their coolness, but in mains laid near the surface this advantage rapidly disappears. The importance of temperature is seen in the considerations that—

1. Great fluctuations indicate imperfect protection, or variability in the source, with possible extraneous pollution.

2. At a higher temperature the growth of bacteria, especially "blood heat," including pathogenic, organisms, is encouraged; the chemical changes are also more rapid.

3. When used for cooling purposes, every degree of rise marks less efficiency.

4. The amount of oxygen and other gases capable of being dissolved is less as the temperature becomes higher (see p. 22).

Suspended Impurities of Natural Waters.

A. Plants.

Observers are not entirely agreed on the classification of the lower plants occurring in land waters, but the following grouping is a useful one. For the genera and species special works must be consulted.

1. *Diatomaceæ*, generally brown or nearly colourless, skeleton silicious, with two box-like valves and fine markings. Free, or connected in stars or chains.

2. *Cyanophyceæ*, algæ of various colours, never pure green, the chlorophyll being associated with other colouring matters.

3. *Chlorophyceæ*, or green algæ, including Protococcoideæ, Desmideæ, and Confervoideæ.

4. *Fungi*, without chlorophyll, including:—

(*a*) Schizomycetes: Cladothrix, Leptothrix, Crenothrix, Beggiatoa, and Bacteria proper.

(*b*) Spores and mycelium of yeasts and moulds.

B. Animals.

5. *Protozoa*. Rhizopoda (Amœba); flagellate and ciliate Infusoria.

6. *Rotifera*, or wheel-bearing animalcules.

7. *Polyzoa* or *Bryozoa*: coral-like forms.

8. *Spongidæ*: fresh water sponges.

9. *Crustacea* (Cyclops, Daphnia and others).

10. Worms and their eggs, acari and small insects, &c., and occasionally small fish and amphibia.

C. Non-living matters.

(*a*) *Mineral.* Clay, sand, chalk and carbonate of lime crystals, soot, oxide of iron and occasionally of manganese.

(*b*) *Vegetable.* Hairs often of marked types; vessels, spiral or other forms; cellular tissue recent or decayed, including wood fragments; starch and pollen granules; fibres of paper and clothing; amorphous brown humus.

(*c*) *Animal.* Hairs, epidermal and epithelial scales, fibres of muscular and other tissues, fæcal matter, portions of insects, dead animalculæ.

The suspended bodies may be often accidental, and can be removed almost entirely by filtration or subsidence. Even in a water polluted by organisms causing disease these are often so few in the bulk that they are not found in the individual sample, whereas chemical products, being dissolved, are present in each unit. The substances in solution are therefore a better index of the permanent character, and exist in great variety, as shown by the following table :—

DISSOLVED MATTERS.

Organic ..	Peaty and other vegetable matter, urea and other constituents of excreta and animal fluids, products of putrefaction, as alkaloids (ptomaïnes) and amido-acids, phenol and its derivatives, with waste products from factories such as fat, soap, oils, tar, colouring matters, &c., sulphocyanides and benzene from gas works.

Dissolved Matters—*continued.*

Inorganic or mineral solids	*Usual* (harmless unless quantity excessive)	Carbonates, chlorides, sulphates, nitrates of calcium, magnesium, sodium, potassium, iron; silica and phosphates, with minute traces of other bodies and small quantities of ammonium salts.
	Occasional (generally extraneous and noxious)	Nitrites; poisonous metals: lead, iron (in excess), copper, zinc, arsenic, manganese, barium, strontium; medicinal salts containing iron, iodine, bromine, silica, boron, lithium, &c.; products of manufacture: mineral acids, alkalies, and salts.
Gases	*Normal*—	Oxygen; nitrogen; carbon dioxide.
	Abnormal—	Sulphuretted hydrogen, sulphur dioxide, ammonia, &c.

The Dissolved Organic Matter.—All organic matter is objectionable, as it is necessarily a sign of contamination. But the quantity of organic matter is not so important as the quality. For instance, an upland water may contain a large quantity of brown humous matter, almost entirely carbonaceous; yet, beyond being slightly astringent or laxative, according to the nature of the organic matter it has absorbed, it will not convey disease. On the other hand, a bright, clear water with less organic contents may include such dangerous elements as will infect a whole neighbourhood with a fatal epidemic. But the peaty water is not therefore to be approved; it contains abundant food for the growth of organisms that may accidentally enter. It must be purified by oxidation or precipitation before being passed as potable. There is another objection to peaty waters: they are usually acid from the presence of humic (*humus*, the ground), crenic and apocrenic, and other brown vegetable acids produced by the decay of vegetable matters. These waters have a tendency to dissolve metals, rapidly corroding iron, and therefore are unfit for use in steam boilers. They also attack lead pipes, and thus render the water poisonous. Their colour alone makes them unfit for many technical purposes. Fortunately they can be easily and cheaply improved by a method which will be described later (p. 158).

In other respects there is a distinction between *peaty waters* which have derived their brown constituents from percolation through roots of heather and grass on uplands, then passing over the stony bed of mountain streams, and *marsh or swamp waters,* which have lain stagnant. The former are usually clear and almost free from organisms ; the latter are frequently turbid, foul-smelling, and swarming with infusoria, rotifers, amœbæ, and bacteria. It is possible by habit to acquire immunity to both classes, but there are abundant instances where diseases of malarial or diarrhetic character have been caused especially by swamp waters. As François Coreil says (*L'Eau Potable*, Paris, 1896, p. 11) :—" Waters charged with organic matters can create true symptoms of poisoning, although they are incapable of producing specific maladies if they do not contain the specific germs of the disease."

Hippocrates* speaks of the injury to general health occasioned by drinking impure waters. The effect of marshy waters in causing ague, dysentery, &c., is so well recognised that the term "paludism" has been introduced for it.

Animal matter of recent origin and undergoing rapid change is a specially dangerous feature in drinking water. In the putrefaction effected by bacteria it is broken up into simpler organic compounds with evolution of gases, chiefly carbonic acid and nitrogen, which may give the liquid the sparkling property already alluded to. The intermediate products include enzymes, amido-acids like glycocine, leucine, tyrosine, and others, and a number of alkaloidal bodies or amines, such as ethylene-diamine,

* Treatise *περι ἀέρων ὑδάτων τόπων*, Vol. I., p. 532, Kühn; Vol. II., p. 26, Littré. The passages in Chapter VII. relating to water are worth quoting as illustrating the early knowledge of the subject.

Περὶ δε τῶν λοιπῶν ὑδάτων βούλομαι διησήσασθαι, ἅ τέ ἐστι νοσώδεα και ἅ ὑλιείνοτατα και ὁκόσα ἀφ' ὕδατος κακὰ ἐικὸς γίνεσθαι και ὅσα ἀγαθα. Πλεῖστον γάρ μέρος ξυμβάλλεται ἐς τὴν ὑγιείην. Disadvantages of standing water in marshes and lakes, *τοῖς σὲ πίνουσι σπλῆνας μὲν ἀιεί μεγαλους ἔιναι κὰι μεμυωμένους* (have always an enlarged and hardened spleen). Then he condemns hard waters from stony districts, *ἁι πηγὰι ἐκ πετρέων σκληρὰ γὰρ ἀνάγκη ἔιναι.* In the eighth chapter he passes on to the consideration of rain and snow waters. *τὰ μὲν δυν ὕμβρια κουφότατα και γλυκύτατά ἐστι και λεπτότατα καιλαμπρότατα* (rain waters are the lightest, sweetest, thinnest, and most limpid). On p. 36 (Littré) he gives the warning to boil the water, *δέεται δὲ ἀφέψεσθαι καὶ ἀποσήθεσθαι* (filter) *ἐι δὲ μὴ ὀδμὴν ἴσχει πονηρὴν.* Snow and ice water are condemned, *τὰ δὲ ἀπὸ χιόνος καὶ κρυστάλλων πονηρὰ πάντα.*

At p. 40 (Littré) *κὰι φημὶ ἄμεινον ἔιναι τοῖσι παιδίοισι τὸν δινον ὡς ὑδαρεστατον διδόναι ἧσσον γὰρ τὰς φλέβας ξυγκάιει κὰι ξυναυάινει.*

An allusion in Pliny states: "Nube latent amnes puti, ære tantum mixti: terra calcem, salem, lutum addit, homo sordem" (the rivers rest pure in the cloud, mixed only with air: the earth adds lime, salt, mud; man adds filth).

with great physiological power. Therefore a polluted water, though freed from bacteria by filtration or boiling, may still be unwholesome. Further bacterial action can change these bodies into ammonia, which finally, by the aid of atmospheric oxygen and of nitrifying organisms, is converted into nitrates. This is what is meant by the natural purification of water, and forms a most important factor in dealing with supplies.

Recent excrementitious matter sometimes enters into waters through leaky pipes or wells near middens or manure heaps. In country villages it was formerly common to see closets on the banks of brooks discharging directly into the stream, the water of which was actually drunk by people living lower down before there had been time for oxidation or natural purification to take place. Such conditions have caused many violent epidemics, notably the one at Terling, in Essex. This form of pollution is easily recognisable by the odour, fæcal or urinous, produced on warming the water. The urea present in the urine may sometimes be detected in such waters, but it rapidly passes into carbonate of ammonia. Phenol has been stated to be a constant constituent of sewage, and a test for the presence of soluble animal matter in waters is founded on its detection. It has been proved that water polluted by fæcal matter can be drunk for a time with impunity by persons in health. This fact, together with the immunity of many individuals from certain forms of infection, probably accounts for the escape from apparent consequences for long periods of persons who have habitually made use of wells and streams which were obviously contaminated with excreta, a fact which has often been adduced by unthinking persons in order to throw doubt on the importance of securing a purer water supply. But, apart from the repulsiveness of the idea, the immunity may at any time be terminated by the passage into the water by the same channel of special pathogenic organisms.

The nature and amount of the mineral salts present in water will depend on the rocks or soils over which it has passed or through which it has percolated. Almost all substances are to a certain extent soluble in or acted on by water and air; the quantity dissolved will be affected by the amount of substance present, the surface exposed and the time of contact—rapid transit allowing relatively less solution—on the degree of solubility of the substance, and the presence of accessories like oxygen and carbonic acid. Temperature and pressure, with certain exceptions (notably sulphate of lime, p. 226) increase solubility, hence many thermal deep springs contain abnormal amounts of dissolved ingredients, such as silica, which are deposited as crusts on exposure to air. The mineral constituent which is usually present in largest quantities is calcium carbonate, dissolved by the carbonic acid in the water as bicarbonate. Magnesium carbonate is acted on in a similar manner, and the chloride, sulphate, and nitrate of these two metals are generally to be found in natural waters. These earthy salts cause "hardness," and will be discussed in Chapter X. It is sufficient to say that in moderate quantities they seem to make no difference to health. But, on the other hand, goitre has been suspected to be occasioned by waters containing a large amount of these salts, and constipation and dyspepsia are known to be sometimes produced by very hard water. At Leicester, in 1898, considerable opposition was offered to the introduction of a water supply from the upper Derwent as being goitrous, but it was shown that the water was pure and soft and not likely to cause goitre, the few cases on the mountains having been attributable to other reasons. Waters containing large quantities of magnesium salts or sulphate of soda are purgative, and frequently cause diarrhœa. Potassium salts are not usually present in any quantity, except in sewage-polluted waters.

Common salt ($NaCl$) is a frequent constituent of waters found near the sea or brackish estuaries, but unless it can be traced to a marine origin or is derived from rocks like the new red sandstone, which contain deposits of salt and brine springs, its presence in quantity is indicative of animal contamination.

Natural waters are usually faintly alkaline from the presence of carbonate of lime, and at the same time are acid to phenolphthalein, owing to free carbonic acid also being present. Any other acid or alkaline constituent would render the water injurious to digestion. It is found by experience that certain proportions of mineral salts are beneficial in waters; beyond these proportions they may be injurious and deteriorate the water for most purposes. The approximate limits will be considered in a subsequent chapter.

Ammonia (NH_3) and its salts are almost entirely absent from pure waters. Ammonia, being one of the final products of the decomposition of animal matter, is usually an indication of pollution, and frequently indicates contamination by urine. It, however, is comparatively easily oxidised by water organisms into nitrites and nitrates. Its relation to these compounds is further discussed in a later section.

All waters contain minute traces of iron. Its presence in amount as low as one-fifth grain per gallon imparts a disagreeable chalybeate taste to the water, and renders it unfit for general consumption and most industrial purposes. It can generally be removed by precipitation with lime-water and oxidation, and the water so purified contains less bacteria, but frequently has still a somewhat unpleasant taste. For this reason it is rarely economical to resort to the purification of mine and pit waters or those arising from ferruginous strata.

Silica (SiO_2), derived from the passage of the water over sand, flints, or quartz rocks, is always present in waters, but is frequently overlooked. It often amounts to one grain or more per gallon, and is precipitated with the earthy carbonates on boiling. In very soft waters, such as those which are derived from the uplands of igneous rocks, the silica in a gelatinous form constitutes the major portion of the precipitate on boiling. It is present in considerable amount in boiler incrustations, especially those from sea water (Table B). If in unusual quantity, it is a bad feature for industrial waters, though for medicinal use it may be of value.

Salts which give a water a medicinal value, and contaminations from manufactures, are considered in a subsequent chapter.

Even traces of poisonous metals condemn a water at once. Lead especially is known to accumulate in the system and occasion paralysis and other serious effects (p. 147). Although many of the metals can be removed from a water by filtration through animal charcoal, the action cannot be trusted, so that, unless the source of the metal can be detected and the contamination stopped, it is imperative that the supply should be disused for drinking.

A water to be palatable should be fully aerated; *i.e.*, it should contain fairly full amounts of the natural constituents of the atmosphere, oxygen, nitrogen, and carbonic acid, otherwise it tastes flat and insipid. Deep waters have, as a rule, a larger quantity of nitrogen and less oxygen. Dissolved oxygen is necessary for fish life, and also for the self-purification of rivers, since it oxidises the organic impurities they contain. River water on boiling gives off about one-twentieth of its bulk of a mixture of oxygen, nitrogen, and carbonic acid. Water can dissolve under ordinary conditions about its own volume of carbonic acid, three per cent of oxygen, and $1\frac{1}{2}$ per cent. of nitrogen, when in the presence of each gas singly. In contact with mixtures like the atmosphere, however, water dissolves each gas in proportion to its co-efficient of solubility, and to its gaseous tension. Since air contains about one-fifth of its volume of oxygen and four-fifths of nitrogen, the relative tensions of each gas will be $\frac{1}{5}$ and $\frac{4}{5}$. Then the amounts dissolved from air will be approximately $3\% \times \frac{1}{5} = 0{\cdot}6\%$ for oxygen, and $1\frac{1}{2}\% \times \frac{4}{5} = 1{\cdot}2\%$ for nitrogen.

Argon has been detected as a constituent of such gases, proving its atmospheric origin. Free nitrogen in waters may also be due to reduction of nitrates by organic matter, or to anaerobic decomposition of the organic substances themselves.

Dittmar states that if one volume of water at t° is shaken with constantly renewed portions of a mixture containing m_1 of oxygen, m_2 of nitrogen, and m_3 of carbonic acid per unit volume until absorptiometric equilibrium is established and the dry-gas pressure at the end is p millimetres, the water dissolves of oxygen $m_1 p \beta_1$ volumes, of nitrogen $m_2 p \beta_2$, of carbonic acid $m_3p\beta_3$, measured at 0° C. and 1 mm. dry pressure, the β's being the coefficients of absorption, of which he gives a table for different temperatures (*Chemical Arithmetic*, 1890, p. 154). The three absorbed gas volumes, if measured at p millimetres, occupy $m_1\beta_1$, $m_2\beta_2$, $m_3\beta_3$ volumes. Hence, at any pressure, unit volume of the *absorbed gas* contains:—

Oxygen ... ... $\dfrac{m_1\beta_1}{m_1\beta_1 + m_2\beta_2 + m_3\beta_3}$

Nitrogen... ... ... $\dfrac{m_2\beta_2}{m_1\beta_1 + m_2\beta_2 + m_3\beta_3}$

Carbonic acid ... ... $\dfrac{m_3\beta_3}{m_1\beta_1 + m_2\beta_2 + m_3\beta_3}$

From these formulæ he calculates the amount dissolved by 1 litre of water at 15° C. and ordinary pressure as: oxygen, 7·196; nitrogen, 13·96; carbonic acid, 0·30; total, 21·46 cubic centimetres.

E. Frankland gives the following as the actual volumes of gases expelled on boiling 1 litre of five typical waters (*Water Analysis*, 1880, p. 3):—

Cubic Centimetres per Litre.

	Rain-water.	Cumberland Mountain Water.	Loch Katrine Water.	Thames Water.	Deep Chalk Well Water.
Nitrogen	13·08	14·24	17·31	13·25	19·44
Oxygen	6·37	7·26	7·04	5·88	0·28
Carbonic acid ...	1·28	2·81	1·13	40·21	55·20
	20·73	24·31	25·48	59·34	74·92

The above carbonic acid figures include not only the dissolved gas, but also that present in combination as bicarbonate, as this is also evolved on boiling.

As a general rule, when the dissolved oxygen falls below 7 c.c. per litre, except in hot weather, it indicates the presence of putrescible organic matter by which the oxygen is being consumed. In the case of deep well waters, to which air has had little or no access, this process of natural purification has occurred long previously, and has produced nitrogen gas, the free oxygen almost disappearing.

Roscoe and Lunt (*Trans. Chem. Soc.*, 1889, 552) have constructed the following table of the amounts of dissolved oxygen in fully aerated water for each half degree between 5° C. and 30° C., and for an observed pressure of 760 mm. (29·93 in.). When the observed pressure is below 760 mm., $\frac{1}{76}$ the value must be subtracted for every 10 mm. difference; the same value must be added when the pressure is above 760 mm.

Temp.	Cc. Oxygen.	Temp.	Cc. Oxygen	Temp.	Cc. Oxygen.
5·0	8·68	13·5	7·20	22·0	6·04
5·5	8·58	14·0	7·12	22·5	5·99
6·0	8·49	14·5	7·04	23·0	5·94
6·5	8·40	15·0	6·96	23·5	5·89
7·0	8·31	15·5	6·89	24·0	5·84
7·5	8·22	16·0	6·82	24·5	5·80
8·0	8·13	16·5	6·75	25·0	5·76
8·5	8·04	17·0	6·68	25·5	5·72
9·0	7·95	17·5	6·61	26·0	5·68
9·5	7·86	18·0	6·54	26·5	5·64
10·0	7·77	18·5	6·47	27·0	5·60
10·5	7·68	19·0	6·40	27·5	5·57
11·0	7·60	19·5	6·34	28·0	5·54
11·5	7·52	20·0	6·28	28·5	5·51
12·0	7·44	20·5	6·22	29·0	5·48
12·5	7·36	21·0	6·16	29·5	5·45
13·0	7·28	21·5	6·10	30·0	5·43

Sulphuretted hydrogen and sulphurous acid are naturally present in some mineral springs, the former constituting hepatic and the latter "sulphurous" waters. Certain organisms, such as *Oscillatoriæ* and other algæ, and many bacteria, can reduce the natural sulphates to sulphides, and the water then becomes foul and unfit for drinking; this action occasionally takes place in samples sent for analysis which have been kept too long in closed bottles, and is an indication of organic matter of a very objectionable kind. The presence of sulphuretted hydrogen is at once revealed by an odour of rotten eggs and an unpleasant hepatic taste.

Suspended particles, if of an appreciable size, soon sink to the bottom and constitute a sediment, from which the water may be poured off in a clear state. In depositing, the suspended matter may carry down with it most of the minute animals, algæ, and even bacteria, so that an examination of this deposit by the microscope is of great value in revealing the nature of the solid impurities present. By such deposition rivers become to a certain extent purified in the quieter tracts of their flow, and become clear, although the silt or sediment is apt to be again raised by an unusual current, causing "storm water" to be always more or less turbid, as is seen at intervals in many of the London supplies derived from the Thames. The colour and character of the suspended impurities may be judged by looking at a considerable volume of the water alternately before a bright light, as a window, and a dark surface, such as cloth. Contrary to general opinion, most suspended particles in moderate quantity do not affect the flavour of the water, as can be proved by tasting in the dark a water which is "thick" and one that is perfectly clear. But, besides being unsightly, they afford evidence that the water has not been efficiently filtered, and it is mainly for this reason that a turbid water is condemned. Finely divided mineral matter in suspension is believed by some to be a cause of intestinal irritation and diarrhœa. Clarification can in most cases be effected by dissolving in it a small quantity of alum, from one to six grains per gallon, afterwards adding the equivalent amount of carbonate of soda (see p. 158) and allowing the gelatinous precipitate of hydrate of alumina, which carries down with it the suspended matter, to subside. Such a process must be carried out with care, as its success depends on the character of the water, and if more than the requisite quantity of either reagent be used, the liquid will be rendered unfit for drinking. The water should always be poured off directly the deposition is complete, as the bacteria and other organisms commence to multiply very rapidly when in such close contact with their food, and will then re-enter the water, making its condition worse than before.

It is obvious that there are two kinds of insoluble or suspended matters, inorganic or mineral and organic, the latter being of either animal or vegetable nature and either living or dead. Organic matters, from being lighter, would be supposed to remain longer in suspension than mineral matters; but the very minute particles of clay, and in a less degree those of chalk, are exceedingly slow in subsiding, so that clayey waters remain for a long time turbid. Such waters are very difficult to clarify, and rapidly clog the pores of any filter.

Particles of soot are somewhat frequent in the water of towns, and are an indication that the water has not been sufficiently protected from atmospheric dust, or that an admixture with rainwater has occurred. Oxide of iron may be recognised in a sediment by its rusty colour; it is common in waters derived from the clay, and is not a good sign if present in more than minute quantities. Moreover, it renders the water unfit for washing and for several industrial purposes. Minute crystals of carbonate of lime are frequent in hard waters, such as those from the chalk; these and angular fragments of sand are easily distinguished under the microscope. They rapidly settle, and are only of importance as showing the water to be derived from calcareous or siliceous rocks.

Methods for collecting the Sediment.—About a gallon of the water is allowed to stand, carefully pouring off the top and transferring the lees to a conical glass. On settling, the deposit may be dipped out with a small pipette or glass tube drawn to a point; the drop containing the sediment may then be placed on a glass slide between two slips of gummed paper (to allow room for the water), a cover glass placed over, and the water examined under the microscope. Portions should be tested with dilute hydrochloric acid (carbonate of lime dissolves with effervescence; oxide of iron dissolves with a yellow colour in stronger acid; sand is not affected) and with iodine (starch turns dark blue; animal matters are generally dyed brown). Bacteria may be stained with aniline dyes, such as methylene blue, methyl violet, or fuchsine.

Mr. Dibdin, late chemist to the London County Council, has pointed out that the sediment by no means represents all the solid matters in water, that a good deal settles on the sloping sides of the glass, and that many moving organisms remain suspended. He has introduced a method by which the whole of the insoluble matter is collected and measured. A litre (1·76 pints) of the water, or less if it be of bad character, is filtered through one of the smooth "hard filter papers" now commonly used in laboratories, and the deposit washed into a "micro-filter." This is a glass tube drawn out for some distance to a diameter of two millimetres (0·078 inch), and closed below by a short plug of clay burnt till porous. The sediment settles on the plug when the water is drawn off by a vacuum, and its depth is recorded in millimetres. The lower part of the tube is then cut off, and the deposit transferred to a glass slide, and examined under the microscope. By this treatment waters usually returned as "clear, no sediment," often show a large and varied deposit. So delicate is the method that the presence of most objectionable matters has been repeatedly demonstrated in a single tumblerful of so-called good drinking water. Water from chalk wells only yields a minute quantity of deposit, consisting of a few infusoria, fibres, and *débris*. Blank experiments with pure water yielded only a minute quantity of fibre, and occasionally a few starch granules from the filter paper.

It need hardly be said that in all these inquiries the greatest care must be taken to exclude dust. Samples should be taken in perfectly clean stoppered bottles, and if from a tap it should be allowed to run for some time, and the bottle washed out with the water. From rivers and pools the water sample must be collected some distance from the shore by sinking the bottle and then withdrawing the stopper, so as not to collect any substances which may be floating on the surface. As bits of duckweed, straw, &c., would make a great difference in the percentage amount of suspended matter found by this method, it is important that they should be either excluded when taking the sample or removed mechanically before analysis.

In the Sedgwick-Rafter method, used in America, the sediment is collected on a layer of clean sand supported in the bottom of a funnel by a perforated cork covered with fine cloth. The deposit is washed out of the sand into a standard cell and the organisms counted (p. 289). Centrifugal machines are also used, and, on a larger scale, the Plankton net, "plankton," from πλανκτος, wandering, being a general term introduced by V. Hensen, of Kiel University, Germany, for microscopic organisms floating freely in water. Delicate and fragile species like Uroglena, Synura and others may require immediate examination. The American Public Health Association has issued a detailed report recommending certain standard methods of collecting samples, of physical tests, and of chemical and bacteriological analysis (Eng. Record, N.Y., Oct. 27th, 1900). The report of a committee of the British Association on the same subject was published in the B. A. Reports of 1899, p. 255.

CHAPTER II.

ANIMAL AND VEGETABLE IMPURITIES.

We are even now occasionally confronted with the argument that a water condemned by chemists and bacteriologists cannot be so dangerous as it is represented, since it has been drunk by many people with apparent impunity, or at any rate with no direct production of disease.*

It would hardly be worth while to combat such a contention, in the face of the opposite propositions that have been demonstrated by recent visitations of cholera and by the periodic severe outbreaks of typhoid and other water-borne diseases, were it not that the argument is constantly used to fortify the objection of expense, with the effect of quashing or delaying local schemes for obtaining a proper supply of pure water.

M. Monod, Director of Public Health in France, examined the mortality of twenty-four towns for two years before and two after they had been supplied with a purer water. In three there had been no change (perhaps the water had not been really improved), but in twenty-one it had been reduced

* At Maidstone, in 1898, the springs that occasioned a violent epidemic of typhoid had been supplying the town, more or less innocuously, for twenty-five years.

from twenty to thirteen and a half per 1,000, and fatal cases of typhoid had almost disappeared.

There is no doubt that a robust system may be trained to an extraordinary tolerance of substances otherwise poisonous. The peasants in Styria, for example, are accustomed to eat arsenic without ill effects, and heavy drinkers and opium-eaters might argue that alcohol and opium could never do harm.

Under ordinary circumstances the body in health possesses a considerable power of resisting the germs of disease and of actually destroying them in the blood. But this process itself is a drain on the vital resources, and if at any time the system be enfeebled, or the activity of the contagion be intensified, the natural resistance is overpowered, and the disease has its way. When once the disease is established in some weaker member of the community, its spread as an epidemic is rendered more likely, and then even the strongest succumb.

It is not pleasant to enumerate the different kinds of filth and polluting matter which have been found by the microscope in drinking waters. It is obvious that *anything* may get into water that is unprotected. Less trouble is often taken to guard this most important food than is used for meat, bread, or other necessaries. Milk is carefully covered, provisions are kept in safes with wire or perforated casings admitting air and excluding dirt, but water is stored in open cisterns rarely cleaned, or directly drunk from streams that are open to every kind of contamination.

Dead animal matters are of more dangerous import than vegetable, as the former may indicate direct contamination by a living animal, and even if only introduced with dust, they are quite capable of being a vehicle of contagion. Hairs are often found, and may be easily identified as the product of a particular animal, such as a human

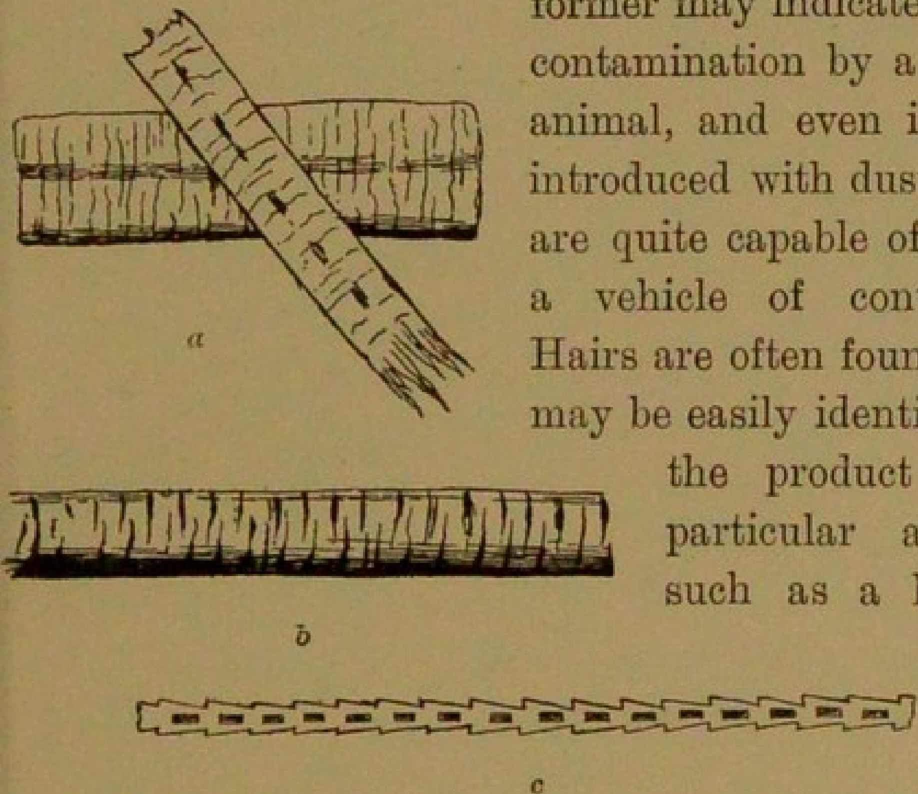

FIG. 1. *a*, Human hair; *b*, hair of rat; *c*, hair of mouse.

being, dog, mouse, &c. (Fig. 1). Epithelial scales (Fig. 2 and Fig. 5 *b*) from the lips or from the excretory organs are met with, and are a very bad indication. Even the dead bodies of animals, such as mice, beetles, frogs, and worms, have been repeatedly found in uncleansed water cisterns and reservoirs. Wing-scales of butterflies

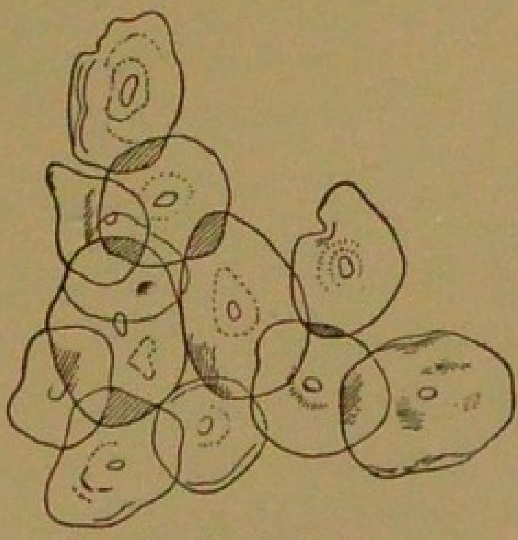

FIG. 2. Epithelial scales.

and moths and parts of insects are occasionally present. An acarus of a species allied to the cheese and sugar mites, but also belonging to the same family

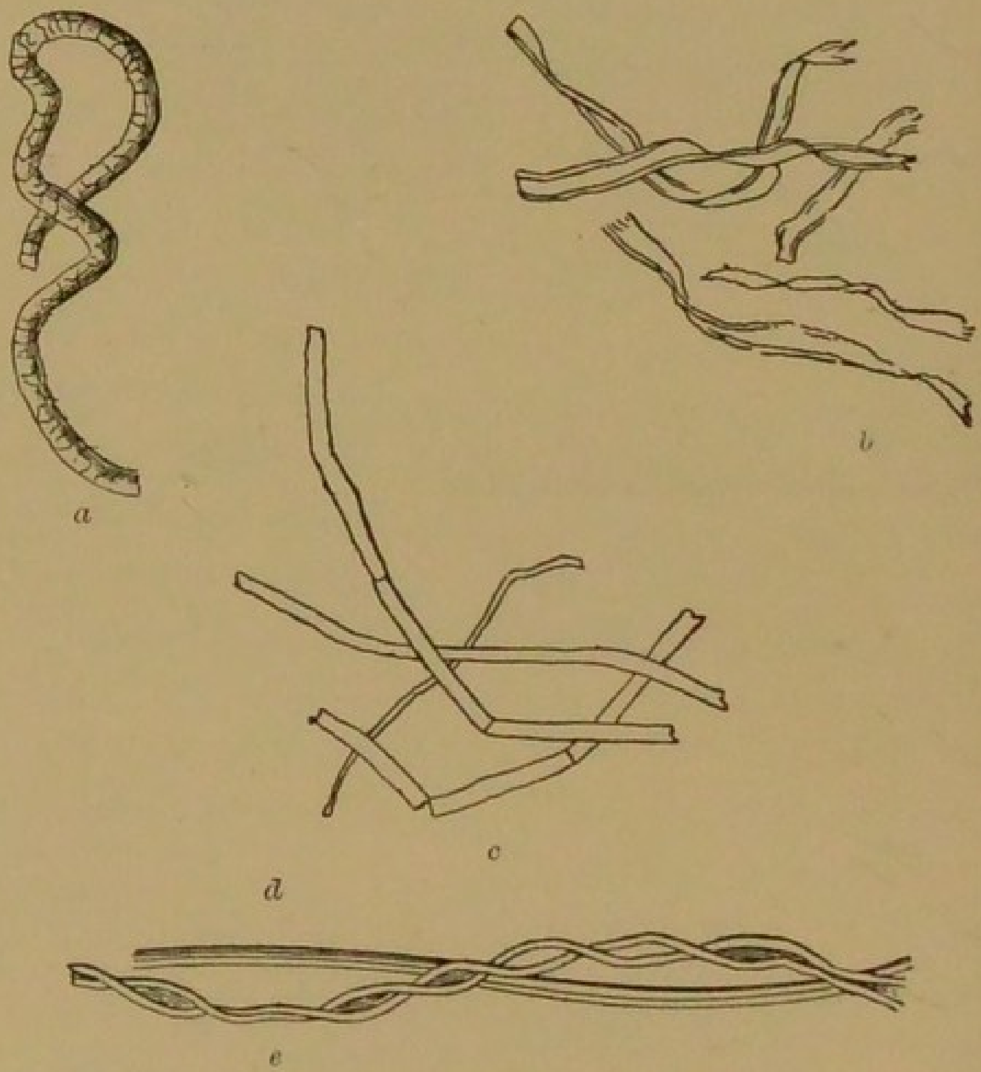

FIG. 3. *a*, Wool; *b* and *e*, cotton; c, linen (flax); *d*, silk.

as the itch insect and several animal parasites, sometimes occurs in the London waters derived from the Thames (Fig. 10, p. 38).

Fibres of clothing, sometimes dyed, are of frequent occurrence, and may be identified under the microscope as silk, cotton, linen, or wool (Fig. 3). They usually point to contamination, but cotton and linen fibres in the water of drinking vessels generally arise from the wiping cloths, or may come from paper. Particles of muscular fibre (Fig. 4), when found in drinking water, are considered to be evidence of contamination with fæcal matter. Lionel Beale has pointed out that actual fragments of fæces can be identified under the microscope (Fig. 5).

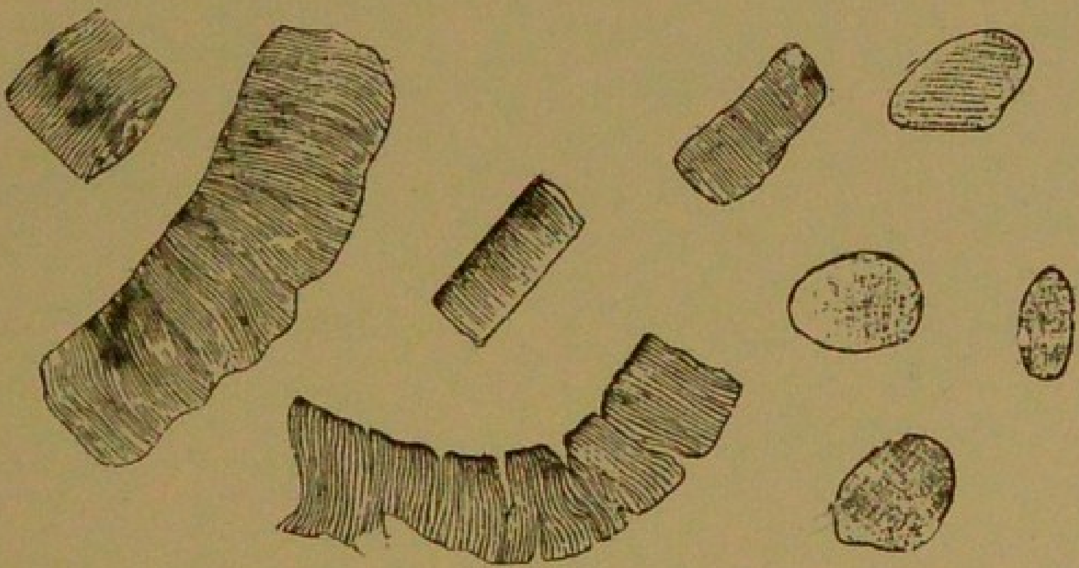

FIG. 4. Muscular fibre partially digested found in outfall sewer near Trinity Ballast Office (Lionel Beale).

Splinters of various woods are common, and those of deal or fir-wood are known by the rows of pitted markings in the fibres (Fig. 6). Plant hairs (Plate I.), spiral vessels, epidermis of leaves, fragments of straw (Fig. 7) and of the coverings of seeds, especially those of the cereals, and vegetable tissue more or less discoloured from decomposition, are met with in a large number of waters; if at all frequent, an excess of vegetable impurity is to be suspected.

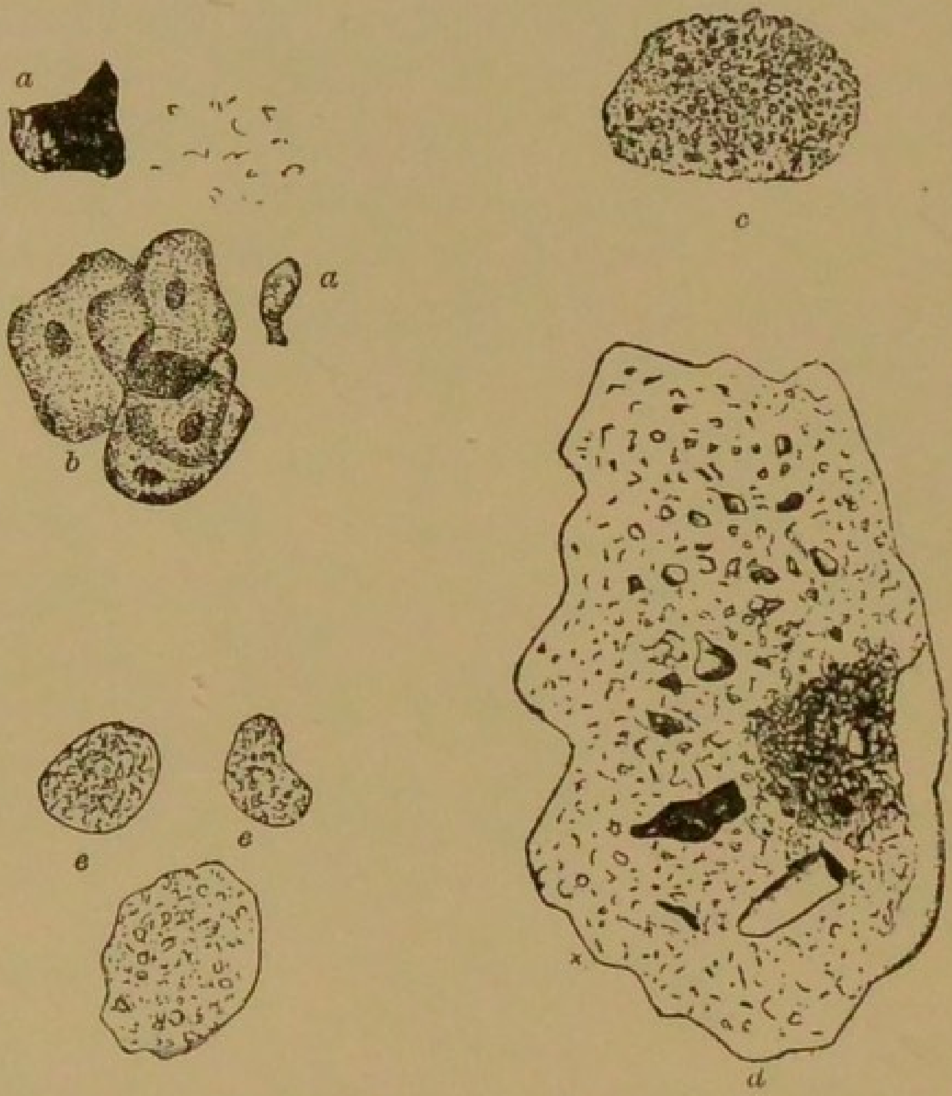

FIG. 5. Substances found in sewage-polluted water (Lionel Beale). *a*, Fragments of coal; *b*, epithelial scales, probably from mouth; *c*, yellow fæcal matter disintegrating; *d*, mass of fæcal matter, siliceous and other fragments embedded in its viscid substance; *e*, fæces with granules and oil globules.

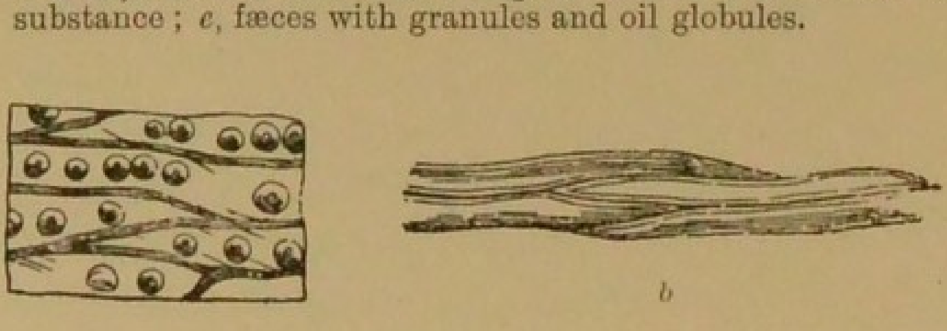

FIG. 6. *a*, Fir-wood, showing pitted markings; *b*, ordinary woody tissue.

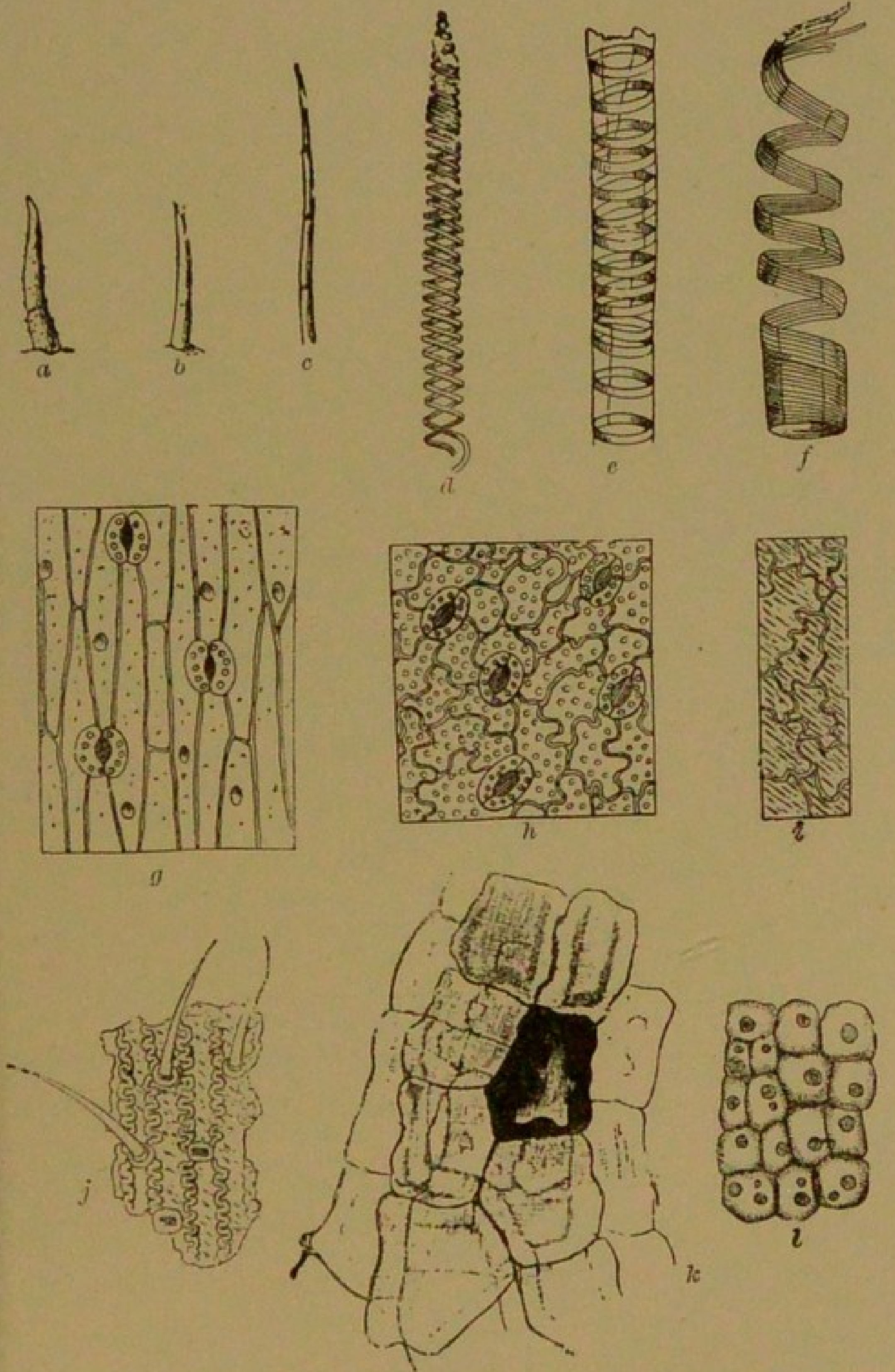

PLATE I. Illustrations of vegetable impurities. *a, b, c*, Plant hairs; *d, e, f*, spiral and annular vessels; *g, h*, epidermis of leaves; *i*, coat of seed showing star-shaped cells; *j*, epidermis of wheat; *k*, vegetable cellular tissue found in sewage undergoing decomposition; *l*, young vegetable cellular tissue.

Pollen granules (Fig. 8) from flowers are frequently wafted into waters in the country. Wheat starch

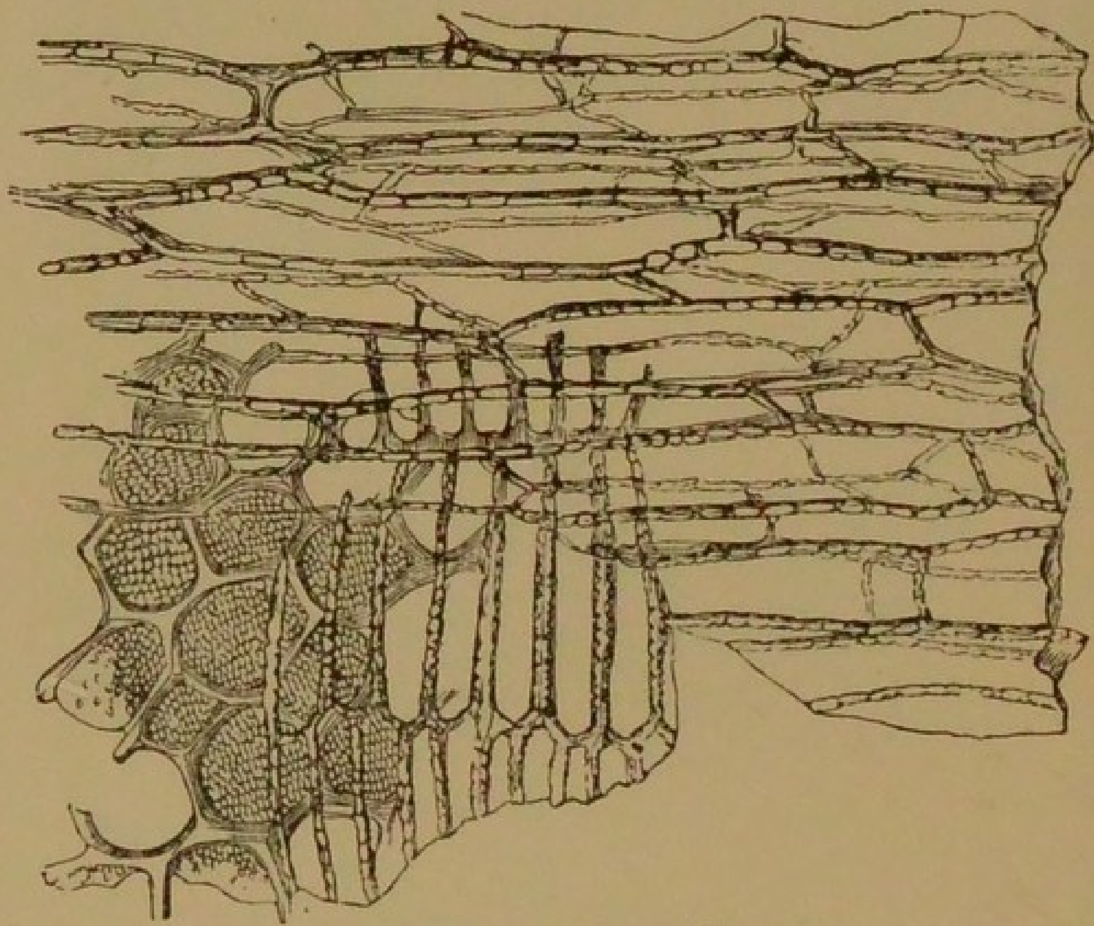

FIG. 7. Fragment of Straw.

from flour and occasionally potato and other starches are found. All these are important as evidences of

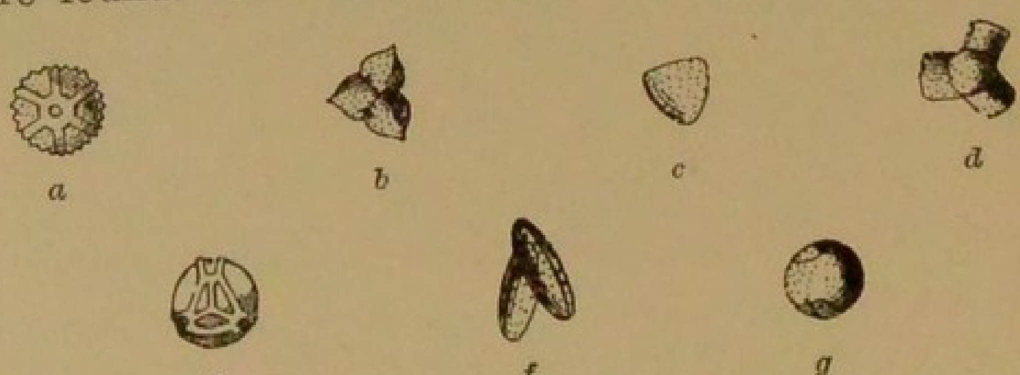

FIG. 8. Pollen granules. *a*, Dandelion; *b*, heath; *c*, liliaceous plant; *d*, heath; *e*, sowthistle; *f*, furze; *g*, violet.

bad filtration or careless storage (Fig. 9). It has been pointed out that starch granules and hard portions of food pass undigested from the intes-

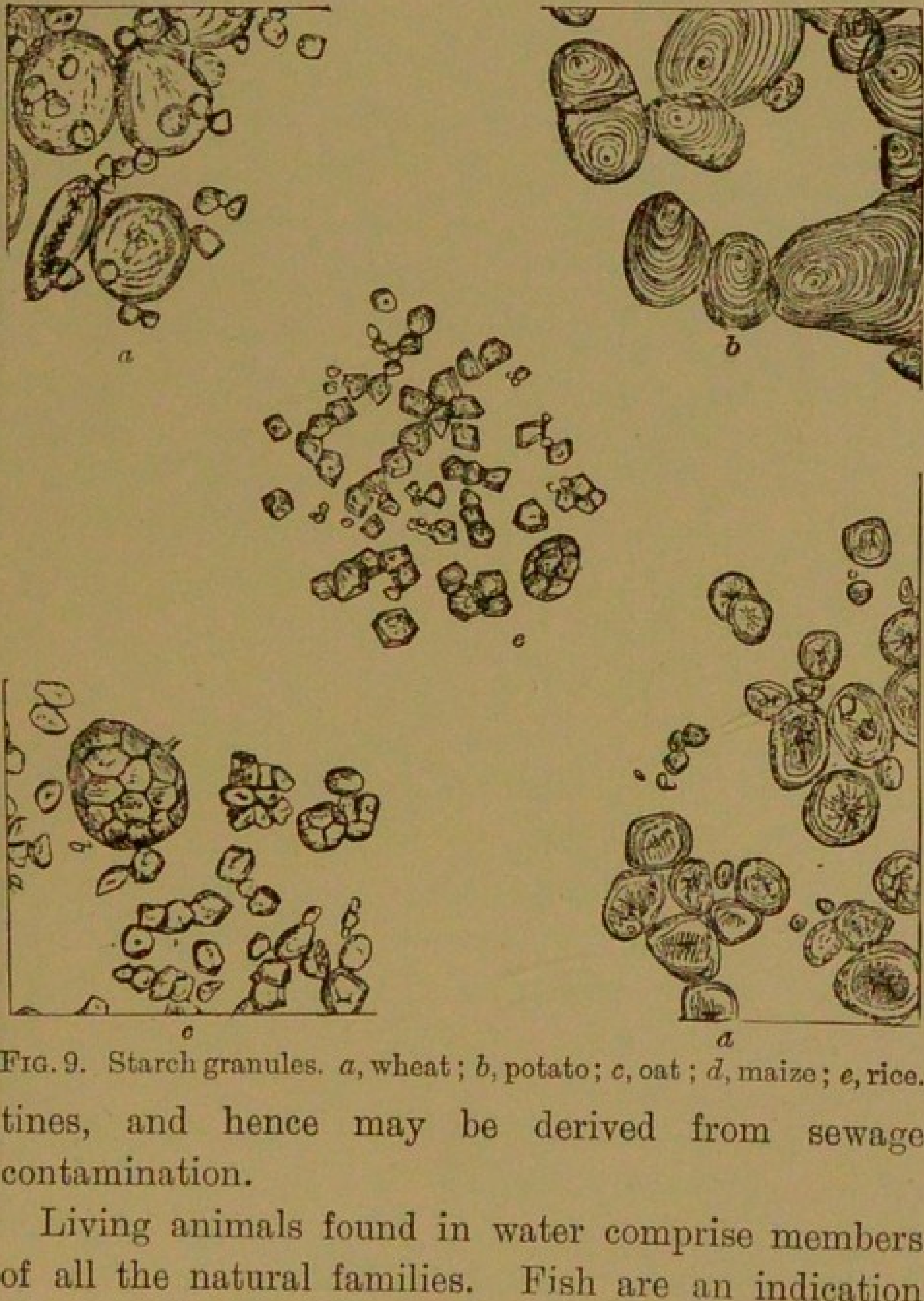

FIG. 9. Starch granules. *a*, wheat; *b*, potato; *c*, oat; *d*, maize; *e*, rice.

tines, and hence may be derived from sewage contamination.

Living animals found in water comprise members of all the natural families. Fish are an indication that the water is fairly aerated. As a river becomes increasingly foul the fish disappear, and in the case of the Thames, for instance, the improvement effected by the construction of the embankment and of the

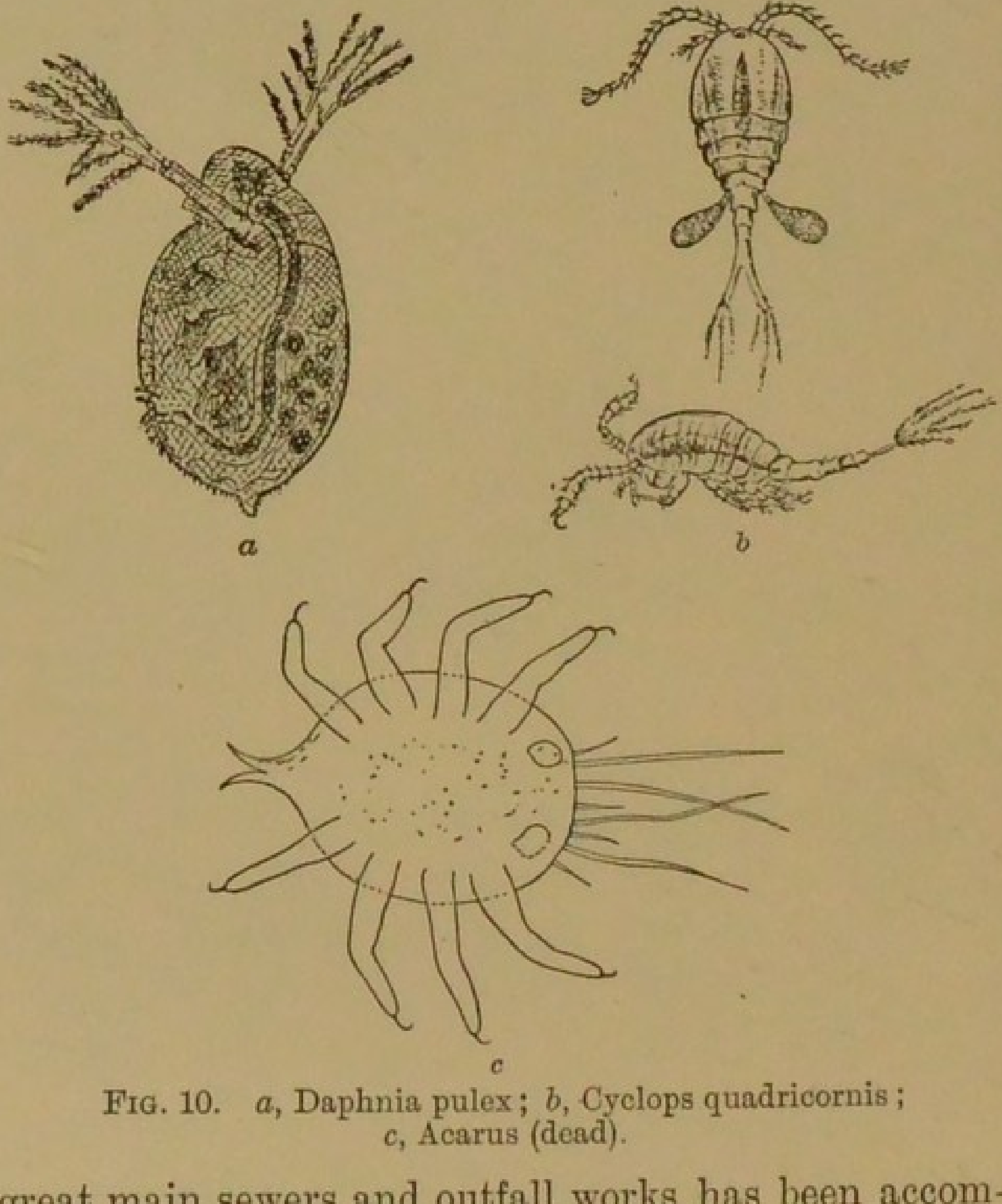

FIG. 10. *a*, Daphnia pulex; *b*, Cyclops quadricornis; *c*, Acarus (dead).

great main sewers and outfall works has been accompanied by the ascent of whitebait and other fish to the upper tidal reaches. At the end of 1895, a large number of excellent whitebait were actually taken by the London County Council from one of the effluents of the sewage filters at Barking. But it must be remembered that fish in large numbers are often seen to congregate at the mouths of sewers where fæcal matter is visibly floating, being attracted by fragments of food and insects carried down by the sewage. Fish, in fact, are more affected by muddy water and by chemicals from factories than by excreta, so that their presence is by no means conclusive that a water is not dangerous for man to drink.

Among minute animals living in water, a few are visible to the naked eye, such as the water flea, *Daphnia pulex*, and *Cyclops quadricornis* (Fig. 10). A small round worm, called *Anguillula fluviatilis* (Figs. 14 and 15) is common in rivers and ponds, and sometimes makes its way into London waters. It is believed to be capable of living in the human intestine, and therefore might be dangerous, and must be regarded as a very bad feature in a potable water.*

On numerous occasions letters to the papers have asserted the presence of small eels in the water drawn from the taps on constant supply. It would appear that eels and sometimes other fish have been found in the mains, and house-pipes have sometimes been stopped by their bodies. Their occurrence had been traced to accident or malice, and in one or two instances the bye-pass of a filter bed, used in reversing the current so as to wash out the impurities, has

* *Bilharzia*, or *Filaria sanguinis hominis*, has been traced to drinking water.

been improperly left open. No filter bed could permit the spawn of fish, still less the animals themselves, to penetrate unless it contained channels, formed by too rapid running or by careless laying, as has sometimes happened, that would allow unfiltered water to pass. There is proof that in many cases, both in times of flood and in seasons of scarcity, water imperfectly filtered or not filtered at all has been allowed to gain access to a town supply.

Protozoa, like *amœba*, are looked upon as a bad sign; they are most frequent in badly aerated waters containing much organic matter. Some of them have been recently proved to be pathogenic. Piana and Galli-Valerio, in the blood-corpuscles of dogs which sickened of fever and jaundice after a few days' hunting in a marshy locality, found a pyriform protozoon called *Pyrosoma bigeminum*, similar to those discovered by Smith and Kilborn in Texas fever (*Moderno Zooiatro*, May 10th, 1895). Dr. Schurmayer, in the case of a child seized with cramps, vomiting, and diarrhœa, found in the intestines large numbers of flagellate infusoria.

Grasset, in 1899, attributed goitre to a paludic hœmatozoon. The amœboid *Plasmodium malariæ* can be derived from water, as well as from mosquitoes (Curtis). Similar organisms have been discovered in blackwater fever, Tsetze fly disease, and forms of dysentery.

The large class *infusoria*, mostly motile, and some containing green chlorophyll, are broadly divided into *flagellate*, or moving by whip-like appendages, and *ciliate* (Fig. 11), having rows of vibratile filaments, or cilia, over parts of their bodies. Large rotifers, vorticellæ, and other forms occur in water sediments (Figs. 12, 13, 14, and 15). These organisms are found in waters remote from any chance of animal contamination; hence their significance is confined to the fact that, if they are in large numbers and actively moving, there must be also present a large quantity of matter to serve as their food, such as, of course, would also supply plenty of nutriment for directly dangerous

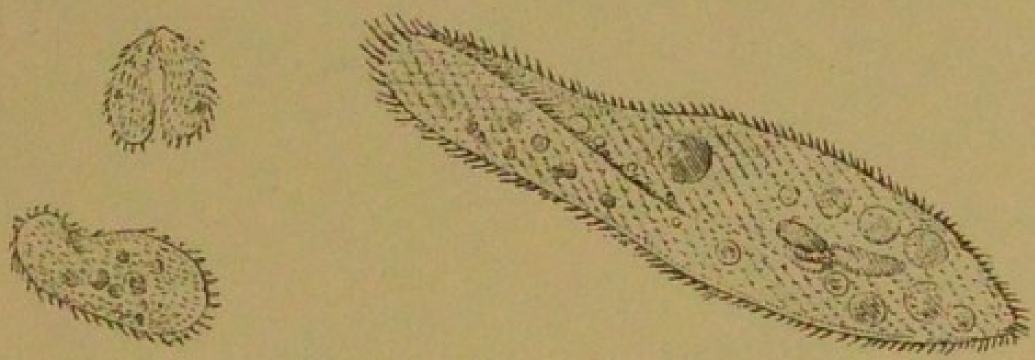

FIG. 11. Ciliate infusoria.

organisms. Apart from vegetable matter in solution in unusual quantity being known to be laxative and enfeebling to human beings, the water is likely to favour the rapid multiplication of any microbes of disease that might accidentally enter, and thus would contribute to the propagation of any epidemic.

Diatoms and desmids in small numbers occur in excellent waters. Filaments of confervæ are generally derived from the stones or walls of the source. Water weeds in moderate numbers effect a purification of the liquid by the oxygen they give off from their leaves. In aquaria this improvement in the quality of the water may be seen; but in rivers, if the growth is too luxuriant, the flow of the stream may be retarded and the water may be fouled by the

FIG. 12. Nos. 1, 2, 3, 5, 7, 9, 10, 27, Infusoria; 8, Vorticella; 11, 28, Paramœcia; 12, 19, Confervæ; 13, 14, 15, 16, 22, 23, 33, Diatoms; 26, Desmid; 6, Anguillula fluviatilis; 17, Wool; 20, Hair; 18, 25, 29, Vegetable *débris*; 24, Torula. (After Hassall.)

decay which would then take place. A very good idea of the character of a stream or river may be formed from an inspection of the kinds of plants growing on its banks. When such growth is very luxuriant, and the stems and leaves of the plants are succulent, then a pollution of the river with sewage is to be suspected. A pure mountain stream shows either no, or only very stunted and slight, vegetation.

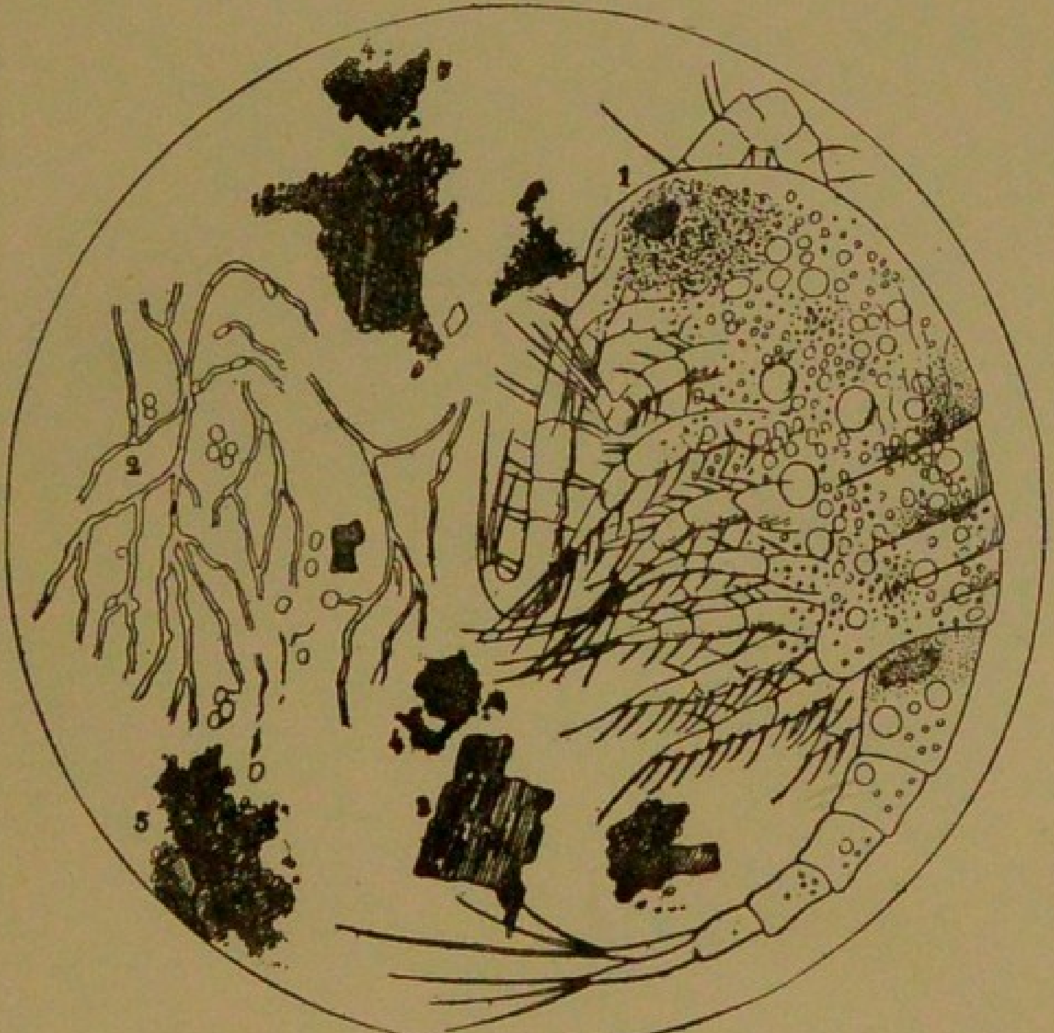

FIG. 13. Water from a well near the Seine at Paris. 1, Cyclops; 2, Mycelium with spores; 3, Woody débris; 4, Zooglœa; 5, Humus. (Diagrammatic.)

Sedges and flags grow in a water which is running and aerated. Smaller rushes and marsh plants indicate a brown, peaty, stagnant water, which is probably unwholesome for drinking.

The spores of fungi, and more especially the interlacing threads called mycelium, are usually accompanied by a flatness and want of aeration in the water. Artesian wells, like those at Grenelle, near Paris, and

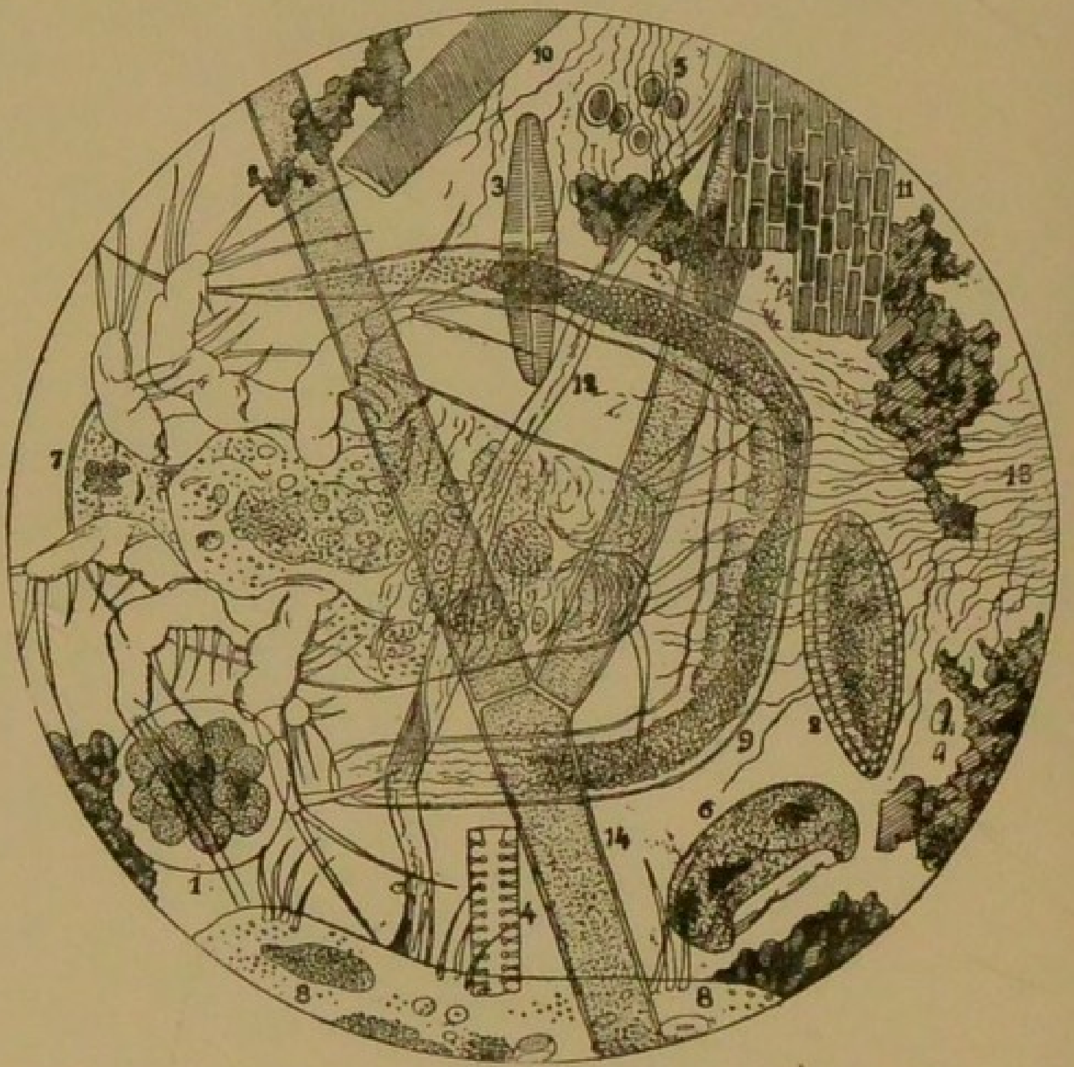

FIG. 14. 1, 5, Desmids; 2, 3, 4, Diatoms; 6, Infusoria; 7, Daphnia pulex; 8, an Entomostracan; 9, Anguillula; 10, Muscular fibre; 11, Vegetable tissue and earthy matter; 12, Cotton fibre; 13, Fungus mycelium; 14, Cladophora (an alga).

occasionally those sunk in the chalk belonging to the Kent Water Company, yield waters showing fungoid filaments and a few diatoms; these are found in the sediments of such waters, which sometimes contain also crystals of carbonate of lime, particles of chalk, oxide of iron, and silica. The few organisms found in such

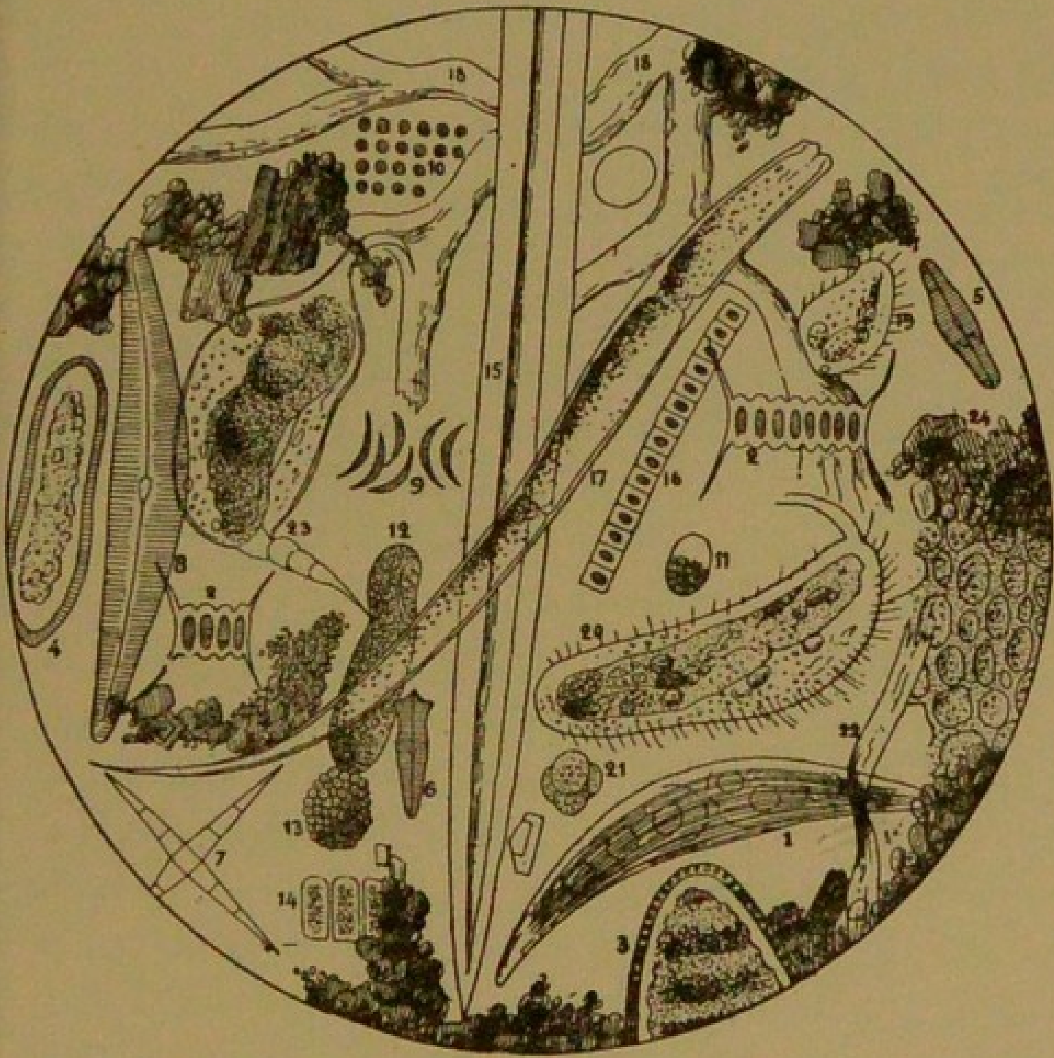

FIG. 15. Seine at Port à l'Anglais. 1, 2, Desmids; 3—8, Diatoms; 12, 19, 20, Infusoria; 15, Sponge Spicule; 14, 16, Confervæ; 17, Anguillula; 23, Rotifer.

waters probably drop in from falling atmospheric dust, and when growths of organic matter occur in deep well waters, usually they may be traced in such accidental origin, and can be prevented by covering the well. In less pure waters one frequently finds that in the darkness of the water-pipe filaments of considerable length grow, and sometimes to such an extent that the valves and taps become choked.

It is very important that all drinking waters used by man should be kept away from animals, as parasitic maladies, like tapeworm and hydatid disease, have been frequently traced to water which has been polluted in this way. Dogs are especially liable to such diseases, and in Queensland it is said that the shepherds, while not too particular as to the water they drink, refuse to make use of any which bears evidence of having been drunk by a dog. Sheep and other animals may also convey parasites, so that it is imperative to avoid drinking any pond or brook water unless it has been filtered or boiled. The danger is more imminent in tropical countries, as in India, where the ova of a filaria, or kind of thread-worm, have been several times discovered in the waters of tanks and streams. *Filaria dracunculus*, the guinea-worm, was proved by Hirsch to be communicated by drinking the foul water of streams. Many other species of parasitic worms have also been traced to water, and animals often suffer from epidemics which have originated in this way (Fig. 16).

Fresh-water sponges occur as soft, fibrous masses of brown or greenish colour in tanks and water-butts where the liquid is continually in motion. When they die, the spicules which form their supporting skeletons are liberated, and may be detected in the water sediment by the microscope as minute pointed bodies of characteristic shape (Fig. 15, No. 15). The brown or grey sponges occasionally grow in water-mains and cause obstruction, and the products of their growth and decay contaminate the water, and

FIG. 16. Eggs of parasitic worms. *a*, *b*, Botryocephalus latus; *c*, Ascaris lumbricoides; *d*, Oxyuris vermicularis; *e*, Trichocephalus dispar; *f*, *g*, *h*, Anchylostomum duodenale in different stages.

occasion an unpleasant odour and taste. They thrive most in summer, and will not grow in a water properly filtered and therefore free from the organisms which constitute their food; consequently the presence of sponge spicules in a sediment is a bad indication.

The sanitary significance of the presence of living organisms in water rests chiefly in the fact that where they are thriving there must be an adequate supply of their appropriate food. Green algæ require the presence of considerable quantities of mineral ingredients, such as lime, salts of potassium, ammonia, and nitrates, which can all be derived from sewage, while certain crustacea and infusoria feed upon solid organic matter undergoing decay.

A green unicellular alga, a species of protococcus, is frequently seen encrusting decanters in which water has been allowed to stand.

It is found that the growth of green algæ can be prevented by excluding light from the water during storage. With this object, as well as to protect from dust and smoke and to prevent freezing in winter, reservoirs and wells are often covered over with brick arches. On the other hand, the beneficial effect of light in destroying the germs of disease (p. 160) is in this way hindered or lost. The algæ are infinitely less dangerous than the pathogenic bacteria, and as they undoubtedly cause a disappearance of some of the organic matter present, their presence may be useful in some cases.

Dr. O. Strohmeyer finds at the Hamburg waterworks that the green algæ are very effective agents in removing bacteria from the water. In some cases the water has been rendered practically sterile in this way. And it is suggested by Dr. Kemna that the oxygen, or possibly ozone, liberated by the algæ brings about this result. Algæ are especially abundant on the surface of filter-beds, and different species appear regularly at different seasons. *Hydrodictyon*, a green form having a hexagonal network, seems to be most useful in this respect (p. 175).

The most important of the solid bodies present in water are the vegetable organisms called bacteria, which are usually invisible to the naked eye and to the lower powers of the microscope. Under higher powers, they appear as minute points or as moving rods, which congregate together into groups and lines, but sometimes associate in pairs or form long segmented filaments (p. 282). To make out their form and structure requires the highest powers, with the aid of immersion lenses and special illumination. Even then these minute forms of life frequently so resemble one another that further experiments are necessary before it is possible to form any conclusions as to the species to which they belong. Their cultivation and isolation require considerable care, and their importance has increased since the discovery of the close connections which exist between certain diseases and these microbes. A bacteriological examination of a water is therefore as necessary as a chemical analysis, if it is required to ascertain the absence or presence of specific disease-producing organisms.

It is a familiar fact that yeast is capable of converting sugar into alcohol and carbonic acid, and that, when examined under the microscope, it is seen to consist of round cells of a species of fungus called *Saccharomyces*, or *Torula, cerevisiæ*. Many years ago, Döbereiner proved that, before alcohol was formed, an intermediate body called "invert sugar" was produced, and other investigators noticed that similar changes could be effected in starch without the presence of any living cells, provided a substance called diastase, which exists in malt, was present. Liebig argued from these facts that diseases might have a similar origin, and, from the idea of *contact*, the theory was called "catalytic." It was consequently recognised that many matters undergoing change could propagate that change to other unstable molecules near them. Diseases were therefore presumed to be due to the action of organic ferments, or "enzymes," from which idea such affections were termed "*zymotic*" (ζυμα, yeast), a term which is still retained. As a consequence of this theory, *all* organic matter in waters was looked upon with suspicion, and the determination of its amount by chemical analysis was regarded as a measure of the wholesomeness or otherwise of a potable water.

But Pasteur subsequently found that, provided the living cells of yeast were excluded, no fermentation took place, and that substances and temperatures which hindered the growth of the ferment also hindered the change into alcohol and carbonic acid; that, in fact, the fermentation was a vital act of assimilation and excretion on the part of the fungus, that the sugar was really its food, and the other products its excreta. He further demonstrated that germs conveyed by dust and from water were the causes of change in milk, blood, broth, &c., and if the germs were killed by boiling or removed by careful filtration, and the liquids, contained in a perfectly clean vessel or one that had been sterilised by heat, were then protected from dust by plugs of sterilised cotton wool, that then the fluids, although perfectly accessible to air filtered through the wool, would remain without putrefaction for an indefinite period. Since disease presented many analogies to putrefaction, he developed the germ or microbic theory of disease, which has been established by subsequent investigators for several of the more dangerous diseases, and is believed to explain the origin of many others.

Pasteur himself and his pupils, by long-continued investigations, succeeded in demonstrating the existence of bacteria in the blood and tissues of infected patients, and by inoculating animals with cultivations of these bacteria proved that they were pathogenic, or capable of re-producing the symptoms of the disease. A very large number of bacteria have thus been studied, and their characteristics described, but subsequent research has shown that in some cases what have been described as apparently different forms are merely transitional stages in the life history of a single species. The variation in the conditions under which the organism lives, the temperature and the food, and other circumstances, have to be carefully studied before the true nature of the species can be ascertained. In some cases these variations produce such changes in the physiological action and structure of the organism that its nature is entirely altered. Thus the bacilli of anthrax, or wool-sorters' disease, sometimes pass into what is known as the spore condition, and in this state, according to Koch, will remain dormant for months, perhaps for years, until they reach the temperature of 16° C. (62° F.), when they will again commence to grow and multiply. The mature organisms, on the other hand, when placed in Thames water at 12° C., according to Percy Frankland, disappear in less than five days; they are also killed by a much lower temperature than that which destroys the spores. As a general rule, the spores of bacteria, like the seeds of higher plants, are possessed of much greater vitality than the fully developed organism, the latter being killed by a temperature of 60° C. or less, and more easily destroyed by disinfectants, while the spores can withstand any temperature below that of boiling water for a considerable time, and are also less affected by chemical reagents. Cold and dryness have little effect on the spores. On account of this variability, although the number of species of bacteria have been greatly reduced, the difficulty of identifying a particular bacillus and following its life history is very considerably augmented.

It is only a few bacteria which, up to the present time, have been definitely branded as "germs of disease." As all natural waters contain microbes, and some immense numbers of them, and as they are almost universally distributed through the air and in our food, it is fortunate that the majority are harmless and even useful to man by destroying organic matter, which they turn into carbonic acid, water, ammonia, and nitrates. It is also more than probable that these harmless bacteria which exist in waters wage war upon any pathogenic organisms that may be present, either by starving them out or by poisoning them with the products they excrete. In this latter way they even render the water unfit for themselves to live in, and dying, sink with the sediment to the bottom. Such a process naturally happens in settling reservoirs. Percy Frankland demonstrated that ordinary surface waters, like that of the Thames, were capable of rapidly getting rid of certain injurious bacteria, independently of the further multiplication of the common water organisms, and, therefore, attributed the action not to "crowding out," or "struggle for existence," but to the elaboration of products by the latter, and possibly also by vegetable life, which are inimical to, for example, the typhoid bacillus. Frankland added this organism to Thames water, and found that it disappeared in nine to thirteen days, whereas in the purer deep well water of the Kent Company it survived for thirty-three to thirty-nine days (*Proceedings Royal Society*, lvi. 543).

The fact that the excretory products of bacteria are inimical to bacteria themselves is the foundation of the processes of inoculation against disease. The microbes are grown abundantly in a "culture medium," which is filtered through porcelain to remove the organisms, and the liquid containing the product of their lives is found on injection into the veins of animals to be more or less protective against their future inroads. Duclaux, indeed, has termed these bacteria "the scavengers of the waters." Natural purification, then, by subsidence, light (p. 160), oxidation, and life action, accounts for the fact that, though myriads of disease germs must pass into rivers from the drainage and sewage polluting their upper course, they can rarely be discovered in the water after a flow of a few miles. Dr. Tidy contended that a few miles of flow were sufficient to purify any river, but the contention is not a safe one, since, if any survive, transplantation into purified water will cause them to recommence multiplication with extraordinary vigour, and may give rise to a fresh outbreak. Many epidemics which have often suddenly occurred may be explained in this way. It is also important to note that a water is not necessarily wholesome because by bacteriological examination it is found to be sterile, or free from microbes, as in that case a "sterilised"—*i.e.*, perfectly filtered or heated—sewage would be fit for drinking, whereas it might be poisonous from the presence of "ptomaïnes," or other products of bacterial growth, or might be injurious from excessive quantities of mineral salts. A chemical analysis is, therefore, always necessary, in addition to a bacteriological examination, before a reliable opinion can be formed upon the purity of a water.

The distribution of bacteria in water is modified by every shower of rain, as the rain carries down large numbers of organisms or their spores floating in the air. Miquel, Hare, and others have shown that the number of micro-organisms in the air rapidly decreases as we ascend; therefore the water of upland surfaces at first contains very few. Surface waters that are still or in very slow motion develop large numbers; but as they are always depositing, in lakes they are almost absent. Rapid streams flowing over gravelly beds generally become purified from microbes, though they may be turbid from mineral matter, and springs at their origin are usually free from life. Rivers contain the drainage of their entire basins, and must necessarily hold a collection of all the surviving organisms of the land, of the air, and of the towns and villages that they have passed. A river in flood contains, of course, a larger number and variety than at ordinary times. Sea water has fewer microbes, and is a conspicuous example of a water that would pass a bacteriological examination and yet would not be potable.

Among zymotic diseases which have been directly traced to special bacteria in drinking water are Asiatic cholera and typhoid fever, whilst diphtheria has been proved to have originated from impure milk. In many other diseases the causation by water is almost certain, although the bacillus has not been found. There are a large number of instances in which typhoid seems to have been specially due to bad water. Many of them are given in the reports of the Medical Officer of Health of the Local Government Board from 1868 to the present time.*

The bacillus of anthrax, or splenic fever, is of common occurrence in hair, wool, and fur, and is easily transferred to water, in which its spores were found by P. Frankland to be capable of surviving for two years, besides enduring great variations of temperature. An outbreak of the disease in Wurtemburg (*Zeitschrift für Hygiene*, viii. 179) was traced by Rotz to water, while Diatroptoff found the Bacillus anthracis in the mud of a spring (*Annales de l'Institut Pasteur*, 1893, p. 286). Consequently there is danger of this disease being transmitted to a river water from wool-scouring or fur factories or tanneries on its banks. Fatal cases of anthrax, or "wool-sorters' disease," periodically occur in London.

The outbreak of enteric fever in the Tees valley in 1891-2 is a good illustration of a water-borne epidemic. According to Dr. Barry, two sudden and marked outbursts of this disease occurred at a time of year when they were not usual. The localities supplied

* Also P. F. Frankland, *Proc. Roy. Soc.*, lvi. 396.

with water from the Tees suffered very heavily, while others not so supplied escaped. This river is subject to the grossest fouling by human excreta, and, previous to the epidemics, sudden floods washed vast masses of filth which had been accumulating on its banks down the stream up to and past the points of intake from where the water was being pumped, after a doubtful filtration through gravel and sand, and delivered to certain populations. It was these populations that suffered from the exceptional prevalence of enteric fever. Dr. Thorne Thorne remarks, "Seldom has the relation of water so befouled to the wholesale occurrence of enteric disease been more obvious" (Report of the Medical Officer to the Local Government Board, 1893). This evidence, however, was not deemed conclusive by the Royal Commission on the Metropolitan Water Supply.

Although typhoid is, without doubt, water-borne, the difficulties attending the isolation and identification of the typhoid bacillus make it often impossible to prove its presence in waters which have certainly been the source of the disease. On removal, however, of the pollution, the disease has disappeared, so that the connection is undoubted. Although it appears to be established that organisms survive for long periods in soil, they die rapidly both in sewers and rivers. Parry Laws and Andrewes, in a report to the London County Council, Dec., 1894, state that they failed to find the typhoid bacillus on careful bacteriological analysis of many sewages, and only discovered it in sewage from the *main drain* of the Homerton hospital when forty cases were under treatment, and the disinfection of the stools had purposely been discontinued for two days previously. As to cholera, the reports of the visitations of 1854 and 1866, and of the epidemic of Hamburg in 1892, leave no doubt as to the agency of water in propagating the disease.

A great number of bacteria live in soil, a few of them pathogenic, such as *Staphylococcus pyogenes aureus*, an organism that may be the cause of wounds festering so frequently when dirt enters them. These bacteria naturally find their way into the water of shallow wells. Among the many ways in which dangerous organisms may gain admission to water, drainage from cultivated and especially manured land, sewage of towns, cesspools, privies along the banks of streams, animals drinking from or discharging into wells, springs, or watercourses,* and the floating dust of the atmosphere are the most prominent.

* Besides anthrax and typhoid, glanders, hog and chicken cholera, and diphtheria have been thus occasioned in animals, and in some cases have been undoubtedly transferred by their milk or flesh to man.

CHAPTER III.

DIFFERENT KINDS OF WATER.

NATURAL waters may be classified as:

1. *Rain water*, or that which is precipitated from the atmosphere under any conditions, as dew, frost, snow or hail.

2. *Surface water:* all collections in free contact with the atmosphere: streams, lakes, ponds and ditches.

3. *Subsoil or ground water*, not in free contact with the atmosphere, percolating or flowing through the soil or rock at a moderate distance below the surface, and derived in great part from the rain or surface water of the district.

4. *Deep spring or artesian water*, accumulated at a considerable distance below the surface, the subsoil water having been excluded by difficultly permeable strata.

5. *Mineral waters, sea water*, and that of saline lakes.

When any of these varieties are heated in a glass vessel, it will be noticed that bubbles form and ascend through the liquid: these are mainly oxygen and nitrogen dissolved from air, and liberated because gases are more soluble in cold than in hot liquids. Bubbles of steam next appear below and at first condense higher in the liquid, but as the heat increases they at last mount to the surface and the liquid boils.

If an apparatus be arranged so that the steam shall pass through a "worm," or tube surrounded by cold water, it is possible to collect any quantity of the condensed steam (Fig. 17). The worm should be of *tin* (not tin-plate) or stoneware, *on no account of lead*, because this metal is easily dissolved and contaminates

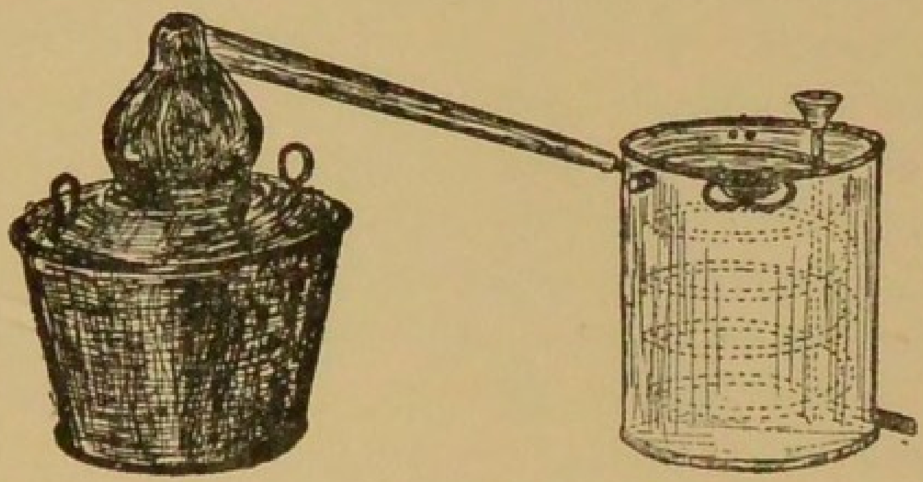

FIG. 17. Simple Still and Worm.

the water. The solid bodies in water are not volatile at the boiling temperature; consequently the distilled water is free from all solid matter, such as salt, carbonate of lime, &c., and only contains some of the *gases* of the water. Distillation therefore is used for purifying waters for chemical purposes and for making ice and some aerated beverages, also at sea, or wherever it is necessary to obtain fresh water from that which is too salt or foul to drink, or too hard to be used in steam boilers. By multiple evaporators, such as the Yaryan, large quantities of distilled water can be obtained; but this liquid is not pleasant to drink, having a flat and sometimes burnt taste from the contact with heated metal, while any natural odour of the water is intensified. Distilled water also attacks lead very rapidly, and therefore must not be conveyed in pipes or stored in cisterns of that metal. It can be aerated and thus rendered more palatable by shaking vigorously with air, or better by being allowed to trickle over a long column of granular charcoal, with a current of filtered air passing upwards, as is done at sea.

The author finds that a small quantity of bicarbonate of soda, about two grains per gallon, gives a palatable result, which is improved by adding about two drops to the gallon of *pure* hydrochloric acid, previously diluted to about 10 per cent. strength. In this way a minute quantity of sodium chloride (common salt) is formed, which is, of course, innocuous, and communicates an agreeable slight flavour, while the carbonic acid liberated supplies the deficient piquancy. Such water obtained from a simple portable still, heated over the camp fire, is useful in expeditions through countries where the natural water is malarial or saline. The first portions distilled should always be rejected, and the distillation not carried too far. It is in many cases perfectly possible to arrange a constant supply of water from a tank elevated on a pole support. Bicarbonate of soda and hydrochloric acid could always be carried, as they are almost indispensable for other purposes. The water so yielded would be more wholesome than any that could be obtained by filtration.

Condensed water from steam engines is always contaminated with oil, and is therefore generally not of much value.

It has been shown that many germs multiply more rapidly in distilled than in ordinary water. Hence the former is found to become rapidly foul and ill-tasted when exposed to the air.

Rainwater.—A process exactly parallel to the above is continually going on in nature. Wherever water is exposed to the air at any temperature, it is always evaporating, and so much the faster the more surface is exposed, as may easily be shown by the rapidity with which spilt water dries up when spread out in a thin layer by a cloth. As in artificial distillation, the solid matters remain behind, while the liquid rising into the atmosphere collects in clouds, from which it descends as rain, or sometimes as snow or hail. Rain, therefore, should be the same as distilled water were it not that it carries down with it most of the dust of the atmosphere and various germs which have been floating in the air, and also a quantity of the gases of the air. Out in the open country the rain is of considerable purity as regards solid matters, hence it is almost perfectly soft, but it contains somewhat large quantities of ammonia and varying amounts of nitrates and nitrites (according to the electrical condition of the atmosphere), besides the germs and other constituents of the dust. These solid impurities are less in amount the greater the elevation, but are never entirely absent, several observers having found them in water collected at the greatest height ever reached by a balloon. In fact, Aitken and others have experimentally shown that solid particles are absolutely necessary before condensation of aqueous vapour can take place. Rainwater, as is well known, is admirably suited for washing, on account of its softness, but it possesses the same faults of unpalatability and of attacking lead that are shown by distilled water, and requires to be treated in the same way when used for drinking. Under the microscope rainwater shows minute sandy particles, believed to be meteoric dust, which is ever present in the remotest alpine regions (Tyndall), fragments of decayed and dried vegetable tissue, occasionally animal hairs, pollen granules, small insects, spores of fungi, and always bacteria. On account of the ammonia which forms their food, the latter rapidly multiply, and render the stored water so polluted that rainwater should always be filtered through a germ-proof filter when required for drinking purposes. Near the sea the rain contains salt, carried by the winds from the spray of the waves.* In the neighbourhood of towns

* During a storm Professor Church found the rain thirty-five miles from the coast to contain 6·97 parts per 100,000 of chlorine, due probably to a cyclone of sea spray. Such water would also be hard.

it is often exceedingly dirty from soot and the products of respiration, and is then quite unfit for washing until it has been strained. It is also acid from the presence of sulphuric acid derived from the sulphur in coal.

Angus Smith found in 100,000 parts of London rain-water two parts of sulphuric acid, in Manchester and Liverpool four to five, and in Glasgow eight parts. Such rain when it falls on buildings dissolves lime, iron, lead, &c., from the roofs, walls, gutters, and pipes, and, besides containing much soot and tarry matter, may become very hard. *Snow* is even more impure, as after falling it absorbs gases and dust from the atmosphere. The foulness of the water that is melted from London snow is a good example of how great may be the contamination caused in this way.

After the rain has fallen for some time and has effected a cleansing of the atmosphere, it becomes much purer even in towns. In country districts and in arid regions especially, rainwater is of great value, and should be collected with care in gutters regularly freed from the droppings of birds and from dead leaves and dust, and stored in tanks or barrels charred or tarred inside. With these precautions, rainwater should be used much more than at present. In some parts of South Africa it is the only good supply attainable, and is collected from the roofs of farms and outbuildings by means of galvanised iron or tarred wood gutters. Venice and many other continental cities are still supplied with rainwater both from public and private reservoirs, which are commonly constructed underground. In Jerusalem every house is built over its own cistern; many have three or four, or even more, the whole supply of water for the consumption of each family in a year being contained in them. These cisterns are stone chambers, generally vaulted, into which the rains that fall on the flat terraces drain. The houses are damp and unhealthy, and ague is almost universal. Some are provided with sand filters, from which the clear water runs into covered wells. The necessity of a reservoir is due to the fact that otherwise, on account of the extended surface of collection, evaporation would carry off the water as fast as it falls. Farmhouses in many rural districts in England collect the water from the roofs in underground brick or cement cisterns arched over, from which it is pumped into the houses, where it is used constantly for washing, cooking, and tea-making, for which purposes it is especially suitable from its softness. After subsidence it is clear, and is even used for drinking in times of scarcity. There are many similar arrangements in the neighbourhood of London.

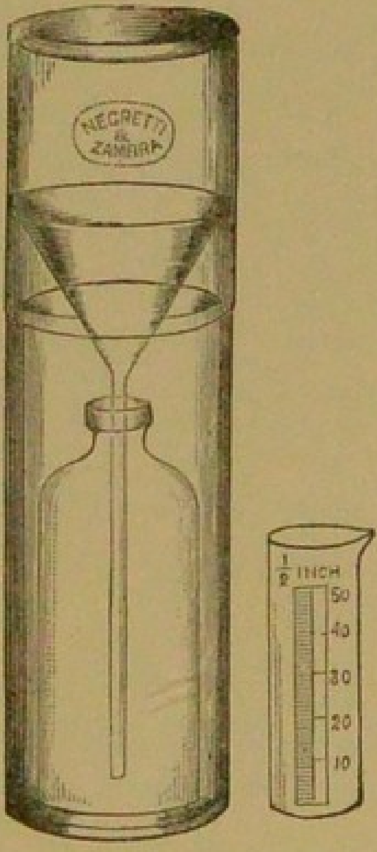

FIG. 18.
Standard rain-gauge.

Rain Gauge.—A form used in the Meteorological Office has a circular metal funnel eight inches in diameter, protected from dust and evaporation by a closely fitting metal cylinder, open at both ends and reaching about six inches above the funnel. The simple form (Fig. 18) has a rim directed inwards to prevent loss by splashing. The area would be about 50 sq. in. if round, or 64 if square. Larger gauges are usually measured by a float and rod, while for continuous observations self-recording instruments, like Beckley's and Richards', must be employed. The Rothampstead gauge is an inverted hollow pyramid of cemented brick, with a base measuring $\frac{1}{1000}$ acre. The height above the sea must be recorded, as at the top of a building less rain is collected than at the bottom, owing possibly to the lower layers of the atmosphere being generally more saturated with moisture than those above.

The amount collected in 24 hours, measured in inches, gives directly, or by calculation, the depth in the layer of rain that would form over a whole level country, if none were lost. The numbers for all the days added together give the *annual* rainfall, which varies considerably, being in London about twenty-five inches, in hilly districts forty to fifty, with an average for the whole of England of about thirty inches. At Borrowdale, Cumberland, it is 140, while at Cherrapungi in Assam it is the heaviest known, namely 500 inches. It also varies from month to month, being greatest generally in November. The rain which falls on roofs measures from two and a half to three gallons per day for each person,* as compared with the ordinary town supply of 20 to 30 gals. Yet, being, when carefully collected, a water naturally very soft, and therefore specially suited for washing, cooking, and trade uses, it is a great extravagance to allow it to wash the streets and flush the drains, which objects might be served equally well by surface or sea water. One of the great difficulties in sewage disposal is the needless volume which is received at the works in periods of rain, especially when pumping is required. The dilution should be effected, not by the uncertain rainfall, but by properly arranged flushing tanks, in which again sea water or any common surface water could be used.

In country houses, the rainwater can be received in a special automatic separator (Roberts') fixed to the end gutter of the house, so that the first dirty rain that falls is rejected. The collector consists of a movable bucket, which does not recover its position after the rejection of the first washings, and allows the subsequent nearly pure rainwater to be gathered. If the object be, as in certain outlying districts, such as the Western United States and South Africa, to

* The following rule is approximate: Area of roof in sq. ft. $\times$ annual rainfall in ft. $\div$ 100 $=$ supply in gallons per day for a very dry year.

collect all available rainfall without loss by evaporation, high-pitched roofs and non-absorbent materials should be adopted. Slates are the cleanest material, and absorb only about 1 per cent. of the water falling on them, if they are of good quality, Bangor slates being the best; whereas tiles, besides being heavier, take up from 3 to 18 per cent. In the freight to distant countries the advantage of lightness in slate has also to be taken into consideration.

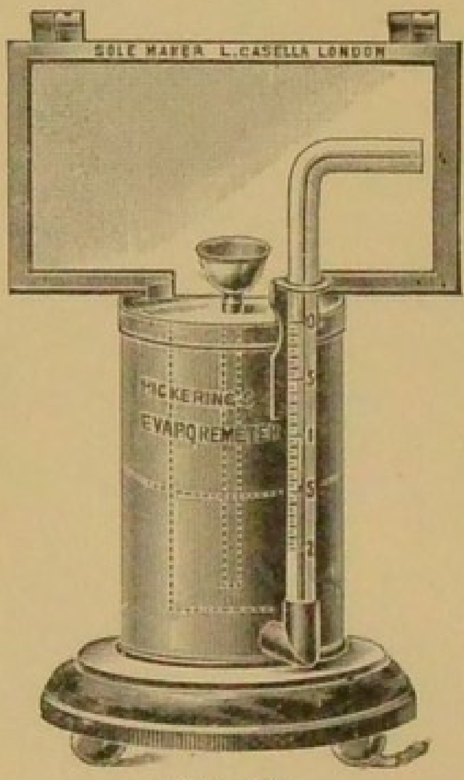

Fig. 19.
Pickering's Evaporometer.

The "Patent Standard Evaporometer" of Spencer P. Pickering, F.R.S., is devised for directly measuring the volume of water evaporated from a moist surface: A framed sheet of blotting-paper is provided with a tongue which dips into distilled water in the vessel beneath. The side tube is graduated to indicate the units of volume evaporated per unit area of paper exposed. It is made by Casella (Fig. 19). The rate of evaporation is an important factor in reference to the loss of water in reservoirs. Tables of evaporation are of very little value, as there are so many disturbing influences, such as the direction and force of the wind, the character of the soil, influence of vegetation, &c., that the result is of very local application, and should be determined specially for each place and time.

Surface Water.—It must be distinctly understood that the whole of our supply of fresh water, or water fit for drinking, comes originally from rain. Of this about one-third is lost by evaporation—*i.e.*, dries up—and eventually comes down again from the clouds. Another third sinks into the ground more or less deeply, and the remaining third runs over the surface as streamlets, which unite to form rivers. As it sinks into the soil, water, which is almost a universal solvent, takes up the soluble matters which it meets with, and becomes, according to the distance to which it penetrates and the character of the rocks which it traverses, more and more a solution of the earthy constituents, and further departs from the purity of rainwater. But in its underground course it undergoes a process of natural filtration: solid matters of an objectionable character are gradually sifted out, and the extent to which this natural purification has gone makes the difference which is recognised, although sometimes it is hard to define, between surface waters, ground or subsoil waters, deep waters, and springs.

Surface water is generally that which has penetrated the coarse alluvial gravel or drift which in most regions overlies the solid strata. It is easily obtained by a shallow well, and in the extension of

London in former times, as is shown by early maps, was so entirely a source of supply that the population followed the porous strata or beds of gravel, and left at first uninhabited those districts which were underlaid with clay.

But the danger from surface water only filtered through a few layers of gravel, and therefore insufficiently filtered, became more pronounced when the population grew, and the amount of excrementitious matter soaking into the soil became greater, until at last the surface water in inhabited districts was actually a mere solution of the sewage that had soaked into the soil from the countless privies and cesspools, and was capable of transmitting over a large area any disease that might be prevalent. This fact, which has been repeatedly proved in numerous epidemics, led to the closing of shallow pumps and wells in towns, even when, as occurred in some cases, they were actually popular from their bright and sparkling character—qualities which, as already shown, are by no means inconsistent with serious and dangerous pollution.

Even in the country, the surface wells of farmhouses are mostly for convenience placed in close proximity to piggeries, middens, and other sources of pollution, and every analyst knows that among these shallow well supplies one meets with waters of the very worst type.

For these reasons surface waters, and what are called "land springs," as a class, are to be rejected as unsafe for potable and culinary purposes. Great care must also be exercised to exclude such water from deep wells and reservoirs. The means of doing so will be further considered.

Upland surface waters from moors or mountain streams are, on the other hand, almost free from animal pollution, and where they have risen and flowed over the older rocks, like granite and slate, they are also peculiarly soft, or free from lime and magnesia salts, not having had time to dissolve much solid matter from the soil, but they frequently contain much vegetable or peaty matter. Among these some of the purest natural waters are to be found, like the Glasgow and Manchester supplies, and the proposed London supply from Wales. The amount of dissolved solids in the upland surface waters was found in a series of nearly 200 analyses by the Rivers Commission to vary from about 1½ to 3 parts per 100,000 from the igneous rocks, to about 15 parts from shales and sandstones, and reached as much as 77·5 parts in waters from chalk and limestone hills. The latter, of course, would possess considerable hardness. The small amount of organic nitrogen, as well as the almost entire absence of nitrates and chlorides, proved the organic matter present to be of vegetable origin and to be the drainage of uncultivated land. Where cultivation occurs and manure is used the water approximates to the constitution of lowland drainage, of rivers, and of shallow wells. In some towns on the Tees, where human manure was extensively distributed to fertilise the upland districts, the whole water supply became so contaminated as to cause serious epidemics of enteric or typhoid fever.

Another example of this is described in the Local Government Board Report for 1892–3. In 1891 enteric fever attacked Rotherham and two adjoining districts in South Yorkshire. It was proved to be almost confined to those portions having a certain high-level water supply derived from a gathering ground of 2,200 acres and two springs. The greater part of the gathering ground is cultivated, and much of it was found to be covered down to the very margin of the streams threading their way to the reservoir with manure, in which human excreta were detected. Dr. Klein, in a bacteriological report, stated, "that the water is most probably polluted with excrementitious matter." For this reason at Bury and elsewhere the policy has been pursued of buying up the farms on the watersheds wherever possible, with the result that the gathering grounds can be cleared of human habitations and freed from any likely sources of pollution. It is obvious, however, that unless the policy of clearing the watershed were thoroughly carried out it would be a delusion, and would not obviate the expense and necessity of subsequent filtration. In most cases, compulsory powers from

Parliament would have to be obtained, as the short-sighted opposition of local landowners is often extreme, and their demands exorbitant.

There is a serious local objection to the appropriation of a large part of the water of an upland surface for the use of large cities; thus the new scheme of London water supply from Wales has been objected to locally, on the ground that the Wye and the Usk would lose a considerable quantity of water, the supply to Birmingham would be affected, and the salmon fisheries of both rivers injured. It will be seen, however, that a very great reduction could be made in the waste that occurs in the water supply of towns, and that by using the purer mountain water exclusively for drinking, and employing ordinary waters for washing, trade, and sanitary purposes, a much less demand would be made on the upland area, and the objection would disappear.

When springs are cut off from a river, the quantity of water thus abstracted must be compensated by the construction of reservoirs sufficiently large to keep up the flow of the river during the dry season, as is the practice with canals.

[Note.—The volume of water absorbed and evaporated on a gathering ground varies considerably, so that the general statement, p. 69, which is true as regards the Thames and Seine, is not by any means of universal application.]

CHAPTER IV.

SPRINGS AND WELLS.

ALL porous materials that are wetted by a liquid are capable of retaining it in their interstices by "capillary attraction," just as a sponge does, and in the same way, when they are saturated, will allow the excess to drip out, and when they are compressed will give up a further quantity according to the pressure. The same is the case with rocks: sandstone, sand, and gravel* will absorb, as a rule, about one quarter of their weight of water without allowing any to flow out by gravity before they become *saturated.* If, afterwards, any further quantity of water flows in at one end a corresponding amount flows out at the other. But there are certain soils, such as clay, which do not allow water to penetrate them readily, and are known as "impervious strata." If rocks were laid horizontally, the one-third of the rainfall that permeates into the ground would be stopped by a layer of clay, and would form an underground reservoir of what has been called "ground water." But the internal forces acting in the body of the earth

* The ordinary idea of "rock" is something compact and hard, but geologically it is more convenient to speak of all formations of the earth's crust as rocks, and such is the universal custom in geological works.

have twisted and bent the strata into curves, which are called *anticlinal* when the sides descend away from one another, like the letter A, and *synclinal* when they slope towards each other, like a V, the highest and lowest points tracing respectively an anticlinal or synclinal *axis*. The angle made with the horizon is called the *dip*, which is expressed in degrees, and also described as east, west, &c., according to its bearing. The subsequent action of water in denuding or wearing away the upper portions of the rock leaves the synclinal curves as basins, with the edges of the strata exposed at the surface. The line of emergence of a stratum at the surface is called its *outcrop*, and its direction the *strike*. The outcrop on a flat surface coincides with the strike, but this relation is much disturbed by inequalities on the surface, so that the outcrop becomes a sinuous or wavy line. Rain falling on the upturned edges of a porous bed, such as gravel, descends till it meets with an impervious or saturated layer. If there be no outlet the entire stratum becomes in time saturated, and is then said to be *waterlogged*. But in cases where a valley has been cut by a river or by prehistoric glaciers through a lower portion of the beds, the rain that has entered above escapes at the lowest level as SPRINGS (Fig. 20).

Along the South Coast in places near the sea-level at the base of the chalk, considerable volumes of water escape into the sea, derived from the rainfall on the Weald, and it has been suggested that such water might be rendered available not only, as at present, for the seaside towns when not wasted, but even as a supplement to the metropolitan supply.

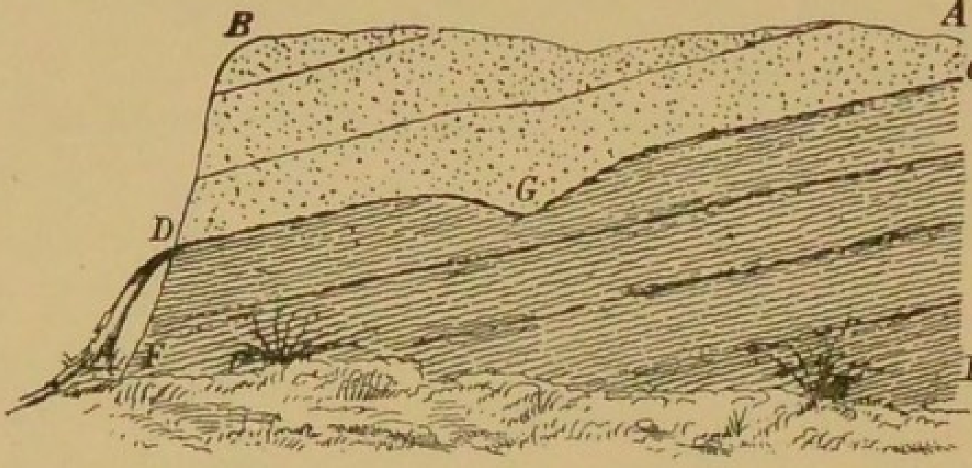

FIG. 20. Diagram of spring. AB, porous rock; CD, impervious strata; G, pocket; D, spring.

In other cases where the side of a synclinal curve has been worn away unequally, the body of water on

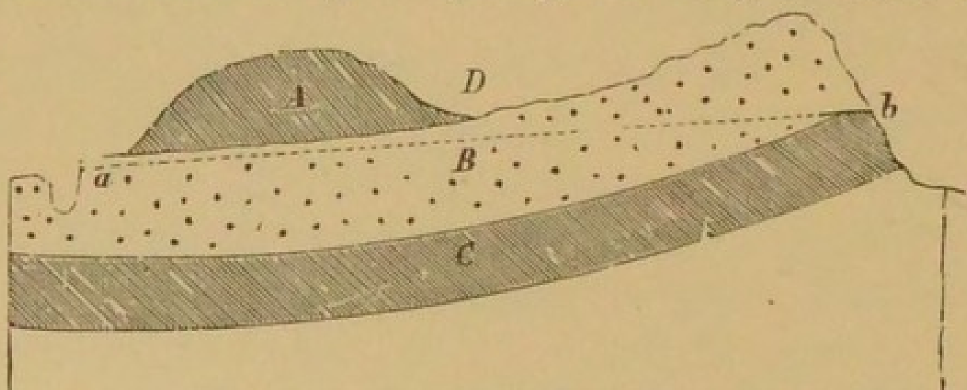

FIG. 21. Springs in synclinal.

the longer slope will appear as springs on the lower outcrop (Fig. 21). During the passage of the water through the rocks it dissolves a number of their mineral constituents, assisted greatly by the carbonic acid which it has absorbed from the atmosphere, and by that which has been formed by the oxidation of organic matter derived from the surface. In this way it may become saline or hard, aerated or chalybeate, according to the composition of the strata it has traversed. This solvent action on chalk and limestone frequently excavates underground channels and large caverns, which in many cases constitute natural subterranean reservoirs of very considerable capacity. Occasionally rivers in cretaceous districts disappear in a "swallow hole" of this kind and reappear at a point some distance further, as is the case with the Mole near Dorking and other rivers. Such an appearance may sometimes be mistaken for a spring, but its composition will generally reveal that it is really a surface water.

Another condition almost necessary for the formation of underground reservoirs of water and of springs is the inclusion of the porous water-bearing strata between upper and lower layers of an impervious material like clay, heavy marl, or shales. The weight of the superincumbent water often causes the spring to emerge with considerable force, as at the fountain of Vaucluse and other places.

In its transit through the porous rock the water will undergo a natural filtration, which will be proportionately complete according to the distance traversed and the rate of progress, which will in its turn depend on the fineness of the filtering strata.

At the same time, by contact with dissolved oxygen and by the action of the bacteria which it gathered at its first entrance into the soil, the organic matters will be decomposed into harmless mineral substances, like ammonia and carbonic acid, which are often present in considerable quantities in moderately deep or subsoil waters. Later, the ammonia is oxidised into nitrates, the bacteria and all suspended particles are removed, and the water emerges as springs or remains as deep water to be reached by boring, in either case being clear and bright, and almost absolutely free from germs and organic matter. For this reason spring water has always been considered to be an ideal supply. But, inasmuch as mere mechanical filtration cannot remove the dissolved mineral constituents, many springs, especially in Gault, Greensand, and New Red Sandstone, are so charged with salts of soda, magnesia and lime, or so impregnated with iron, as to be quite unfitted for drinking.

In Hertfordshire and Surrey an exceptional rainfall results in the formation of "bournes," or the outbreak of springs in places where the water level, in permeable rocks, is usually at some depth underground. Rapid streams arise in valleys usually dry: the water is often of considerable organic purity, and would probably pay for storage in small reservoirs on the South African principle, in this way also avoiding the damage by floods.

Springs are of two classes, LAND SPRINGS and DEEP

SPRINGS; the former are mostly found on the face of slopes, and are caused by the outcrop of the impervious floor, of clay, for instance, which hinders the water from descending further. Deep springs may arise from fissures in the impermeable strata, which allow the water in the layers beneath to rise to the surface.

The former class frequently become dry in periods without rain, and consist of surface water more or

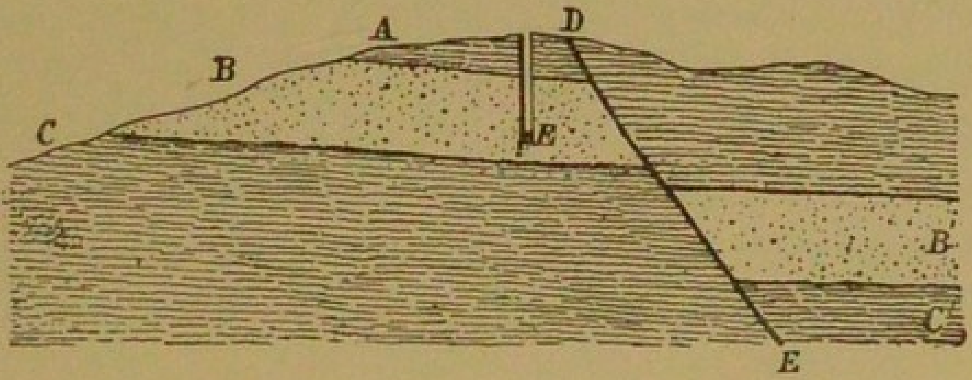

FIG. 22. Fault cutting off springs from water-bearing strata.

less filtered and oxidised. Deep springs are nearly always permanent, and yield water free from organic impurities if surface drainage has been excluded.

Owing to upheaval and depression, the rocks have frequently experienced dislocation by cracks or faults which often interrupt the strata and throw them for great distances out of their level. A continuous line of springs often reveals the presence of a *fault* (Fig. 22). The course of the underground water may also be cut off or diverted by this cause, as shown at D, so that the final lowest outcrop of the original water-bearing strata may be totally devoid of springs. Moreover, the underground current may pass to great depths, and even to points horizontally far remote from where it penetrated, particularly in the mountain limestone and in chalk. Therefore, in seeking for water geological maps and sections must be consulted, particularly as to the occurrence of faults.

In regions imperfectly explored the surface must be carefully inspected for outcrops, and all natural sections which may be revealed at the sides of valleys and precipices must be examined to ascertain the nature and dip of the strata. A line of springs at the side of a valley may often be traced by a strip of marshy land or by the extra greenness of the herbage, marking either a natural outcrop or a fault. Such a junction of the strata should be followed across the country, and sinkings or borings made in portions of the line that showed no springs might be expected to tap hidden sour cs of supply which had not risen to the surface owing to less pressure or less permeability of the strata.

Faults are more difficult to trace, and would require the assistance of a geological map or of an experienced geologist, but they frequently include subterranean spaces or pockets in which large quantities of water have accumulated. They are marked in geological maps by straight or curved lines on the opposite sides of which the strata are interrupted or broken. The dips are denoted by arrows showing the direction in which the beds slope downward, and a figure to show the angle to the horizon.

The proportion of water held by a rock or soil is often much larger than would be supposed. It has been stated that a square mile of sandstone 130 feet deep contains water sufficient to maintain a flow of a cubic foot a minute for more than thirteen years, as the average content of porous soils when saturated is from 25 to 33 per cent.; this estimate is a low one. The quantity cannot be well judged by the feel or appearance, as it depends almost entirely on the state of aggregation.

It is estimated by steeping a weighed dry sample in water for some hours, removing the loose water, and again weighing. Loose sandstones have been found to absorb 4 to 29 per cent., chalk 10 to 25: clay and loam retain more, increasing with the fineness of the particles.

Permeable rock below the permanent water level of a district may be regarded as a reservoir of which the cubic content is limited by the size of the spaces between the grains and the width of the fissures and cracks by which the rock may be traversed. When water passes directly through such fissures and cracks and does not percolate, as in the Carboniferous

Limestone, it is often mere unpurified surface drainage. It was given in evidence by Professor Boyd Dawkins, at a Local Government Board inquiry at Coventry, in 1896, that fissures in the Permian rock might account for contamination of the corporation well by the polluted waters of the river Sherbourne, distant half a mile away, and analyses by the author seemed to confirm such view. Shingle and gravel always contain water, which, however, is often brackish from old marine strata, even at distances from the sea, and in inhabited districts is generally contaminated by surface drainage, except at great depths. In some places on the sea-shore fresh water can be gathered from the shingle directly the ebb tide has removed the layer of salt water. A great number of Continental cities, such as Paris, Vienna, &c., are supplied by springs, also a number of cities in the United States, especially in the west. Such supplies generally require to be brought from a great distance, but if the conduits are well made and properly protected, the expense of filtration is obviated.

The best spring water is that which rises from granitic, jurassic (oolite), and cretaceous strata. That from gypseous, saline, pyritous, anthracite, bituminous, or clayey beds, or from deep alluvial deposits like the "dirt bed" of the South of England, is almost invariably of bad quality. If a spring augments in volume during winter or after rains, or if its temperature shares the fluctuation of the seasons, it is to be looked upon with suspicion as being wholly or partially fed from the surface.

Spring and deep waters require to be guarded with special care on the way to the consumer, as they furnish a medium in which adventitious germs very rapidly propagate.

Where a water supply is taken from springs, it is necessary, in order to avoid the risk of pollution from manured land, that each spring should be protected to the source, and proper intake works constructed with a watertight conduit from each intake, and that sufficient land should be acquired round each spring to secure the water against pollution by surface or subsoil drainage.

The divining rod, *virgula divina, baculus divinatorius*, or in French *baguette*, allied to the *caduceus* of Hermes and to the rod of Aaron, is still used in exploring for underground water. In the Middle Ages it was relied on for the detection of criminals as well as for finding buried treasure and running water. It had various forms, as seen in the annexed illustrations (Fig. 23). It is believed to have been transmitted from the Mongols, through Scythia and the Tartars, to the Persians and Jews. It is said to be still in vogue in Pennsylvania for petroleum, and in Cornwall for metallic lodes. But in these practical times, when still employed, as it is extensively for the discovery of springs, it appeals only as a kind of scientific instrument, depending on some yet unexplained force

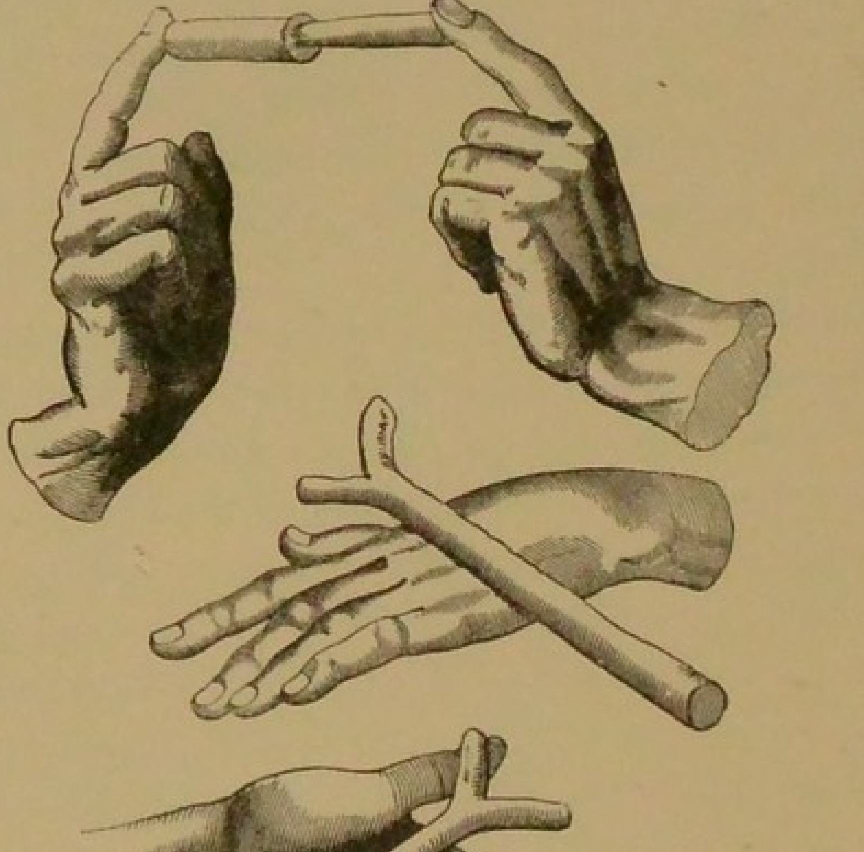

FIG. 23. Various forms of divining rod (Baring Gould).

of nature. Just as the magnetic needle moves towards iron always, but towards copper only when carrying a galvanic current, a fact which we cannot really explain further than by calling it a "property" of iron, so it is perfectly possible that a rod in the hands of a specially sensitive individual may move under the "induction" of running water. That water in an immense number of cases has been found by means of the "divining rod" admits of no doubt. De Quincey affirmed that he had repeatedly seen it applied with success. Lord Winchilsea writes of a well-known "dowser," or water-finder, in Wiltshire: "First he cut a forked twig from a living tree and held it in his hands, one fork in each hand, the centre point downwards and the two ends protruding between his fingers. Stooping forward, he would walk over the ground to be tried. Suddenly he would stop, and the centre point would revolve in a half-circle until it pointed the reverse way. This he stated to be owing to the presence of a subterranean spring, and further, by the movement of the twig, he could gauge the approximate depth. My brother (Hon. H. Finch-Hatton) and I each took hold of one end of the twig protruding, as stated above, and held them fast while the phenomenon occurred, to make sure that it was not caused by the movement of the man's own hand or fingers. The tendency to twist itself on the twig's part was so great that on our holding firmly on to the ends it split and finally broke off. The same thing occurred on a bridge while standing over a running stream. Stagnant water seems to have no effect on the twig." Other crucial tests being applied, "all present considered the trial satisfactory in every way, and it certainly was conclusive of two things: first, the man's perfect good faith; secondly, the effect produced on the twig emanated from a power outside himself, and appeared due to the presence of running water." Similar testimony is given by Lord Heytesbury, the Earl of Jersey, Col. Wilson (who found the power less rare than is commonly supposed), and many others.

Another successful water-finder states that he is only affected by running water, and quite passive to stagnant. He says that "various kinds of wire or a watch-spring answer the same purpose as a twig or rod. A large number of people have the power to a certain extent. . . . I now use my hands alone, holding them out with palms towards the earth. I reckon the rod as an instrument only, and that the power itself is in the person."

The Rev. S. Baring Gould, in an interesting paper on the divining rod in his *Curious Myths of the Middle Ages*, from which the illustration on p. 84 is taken, says that he found it impossible to accomplish rotation of the rod at will.

There is no doubt that the employment of a "water-finder" has in a large number of cases led to success, although in numerous cases they have hopelessly failed, and the auditors of the Local

Government Board have recently disallowed their fees. If further research should discover a physical law underlying the process, its utility would become more certain and extended.

Testing for the Source.—When a water is proved by analysis to be polluted, it is often difficult to discover the origin of the contamination, which may sometimes be situated at a considerable distance. In the case of *Ballard* v. *Tomlinson*, 1884, the water in plaintiff's well at a brewery had been polluted and his brewings spoilt by percolation of foul matter, through several yards of chalk, from a disused well which had been turned into a cesspit. Damages were obtained.

Prof. E. Pfuhl has ascertained by direct experiment that certain bacteria could traverse in one hour 8 metres (26 feet) of gravel soil, further that the supply of a tube-well became contaminated by *B. prodigiosus* when cultures of the latter were inserted into the surface 3·7 metres (12 feet) from the top of the well (*Zeit. f. Hyg.*, 1897, p. 549). Characteristic bacilli, like *prodigiosus* and *violaceus*, have frequently been used with success for testing filters and leakages. Where the suspected source is accessible, a quicker method is to add a quantity of some easily recognisable substance, either in solution or suspension, and to look for it in the incriminated water. The same process is of service in tracing the course of underground streams, leakages, &c. Of soluble substances, common salt is the cheapest, and is often sufficient; the amount of the white precipitate obtained on adding nitrate of silver will reveal any great increase of the chlorine.

Lithium chloride is sometimes used, the quantity required varying with the distance, rapidity of flow, permeability of the strata, &c. It is shown by the crimson lithium flame or by the spectroscope. Of course the original water must be tested for lithium first, as traces are often present.

Soluble strontium salts have also been suggested, as they can be recognised in the same way, but they have the disadvantage that they may be rendered insoluble during the passage.

Fluorescin ($C_{20}H_{12}O_5$), an orange dye with a very strong green fluorescence, is one of the best agents for this purpose, as it is easily visible when diluted with many thousand times its weight of water, and an entire river may be coloured by a few kilogrammes. By its use underground communication was proved between the Danube and Auch, a small river which flows into Lake Constance. It only gives a coloration in alkaline liquids; therefore soda should be added with it. Magenta and other dyes have been employed. Prussian blue, bran, starch, or other finely divided solids, suspended in water, are used to ascertain whether the water has undergone proper filtration.

An example of the use of salt and starch for this purpose was reported from Switzerland in 1872. The village of Lausen was visited by a severe epidemic of typhoid. Some time previously four cases had occurred at an isolated farmhouse in a neighbouring valley, separated from Lausen by a mountain of porous glacial moraine. It was suspected that the spring supplying Lausen was fed by the Fuhler brook, which ran past the farmhouse in the next valley. Eighteen hundredweight of common salt was put into a water-hole connected with this brook. In a short time the chlorides in the Lausen water showed a great increase, and the water actually became brackish. Afterwards two and a half tons of flour diffused in water were thrown into the hole, but no starch granules appeared at Lausen. Hence it was proved that the water had filtered through the mountain, and that the filtration had been sufficient to remove the starch granules, but not the typhoid germs. Non-pathogenic organisms of easy identification have been used for testing the efficiency of filter beds. A common method of proving pollution is to pour carbolic acid or kerosine down privies or cesspools and seek for the odour in the well.

When the source is inaccessible, as in cellars and other places, the water may come from a leaky hydrant, sewer, drain, or from a subterranean current. It will generally have passed through a considerable distance of soil, and in "made ground" districts will have almost certainly suffered pollution by organic refuse. It is necessary in such cases to first ascertain the general characteristics of the subsoil water of the district and of the public supply. As a rule, sewage passing through moderate thicknesses of soil does not materially alter in mineral constituents. So that if the polluted water contains more dissolved matters, and those of a character usual in sewage, than the general supplies of the district, it may reasonably be inferred that a drain or sewer has added the impurity. It is commonly sufficient to determine the total solids, chlorine, odour on heating, nitrates, and nitrites.

An example is given by C. F. Kennedy, of Philadelphia (parts per 100,000):—

	City supply.	Cellar No. 1.	Cellar No. 2.	Cellar No. 3.
Total solids.. ..	11·5	14·0	66·1	64·0
Odour on heating..	Faint	Faint	Strong	Urinous
Nitrogen as nitrates	0·07	0·10	0·35	None
,, nitrites	None	Present	Present	None
Chlorine	0·4	0·64	7·7	12·8

In No. 1 cellar a small quantity of water had been almost constantly present for a long time, of which the source could not be ascertained. Analysis shows it to be similar to the general water supply, and points to its source being a leaky hydrant or pipe. Examination of a hydrant on the adjacent property showed a leak, and when it was repaired the water in the cellar ceased. It had passed through twenty-two feet of earth. No. 2 suggested a leaky drain, and this also proved to be correct. As to No. 3, the high chlorine, odour, absence of nitrates and nitrites, pointed to recent and profuse admixture with sewer water. This also was verified on examination.

Occasionally the indications are ambiguous, but when more samples are analysed to see the influence of rainfall, &c., unusual substances, like paraffin oil, soap, &c., sometimes appear, and afford a clue to the contamination.

Wells may be of three classes: *shallow wells*, fed by the surface water, and to be condemned in nearly all cases for the reasons already stated; *subsoil wells*, drawing the ground water from a greater depth; and *deep wells*, carried through the impervious strata on which the ground water rests into the water-bearing strata below. It will be seen that the depth of the well will depend on the distance of the impervious strata from the surface (Fig. 24).

Dip-wells are those in which the water rises to near the surface and can be ladled out, and are to be

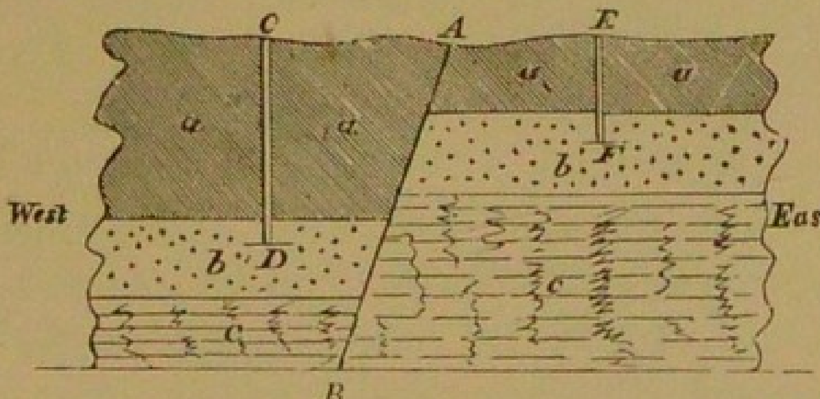

Fig. 24. Wells of different depths due to a fault.

distinguished from *draw-wells*, where the water must be raised by a pump or bucket.

A surface well drains an area which is greater the more the level of water is lowered by pumping, and the greater the porosity of the soil. The distance has been found by experiment to vary from fifteen to 160 times the amount of depression. Thus overflow or leakage can enter a well from a distance that at first might appear safe. Pollution has in many cases been proved to have crossed a road. A roadside well in Argyllshire, supplied by a spring from a fissure in the granite, was found by the author to contain large quantities of substances characteristic of animal contamination. No habitations were near, but on the hill above, about 500 yards away, were fields which were liberally watered by liquid manure. At Maidstone, in 1892, "Hill's Well," 100 feet deep, was found to be contaminated by the subsidence and consequent leakage of a sewer 500 yards distant. Well water has been observed to smell of disinfectants which have been thrown into neighbouring drains. Surface water without filtration is prohibited by the German Imperial Board of Health.

Dr. Wheaton* traced an outbreak of typhoid at Quarry Bank to polluted draw wells constructed of loose blocks, close to houses and near leaking privies and drains. Country wells of this kind are daily being closed. In most large towns this has been done, but in outlying districts a great number are still tolerated on account of the difficulty of procuring a better supply. It was estimated in 1893 that there were still about twelve

* Local Government Board Report, 1895.

millions of people in Great Britain supplied with domestic water from shallow wells.

Town pumps in the Middle Ages were the chief sources of the public water. It has already been mentioned how the increase of population caused the soil to become saturated with sewage, and how, therefore, the necessity arose that such sources, derived in nearly all cases from shallow wells, should, in the interests of health, be closed. Except in remote villages, street pumps have now almost entirely disappeared. On the Continent, particularly in Germany, the people still draw from the public fountains; these in the majority of cases, being fed by deep springs, are free from objection, except from the danger of the spread of infectious disease by the use of imperfectly cleaned vessels. In the East the public wells are centres of population, and their possession is of supreme importance. For example, in the Soudan campaign of 1896 the Murat and Ambigol wells were the first points seized and strongly held. The water of most of these Nubian wells, or rather pools, is brackish, and has a sulphuretted smell; but some rock cisterns give a small supply of pure water, which is supplemented at times by water sent up from the Nile on camels. The taste and odour imparted by the skins in which water is commonly transported in the East are highly unpleasant, but do not seem to be injurious.

Subsoil or *ground water* is surface water which has percolated to a depth of about thirty feet through the alluvial gravel and sand which in many cases overlie the bed rock or floor of clay. It contains considerable amounts of nitrates and chlorides derived from previous sewage contamination (p. 272), but in itself is generally innocent, though, like river water, it requires to be carefully watched. Dr. Koch considers it entirely suitable for drinking, and the town supply of Frankfort is derived from the subsoil water of an extensive wood, which is carefully kept free from habitations and other sources of contamination. But in the neighbourhood of large cities such care could hardly be exercised on account of the value of the land. The extraction of subsoil water often effects a remarkable improvement in the health of a locality by removing the dampness.

The "line of saturation," or water-line, is the level at which the water stands, and to which it will rise in wells, in any water-bearing stratum. If the water were perfectly free to move this would be a horizontal line at the level of the lowest point of escape; but by the resistance of the rock or soil it is raised into a straight line or curve sloping upwards to the point of entry of the rainwater at the outcrop of the strata. In the London basin the highest point is the outcrop of the Gault clay below the chalk near Tring, in Hertfordshire. Thence it runs in a slightly curved line to the Thames near Lewisham, more or less disturbed by two intersecting faults and by some inequalities in the clay floor. Where, as at Watford the surface lies below this line, springs,

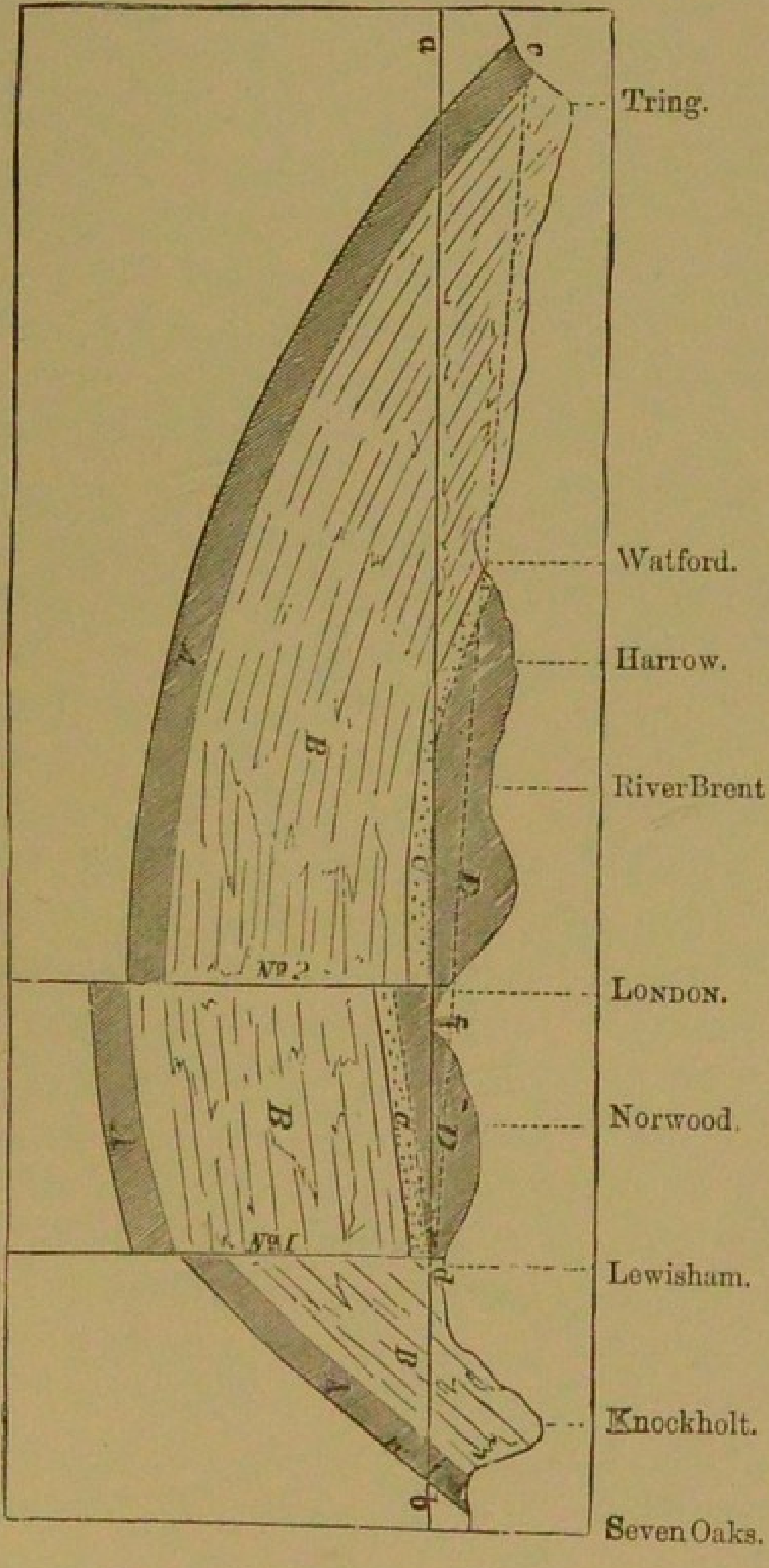

Fig. 25. Section through the London basin showing line of saturation.

are frequent (Fig. 25). Although the main run of the saturation line can be deduced from geological sections, the actual details can only be worked out by observations of existing springs. The smaller springs of a district which run over beds of an impermeable nature may often be at a higher level than the general saturation line, but the lower end of this line is always found at the high-water mark of the main river or lake of the district, or at the level of the sea.

When a well or boring reaches below the saturation line the water will stand at that level, only affected by pumping, which will lower the line for a considerable distance round. The effect will then be to exhaust the neighbouring wells, and if it continues at a rate faster than the incoming rain can percolate the whole stratum will be depleted. It is therefore necessary to leave periods of rest. It is a singular fact that in London, Saturdays, Sundays, and holidays are recorded by the higher level of the water in the great brewers' wells. When more water is wanted there is no advantage to be derived from deepening a well beyond the chance of opening into fissures or new strata; it is better to drive horizontal tunnels, or "adits," to extend the area of connection, and also to form an underground reservoir to make the supply more constant. These adits, or "headings," may be only borings from three to twelve inches in diameter; they immensely increase the yield and regularity of a well.

Two of the artesian wells at Trafalgar Square, which supply the Houses of Parliament, are connected by a horizontal tunnel 400 feet in length, which forms a reservoir with a capacity of 112,000 gallons. It must be remembered that an injunction and action for damages may sometimes lie against the sinkers of a well if the operations cause a loss or deviation of water from any well-defined channel, although there is no right to underground waters. (As to sinking and lining wells, see Mansergh's Chatham Lectures, 1880, and Swindell on "Wells and Well-digging," 1891.)

In every case the greatest care must be taken by properly cementing the bricks inside and, if possible, by coating them with tar outside, to exclude the surface water. The lining must also be inspected at intervals, and any cracks filled up. The upper portion is often made of a succession of lengths of iron tubes screwed or jointed together with a watertight packing.

It is now possible to obtain large earthenware pipes of three and a half feet diameter with an internal flange to facilitate sinking. Where such pipes are carefully jointed together by cement and used for the upper fifty feet of a new or old brick well, security against surface water is generally assured.

Artesian wells are drilled through the rock by a boring machine, and are generally lined by lengths of iron tube screwed together. The water sometimes rises to a greater height under rock pressure caused by faults than can be accounted for by the probable head of water in neighbouring hills. The great force with which the water often at first issues is probably caused by compressed gases. In Fig. 26, the outer wells require pumping, while the centre one will rise above the surface naturally, *a b* being the line of saturation. The well at Grenelle is 1,798 feet deep, and gives 516 gallons of water per minute. One at St. Louis, U.S.A., is 3,843 feet deep. Deep wells yield water of great organic purity, but often of high

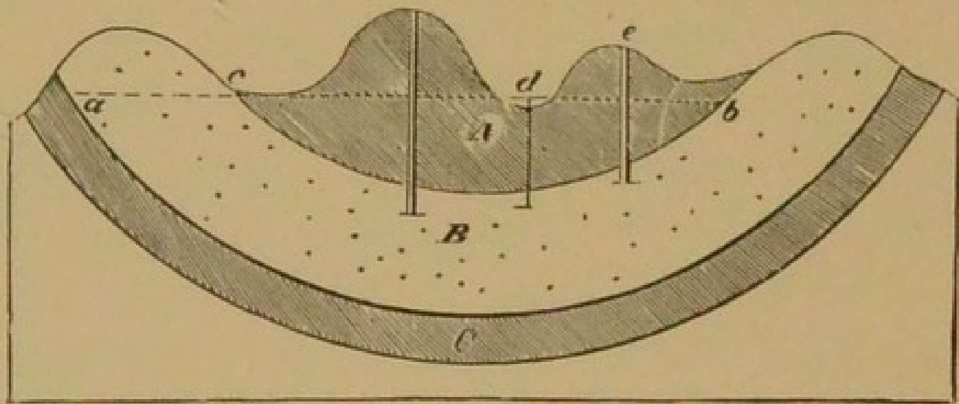

FIG. 26. Artesian wells.

hardness, as in the Kent Water Company's supply from deep wells in the chalk. G. Webster some years ago proposed to supplement the London water supply from borings in the chalk near Rickmansworth. From five wells sunk in this district a yield of about 10,000,000 gallons of pure water was obtained daily.

The artesian wells of Dakota, U.S.A., are, perhaps, the most remarkable examples of their kind which have ever been opened, both as regards the pressure and the volume of the escaping water. More than 100 wells, from 500 feet to 1,600 feet deep, are at present in successful operation in the district north of Yankton, and they yield a constant stream of water, which is apparently never affected by any of the surrounding influences. The pressure of the water is abnormally high in many instances, and up to 180 pounds per square inch has been registered by the gauges. The power is utilised in the more important towns for water supply, for protection from fire, and for driving machinery; and a very considerable saving is effected by the adoption of hydraulic apparatus in place of the steam engine. Artesian wells on up-country farms in Australia have been attended with considerable success, yielding at 1,500 to 2,000 feet constant supplies of 2,000,000 to 4,000,000 gallons daily, and thereby converting a waterless country into one supporting thousands of cattle and sheep.

At St. Denis, near Paris, there exists a well that is rather more than a curiosity. In sinking, three consecutive water-bearing strata were found actually representing the shallow, subsoil, and deep supplies. It was decided to sink three concentric tubes, the inner one to the lowest source, the middle one to the next, and the outer one to the layer next the surface. Thus three separate waters were obtained from different strata. The lowest was the only one safe for drinking purposes, but the others were suitable for technical use. The experiment opens out possibilities in sinking an artesian well of using by concentric pipes the water from upper layers for ordinary non-drinking purposes.

H 2

Driven wells are claimed to be an American invention. The idea is said to have originated from some successful attempts made by the soldiers during the

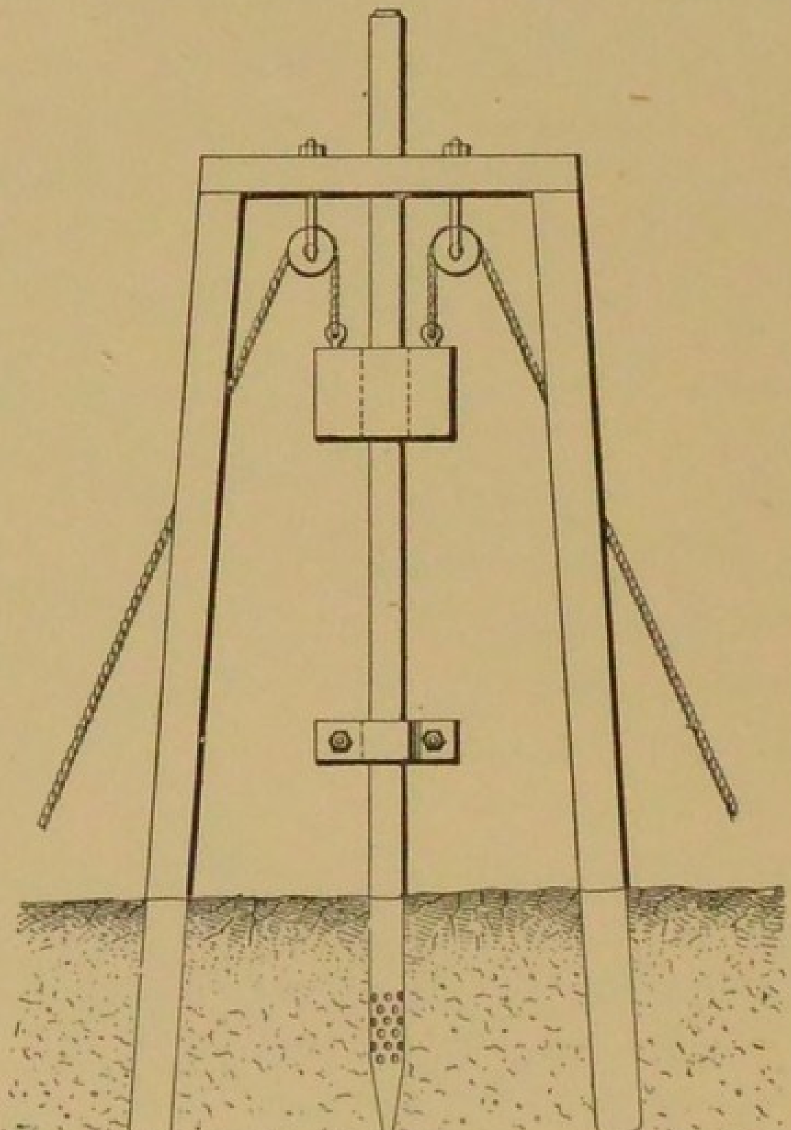

FIG. 27. Driving a tube-well.

Civil War to obtain water by driving gun-barrels into the earth. Norton's tube-well was first extensively used in the Abyssinian expedition, and in the Nile and other expeditions since. It is driven by a ring weight, which is raised and allowed to fall (Fig. 27). When one length of tube is driven another length is screwed on, until the water is reached. More than 2,000 years ago the Chinese bored for water in much the same way, and erected water-towers when the pressure from the bore was not sufficient.

Dr. Koch (*Zeitschrift für Hygiene*, xiv., 1893) has recently condemned all brick wells as "irrational and dangerous, on account of unavoidable fissures in the walls, because they are always open or insufficiently covered, and, lastly, because laundry operations and the washing of utensils are often conducted at their margins, whence infective matter might easily find its way." But each of these faults could be easily obviated, except, perhaps, the permeability of the walls. The mouth should be raised, and the wall carried about a foot above the surface. He proposes that an iron pipe should be inserted and the well filled up with gravel and sand, while the pump should be placed at some distance off and connected by a properly protected pipe.

Tube-wells have two great advantages: they are cheaply driven, and the tube, in case of failure to find water, can be taken up and sunk in another place. Of course they will not penetrate hard rock, which can only be pierced by a percussion drill, as used for an artesian well. They are especially suited for loose gravels and sand, which are difficult to deal with in ordinary well-sinking operations; and if properly screwed together the tubes effectually exclude surface water. Besides frequent examinations of the borings brought up by the drill to ascertain the character of the strata, at intervals an analysis should be made of any promising supply of water reached in regard to its purity and constancy of composition. Rapid variations either in the volume or constituents indicate that the underground source is neither permanent nor copious. The author was recently consulted as to a tube-well driven through sea-sand and gravel at Netley. The high percentage of salt in the water at once indicated a serious leakage of sea water into the tube. Greenwell and Curry* state that a thirty-foot tube-well can be driven for a total cost of about £10.

P. Griffith (Society of Engineers, May, 1896) has given a detailed description of borehole and other pumps which have recently been employed, and of various modern provincial waterworks.

In the history of Eastern nations, the sinking and protection of wells constituted an all-important part of tribal existence. The oases of deserts were originated by natural springs, but towns and villages centred round wells, most of them dug in the rock, but many in looser strata were constructed with sometimes elaborate timber or brick casings. Contests often occurred as to the possession of these wells, such as the one between Abraham and

* *Rural Water Supply.* London: Crosby Lockwood & Son, 1896.

Abimelech (Gen. xxi. 25). An invading army generally destroyed or filled in the wells; the defenders sometimes poisoned them. This latter practice is now forbidden by universal consent in the articles of war. Large quantities of water were required to be raised for the use of man, of the numerous flocks and herds, and for the irrigation of the pastures. The simple rope and pitcher was at an unknown date improved upon by the windlass, which is said to figure in some Egyptian inscriptions. Afterwards a string of buckets on a chain was adopted, and later on other appliances, such as the lift, force, and centrifugal pumps.

The so-called Joseph's well at Cairo, which is probably over 1,000 years old, is a marvellous example of early well engineering. It is cut in the solid rock to a depth of 297 feet, and raises the water in two stages by means of an upper and lower system of buckets worked by oxen at the middle and at the top. A spiral way winds round the upper shaft to allow the oxen and labourers to gain access to the middle chamber.

It must not be forgotten that an increase in the amount of water raised from a well, by enlarging the sphere of collection may alter the quality, so that periodic analysis is desirable.

CHAPTER V.

RIVERS.

Since one of the most elementary necessities of life is water, the proximity of a water supply is always a determining factor in the choice of a locality for human habitation. Great regions in the Asian, African, and American continents, and the vast extent of Central Australia, owe their deserted character primarily to their dryness. Large cities have usually been established somewhat inland from the mouths of rivers, in order to be in reach of abundant fresh water. Where for protection, or for mining reasons, habitations have been constructed in high places, they have either been in the neighbourhood of a mountain lake, like the city of Quito, or have depended on wells sunk in the rock.

As the area of cultivation extended, migration proceeded up the smaller rivers and streams, outlying districts being supplied by shallow wells sunk in the surface gravel of former river-beds, or in favoured cases by springs. The only contamination to be ordinarily met with in drinking water then arose from suspended mineral matters or from decaying vegetable debris. The former were dealt with by simple subsidence or by crude sand filtration; the latter is still a difficulty in forest regions, especially in the tropics, where dysentery and fevers attend the use of marshy waters. Malaria, which signifies "bad air," has been attributed to bad water, as travellers who have boiled or properly filtered the water have escaped infection, but it is now known to be frequently communicated to man by mosquitoes.

At a very early period, lakes and pools and rivers were subject to contamination by the visits of animals, many of whose parasitic diseases are known to be communicable to man (p. 58). But as the population in certain districts grew denser the quantity of water used and fouled became progressively greater. At first only the water used for domestic purposes, cooking, and ablution found its way into the streams, the excreta being disposed of in dry earth in the primitive manner still common in the East; but as the population augmented the contamination of the soil increased. At first the greater part of the polluting matter was consumed and rendered harmless by vegetation, just as a properly managed sewage farm will deal with the excreta of a district; but with the aggregation into villages and towns the upper layers of soil became saturated with excrementitious matters, which passed without appreciable purification into the water of surface wells. The neighbouring streams were polluted by drainage, and in their course joined with the other affluents in carrying the diluted sewage of the towns and villages into the rivers and thence to the sea. A considerable amount of purification took place in transit by deposition, oxidation, and aquatic life; but this became less and less effectual as the proportion of discharge increased. A further element of impurity was added by the advent of manufactures, the effluents from dye-works, breweries, and other industries being discharged into the streams. By these combined causes the water in most populous districts was rendered unfit for consumption, and new sources had to be sought for at a greater distance. In 1894 the Seine was so polluted near Clichy that Dr. Billings observed, "Bubbles of gas from the putrefying slime at the bottom escaped from the dark surface, and no fish could live in it"; the sewage, in fact, was undergoing its bacterial change.

Dr. Bruce Lowe's recent report to the Local Government Board on the examination of the Dee above and below Chester shows that he and Dr. Ballard found that "the raw sewage of several large towns was poured directly into the Dee, and that pollution of the stream below the weirs could be carried by the tidal wave into close proximity to the Chester waterworks intake. The water was so polluted as to destroy the fish that came up the river." They concluded that "a stream receiving such contaminations could not be regarded as a safe source of public water supply, even if before it was delivered to the public it was subjected to the best process of sand filtration."

It will be within the memory of many Londoners how black and offensive the Thames was formerly between the bridges. Since 1859 the Main Drainage scheme and the embankment of the Thames have immensely improved the condition of the river, so that fish that could not formerly live in the foul water have now been noticed as high as Westminster Bridge. At that time, as Sir E. Frankland reported, "the silvery Thames was for several weeks converted into a black, seething, and stinking canal, its sluggish waters being carried backwards and forwards by the tide through London and Westminster, and the stench in the committee-rooms of the Houses of Parliament became so unbearable as to render necessary the filtration of the outer air through cloths wetted with chloride of lime."

An instance of how such injury to watercourses was permitted quite recently occurs in a report to the Halifax Council as to the district of Upper Greetland, Yorkshire, in April, 1896. The local stream is stated to be "as badly polluted as ever, and although it had been condemned by three medical officers, it was still allowed to be used for cattle, and even by human beings. The milk from the cows which drank from the stream was sold in the Halifax district." The connection between polluted milk and disease has been so frequently demonstrated that it is obvious cattle should not have access to such water. It also appeared that pigs were in the habit of wading in the stream, and this animal is particularly subject to parasites.

A striking example of the pollution of a river by the domestic and manufacturing sewage of a town is given in the Report of the Massachusetts Board of Health, 1890, p. 472. Above the town of Fitchburg, of 22,000 inhabitants, the water of the Nashua river has the following composition: free ammonia, ·0004 parts per 100,000; chlorine, 0·39; nitrogen as nitrites, ·0001. Below the town the respective figures are ·0326, 0·83, and ·0014. Thus the ammonia has enormously increased, the chlorine has more than doubled, and the nitrite is fourteen times as much, three ingredients which are characteristic of sewage pollution. A series of interesting chemical maps, illustrating with exceptional clearness other features of the kind, is included in the Report. This method of plotting certain of the analytical results on sketch maps of the river-basins furnishes an exceedingly useful bird's-eye view of the effect of tributaries and local discharges on the main stream, which would be still further elucidated if the maps were tinted to indicate the geological formations.

A series of such maps drawn on a larger scale, for which the name "hydrochemical" might be proposed, would be an important contribution to the study of our water supplies, and should be undertaken by some of our public authorities. It does not seem creditable to England that, while a state like Massachusetts should institute inquiries with such care and in such detail that their results are of benefit to the whole world, our local bodies should often be battling helplessly with problems in such a crudely experimental way as to cost large sums to the ratepayers for abortive schemes which a little more knowledge would have prevented from being undertaken.

In 1865 a Royal Commission was issued for inquiring how far the present abuse of rivers in England for the purpose of carrying off the drainage of towns and the refuse of manufactures might be remedied, and how far such products could be utilised or rendered harmless before reaching the rivers. The reference included also an extensive inquiry into the water supplies then existing. The results were recorded in the series of reports of the Rivers Pollution Commissioners ending in 1874. Their researches were very valuable, but their suggestions as to the limits of impurity in discharges which should be permitted to pass into watercourses were ultimately abandoned or postponed by Government. A great improvement was effected when the intakes of the London companies were transferred to points higher up the stream, as, for instance, that of the Southwark and Vauxhall Company, from Battersea to Sunbury, near Hampton Court. But it must be remembered that these intakes still include the local sewage from the upper portions of the river.* The filtration to which the water is afterwards subjected is considered in Chapter IX.

* To show how important is the position of the intake, the following may be cited from the Report of the Medical Officer to the Local Government Board, 1894 (p. 18): "In the cholera epidemic at Paris in 1872, the inhabitants of those communes drawing their supply from below the main outfall sewer died of that disease at a rate nearly fourteen times as great as those who were supplied from the same river at a point above Paris."

The pollution of streams is prohibited under penalties by the Public Health Act of 1875, the Rivers Pollution Prevention Act of 1876, the Local Government Act of 1888, and by local Acts, such as the Public Health (London) Act of 1891, and by bye-laws of sanitary authorities. Many of these Acts, however, are largely inoperative owing to the numerous excepting clauses, but in any case the discharge of solid or liquid sewage, or indeed of any solid matter, into streams, is illegal. It is, therefore, the duty of an inspector of nuisances to guard against the common practice in towns and villages of allowing the washings of stables and pigsties to flow into any watercourse, and he should insist on the removal of all closets on the banks of running streams and prevent the discharge into them of all house refuse, &c.

Since the operation of these Acts it has been found possible and even remunerative for manufacturers to utilise waste products by precipitating, filtering, evaporating, distilling, and burning, so that chemicals are recovered, organic matters used as fuel or manure, and clean effluents only allowed to be discharged.

On August 21st, 1896, Mr. Justice Gye made an order, with full costs, requiring the Corporation of Andover to abstain from polluting the river Anton with sewage. He found that the Council had not used any means of rendering harmless the sewage so falling into the stream. This was one of the rare cases where private persons had taken action under the Act, the plaintiffs being riparian and mill owners.

The Local Government Board has of late declined to sanction schemes for the drainage and sewage disposal of districts unless the manufacturers submitted their effluents to a preliminary treatment before passing them into the sewers.

The standards of the Thames Conservancy for districts below the intakes of the London Water Companies are that any discharge into the river should be—

1. Free from offensive odour.
2. Free from suspended matter—*i.e.*, perfectly clear.
3. Neither acid nor alkaline to test-papers. (This is impossible: natural waters are almost invariably acid to one test, on account of free carbonic acid, and alkaline to another, owing to carbonates. Hence "acids and alkalies not naturally present" should be specified as prohibited, or limits of permissibility stated.)
4. Not more than sixty grains per gallon of total solids.
5. Not more than two grains per gallon of organic carbon and 0·75 grains of organic and ammoniacal nitrogen.
6. Not less than one cubic inch of free oxygen per gallon.

Such a water undiluted would usually be still not potable.

The German Government Act of 1894 prohibits the discharge into rivers of (*a*) substances of such a nature that their introduction may give rise to an infectious disease, (*b*) or in such quantities as may involve an injurious pollution of the water or of the air or a distinct annoyance to the public. A special officer of the province is to determine as to the things and quantities covered by this Act.

During their rapid upper course, mountain streams are generally turbid. The suspended matters are gradually deposited as the current slackens; but, owing to fresh accession from tributaries, river water is rarely bright, and is sometimes very difficult to clarify by filtration. An example of the change of a river in its flow is furnished by the Schuylkill, which rises in the anthracite region of Pennsylvania, receiving much refuse mine water and becoming so impregnated with iron salts and free mineral acids as to be quite unsuited for drinking or manufactures. In the course of 100 miles it passes over an extensive limestone district, and receives several large streams highly charged with carbonate of lime. In this way the acid is neutralised, and the iron and most of the lime are precipitated, with the result that the river becomes purer; and at its junction with the Delaware at Philadelphia it contains neither free sulphuric nor hydrochloric acid and only small traces of sulphate of lime, and is, in fact, a soft water.

Rivers which are hard at their source generally undergo some softening during their flow, while the total solids increase from the influx of salts from the land.

Thus Thames Head water near Cirencester contains 27·44 parts per 100,000 of solids; hardness, 23. As supplied to London it contains 30·94 solids and 17·3 hardness.

As to the natural organic purification of rivers, very opposite statements have been made. The late Dr. Tidy contended that water containing 20 per cent. sewage became purified by natural oxidation in a flow of ten or twelve miles; whereas Sir E. Frankland, by a series of experiments on the Irwell and on the Thames, sought to establish that 200 miles would not be sufficient for the purpose. But at that time the *rôle* of bacteria was not properly understood. Atmospheric oxygen alone will not readily attack organic matter in the absence of microbes; it is the number and nature of the latter that determine the rate and completeness of natural purification. In this process the organic matters containing carbon and nitrogen are partly absorbed by microbes as food and converted into their cell-walls and protoplasm, and in part are changed into compounds of volatile vegetable acids, such as butyric, which communicate unpleasant odours and taste. Other products are the ptomaïnes, some of which are powerful poisons; these remain in the water after filtration.

On the continent, the Isar, Spree, Limmat, and Danube have recently been examined by bacteriological methods, and the purification effected determined during the flow under different conditions.

Not the least important agents in the natural improvement of waters are the "nitrifying organisms," very minute micrococci of at least two species, which have been isolated and described by Winogradsky, Warington, and P. F. Frankland. One kind effects the conversion of ammonia into nitrites, and the other of nitrites into nitrates. In the process of nitrification, which has long been known in connection with the manufacture of saltpetre, nitrogenous organic fluids, like urine and the runnings from manure, when mixed with alkalies or lime and exposed to air, have their organic carbon converted into carbonates, and the nitrogen into ammonia, to be, in its turn, changed into nitrites and finally into nitrates, in which simpler form the whole becomes "mineralised" and is no longer injurious. The organisms which effect these changes are present in almost all soils and waters, but their activity is dependent on certain conditions:—

1. The solution must be neutral or alkaline; hence heavy and sour soils will not nitrify. Acid discharges from factories also entirely put a stop to the natural process of purification.

2. The presence of air seems necessary. Nitrification does not occur more than a few feet deep in soils (Warington), and then only when such soils are porous, like sand or gravel.

3. The action is more vigorous in the absence of light, so that in waters exposed to full sunlight it is suspended, and the organisms may actually be killed.

In waters loaded with organic matter and containing little dissolved oxygen, *denitrifying* organisms reduce the nitrates to nitrites, and may eventually convert them into nitrous and nitric oxide, or even into nitrogen gas. These gases dissolve in and finally escape from the water, and thus explain the well-known fact that the amount of nitrogen in the nitrates and ammonia produced is always lower than the nitrogen in the original organic matter. In comparing a sample of water taken from a stream at a point where it is much polluted with one taken further down, there is often a very marked improvement at the lower point, owing to the dilution caused by purer tributaries and by water filtering into the stream from underground sources. If the flow of a river be steady, different sources do not mix; the water of a turbid or coloured affluent can often be traced as a separate streak along a river for a great distance.

In regard to the self-purification of rivers, Dr. P. Frankland ("Bacterial Purification of Water," *Proc. I.C.E.*, November, 1896), instances his examination of the river Dee for forty miles of its course. Above Braemar the Dee was found to yield only eighty-eight microbes per cubic centimetre; after receiving the sewage at Braemar, however, the number went up to 2,829 per cubic centimetre, whilst some miles further down the number had fallen to 1,139; below another point, where some more sewage had gained access, the number rose to 3,780, while some miles further it again fell to 938; with fresh access of sewage it rose to 1,860, lower down again falling to 950 microbes per cubic centimetre, "a most striking example of repeated pollution and purification within a limited distance." Dr. Frankland states that the chemical examination was not sufficiently delicate to reveal these changes.

By waterfalls and weirs the water is thoroughly mixed and also aerated. The improvement effected thereby is not so considerable as was formerly supposed. Dr. Leeds in 1890 examined the water above and below Niagara falls, and showed that the aeration did not cause any decrease of the free ammonia or in the oxygen consumed, and gave only a small reduction in the albuminoid (*Journal of Amer. Chem. Soc.*, November, 1890). Dr. P. Frankland (Third Report to Royal Society, 1894, p. 516) found that moderate agitation, with intervals of rest, on the whole promotes the growth of bacteria. In low-lying districts the construction of weirs and dams for mills, &c., frequently causes great injury to the health of the locality by rendering the soil damp and water-logged above the obstruction. In such a case the watercourse should be securely embanked, and the drainage carried to the lower part of the river, as it is to a great extent in London. According to section 33 of the Sanitary Laws Amendment Act of 1874, "any sanitary authority may, subject to the provisions of this Act and of the Sanitary Acts, buy up any water-mill, dam, or weir which interferes with the proper drainage of or the supply of water to its district." A free growth of algæ and larger water plants uses up a large part of the ammonia and nitrates in a water; but, on the other hand, they always render the water offensive to the smell and taste, and corrupt it by the products of their decay.

It is of the highest importance that the current of a river should be kept strong enough to carry along the solid matters contained in it, otherwise they deposit in foul banks along the shore. These at low water are converted by the heat of the sun into fœtid breeding grounds of germs, and the shallow water is a concentrated solution of highly deleterious matter. And it is probably due to this fact that it is generally in the time of, or just after, periods of drought and warmth that epidemics arise. "Compensation" reservoirs, to divert floods and store the water so that the river becomes less overcharged, are also made necessary by the fact that the water, in addition to being turbid, is always greatly increased in foulness, as, besides the washings of manured land and of streets in towns, numberless abominations, which get into the smaller tributaries and are left there to putrefy, are washed out by floods into the main stream. Thus in some cases small villages have produced epidemics in riparian towns situate below on the same river. Intermittent stagnancy, succeeded by flood, is favourable to the growth and dissemination of the more dangerous organisms. The storm-water collected in a reservoir would have time to deposit, and would be a reserve against periods of drought such as recently visited, with such serious results, the town of Leicester. By reservoirs the "scouring action" of the stream can be kept continuous, and the stored water used to supplement a slackened flow in times of drought.

Dr. Shirley Murphy has shown that in 1894 sporadic cases of enteric fever occurred in London after the delivery of inefficiently filtered Thames water when the river was in flood in the late autumn. Thus, at St. George's, Hanover Square, out of the sixty-five cases of enteric fever which had occurred in the district during 1894 no fewer than twenty-nine were notified in November and December and only fourteen in the three previous months, when the seasonal prevalence of the disease usually takes place.

The pollution of smaller tributaries from mansions, farms, and ditches is seldom prevented except in those cases where the river is under the control of an active authority, which has special powers conferred on it by Act of Parliament, as in the case of the Thames Conservancy.

In the lower reaches of rivers large quantities of sea water are carried up by the tides. As sea water contains a high proportion of salt (chloride of sodium), the amount of chlorine furnishes a measure of the admixture. By this test it has been found that at London Bridge the river contains about one-fourth of sea water. The first effect is a considerable deposition of solid matters, due both to retardation by the tidal wave and to the precipitating action of salt water. Dr. P. Frankland finds that the influx of chlorides favours the multiplication of some bacteria to an extraordinary extent, especially the germs of cholera. The high percentage of salt (or chloride of potassium) in the Elbe may have accounted for the severity of the cholera epidemic at Hamburg. In London also during some of the earlier outbreaks, the East London supply, where the disease was most fatal, was mainly derived from the tidal portion of the Thames. Brackish waters from the estuaries of rivers, as well as those drawn from the gravel near the sea (except from the occasional fresh-water springs, pp. 75, 82), are quite unfit for drinking, apart from bacteriological reasons, on account of the large amount of sodium and magnesium chloride, which render them purgative and unwholesome. Some inland waters from marine formations like the Trias (p. 329) are unsuitable for drinking purposes.

The measurement of the volume of flow of a river is easily understood in theory, but there are many practical difficulties. If the width and the depth at several points be found, the transverse section can be plotted, and the area found by ruling squares on the drawing. A great number of such sections being made, an average is obtained in square feet. The mean velocity is then determined by boards sunk at different depths attached to floats. A series of observations being made, the average rate of flow in feet per hour is obtained. This, multiplied by the average sectional area, gives the number of cubic feet of water passing per hour. To calculate into gallons, 6·24 gallons equal 1 cubic foot. The average daily flow of the river Thames at Ditton is 906,000,000 gallons, of the Severn 300,000,000, the Ouse at York 140,000,000, the Tiber at Rome—a very rapid river —5,500,000,000.

It may be generally stated that the water supply of towns should not be taken from rivers if it can be avoided. The unfiltered water of rivers is never safe to drink, especially in their lower portions, where many of them, as shown by their appearance and odour, are practically open sewers. In the Seine, where numbers of wash-houses for linen are established on the banks and in the stream, Miquel found that the river water, containing originally 10,000 bacteria in one cubic centimetre, contained no less than 20,000,000 after passing through a wash-house, and many of these organisms would be of the more dangerous class.

There are a large number of rivers throughout the country furnishing water for domestic purposes which are scarcely ever examined by chemical or bacteriological analyses. The purity of sewage effluents and the character of the discharges from factories are occasionally examined by local authorities, but usually not until a complaint is made. The existing Acts having to a great extent failed in operation, it must be laid down as a sanitary necessity, if rivers are to be used for any water supply, that a regular system of inspection by officers of the Local Government Board be established, similar to the existing system under the Alkali Works Regulation Act, 1884, with regard to the purity of air.

In respect to the London supplies from the Thames, in which much more care is taken, there is some divergence of opinion. The Royal Commissioners of 1892 reported as follows: "We are strongly of opinion that the water, as supplied to the consumer in London, is of a very high standard of excellence and of purity, 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 the 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*. . . . . With respect to the quantity of water which can be obtained within the watersheds of the Thames and Lea, we are of opinion that, if the proposals we have recommended are adopted, a sufficient supply to meet the wants of the metropolis for a long time to come may be found without any prejudice to the claims or material injury to the interests of any districts outside the area of Greater London."

Sir Edward Frankland, in a lecture at the Royal Institution in February, 1896, supported this conclusion, and also stated that "not a single harmful organism had ever been discovered, even in the unfiltered river water as it entered the intakes of the various companies, although these organisms had been diligently sought for." This is partially explained by the difficulty of isolating them from such an immense volume of water, and of identifying them conclusively when found. Probably Pasteur filtration (p. 305), worked on large quantities of water, will eventually succeed in discovering survivors of the typhoid and other pathogenic bacilli that undoubtedly enter the Thames. But the real reason is to be found in the fact proved by Dr. Percy Frankland and others, that unsterile surface water, like that of the Thames, possesses bactericidal powers irrespective of the further multiplication of any of the contained water-bacilli. He has, however, also proved that typhoid and other bacilli might, if of strong growth and in extra numbers, become habituated to their surroundings; and that, even if only a few remained, perhaps so scattered as to escape observation, they would, when by chance introduced into a purer and naturally sterile or sterilised water, recommence multiplication with extraordinary vigour, so that in this way a severe epidemic might be occasioned.

The Report of the Royal Commission was by no means universally accepted by scientific men. Indeed, the highest medical and scientific opinions are practically at one in stating that the drinking water of a populous town ought not to be taken from rivers running through cultivated and inhabited lands. No fewer than three of the members of the recent Royal Commission were examined as experts on the Birmingham Water Bill in 1893, and they all expressed this view with more or less emphasis. No doubt, careful filtration will remove much impurity, but it is admitted that no system of filtering on a large scale can be relied on to remove all pollution. The Royal Commissioners themselves found serious fault with the filtering and reservoir arrangements of some companies. It is well known to any analyst who has examined daily samples of London waters that most of the companies supply at intervals, and invariably at times of flood, water that is more or less turbid, and therefore has not been efficiently filtered. And it is obvious that where suspended visible matter is present the more subtle bacteria may also certainly penetrate.

In favour of the proposed supply from Wales, which will be described in Chapter VI., p. 130, it may be pointed out that the present Thames system not only robs the other towns of the Thames Valley for the benefit of London, but subjects them to a heavy expense in treating their sewage.

The average daily supply from the Thames during November, 1895, was about 123,000,000 gallons; from the Lea, 45,000,000; from springs and wells, 42,000,000: being in the proportions of fifty-nine Thames, twenty-one Lea, and twenty from springs and wells.

The amount of solid matter carried down by rivers is frequently enormous. The Mississippi has been calculated to carry down 400,000,000 tons of suspended matter yearly; the Ganges over 6,000,000; the Thames about 2,000,000.

Note.—The Royal Commission on Sewage appointed in 1898, issued in July, 1901, an Interim Report which concludes—"that the simplest possible means should be provided for adequately protecting all our rivers," and that "scientific experiments should be carried out to ascertain all the real dangers of pollution against which they should be protected." They recommend "the creation of a separate commission, or a new department of the Local Government Board which shall be a Supreme Rivers Authority . . . which, when appeal is made to them, shall have power to take action in cases where the local authorities have failed to do so."

CHAPTER VI.

STORAGE.

It has been already stated that all the varieties of water on the earth's surface have originally fallen as rain. The fluctuations of seasons affect the volume of rivers and of every spring that is not fed by a large underground "pocket" of water, or a system of extensive fissures, as in the chalk. Storage of water then becomes necessary. In some localities nature has effected this by means of lakes, sometimes of vast extent, as in Canada and Central Africa. Where fed by mountain streams they have the character of upland surface water, as described on page 71, with the further advantage, when the lake is large, that it has undergone a long subsequent purification by subsidence and oxidation, so that it often attains a high degree of clearness and of organic purity. Most of the chief towns in the North of England derive at least part of their supply from mountain lakes, either natural or artificial. On account of their distance from contamination, and of their great depth permitting the solid particles to subside beyond the reach of disturbance, such water is fit for consumption without filtration, the only precaution being to keep the long aqueducts watertight and free from organic life. As has been already mentioned (p. 53), the germs of disease, which are rapidly enfeebled or even killed by such an impure water as that of the Thames, multiply with extraordinary rapidity in a pure liquid like the water of Loch Katrine; while the conditions are also favourable for other minute plants, other infusoria or animalcules which live on these plants, and microbes, which consume both plants and infusoria after their death, to freely develop. This fact, which has actually been advanced as an argument against a mountain supply for cities, only proves that when pure water has been obtained the greatest care should be taken to protect it from pollution. That any one should continue to drink an impure or doubtful fluid when a better one is attainable, will not be seriously contended, as, although disease may not be directly or obviously communicated, the effect of a bad water, even when perfectly filtered, has been shown to be distinctly lowering to the constitution, and to pave the way towards the reception of further injurious influences on health.

Loch Katrine is about forty miles from Glasgow. The water is brought to the city by a closed conduit, and is very clear and bright. It contains in 100,000 parts, 3·28 of total solids, 0·256 of organic carbon, (p. 274), ·008 of organic nitrogen, ·031 of nitrogen as nitrates and nitrites, 0·36 of calcium carbonate, 0·25 of chlorine, ·002 of free ammonia, and has a hardness of about half a grain per gallon. The colour is faintly brownish. It will thus be seen that it is an exceedingly soft water, the high relation of carbon to nitrogen showing that the organic matter is of a vegetable nature. It is said that Glasgow saves in soap, since using Loch Katrine water, £36,000 annually. For manufacturers the softness of the water is of great value. Bala Lake, one of the sources proposed for London, Thirlmere, which supplies Manchester, and other lakes of Westmoreland, are of similar character.

An example of the effect of depth and stillness in attaining clarification is furnished by the River Rhone, which enters the Lake of Geneva full of suspended matter, but emerges clear and bright.

To increase the storage capacity of a natural reservoir such as a lake, and also to form one where the sides of the valley through which a stream flows are sufficiently impervious, an embankment is built across the outlet. Reservoirs of the kind are very common in the United States, where small lakes are plentiful. Manchester is also supplied from Longerdale valley by six storage reservoirs, arranged in steps, with dams seventy to 100 feet high. The Bolton embankment at Entwistle is 120 feet deep, while one at Villar Madrid, in Spain, is 158 feet, and another at St. Etienne, in France, 164 feet. The new waterworks of the Bradford Corporation include a reservoir at Gouthwaite, covering 330 acres, over two miles in length, and holding 1,500 million gallons of water.

Before proceeding to the selection of a site for a reservoir, it is necessary to make an accurate and continuous observation on the flow of the streams that may feed it and the amount of rainfall. Where there is considerable storage accommodation, the ill-effect of a dry season is not felt to its full extent during the drought, but ensues some time after the rains have begun again. It is not uncommon to lose a large proportion of the first rains by their rapid flow over parched or frozen ground. About 15 or 16 inches of the ordinary rainfall is estimated to be lost by evaporation, soakage into the ground, &c. The greater number of watersheds of England are already appropriated by towns, even beyond their present needs, "to make provision against future increase of population." Towns like Middlesborough and Barrow, which have suddenly grown up from small beginnings to considerable magnitude, are threatened under the present haphazard system with having either to remain content with insufficient or possibly unwholesome supplies, or to buy watersheds at fancy prices from the forestalling neighbours.

Here is a case when it is the province of the State to apportion the upland water sources according to the needs of the populations, and to see that "private ownership" does not offer such hindrance as it has frequently done to local enterprise. It is hardly necessary to mention that high cultivation with manuring should not be permitted on the lands providing water for storage reservoirs.

The selection of a source from which to obtain a water supply depends principally on the following considerations:—

1. Purity, volume, and permanency of the supply.
2. Its elevation and distance.
3. Nature of the intervening ground.
4. Purchase of water rights and easements.

English law has decided that the property in water in a river or stream flowing in its natural course belongs to no one, but the use of it to every one having the right of access. Thus a local sanitary authority must first come to terms with the owner of the land whereon the spring rises, or the riparian owners at or below the point at which the water is sought to be taken. Sometimes "compensation reservoirs" have to be constructed to store the flood water (see p. 73), which is then allowed to flow as required, so as to minimise the interference with the stream. An "easement" is the right to lay pipes or tunnels through private property, and to have access to them for repairs. (For further details, see *Rural Water Supply*, by Greenwell and Curry: Lockwood, 1896.)

Where the source is elevated, water descends by gravitation, but in other cases pumping has to be resorted to. The former generally involves a larger first outlay, but a heavy annual expense is avoided.

"Impounding" reservoirs serve to remedy irregularities, their size and number depending on the population. In England, 20 gallons per head per day is generally allowed for non-manufacturing, and 30 or more for manufacturing towns, but with reasonable economy less would be needed.

The construction of storage reservoirs involves an examination of the ground for the foundations, and the subsequent erection of an embankment. Springs and porous beds often cause trouble. The slightest leakage, if neglected as at Johnstown, U.S.A., permits the water to gradually wear a passage until suddenly the whole gives way. The Holmfirth reservoir, which burst in 1852, was based on fissured sandstone, through which water leaked till the barrier was undermined; then a flood completed the destruction.

Jerome Park reservoir, New York, for high upland water, will be 299 acres, and will hold 1900 million gallons. The new Staines reservoirs, London, will draw from the Thames above Bell Weir by a conduit partly open and part closed, passing under two rivers and two railways. The pipes will be 6 feet 3 inches, and 8 feet 8 inches diameter, and the reservoirs 1¼ miles long, with a capacity of 3,300 million gallons, for the New River, West Middlesex, and Grand Junction Companies.

The scheme for supplying London with pure upland water from Wales, due to Sir Alexander Binnie, late engineer to the London County Council, proposes to collect the head waters of the Usk, Wye, and Towy in five large reservoirs, from which the water would flow by gravity to London through two aqueducts of masonry and concrete 150 and 175 miles long. Two tunnels would occur in the course, a siphon pipe 13½ miles long under the Severn, and several bridges of iron pipes across the valleys. The service reservoirs would be at Elstree and at Banstead Downs, at a height of 312 feet above sea level, from which the water would flow by gravity to all parts of London. The impounding reservoir near Llanynis would contain 31,000,000,000 gallons; its dam, of masonry, would be 166 feet high. The rocks over which the head waters flow are of Silurian and Old Red Sandstone, and the water is similar in purity to that of Loch Katrine. The rainfall varies from forty-five to seventy-five inches per annum, or about three times that of the Thames valley, and is usually very regular. It is estimated that 415,000,000 gallons could be supplied per day to London, which is sufficient for the probable increase of London in the next fifty years.* But, as previously mentioned, it would be neither necessary nor advisable to take so large a supply, and risk incommoding the local populations.

The winter of 1895 proved that the present distributing mains are not laid deep enough for protection from

* In the London Water Companies' Bills of 1896 it was proposed to take a total of 149 million gallons from the Thames daily.

frost; they have also frequently been injured by heavy loads passing over them. Whilst repairing, a second set of mains could be laid, so as to provide Thames water for common purposes, and the purer mountain water exclusively for drinking. Frankfort-on-the-Maine has already a double water supply, where spring water is supplemented from river and ground sources. Vienna has also successfully carried out a dual plan.

The improvement of water in reservoirs is largely due to the deposition of suspended mineral matter and bacteria, but, in addition, open storage favours the beneficial action of aeration and light. It would seem at first sight desirable that service reservoirs should be open to light and air, as by such means the brown colour of moorland water would be bleached, matters derived from sewage oxidised to ammonia and nitrates, and the bacteria antagonised. This would be the case if the water could be kept free from algæ and infusoria, but unfortunately these are favoured as much by light as the lower organisms are enfeebled. The minute algæ which render the water green (Scenedesmus, Closterium and others related to the Desmids, are specially active), also cause an unpleasant fishy odour and taste, which, though not poisonous, give rise to complaints from the consumers. Many attempts have been made to remedy this evil by fountains, circulation, and scouring, but the algæ grow so rapidly when supplied with fresh water, that it has been found impracticable to suppress them at certain seasons, especially in hot countries. The Massachusetts Board, after lengthened experiments, concluded that while surface waters were generally improved by storing in open reservoirs or tanks, ground or subsoil waters underwent rapid deterioration from algæ unless kept in the dark. They also conclude that "the colour of water exposed to the sun in open reservoirs is reduced by storage; but it must be stored for several months to cause any material reduction of colour, and from six months to a year to remove practically all of it."*

The main distributing reservoir at Vienna is in three sections, lined with smooth Portland cement and covered with a roof supported by granite pillars. Conical glazed openings and ventilators supply light and air to the interior (Fig. 28). The capacity of the third extension is 10,470,000 gallons.

Deep well waters are not improved by storage, but are better delivered as pumped, provided they are clear, which is almost always the case after the well has been worked for some time. It has already been pointed out that pathogenic and other bacteria multiply in them with great rapidity. At their source they do not usually contain more than two or three bacteria per

* G. Bertrand is investigating certain soluble ferments termed "oxydases," which possess the power of bleaching and precipitating the organic colouring matter with absorption of oxygen (*Comptes Rendus*, cxxii. 1215).

cubic centimetre, and these have probably got in mainly by accident. But on exposure for a few hours in any vessel, there will be hundreds of bacteria, and perhaps millions in two or three days, after which time they will diminish by mutual exhaustion and destruction. Surface water on the other hand does not show any such multiplication, this change having taken place to its fullest extent during the previous history of the water.

It may be summed up that the only waters which deteriorate on storage in properly prepared reservoirs are those which are filtered or taken from subterranean sources. When they must be stored, they should be kept in closed reservoirs arched over like those of the Kent Company at Deptford. But surface waters are never injured by *proper* storage; on the contrary, in the great majority of cases they are very materially improved, and the poorer the quality of the water and the greater the amount of organic matter in process of change, the more conspicuous is the benefit of the action of light and air. Even the green algæ and other water plants, as Dr. Bokorny has shown, can use up as a nutriment many of the organic impurities that are drained into waters. And yet the recurrence of the offensive results of these algæ may compel the adoption of covered reservoirs, relying on subsequent filtration for the removal of bacteria, crenothrix (p. 283), and fungi which are encouraged by the dark. The depth of open reservoirs should not be under ten feet, and preferably rather more, as an increase of depth hinders the growth. Covered reservoirs should have about two feet of earth above the roof to keep the water cool in summer, and ventilators should be placed at intervals. A reservoir must of course be covered when close to a town or factories, especially after the water is filtered.

The sides of open reservoirs should be well protected, sodded, and kept free from animals, &c. There are recorded cases of dead bodies having lain for a long time in reservoirs, and intestinal parasites may easily be derived from such carcases.

At Southampton and other places, an ingenious electrical apparatus, worked by a float, signals the depth of water in a distant reservoir to the pumping station.

The average cost (and hardness) of different classes of supply is said to be :—

Surface	4	degrees	total hardness,	4*d.*	per	1,000	gallons.
River	13	,,	,,	9*d.*	,,		,,
Spring	20	,,	,,	1/-	,,		,,

But this of course must vary immensely with circumstances.

Private storage in cisterns will be considered under "Distribution," in the next chapter.

CHAPTER VII.

DISTRIBUTION.

We have seen in the previous chapters how pure water may be recognised, how it can be obtained, and how it is to be stored. Its protection during transit to the consumer is of equal importance. At Mountain Ash, in Glamorganshire, a Local Government Board inquiry into an outbreak of typhoid revealed that the mains had become contaminated from the soil. During the East London inquiry in 1895, it was found that the water from the street hydrants issuing directly from the mains was of the ordinary character of the company's supply, but it was suggested on the analysis of private samples that the supply to houses was much inferior to the water in the company's reservoirs and in the large pipes. Collectors were therefore sent into the small alleys and dwellings, and samples taken from the house taps, after these had been cleaned, to represent the fluid actually drunk by the people. All these samples, when analysed chemically and bacteriologically, proved to have derived impurity from some source in their transit from the mains. The failure of the East London supply during the previous winter had been already attributed to leaks in the pipes, and it was thus demonstrated that not only had water been lost but that dangerous matter from the soil of a populous district had diffused inward through the leaks.

At Eastbourne, in 1895, it was suddenly discovered by a private analysis* that the water supply of a portion of the town had been contaminated by salt water, which had leaked through fissures in the chalk into a well.

It is, therefore, important that a householder, before going to live in a new locality, should become acquainted with the nature and pureness of the water supply, and when the pipes are found to be old, small, or shallowly laid, to either avoid a tenancy or have the defect remedied.

In Roman times pure water was brought from a distance to cities by aqueducts, many of which remain as ruins, while some are still utilised. These were of solid masonry, carrying a conduit lined with cemented bricks or tiles. Across the valleys often three tiers of arches, with a height in many places of more than a hundred feet, were constructed. Some of these structures were completed several centuries before the Christian era. Ancient Rome, with its nine aqueducts, served its people with 300 gallons a day per head, including the supply for the public fountains, baths, circus and amphitheatre, and for sanitary and trade purposes. A special State department administered

* Solids, 113·0; chlorine, 31·75; nitrates, none; nitrites, distinct trace; oxygen consumed, ·040; free ammonia, ·0005; albuminoid, ·0030. A previous analysis had shown more organic matter.

the supply, and, as a result of these efforts, classic Rome was far more healthy than the modern city.

The water of the New River Company was originally brought to London by an aqueduct with several tunnels. The adoption of the built-aqueduct system was probably due to the fact that pipes of sufficient calibre and strength were not available. The ancients were certainly well aware of the fact that water will rise to its own level, and that, consequently, if pipes dip down in a valley, the water will rise to the same height on the other side, but in a clear atmosphere there is great advantage in an open aqueduct, as it can be easily cleaned and guarded, and allows of the beneficial action of light and air.

But in populous countries it is necessary that an aqueduct should be closed, to guard against contamination; hence a line of iron pipes of large diameter supersedes the old open channel. The pipes pass under rivers and canals by an "inverted siphon" (Fig. 29: see *ante*), as mentioned in connection with the proposed London supply from Wales (p. 131). Sometimes it is advisable to cross an obstruction by a closed girder conduit (Fig. 30).* It must be remembered that iron pipes are proportionately weaker as their diameter increases. The inconvenience and loss attending their bursting were exemplified in the rupture of a twenty-four-inch main at Chelsea in September, 1896, and at Hampstead in August, 1901.

* Details of the Bear River irrigation system at Utah are given in the *Engineering News of New York*, Feb. 13th, 1896.

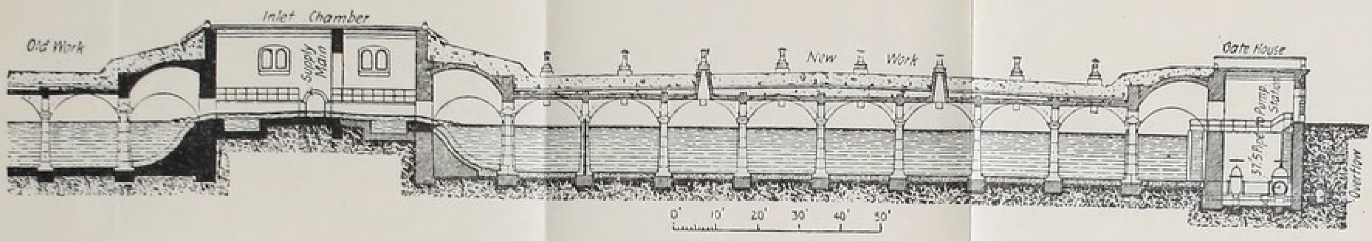

FIG. 28.—Extension of Vienna Reservoir.

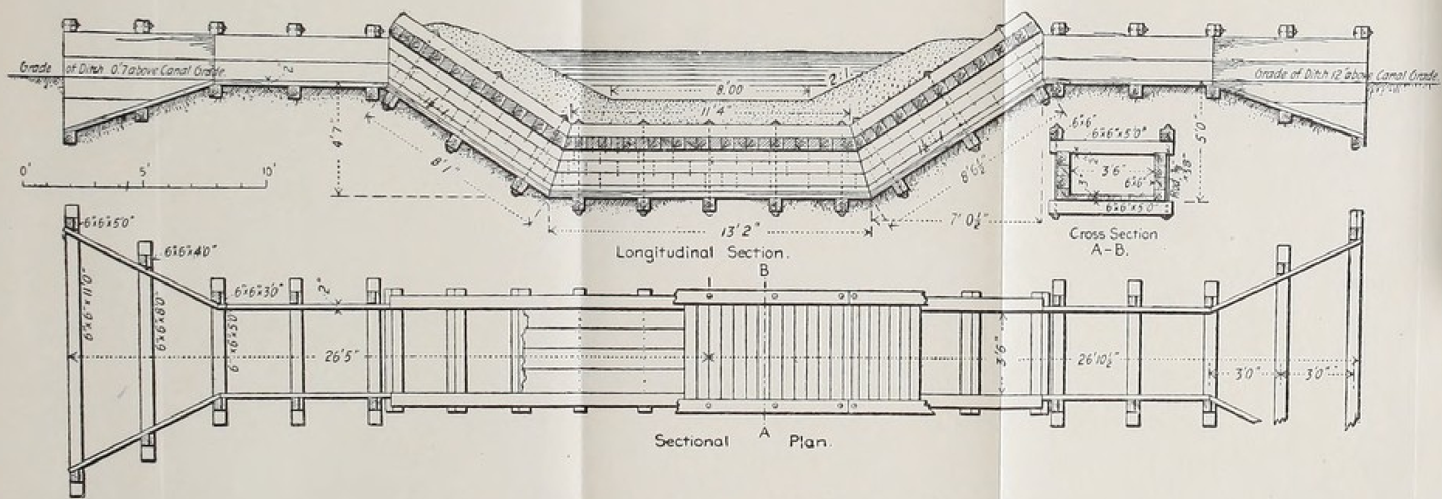

FIG. 29.—Inverted Siphon for passing old canal, Bear River, Utah.

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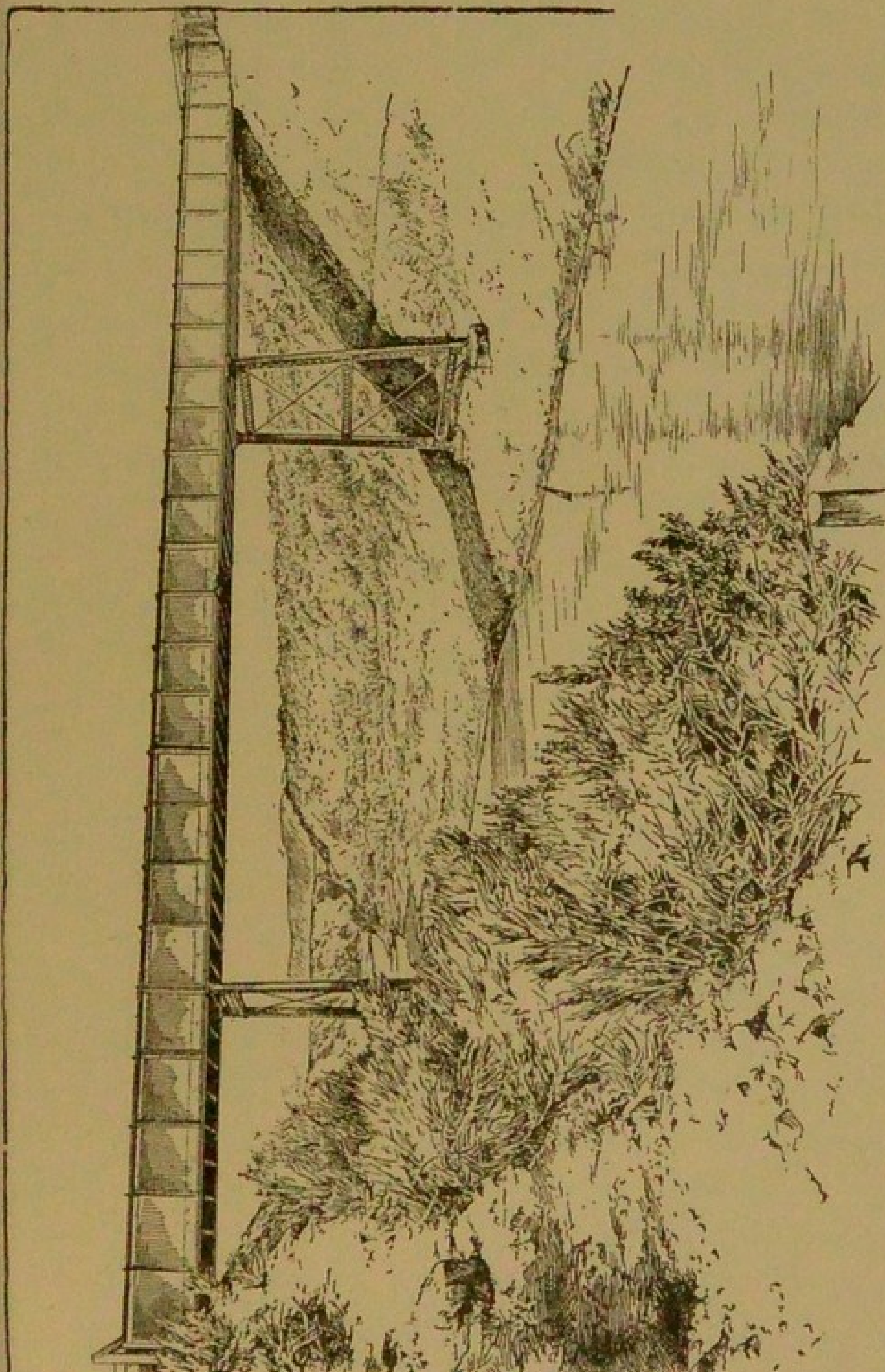

FIG. 80. 130-ft. Plate-girder Flume over Malad River.

One of the latest examples of the modern style of aqueduct is given in the Mourne water scheme for the city of Belfast. It is proposed to furnish an additional supply of 30,000,000 gallons per day by means of an aqueduct thirty-five miles long, comprising seven miles of tunnel (part of it passing under Slieve Donard, the highest of the Mourne range of mountains), with sixteen miles of covered conduit and twelve miles of cast iron siphon pipes, thirty-six inches in diameter. The service reservoir, about five miles from Belfast, will contain 90,000,000 gallons. From it the water will be conveyed under pressure in large mains to the city. The inlet ends of the siphon pipes will be controlled by automatic valves, so that the water is cut off immediately in case of breakage at any point in the siphon.

Some of the earlier water-pipes were constructed of wood.* During excavations at a brewery at St. Helens, in 1895, the workmen discovered a water-pipe line of considerable antiquity; the pipes consisted of trunks of trees about twelve feet long, chamfered at one end so as to fix in the end of the next pipe. A hole of about six inches diameter had been bored or burned through the irregular course of the trunk. The oak was in an excellent state of preservation, having been buried in clay.

Square wooden conduits are used occasionally in

* In the engineer's estimate for the Liverpool waterworks in 1797, the following items occur:—" Elm pipes at 11s. per yard, £1,000; earthen pipes at 3s. per yard, £1,975."

the Colonies; they should be tarred, or, at least, charred inside. There is no great objection to them beyond the liability to leakage and the bad taste they often communicate to the water. Iron pipes are now, however, generally used, the joints being either turned and bored, or run with lead, or with tar and sulphur, to make a strong and watertight joint.

Pipes of too small diameter are frequently laid to save initial expense, but the friction of a fluid in small pipes is so great that the loss of pressure and the extra pumping more than counterbalance the first cost. The passage of 300 gallons per minute through 500 yards of four-inch pipe will absorb, by the friction of the water against the sides of the pipe, a head of 135 feet, whereas if a five-inch pipe be used only 49 feet will be lost.

Iron mains are used in all large towns, as they better support the jar of traffic in the streets. When buried in the earth they can neither be inspected nor repaired without the great expense and inconvenience of opening the ground. All mains for gas, water, electricity, and pneumatic parcel transit might be laid in a common tunnel separated from one another so that there should be no risk of communication, and that every part of their surface be of easy access. Such a system is in practice in many Continental towns where all the supplies are under municipal control. The chief hindrance in England is the want of co-operation between private companies.

Effects of frost.—In an exceptionally severe frost the freezing of water mains has often led to great privations over large areas, as occurred in the London water famine of 1895. It was proved that in most cases the mains and branch pipes were not laid at a sufficient distance below the surface. A depth of not less than three feet six inches to the top of all pipes should be compulsory. It will be obvious to the consumer that in case of any damage to or defects in the pipes he has to pay for water that he does not receive.

Lead pipes of elliptical section have been proposed which when expanded by freezing become circular, thereby increasing the sectional area of the pipe. Such pipes, however, when once made circular do not return to the elliptical shape, so that a second freezing might cause their fracture.

In America and Australia riveted steel pipes are used successfully. San Francisco has a line over 50 miles long, which crosses the bay in deep sea water. But steel mains have been known to split without frost. At Manchester, in 1893, a 26 inch riveted pipe of $\frac{7}{16}$ inch steel ripped through five 10 feet lengths soon after laying. It was said to be of good quality and workmanship, and had been tested. Cast iron is considered safer, and to be less acted on by water, but a good deal depends on the composition of the latter.

The bursting of pipes by frost is commonly attributed to the thaw instead of to the expansion of the water in freezing. That water on solidifying exerts a great pressure was shown by Major Williams in Canada, by filling a very strong iron bombshell completely with water and closing it tightly with an iron plug. On exposure to the frost the iron plug was forced out with a loud explosion and thrown to a distance of 415 feet, while a cylinder of ice eight inches long issued from the opening. In another case a screw plug that would not yield was used; the bombshell burst across the middle, and a sheet of ice spread all round the crack. In the bursting of lead pipes no explosion is heard, as the resistance is not so great, but the widening out of the portions that have not ripped testifies to the pressure exerted. In this way, water jugs, if left filled at night, are sometimes found in the morning split in long interlacing cracks, with a solid mass of ice within. In nature this action is the principal agent in the disintegration of rocks to form soils, and in the loosening and rendering porous the soils themselves by the freezing of the water contained in them.

Notwithstanding the frequent severe climatic changes in England, few precautions are taken against the grave inconveniences occasioned by frost. House pipes are often left unprotected, and so placed that a burst will cause considerable damage. Cisterns are frequently situated outside, and when they freeze solid are the cause of serious annoyance. The pipes should be run not less than four feet below the surface, right into the house, and should pass within about three feet of the kitchen grate before branching to other parts of the establishment. It is well known that water in agitation is less liable to freeze, as the crystals of ice have not time to consolidate: therefore a common precaution to prevent pipes freezing is to leave taps dripping. Outside pipes may be protected with a casing of rough wood three-quarters of an inch thick and seven inches square, extending three feet into the ground, and filled with sawdust.

In view of the explosions that have been caused by frost in domestic boilers, a circular of the Board of Trade, dated January, 1896, advises:—

1. That all cisterns from which boilers are supplied, and particularly the pipes communicating therewith, should be placed in positions where they are not likely to be affected by frost.

2. That a safety valve should be fixed on every boiler that has not a movable lid.

3. That should the water supply be interrupted from any cause the fire should be at once withdrawn until the boiler is cold and the water supply has been restored. It is very dangerous to put water into an empty boiler while hot.

Glass-lined pipes are also now manufactured, and avoid the chance of zinc poisoning which has sometimes been noticed when galvanised pipes are employed. Tin is sometimes used as a coating for both iron and lead pipes, an objection being that, owing to galvanic action, the corrosion is sometimes more pronounced than when the pipe is left unprotected. So-called linings of pure tin have been found on analysis to consist of an alloy of equal parts tin and lead. Schwartz protects lead pipes internally with a film of lead sulphide formed by washing them with a solution of "liver of sulphur," but the coating is liable to blister, and is acted upon by soft water in presence of air. Iron pipes treated by the Bower-Barff process, or by the modification of Bertrand, have been highly recommended. The pipes or other iron articles are raised to a bright redness in a chamber into which superheated steam is passed. A hard black layer of magnetic oxide of iron is thus formed, which, as long as it remains intact, completely protects the iron from rust.

Waters with little lime but high chlorides act rapidly on iron, acquire a ferruginous taste, and coat decanters, &c., with red oxide of iron. Angus Smith's composition, a varnish of pitch and coal-tar oil, has been long beneficially used for the inside of mains. At Newcastle, it has been recently shown that, while reducing the corrosion, it diminishes the adherence of the rust, and prevents the formation of hard nodules.

Mechanical scrapers are used in many places to remove incrustations, but some of the forms are liable to weaken the pipes. Filtered water has generally less corrosive action than unfiltered. Some instances of the destructive action of carbonic acid have been noted in Germany. Near Beuthen, Silesia, 1¼ mile of cast-iron pipe from a pumping station began to leak after two years, when the upper third was found to be deeply pitted and punctured, the rest being unaffected. At Johann on the Saar, a very soft and pure water became badly discoloured and unfit for use: on examination the water proved to be saturated with carbonic acid, besides much bicarbonate. Foul water in soils is also very injurious to the outside of pipes. Sulphuretted hydrogen, chlorides, nitrates, nitrites and ammonia all have their special corrosive effects. Prof. Weber has found that cast iron under salt water, in about fifty years is converted for one-third of its thickness into a grey graphitoid mass. Pipes traversing infiltrated ground can be protected by a coating of clay, which seems entirely effective, or by pitch or asphalt. Slags and cinders often liberate alkali, which attacks lead. Slag-wool used for packing has been known to corrode wrought-iron pipes.

Iron pipes sometimes become clogged with animal growths. The bryozoa, or freshwater polyps, often grow in this way, and can only be removed by steaming and flushing the pipes. The *Spongilla* and *Synura* have at times led to partial stoppages in the supply, and the former on decaying gives off an unpleasant smell and makes the water unpalatable.

Vegetable growths also cause clogging and contamination (p. 285). Green algæ, cannot, of course, grow in the dark, but are met with in cisterns which are not kept covered. The presence of these organisms in the service pipes indicates imperfect filtration or faulty storage, as their spores should not have been allowed to gain access.

Lead is known to have a cumulative poisonous action, so that even a minute quantity taken day by day accumulates in the system and remains in the organs of the body until serious illness, if not fatal consequences, ensues. One of the most characteristic symptoms of "plumbism" or *lead colic* is a blue line around the gums. Communities have suffered from plumbism for many years before the cause was traced, so that it is now universally admitted that contamination by lead should never be tolerated in water used for drinking purposes.

Very few natural sources are thus tainted. In mining districts the metal is often found in issuing brooks, but is generally entirely precipitated by the sulphates, &c., in the water before it reaches the main stream. In a case which occurred near Hathersage, in Derbyshire, several effluents from lead mines were turbid with lead salts, and contained much of the metal in solution, but in samples of the river Derwent, at a point a quarter of a mile below the outlets of three of them, no lead could be detected in the examination of several gallons. It follows that when lead is detected in water it is usually to be attributed to the material of the pipes or cisterns with which the water has been in contact.

The capacity of waters for dissolving lead varies considerably. As a rule, the softer the water the greater the danger of that kind. In Dublin the soft moorland water of the Vartry was found to attack lead so easily that tin-lined pipes were laid down when the new supply was inaugurated. The equally soft water of Loch Katrine, on the other hand, has little or no action upon this metal. At Sheffield much trouble was caused by some public supplies which were peaty and acid, and rapidly attacked lead, zinc and iron; it was overcome by adding ½ to 3 grns. per gallon of powdered chalk. Treatment with silica, by passing over broken flints and limestone, was found ineffectual. Carbonate of soda, as in the process for softening water, has often been found beneficial.

According to a Local Government Board report (1895), the action is caused by organic acids generated by special organisms which exist in most peaty soils. At Keighley, in Yorkshire, three coke filters, to remove the coarser impurities, and four sandstone and limestone filters have been erected to remedy this evil. It is believed that the limestone will neutralise the organic acids, and so cure the water of its plumbo-solvent properties. At Rishworth Moor, near Halifax, lime is thrown into the reservoirs. Some waters act so rapidly that standing one night in the service pipe is sufficient to determine the presence of lead in poisonous quantities, therefore the first water drawn should always be allowed to escape. During an outbreak of plumbism at Pudsey, Yorks, half a grain of lead per gallon was found in the water supplied in the morning. In other cases, where the direct effects of lead poisoning have not been diagnosed, chronic illness has been noticed to disappear on the substitution of iron piping for lead. Mr. Ackroyd, public analyst for Halifax, states (January, 1899), that the "Fly Flats" water, now disused for domestic purposes, contains about 5 units of acidity, and would dissolve 2 grains of lead piping in an hour. He recommended two or more catch-water drains instead of one, to diminish the length of peat through which the water flowed. The Leeds water, though coming from moorlands, is only slightly plumbo-solvent.

Contamination with sewage, involving the presence of nitrites and chlorides, increases the solvent action of water, as do also a high temperature and pressure and the presence of air.

Sir E. Frankland remarks, in cases where the use of a lead-contaminated water is unavoidable:

1. That no water should be collected for drinking till the tap has been allowed to run some time, and that drinking and cooking water is better collected immediately after a considerable quantity has been drawn for other domestic purposes.

2. That filtration through animal charcoal practi-

cally guarantees freedom from lead. It is important, however, to bear in mind that the charcoal does not retain this power indefinitely, but requires to be renewed from time to time.

3. That hot water acts more powerfully than cold, hence that metal teapots and other soldered vessels should be avoided as far as possible.

New and bright lead is at first rather rapidly attacked by nearly all waters, but after a time the white coating of insoluble lead sulphate and carbonate to a great extent protects the surface from further action. When a lead cistern is cleaned out this coating should be allowed to remain, and cleaning with acids should never be practised, as such procedure has occasionally been attended with dangerous consequences. In all cases in which suspicion is aroused it is advisable that a full analysis of the water be conducted in order to ascertain what method for treatment should be adopted.

Zinc is easily attacked by most waters, and cisterns of galvanised iron have caused symptoms of irritant poisoning. The best material for cisterns is slate. Portland cement is also good, if not too bulky and heavy. It need hardly be said that with new cisterns and pipes the water is usually for some time unfit for drinking. Tanks of cast-iron plates, bolted together and well painted, are durable and inexpensive, but the water should be examined for lead, as sometimes it dissolves the latter from the paint.

Cisterns should be protected from frost, dust, and dirt, and be easily accessible for cleaning.

Constant Service.—Most towns have now a constant service, but in many parts of the metropolis an intermittent supply still obtains. Under a constant system, the pipes being always full and under pressure, a leakage is sooner detected; therefore pollution by drainage is less likely, the pipes are less subject to corrosion, and have therefore a longer life, and the mains need not be so capacious. An intermittent supply makes the consumer depend on a house cistern, and thus increases the danger of contamination, unless the precautions already alluded to and due attention to cleaning be observed. The penetration of sewer gas into cisterns has been shown by Parry Laws not to carry with it microbes, but it nevertheless renders the water offensive and unwholesome by the sulphuretted hydrogen and ammonia compounds which it communicates. Dr. Talbot, of Bow, has patented a self-cleansing storage cistern to be used with a constant service. It is of funnel shape, and is protected by a lid.

The Paddington Vestry, in 1897, took action as to uncovered water cisterns not being in accord with the Public Health (London) Act of 1891.

One of the advantages that has been claimed for cisterns (Sussex County Council, January, 1900), is that, where the supply is not copious, they protect the consumer against the effect of sudden and large demands, as for street watering, a fire, or flushing of sewers, which sometimes so reduce the pressure in the mains as to wholly cut off the supply from houses at higher levels.

In February, 1901, the London Water Companies issued a circular enforcing the provision of cisterns and ball-cocks, but it was subsequently withdrawn. In Berlin and other Continental towns, the whole supply is charged for by meter.

Until recently the storage and distribution of the water supply of towns have been entirely in the hands of private companies, but the example of Glasgow, Liverpool, and other cities in purchasing these undertakings and placing them under municipal management, is being followed by other towns. A great deal of discussion has taken place in London on this point, and although vested interests are opposed to any change in this direction, it cannot be long before a matter of such importance to the public safety as the water supply of the metropolis will be under the control of a responsible and elected body.

Huddersfield, Yorkshire, is an example of a town where every large local service is under municipal control, and with conspicuous success. The capital expenditure on the waterworks, over £100,000, has produced an annual net profit of about £5,000. The storage capacity of their reservoirs is no less than 1,500,000,000 gallons. They are formed by embankments at the end of valleys. Compensation water can be released from the reservoirs into the rivers (p. 73). The supply is chiefly moorland, from the millstone grit. It has been subject to the lead difficulty, but chalk has been used as a preventative, as at Sheffield. The water supply is forty-nine gallons per house daily. A local Water Act was passed in 1896 without restrictions, notwithstanding that clauses as to filtration or treating had been inserted in the Barnsley and Sheffield Water Bills of the same year.

At present, as pointed out in the report of the Select Committee of the House of Commons on the London Water Companies' Bills of 1896, there is in London no general legal control over the periods for pumping nor the proper carrying out of subsidence or filtration. The Committee considered that "the present system of the London Water Companies is not in accordance with the public interests."

In many respects, the United States are ahead of us in the care and management of water supplies. As an example, the regulations passed by the City Council of Wilkesbarre, Pennsylvania, may be of interest:—

"Section 1. Any person, companies, or corporations wilfully or negligently furnishing to the people of this city water for domestic purposes in a state of impurity, or impregnated with the germs of disease, or any other matters dangerous to health, upon conviction thereof shall be required to pay for the first offence a penalty of not more than $100, and for every subsequent offence a penalty of not more than $200.

"Section 2. It shall be the duty of all persons, companies, or corporations furnishing to the people of this city water for domestic purposes, through pipes located in the public streets, to adopt, use, and maintain in the most efficient condition, and without unnecessary interruption, for the purification of the said water, some system of filtration now employed in the cities of the United States or Europe, which experience has shown to be the most effective in freeing water from impurities, deleterious organic matters, and germs of disease, and rendering the same clean and wholesome.

"Provided, however, that the adoption of the system of filtration through sand beds, such as are used in London and Berlin, shall not be deemed a compliance with this ordinance, unless the said sand beds are at least five feet deep, and in working the same not more than forty gallons of water per square foot of area are allowed to pass through said sand beds per twenty-four hours.

"Section 3. It shall be the duty of such persons, companies, or corporations to adopt and use, without unnecessary interruption, and in the most efficient manner, such measures as may be necessary to prevent contamination of the water at its source, and at all places where it shall flow or be collected before reaching the places where it is filtered, in obedience to the requirements of the second section of this ordinance.

"Section 4. Any persons violating sections 2 or 3 pay a penalty of $100 for every day such violation is continued.

"Section 5. For the purpose of aiding the enforcement of this ordinance the office of water inspector is hereby created; the incumbent thereof shall be an expert chemist and bacteriologist, to be appointed and his compensation fixed annually by an ordinance of the City Council; and it shall be the duty of the water inspector to make bi-weekly chemical and bacteriological analyses of the water supplied, and immediately report the results of the same to the Sanitary Committee and to all persons, companies, and corporations furnishing the said water, and also from time to time inspect the system or systems of filtration adopted in obedience to this ordinance, and whenever the same are not kept and operated as herein specified, make report thereof to the parties aforesaid."

CHAPTER VIII.

PURIFICATION ON A LARGE SCALE.

NOTWITHSTANDING the fact that the necessity and, in most cases, the perfect possibility of obtaining a pure water supply has been insisted upon by hygienists for a great number of years, it is still a common practice to attempt the purification of polluted waters by cumbrous and expensive systems of filter-beds and reservoirs. Such systems, however, as was shown at Altona in 1892-3, are liable to accidental breakdowns, which then not only cause widespread inconvenience, but in many cases serious outbreaks of disease. Although such systems are wrong in theory and commercially wasteful, after they have once been started, the value of the plant and vested interests usually provoke such determined opposition to any natural scheme, that large populations are still persuaded to endure as their drinking water what has been described as "diluted and purified sewage." As compared with an artificial conduit for bringing water from an unpolluted collecting ground, a river is at once condemned on account of the certainty that it is open to drainage of all kinds, and that the so-called self-purification of a river in flow is of doubtful efficacy, and is in most cases overbalanced by the constant accession of impurities with which its action is not rapid enough to cope.

Since, in districts distant from a supply, the rivers of the district may be the only source at present available, it is necessary to shortly describe the processes by which water originally unfit to drink can be altered to a state which is ordinarily harmless to the consumer.

Many vegetable juices containing tannin are capable of coagulating the organic matter in very bad waters and rendering them comparatively potable. This property of barks and woods containing tannin was known in very early times, and is referred to in Exod. xv. 23, in which passage the word "bitter" probably means disagreeable. The Indians in South America are similarly in the habit of purifying foul ponds by logs of the Peruvian bark (*cinchona*), and in this case the tannins act as a precipitant and the quinine as a febrifuge. The latter has been recommended to be added to marshy waters in Italy and in other places. *Strychnos potatorum* has also been used in India for the same purpose.

The common process of *subsidence* effected in settling tanks and reservoirs accomplishes the almost complete removal of suspended solid mineral matters, and with them a large proportion of the living organisms. Thus, Dr. Percy Frankland, in an examination of the intake waters of the West Middlesex Company, found 1,437 bacteria per cubic centimetre, whilst after passing through one storage reservoir the number was reduced to 318, and after traversing a second reservoir there remained only 177 per cubic centimetre. During the process of settling, oxidation of the dissolved organic matter also takes place; but, unfortunately, the deposited bacteria are not killed, and continuing to multiply in the muddy sediment, unless this is removed at frequent intervals, necessitate periodic stoppages for cleansing, and additional reservoirs for the maintenance of the service.

Purification by *mechanical precipitation* is sometimes adopted, and consists in the addition of a finely divided solid, such as clay, chalk, charcoal, coke, spongy iron, or porcelain earth, which in its subsidence is capable of carrying down with it all solid matters, including the germs, so as to leave the water clear and almost sterile. Many of these precipitants, however, convey to the treated water an unpleasant earthy taste, and the same objection as to the settling process remains, that the deposit becomes a nidus for the further development of the microbes, which may rise and render the water at any time unfit for use. When waters have a marked colour, alum, in the proportion of about five grains per gallon, generally with the subsequent addition of an equal weight of lime, effects clarification and decoloration, the flocculent precipitate of alumina, by its well-known mordant action, absorbing the colouring matter and also entangling all the solid matters in suspension.

The mixing of the precipitant should be effected without splashing, in order to avoid the gelatinous alumina entangling air, which would retard the rate of settling. After alum precipitation, the sulphates of potash or ammonia, and those of the lime and magnesia formed, remain in the water, so that after such treatment these may be present in such quantities as to render the water undesirable for potable purposes or for use in boilers. Sulphate of alumina, free from excess of acid and iron, is better and cheaper than ordinary alum, and seven-tenths of the quantity need only be used. "Alumino-ferric" may even sometimes be employed, and ferric sulphate ("persulphate of iron"), which has lately been highly recommended, is of especial value for purifying foul river waters, as it throws down sulphides as well as the matters removed by alum. Ferric chloride (perchloride of iron) was formerly much used: it leaves in solution chlorides instead of sulphates, and has been objected to because it commonly contains arsenic. In any case, when such precipitants are employed, it is necessary to carefully determine from time to time by analysis the requisite quantity to employ, as excess may be most prejudicial.

Several chemical reagents have been proposed and used in the hope of killing the bacteria, or at least destroying their food. Manganate and permanganate of potassium or Condy's green and red fluids, when added to a very foul water until a permanent colour remains for at least fifteen minutes, are capable of oxidising the impurities but do not kill the bacteria. When these salts are used a brown precipitate of manganese peroxide is formed, and it must be removed by filtration or settling before the water is fit to drink. In fact, all methods of precipitation require that the water should be subsequently filtered; and the expense of this operation, coupled with that of the chemicals, has caused most of the precipitation processes to be abandoned, except in local and temporary cases.

The various methods used for the softening of hard waters effect a purification of the water from organic matter and organisms at the same time, and the results obtained in this way will be further alluded to in Chapter X. Agitation with air causes a certain amount of improvement, but only a slight effect is noticeable in rivers which flow over weirs or which have waterfalls in their courses. The purifying properties of light have long been recognised, and even as early as 1640, Dr. Hart cautioned his readers against the use of well-water "to which the sun hath no reflection." Westbrook has recently, at Marburg, carefully studied the influence of sunlight upon cholera cultures in water, and has demonstrated that—

1. The heat of the sun as well as the light has an important influence upon organisms in water.

2. *Insolation* in presence of a full supply of atmospheric oxygen effectually and speedily kills germs.

3. Sunlight in the absence of air has no germicidal properties.

4. Solar heat of average intensity, when air is excluded, causes the organisms to multiply at a greater rate.

Other observers have found that at a depth of six or eight feet the destructive property of sunlight ceases. It follows that all reservoirs for *surface waters* should be shallow, uncovered, and freely exposed to the air (except in the immediate neighbourhood of towns or factories, where, however, for other reasons, such reservoirs should not be placed). Deep well and spring waters, on the other hand, should, if stored at all, be kept in covered receptacles, as algæ are thereby prevented from growing (see p. 133).

The immunity obtained by boiling water before drinking is now almost universally recognised, and if regularity of such procedure could be relied on, it would perhaps be the most satisfactory method for ensuring safety.

In an outbreak of cholera in the East Lancashire Regiment at Lucknow, the "E" Company, though living under the same conditions as the rest, entirely escaped.

Mr. Hankin (*Cholera in Indian Cantonments*) says:—"On questioning the colour-sergeant of this company, the mystery at first appeared to deepen, for he roundly asserted that the men under his charge had exactly the same supplies of food and water as the rest of the regiment. But on his being pressed as to how he knew that the water supply was the same, he replied that he ought to know, if anybody, 'as he boiled it himself!' Needless to say, that on making inquiries it was found this simple sanitary precaution had not been taken by the other colour-sergeants."

Sterilisation by heat was first practically applied about 1888 by the late Charles Herscher, while other apparatus, such as the Vaillard-Desmaroux, and in the United States the Waterhouse-Forbes, have since been introduced. Smaller "sterilisers," based on the fact that prolonged heating to 100° C. destroys almost all the germs, are widely used in laboratories. Boiled water, however, is flat and insipid, and the process on a large scale is precluded by the expense. A shorter exposure to a higher temperature under pressure effects complete sterilisation, while the gases dissolved in the water are not lost. If the sterilised water is made to heat the incoming fluid, considerable economy in fuel is effected, so that the water discharged from the apparatus has practically the temperature of that which enters, and in this way the heat required to be maintained is only that which theoretically should be attributed to losses by radiation. Amongst the many different forms of sterilisers, that entitled the Equifex, manufactured under the Geneste-Herscher patent, is perhaps the best known. It consists of four distinct parts: A heater, which is fired in any suitable way, and maintains the boiler at a temperature of between 120° and 130° C. The heater is fitted with a pressure valve, so that the water therein never boils while it remains within the heater for the time necessary to effect sterilisation.

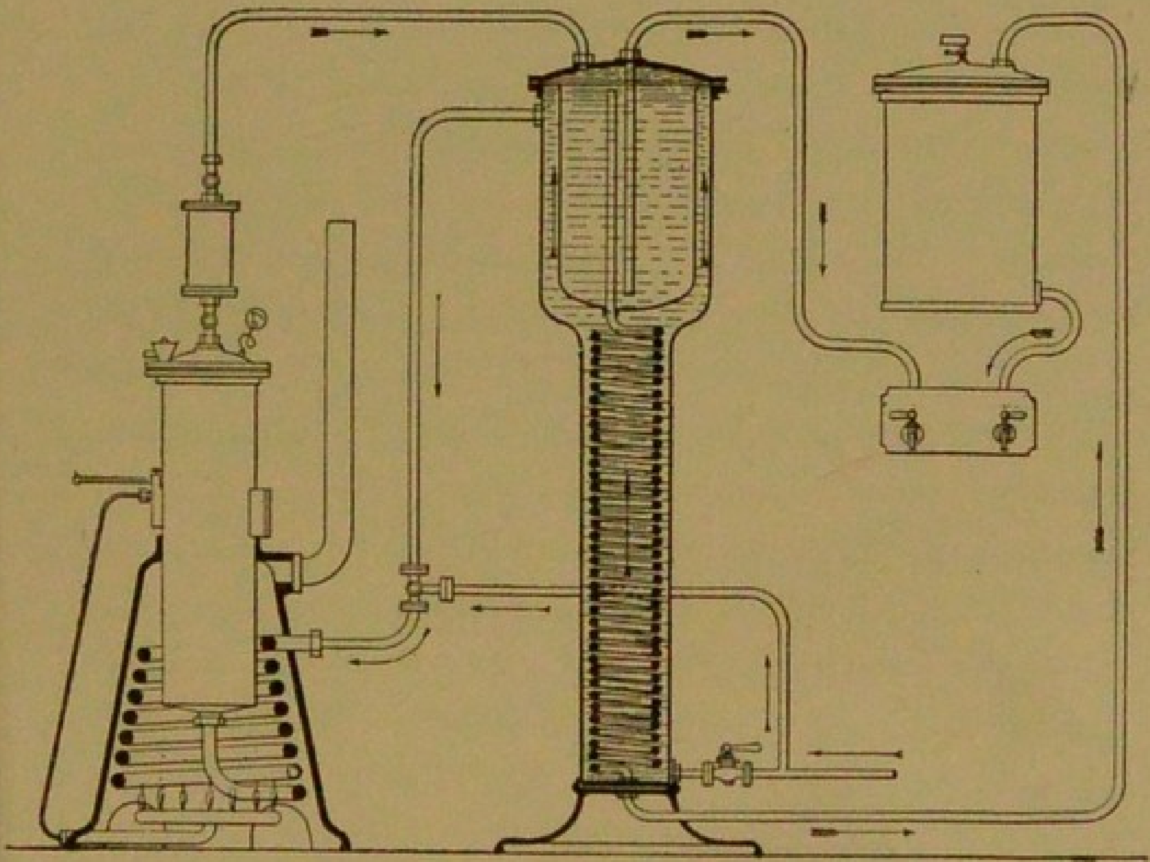

FIG. 31.—Equifex Water Heat-steriliser.

In connection with the heater is a serpentine tube, through which the sterilised water passes and gives up its heat to the unsterilised water entering the boiler. The sterilised water finally passes through a sand-filter, which removes any suspended matter. Such apparatus have been erected in hospitals and infirmaries, and have been used by the French fleet at Brest, and by the town of Parthenay, in France. Kühn, who has devised a similar apparatus, states that, with a steriliser of ten cubic metres capacity, 22,000 gallons of water per day, or double that quantity if worked at night, can be produced, so that a battery of these sterilisers could easily deal with the water supply of a town. Although on a small scale, the cost of heating is high, it is obvious if the regenerative principle be successfully applied, the fuel required is very small, as the only essential of a perfect apparatus is, that each unit of water shall be subjected to a high temperature for a short time, without permanently removing any of the heat required to produce that temperature.

It is important to note that cold or freezing does not render a water safe for drinking purposes. Infectious diseases have been traced to the consumption of ice-creams made from unfiltered and contaminated water. At King's Lynn, in 1892, during a frost, there was a considerable storage of the discharges of typhoid patients on land sloping to a river bank. On the snow melting, thirty-nine houses, drawing their supply from the river, were infected with typhoid fever.

Dr. Christmas, in 1892, showed that citric acid, in the proportion of eight in 10,000, was fatal to the cholera bacillus, but did not destroy that of typhoid in a less strength than one in 1,000. He proposed that in times of cholera, house-supplies should be sterilised by adding about 60 grns. per gallon of this acid to the water daily.

Anderson's process consists in subjecting the water during its passage through revolving drums to the action of a continuous shower of metallic iron. The water afterwards passes over cascades to remove dissolved iron by oxidation, is then allowed to settle in tanks, and is finally filtered through sand. The process is in use at Antwerp, Worcester, and other places, and seems to give both better chemical and bacterial results than those obtained by sand filters alone. The water of the Delaware at Philadelphia, and of the Mississippi at Memphis, have also been treated with iron; and Leffmann and Beam, who examined the process in 1890, showed that in both rivers the amount of organic matter underwent a considerable diminution, and that the action was one of oxidation. Mr. Anderson himself maintains that the effect of his machine is almost entirely a mechanical one, due to the absorbent properties of the flocculent oxide of iron. No iron remains in the finally purified water, and the temporary hardness is reduced.

The process is particularly successful with the water of the Nile, which is completely clarified by mere decantation in a very short time after shaking up with iron, while otherwise it remains turbid for weeks and opalescent for months. The most difficult waters to deal with are those derived from peaty grounds, as it is not easy afterwards to completely remove the iron. Here alum precipitation would seem to be preferable. In the case of the Delaware I am informed that "the difficulty of causing the complete reprecipitation of the iron was very great, and the oxide formed separated in such a fine state of division that it very rapidly clogged up the filter bed."

Schumberg's bromine process for purifying water (Pfuhl, *Zeits. f. Hygiene*, 1900, 53) is specially advocated for army purposes, for sterilising water in the tropics, for use on ship-board, and in the case of water supplies of suspected or infected harbours. It consists in adding 0·06 gram of free bromine, dissolved in potassium bromide solution, for every litre of water. The excess of bromine is removed by adding an equivalent quantity of ammonia, or other "antibrom," so as to render the water palatable. Pfuhl states that the small quantity of bromide present is entirely devoid of the possibility of injury to health, and that the taste can scarcely be distinguished from that of the water before treatment.

In July, 1897 Braithwaite suggested the use of a mixture of bromide and bromate, followed by a tabloid of acid sulphate of soda or potash to liberate the bromine. May, Baker and Co. sell a similar mixture under the name of "bromidine." The quantity of bromine recommended was that obtained from two grains of bromide, or about one grain per quart, which gives only about one part in 17,500 of water.

This quantity is much smaller than the authorities recommend for sterilisation. About one part in 2,000 seems to be a safe quantity to use, or nine times the amount suggested above ; and this would render the quantity of bromide finally formed and remaining in the water rather too high for dietetic use.

The author, in conjunction with Dr. L. Parkes,* has suggested a method of preventing the danger of enteric fever, when, as in the case of armies in the field, the only drinking water available may be polluted, and boiling or proper filtration is not possible. A tin of tabloids is carried, each one containing five grains of bisulphate of soda, $NaHSO_4$. Three of the tabloids are dissolved in each pint of water and allowed to remain at least fifteen minutes before drinking; this is found to be fatal to the typhoid bacillus in the quantities met with. The water so treated has a pleasant acidulous taste, is more effective in slaking thirst, and has no injurious physiological effect. A tin of 350 tabloids weighs about 4 oz.

Iodine, chloride of lime, and other reagents have been proposed, and B. Krohnke, in 1893, suggested cuprous chloride, Cu_2Cl_2, especially for the Elbe at Hamburg. One two-hundred-thousandth part—about a third of a grain per gallon—together with protosulphate of iron, were mixed with the water. At the end of six hours one-hundred-thousandth part of lime

* Epidemiological Soc. of London, January, 1901.

was added, and after deposition the liquid was filtered through sand. The water, which originally contained forty to fifty thousand germs per cubic centimetre, was thus completely sterilised, and was clear, almost colourless, and free from iron and copper. The sand filter could be used a long time without cleaning, and the copper was recoverable from the sediment. Such results would be of great importance were it not for the fact that, in working, any deviation, either by accident or carelessness, from the prescribed quantities, would lead to the water becoming poisonous. Besides, it is well known that as nothing is absolutely insoluble, precipitation never removes the last traces. It may, therefore, be laid down that no poisonous chemical reagent should be used in the purification of water for drinking. To trade purposes the same objection does not always apply.

Complete oxidation would seem to be the natural process for the destruction of organic matter, both living and dead; under the usual circumstances, however, atmospheric or ordinary oxygen will not act on most varieties of organic matter without the help of microbes. Ozone, the specially active modification of oxygen, produced by electricity or by slow oxidation, such as that of phosphorus or essential oils in air, can, on the other hand, attack, bleach, and entirely oxidise organic matter. Even such resistant substances as indiarubber are corroded and destroyed by ozone. Baron Tindal about 1896 proposed to the municipality of Paris to sterilise, by means of ozone, 5,000 cubic metres (1,100,000 gallons) of crude Seine water daily. His system was installed experimentally at Paris, Brussels, and Ostend, and in 1898, was adopted officially for limited supplies in France and Belgium, and since then on a complete scale for the cities of Lille and Moscow.* To save the ozone, much of the impurity is first removed by filtration. The cost is given as about ½d. per 1,000 gallons. One of the most energetic of sterilisers is *peroxide of chlorine*, Cl_2O_4 (Howatson, Neuilly, Paris), employed at Ostend, Brussels, and Lectoure (France). It is prepared from sulphuric acid and chlorate of potash, the gas being passed into water.

Bacteria introduced into waters protected from further admixture almost invariably thrive up to a certain point, and then undergo diminution in numbers, and finally may entirely disappear. Pol and Dumont found that water placed in a vessel simply closed by a plug of cotton wool, and containing on December 24th, 1894, 150,000 microbes per cubic centimetre on December 31st had only 12,000, and on January 16th, 7,000, losses of 94 and 95·3 per cent. respectively.

There are three ways in which the bacteria are reduced:—

1. They may actually feed on one another. Many common and vigorous, but harmless, forms rapidly exterminate the bacteria of disease, such as that of typhoid.

* Marmier and Abraham's process.

2. They may exhaust their food supply and suffer starvation. This occurs when single isolated organisms undergo rapid multiplication.

3. They may evolve products, excreta of their life, which are actually poisonous to themselves. Some of these toxines and "ptomaines" have been isolated, and have proved to be also active poisons to higher forms of life.

As will be further explained in the section on bacteriology (p. 289), several micro-organisms are distinguished by the property of liquefying the gelatine in the "culture tubes" in which they are grown, after which they break it down into simpler compounds in the ordinary course. The changes which take place in water usually follow four distinct stages under "aerobic" conditions—that is, in the presence of air, and by the influence of common water bacteria :—

1. The destruction of pathogenic organisms by non-pathogenic forms.

2. The "hydrolysis" or splitting up of the complex solids by combination with water, yielding simpler compounds in solution.

3. The conversion of these soluble organic substances into still more unstable compounds, and eventually their complete resolution by water and oxygen into carbonic acid and ammonia. This part of the process is analogous to the chemist's procedure in distilling a water with alkaline permanganate in the "albuminoid

ammonia" method of water analysis (p. 270). The "free" ammonia of the chemist represents mainly what the bacteria have previously done; the "albuminoid" the bacterial work in progress. Therefore this method of analysis, although it does not give all the nitrogen, gives a valuable indication of the degree to which a water has been polluted and of the stage at which its natural purification has arrived.

4. The oxidation of ammonia by two classes of "nitrifying organisms" (p. 114) into nitrous and nitric acids. The presence of peaty or humous matters, and of organic matters fermented as above, and of dissolved oxygen, is necessary for this final transformation. Under certain conditions, particularly the absence of oxygen, certain "denitrifying" organisms effect a retrograde change of nitrates into nitrites; and even to lower oxides of nitrogen and nitrogen itself. This action also effects an oxidation of carbon, and must frequently take place in polluted waters, as shown by the loss of nitrogen (pp. 269, 271). W. Adeney uses the name "bacteriolysis" for the second and third of these processes, as distinguished from the nitrification of the last stage.

Mr. Scott Moncrieff has introduced a method for the systematic cultivation of bacteria in tanks, with the object of purifying sewage before its discharge into streams. By this means the solid organic matters are liquefied by the bacteria, so that the formation of "sludge" is avoided, and the organic matter in solution is finally acted upon by the nitrifying organisms. Mr. Cameron, the city surveyor of Exeter, has obtained similar satisfactory results with sewage by the well-known "septic tank process."

All river waters contain a considerable amount of suspended matter, in which the microscopical examination has frequently revealed distinct evidence of animal pollution, besides the presence of large numbers of the smaller algæ, and of earthy matter and vegetable *débris*. A water which is thus a miscellaneous drainage will carry with it any pollution from surviving germs that may occur at any point of the watersheds, and is a likely bearer of any accidental contagion to the localities supplied. Epidemics from such a cause have repeatedly been recorded, when typhoid has been conveyed perhaps from a single cottage by means of a small brook to a large population. The soakage of farm manure is also capable of carrying internal parasites, besides what may be communicated by animals drinking and wading in the brooks on the higher lands. The unguarded supply of a water of this character would therefore be an open danger. It has been established by reports of Royal Commissions and by other investigations that efficient sand filtration is capable of removing these dangerous impurities, and no miscellaneous water supply from ground wholly or partially inhabited or cultivated should be permitted without this precaution. It is not necessary to prove the absolute presence of a pathogenic organism in the water, but only to point out that where such large organisms as are found in these waters can pass, the smaller bacteria of disease could easily travel. Even the algæ and mineral and vegetal *débris* cannot be considered wholesome, as they promote undesirable changes in the water.

That filtered water is comparatively safe, and that unfiltered is certain at some time or another to carry disease, has been proved by the history of a large number of epidemics, from the early outbreak at Terling in Essex, to the more recent experiences at Hamburg. Speaking of the latter city, Dr. Reincke says "that the present favourable and heretofore unattainable status of typhoid fever is to be largely credited to the filtered water supply." It is significant that Rotterdam, with sand-filtered water from the River Maas, has a death-rate from typhoid of only 5·7 per 100,000; Dresden, Berlin, and Copenhagen, all with filtered water originally of more or less indifferent character, have typhoid death-rates of 6·2, 7·1, and 9·0 respectively, whereas Sydney, N.S.W., with impounded unfiltered river water, has 22, and even Glasgow, with the very pure upland water of Loch Katrine, *unfiltered*, has a typhoid rate of 23 per 100,000.

Sand filtration has undergone a great change within recent years, owing to the fact that whereas it was formerly considered that a filter-bed, in order to be active, should be new and frequently changed, it is now known that clean and sterilised sand, beyond straining out suspended matter, exerts no purifying action on the water. It has also been repeatedly demonstrated that atmospheric oxygen will not act on organic matter without microbes. This was incidentally a complete settlement of the disputed question between the schools of Drs. Tidy and Frankland with reference to the natural oxidation of rivers during flow. The final result depends on the nature and number of the microbes as well as upon the aeration.

The first *sand filter* in London was constructed for the Chelsea Company by Simpson about 1829, but the system of sand filtration had been adopted by some provincial waterworks prior to this date. It is now estimated by Hazen that the number of people in Europe supplied with sand-filtered water is over twenty millions.

On the surface of a sand filter-bed a kind of slime, composed of finely-divided clay, together with a felted mass of bacteria, algæ, and diatoms, entangled in a gelatinous layer, accumulates and forms a cultivation bed where the main purification of the water takes place. Dr. Kemna suggests that this surface layer of a matured sand-filter acts similarly to a spider's web, so that the surface tension of the liquid when in an exceedingly thin film on the growth formed on the top of the filter causes it to act as a "microbe trap." Diatoms of few kinds exist in large numbers in winter, but in the spring green algæ appear, the diatoms diminish in number and their species vary. Later in the summer blue algæ make their appearance, and do not die out until the late autumn. At Waelhem, Dr. Kemna finds *Melosira* and *Fragilaria* the dominant diatoms in winter, whilst in the spring species of *Synedra* and *Cyclotellia* are abundant. According to his experience, by far the most effective strainer is *Hydrodictyon*, a green alga with the cells joined in hexagonal meshes, which forms sometimes a layer a foot thick over the whole surface. "The filters then run a good deal longer, and when cleaning the men roll the growth up like a carpet."

A sand filter does not, therefore, attain its maximum efficiency until this jelly layer has been produced. Purification is also effected for an indefinite period by the action of the nitrifying organisms immediately below this film. When through clogging the flow falls below a certain rate (p. 183), the surface is skimmed and renewed with fresh sand; after some days it regains efficiency.

All filters, however, must be worked with periodic testing, since a gradual growth of some bacteria through the substance takes place, and the effluent water is at length found to contain these organisms in undue numbers, so that it becomes necessary for the whole mass to be renewed. The upper layer of a filter-bed thus acts mechanically, by straining off the solids and rendering the water clear, as well as chemically and bacteriologically. At Berlin and other places the formation of the upper active layer is hastened by spreading over the surface some of the top layer, known as "ripe" sand, scraped off at a previous cleaning.

M. Piefke has shown that, to obtain less than 100 colonies of microbes per cubic centimetre, it is necessary for the filter to have been at work for at least eight days, during which the water must be run to waste, whereas, he states, the iron or Anderson process gives the same result in two or three days. The essential features of a good sand filter have been worked out at Lawrence by the Massachusetts State Board of Health.

The new filtration works at Hamburg comprise:—

1. The use of sedimentary basins.

2. Dividing the filtering area into numerous small surfaces, each of which can be readily disconnected without interfering with the others.

3. Systematic and constant bacteriological supervision, as it is only in this way that any proof of the efficiency of a filter at any given time is assured. Occasional chemical analysis of the water in order to ascertain whether the oxidation into nitrates is regularly maintained.

At Hamburg and Berlin Koch's limits are adopted, and the conditions which he has laid down may be summarised as follows:—

(*a*) No water is allowed to pass through a filter at a speed of more than 100 millimetres (about four inches) per hour.

(*b*) Each filter must have a contrivance by which the movement of the water in the filter can be restricted to a certain pace and continually regulated, and must further be provided with an arrangement by which samples of the filtered water may be taken at any time.

(*c*) A bacteriological examination by cultures must be made daily.

(*d*) Water containing more than 100 germs per cubic centimetre must not be allowed to pass into consumption. Although this is an arbitrary rule, it is one which may be regarded as tolerably safe, although, of course, even when such a small number is permitted in the filtrate, pathogenic organisms may be present.

Intermittent Filtration.—Another advantage of having a larger number of filter-beds of smaller size is that short periods of rest can be arranged wherein the layers may become aerated. The purifying organisms are mostly *aerobic*, or require oxygen, hence no filter can work satisfactorily if continuously water-logged. For this reason the Massachusetts Board prefer intermittent filtration. They say (Report, Part 2, 1890): "If we apply one day to the surface of an open body of sand one inch of water and next day another, we shall find that the water will go down each day about nine inches; in this space nearly two-thirds is sand, one-ninth water, and one-quarter air. The water is in an extremely fine layer over particles of sand, and intimately mingled with about twice its volume of air. It is pushed down each day, and the same amount issues at the bottom. Fresh air is brought in with the incoming water, so that if the sand be five feet thick, the water of any day will be slowly moving for a week over sand with two volumes of air." Sand which is too fine may remain saturated with water the whole depth, hence the advantage of using coarse sand and gravel. In London and in large towns where the demand is very great, it is difficult to afford periods of rest with the present large area filters; but with smaller ones, used in rotation, it could be more easily managed.

At Hamburg there are four settling tanks, each holding water enough for a day's supply, and having an area of about twenty acres. Each of these in turn is allowed to fill, and then rest for twenty-four hours, when the clear water is pumped off and the sediment removed.

About thirty filters are alternately in use. The medium employed consists of an eight-inch layer of small stones, then eight inches of gravel, and the same depth of coarse sand, followed by three feet of fine sand. The water is admitted with special care so as not to disturb the surface, and a depth of three feet is maintained above the sand. With this head of water the proper rate of filtration is secured. As the bed becomes choked, the head of water has to be increased, but there soon arrives a limit when the filter has to be thrown out of rotation and cleaned. Each filter has a separate outlet, where samples for analysis can be taken, and arrangements are provided for aeration. The total cost of the works was less than £500,000, and the supply will be ample for many years to come.

At Warsaw the water is kept under cover, but in other respects the arrangements are similar to those at Hamburg. At Lawrence, Mass., the impure water of the Merrimac is passed through four and a half feet of sand, and the bacteria reduced from 9,000 to 150 per cubic centimetre. The average speed of filtration is from five to eight feet per twenty-four hours. At all these places the death-rate from zymotic diseases has been very markedly reduced.

At Zurich four inches of garden soil are introduced into the filter-bed to promote nitrification. The filters are of gravel and about four feet of sand, and are run at four times the rate recommended above, but the lake water which forms the supply is of exceptional purity. At certain periods of warm weather, chiefly from July to September, a slimy layer called "waterbloom," consisting of microscopic algæ, makes its appearance on the surface, which requires removal, as it rapidly blocks the filter and gives the water a bad taste, variously described as "fishy," "marshy," or "mouldy." The same difficulty has often occurred in the United States.

Each filter-bed of the London companies averages about an acre in extent. As already mentioned, a greater number of beds of less area should be substituted. Smaller filter-beds also can be more readily protected and covered from frost. An epidemic of cholera at Altona arose from one of the beds being frozen, and in London water-famines have often occurred from this cause, and the water at other times has been indifferently filtered. The London filter-beds usually consist of a layer of sand two to four and a half feet in thickness, with gravel and stones below. The reservoirs contain from two to fourteen days' supply. The daily rate of filtration should not be more than 2,000,000 gallons per acre, but in times of great demand this is often exceeded.

Dr. Shirley Murphy, in his report to the London County Council for 1894, draws attention to the coincidence which existed between abnormal cases of typhoid in the last weeks of the year throughout the whole of the metropolitan area (with the exception of that supplied by water from the East London and Kent Water Companies) with the insufficiency of filtration, due to the floods in the Thames and Lea, which prevailed at that season. This relation between increase of enteric fever, and insufficient filtration on the part of the London Water Companies, was confirmed by an examination of the outbreaks of this disease in suburban areas, where a similar coincidence was noticed. In provincial towns supplied with adequately filtered water, during the same period the number of cases of enteric fever notified was normal.

Sediment reservoirs occupy an immense amount of ground and are expensive, while in warm climates they cannot be prevented from becoming foul through the rapid growth of vegetation and animal life. The Riddell filter is extensively used in America, and lately in India, for rapidly removing the coarser impurities. Closed iron vessels are fitted with fine sand, through which the water is forced under pressure at almost any required rate. The inlet is through radial arms attached to a piston. When the gauge indicates that the resistance has too much increased, water is forced in from below to disintegrate the bed, then clean water is admitted by the radial arms, which are worked up and down to thoroughly mix and scour the sand, the washings escaping through strainers. Subsequent removal of the bacteria by finer filtration is afterwards necessary.

Although filtration through sand has never succeeded in removing the *whole* of the bacteria from water, the reduction in their numbers is very great, amounting, according to Frankland, to about 99·5 per cent. A few instances may be quoted of the effect of filtration on the health of cities.

The Hamburg cholera outbreak of 1893, which occasioned nearly 9,000 deaths, was traced to the unfiltered water of the Elbe. Altona, drinking the same water after filtration through sand, escaped, except on certain occasions of the break-down of the filters. Since London waters have been filtered, the typhoid rate has fallen 86 per cent. In Warsaw, after the same precaution, the disease, which had been extremely prevalent, nearly disappeared. In Lawrence, Mass , the recurrent epidemics had ceased. The mean typhoid rate in cities both in Europe and the United States employing unfiltered water, was many times higher than those where the water was filtered. Prof. J. W. Hill, of Cincinnati, gives the following typhoid death-rates per 100,000, being the averages of seven years to December, 1896 :—

1. *Cities using lake water.*—Chicago, 71; Milwaukee, 29; Detroit, 30; Cleveland, 46; Buffalo, 34; average, 42.

2. *Cities using river water.*—Pittsburg; 84; Philadelphia, 45; Cincinnati, 49; Louisville, 74; St. Louis, 39; average, 58.

3. *Cities using filtered river water.*—London, 14·4; Berlin, 7·1; Rotterdam, 5·7; Hamburg (since 1893), 7·0.

4. *Cities using unfiltered mountain spring water.*—Vienna, 6·55; Munich, 5·94.*

It has been proposed to seed the upper bacterial layer, "top-slime," or "Schmutzdecke," with cultivations of

* See Fuertes' "Water and Public Health," Wiley, New York.

specially active or rapidly liquefying organisms, but natural selection would soon interfere with this, while practically accomplishing the same end. The number of colonies is greatest at the surface of the sand, and decreases very rapidly in the successive layers beneath, the thickness of the main layer being about half an inch. In intermittent filters the upper slime is not considered of so much importance, the main action occurring in the interior of the bed. With reference to this system, as carried out at Lawrence, Mass., it is said that since it was put in service four years ago, it appears from the bacterial results and the local typhoid rates, not to have attained the high standard of efficiency reached by the continuous sand filters of Europe. "Aeration of the bed, so essential when treating sewage, is hardly necessary when dealing with water, which carries in solution sufficient oxygen to do all the work required."

Subsidence before Filtration (p. 157).—The following is approximately the number of days allowed in various waterworks. A good deal depends on the capacity of the reservoirs: East London, 15; Chelsea, 12; Lambeth, 6; West Middlesex, 5·6; New River, 4·4; Southwark and Vauxhall, 4·1; Grand Junction, 3·3; Hamburg, 1 to 1½; Berlin and Rotterdam, 1.

Rate of Filtration.—This will be by no means the same for all waters. As already mentioned at p. 177, the Berlin standard (Koch's limit) is 100 millimetres—about four inches—per hour, equal to about two million gallons per acre per day. The actual rates for different supplies have been recorded as:—

London.—East London and West Middlesex 2½ inches, Southwark 2·7, Chelsea 3·3 New River and Grand Junction 4·0, Lambeth 4·1.

Bradford 4·2, Carlisle 2·2, Dumfries 8·5, Leeds 4 Leicester 3·4, Liverpool 4.

Stuttgart 3·3, Altona 4, Berlin 4 to 5, Zurich 11·5 to 16·4, Oporto 21·3.

The velocity at Zurich is extraordinary, sometimes amounting to forty-four feet per day (Bertschinger). The Massachusetts Board find that although four inches per hour should not be exceeded in moderately new filters, an older and "riper" one will allow a much higher rate of delivery, stating however at the same time that the proportion of bacteria removed is with two million gallons per acre 99·75 to 99·49 per cent.; with five millions 99·37, and with eight millions 99·2. Koch states that a severe epidemic of cholera at Nietleben asylum was clearly traced to improper treatment of the sand filters and to over rapidity—about seven inches of descent per hour.

Head of Water.—When new or after cleaning, only a few inches of "head" may be required: as the porosity diminishes in use by the accumulation of slime the height must be increased. In Continental cities the head of water varies from 4 feet 3 inches at Schweinfurth to 14 feet 4 inches at Brieg (Kummel), with Hamburg 3 feet 6 inches, and Berlin from 3½ to

32 inches. At Hudson, N. Y., it varies from a few inches to over 6 feet (Mason), but in England the surface is usually cleaned when for an effective rate the head much exceeds 3 feet. Any sudden alteration of the head, or the rate of filtration, disturbs the layers of bacteria and is apt to wash them through the filter, so that in properly constructed plant regulators are provided, consisting of floats controlling the effluent orifice, with sliding valves or sluices for the inlets.

The area of filtering surface required is given by the formula $A = \frac{Q}{F}$, where Q is the maximum daily demand in cubic feet, F the filtering rate in feet, and A the area in square feet, to which must be added a reserve for use while portions are being cleaned.

The rate of filtering will depend upon (1) the fineness of the upper layer of sand, (2) the effective head of water, (3) the condition of the unfiltered water, (4) temperature: near 32° F. the yield is only about half that at 77° (Hazen).

The construction and dimensions of filter-beds are described in detail in engineering works, but a general type of a good filter may be briefly given.

To exclude surface drainage the floor and sides are made impervious by clay puddle, and lined with masonry or bricks set in cement.

Over the drains, in the bottom of the filter, are laid nine to twelve inches of stones or large gravel, then six to twelve inches of smaller gravel in layers diminishing in coarseness, about a foot of coarse sand, and finally three feet of fine sand. Thus the materials are "graded" upwards as to size, and the upper layer is regulated as to uniformity by sifting and elutriation, the finest particles being usually about 0·1 millimetre in diameter. The materials are washed carefully, but not sterilised (p. 174).

Size of Sand.—In mixed materials containing particles of various sizes the water is forced to go round the larger and through the finer portions which occupy the intervening spaces, so that it is the finest portion which mainly determines the character of the sand for filtration.

The Massachusetts State Board of Health have recommended for general use two technical terms which are explained as follows:—

Effective size of sand grain "is that diameter than which 10 per cent. of the mass by weight is smaller, and 90 per cent. larger in size."

Uniformity coefficient "is the ratio of the diameter of the sand than which 60 per cent. by weight is finer, to the diameter than which 10 per cent. is finer." Thus, if 60 per cent. of the sand is less than 0·50 millimetres, and 10 per cent. is less than 0·25 millimetres, the "uniformity coefficient" is $\frac{0\cdot50}{0\cdot25}$ or 2, while the "effective size" is 0·25.

To determine these factors, a weighed quantity of the sand is passed through a series of sieves (generally eight) of graduated fineness, and the weight of the fractions, and the width of mesh, plotted as abscissæ and ordinates on a curve, remembering that the amount that has passed through the coarsest sieve will be the sum of the amounts on all the others, and so on. The diameters corresponding to 60 and 10 per cent. are then found on the scale. A low uniformity coefficient implies regularity in size and larger water spaces; a high one means greater irregularity and smaller voids. The average size in mixed sand is always greater than the effective size, and it was found at Lawrence that the 10 per cent. of finer sand has as much effect on filtration as the 90 per cent. of coarse.

Both the quality of the effluent and the cost of filtration depend on the selection of a sand of appropriate size, as with finer grades the filter clogs quicker and washing is more difficult. In Holland, the finest sand is used, of an effective size of 0·17 to 0·19 millimetre; no sand is re-washed, new being always used for refilling. These waters, however, are nearly clear before filtration, or the beds would soon become obstructed. By sand of 0·04 to 0·06 millimetre, water may be made sterile, but the rate of delivery is impossibly slow, and the use of pressure is not satisfactory. At Berlin (Lake Müggel) the top layer is only 24 inches; in some cities it ranges up to 52. The factors most suitable must be regulated by local circumstances and by tests of the effluent: their chief use is to secure uniformity and intelligent control. The following table gives a few particulars from various sources:—

	Thickness of Sand.		Rate of Filtration in Gallons per Square Foot.			Effective Size.	Uniformity Coefficient.
	Max.	Min.	Max.	Min.	Mean.		
	ft. in.	ft. in.	gallons.	gallons.	gallons.	mm.	
LONDON—							
East London ...	2 6	1 6	1·33	1·33	...	0·40	2·0
New River ...	2 3	1 7	2·3	1·9	...	...	...
West Middlesex	2 9	...	...	...	1·25	...	...
Grand Junction	3 0	1 6	1·9	1·3	...	0·40	3·6
Southwark ...	2 9	2 3	1·6	1·5	...	0·34	2·5
Lambeth ...	3 0	2 6	2·4	2·1	...	0·36	2·4
Chelsea ...	4 6	3 6	1·75	1·75	...	0·36	2·4
LIVERPOOL ...	...	...	...	...	...	0·37	2·6
LEEDS	...	2 0	...	...	1·9	...	...
BERLIN	2 0	1 3	2·4	2·0	...	0·35	1·8
Average of five large German towns	...	...	...	...	...	0·34	2·0
Lawrence, Mass. (intermittent)...	5 0	...	...	...	1·8	0·25	...

It will be shown subsequently (p. 202) that the bacterial efficiency only partially depends on the size of the sand grains, since many of the organisms are smaller than the interspaces of even the finest sand: their removal is due to their entanglement by the zooglœa film surrounding the grains, to their mutual antagonism, and to the destructive influence of nitrification. It was proved, however, by the Massachusetts experiments that "fineness of sand and effective bacterial efficiency march *pari passu*." Sir Edward Frankland gives the following results in confirmation, observing that "the West Middlesex Company, by the use of finer sand, is able with much less storage to attain a higher degree of efficiency than the Chelsea Company."

Company.	Thickness of Sand in feet.	Percentage of Sand of less than four (?) millimetres.	Percentage of Organisms left in.
THAMES.			
Chelsea	4·0	26·10	6·0
West Middlesex ...	2·75	78·19	2·3
Grand Junction ...	2·25	28·70	8·9
LEA.			
New River	1·8	60·26	2·2
East London	2·0	33·12	3·1

"This table also shows that thickness of sand has much less effect than might have been expected—a conclusion which is confirmed at Massachusetts, where it has been found that the depth of sand between one foot and five feet exercises no practical effect on bacterial purity when a proper rate of filtration is maintained."

Cases occur in which waters, especially those of rivers, are only imperfectly clarified even by the finest sand. The Nile water presented great difficulty from this cause, but was cleared with facility by Anderson's process (p. 165). Prof. H. Robinson states that the River Plate, containing a quantity of finely comminuted clay, giving a yellowish tint, passed still turbid through very fine sand and even through the finest filter paper, whereas a filter of alternate layers of finely pulverized cinders and coarse sand was successful in arresting the impurity.

Cleansing.—The filter being emptied and disconnected, the upper layer, which is usually compact and easily separated, is removed by shovels or by a mechanical scraper to a depth of $\frac{1}{4}$ to $\frac{3}{8}$ inch. After an interval for aeration of the bed, filtered water is admitted very gradually from below, since if the entry were too rapid the escaping air would form channels in the sand. In the best construction, as at Leeds, escape pipes are provided in the walls of the filters.

Raw water is then run on cautiously and as uniformly as possible, and the whole allowed to rest for from twelve to twenty-four hours to allow the slime to re-form, and the filtration is then gradually recommenced. At first, the number of bacteria in the effluent is much increased, therefore the filtrate should not be used until it is proved by examination to be in a satisfactory state.

The freezing of a filter is exceedingly injurious (p. 180), therefore in the colder countries the filter beds must be covered. At Hamburg, however, where the filters are open and of large area (nearly two acres), the sand is scraped beneath the layer of ice by the

Mager apparatus, a kind of dredger attached to a float and drawn by cables across the bed.

The minimum thickness of fine sand is defined by the German law to be 12 inches, but it is rarely allowed to fall below 15. After washing by rotary cleansers with filtered water till the latter is clear, the sand is sometimes returned at once to the beds to restore the depth of layer, but the practice is not to be recommended. The general custom in London, on reaching the minimum thickness, is to remove the remainder and replace it by an equal amount of sand that has been washed and stored, then to transfer the old sand to the upper position, thus reversing the layers.

Sir E. Frankland states that the number of bacteria in raw river waters is practically governed by the volume of flowing water, that is, by the rainfall, and gives the following figures for the Thames at Teddington Weir during 1896, observing that the four preceding years show similar results:—

	Million gallons daily.	Microbes per c.c.		Million gallons daily.	Microbes per c.c.
January 10	... 1,152	11,560	July 2	... 262	2,220
February 10	... 948	26,800	August 24	... 216	1,740
March 10	... 1,673	18,000	September 9	... 431	4,300
April 10	... 742	7,520	October 8	... 2,624	39,760
May 12	... 375	2,060	November 4	... 930	8,560
June 10	... 421	6,760	December 8	... 3,840	160,000

With regard to storage, he remarks that, while the number of microbes in Thames water at Hampton averaged during four years 19,258 per c.c., after thirteen days' storage it was 1,649; while the Lea at first contained 20,376, and after fourteen days only 4,304.

As to the original bacterial quality, he does not altogether agree with Koch that this has no connection with the character after filtration. From Frankland's own figures, however, there does not appear to be any obvious relation, except that a filter acting well, and yielding about the same low number of organisms in the effluent will clearly furnish a higher percentage of purification with a fouler water.

In considering these numbers it must be remembered that the bacteria in an effluent consist of some that have passed through the filter, and some from the lower layers and under-drains: these latter are believed to be harmless.

Mechanical Filtration.—The sand filter cannot be relied upon in America to remain unfrozen during winter. Hence many systems of rapid filtration under cover and aided by pressure are in use in the United States, chiefly for the waters of muddy rivers. Alum or sulphate of alumina, in the proportion of one-half to two grains per gallon, is first added, and the water then passed through filters of small area, of which the "Hyatt" and "National" are the best known. The filtering material is usually sand or coke, and is cleaned at short intervals by reversing the current, as in the Riddell filter.

The Morison-Jewell Filter Company, of New York, introduced in 1887 a system of purification on a large scale, which substituted a film of gelatinous alumina for the slimy organic film of ordinary sand filters. The "coagulant" is a "basic sulphate of alumina," formed by mixing sulphate of alumina (containing 17 per cent. of Al_2O_3) with caustic soda, which yields, when dissolved, sodium sulphate in solution and aluminium hydrate as a suspended gelatinous precipitate. This, when run on to the filter-bed, forms a layer which very rapidly removes the colour and suspended matter of the water, and also 98 to 99 per cent. of the bacteria. The medium is quartz, crushed by machinery to a diameter of 0·38 millimetres (·0142 inch) and screened. Steam is also used for cleansing and sterilising, with a solution of soda-ash at intervals. The beds are supported by perforated screens of aluminium bronze. The filter is readily washed by reversing the current and removing the top surface by a mechanical rake, then introducing fresh quartz sand and alumina, the process taking about eleven minutes. Washing is done once every twenty-four hours, and oftener in flood-times. The rate of filtration adopted at Providence, Rhode Island, is 100,000,000 gallons per acre per day with a head of three and a half to six feet. The amount of aluminium sulphate used is 0·5 to 0·75 grains per gallon of water filtered. Prof. Doremus, of New York, has reported favourably on this process.

The objection made to these filters is that the constant addition of chemicals to the water may exercise an injurious influence on the public health. At the Providence waterworks, Mr. Weston found by the logwood test finely divided alumina in the filtered water. Prof. Drown records a decrease of oxide of iron by 0·023 grain per gallon, an increase of alumina by 0·0292, and of sulphuric acid (SO_3) by 0·205 in the filtered water, when about half a grain of aluminium sulphate was stated to have been added. It must be mentioned that officers of health in some forty or fifty towns using alum-treated water attribute no ill effects to its use, and the water has had no injurious action on boilers. The rate of filtration through sand of the London Water Companies is 540 gallons per square yard per twenty-four hours, equal to 2,600,000 gallons per acre. The Jewell filter passes in the same time about 100,000,000 imperial gallons.*

The Fischer system consists of a battery of large flat plates or "plaques" composed of sharp sand and powdered glass fused together to a porous mass, bolted together on each face of an oblong metal frame so as to leave an internal space with an exit tube below. They are washed by reversing the current. The process is a modification of the Pasteur-Chamberland without sterilisation (p. 213). The Worms

* Dr. Swarts and Mr. Weston found at this rate an average removal of 98·6 per cent. of the bacteria (J. Amer. Med. Ass., Jan., 1896). Prof. Appleton found less alumina after than before filtration.

report states that the percentage of bacteria left is somewhat greater than that left by the sand filter.

In many places there is still no attempt at chemical or bacteriological purification; floating and visible suspended matter is simply removed by copper gauze strainers.

Filtering galleries consist of underground water-ways, which are run at a low level parallel to the

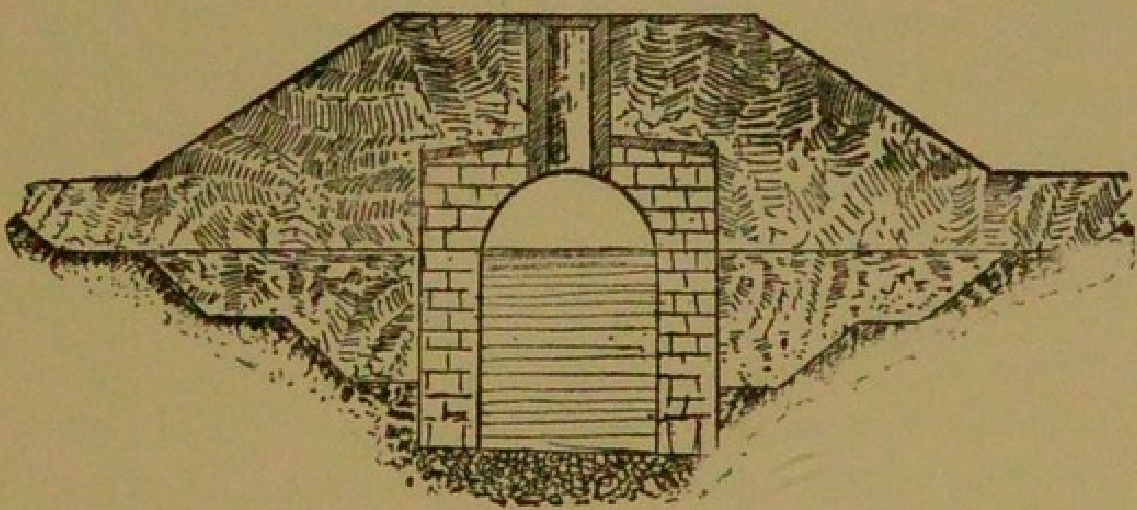

FIG. 32.—Filtering gallery at Lyons.

banks of a river to receive the naturally filtered river water; but the greater portion of the water which collects in such galleries is subsoil water derived from neighbouring higher land, as the bottom of a river is usually almost impervious to water, from the fine deposit of silt and clay. At Toulouse there are long filtering galleries excavated in the alluvium, which yield 2,800 cubic metres of clear water at a uniform temperature daily. A similar gallery at Lyons has deteriorated both in quality and quantity. On the whole, the experience gained from the existing galleries is not favourable, but when the water is derived wholly from the subsoil at sufficient depth, and the surface is kept free from habitation or contamination, as at Frankfort, the water collected in this way is of great organic purity and nearly germless. If the temperature of the water varies on pumping, it shows that admixture with river water is taking place.

Filtering cribs are large boxes of iron or wood sunk in an excavation in the bed of the river or lake, then surrounded and covered with gravel and sand. The water is pumped through pipes to the shore. Being submerged, they are beyond daily inspection, while control and repair may be almost impossible.

It is believed that the auxiliary wells sunk by some of the London Companies in the gravel at Moulsey and Ditton are fed almost directly from the Thames.

Note as to Infiltration and Temperature.

Wells, or reservoirs at low levels, may undergo contamination not only from the surface, but also from beds of rivers or streams which have received sewage. Such pollution often causes the temperature of the water to alter (p. 82).

Dr. Jäger employs the following formulæ for calculating the volume of the admixture :—

If t^1 = the normal temperature of the ground water at a given depth and beyond the influence of the river;

t^2 = temperature of the river near the bottom;

q^1 and q^2 the proportions of the two waters in the mixture Q, taken from the well, deep reservoir, or boring; and having a temperature T; then—

$$q^1 t^1 + q^2 t^2 = QT$$

or—

$$q^1 = Q \frac{T - t^2}{t^1 - t^2}, \text{ and } q^2 = Q \frac{T - t^1}{t^2 - t^1}.$$

He finds that the results are confirmed by chemical analyses, and points out that if the infiltration passes at a depth of two or three metres, the organic matter in the river water would not have undergone nitrification. Meinert, while the Elbe was in flood, found in a Dresden storage reservoir *Bacillus violaceus*, an organism abundant in the river but absent from the ground water.

CHAPTER IX.

HOUSEHOLD FILTRATION.

The original idea of a filter was simply a strainer, which, by keeping back the solid particles, could render a water clear and bright. For this purpose, sponge, sand, and linen were found to be sufficient, and water that had passed through them was supposed to be wholesome. Sponge was convenient, as it could be so easily washed and squeezed out. Sand can be taken out and washed, but a layer of gravel, followed by coarse sand, must be introduced below the fine sand which does the main work of clarifying, and finally a layer of gravel again, to prevent the fine sand from washing up. Such filters were furnished with a perforated plate, or sometimes with a small sponge, to protect the bed and to retain the grosser impurities. All this was so complicated that the arrangement was sealed up when purchased, and was used till it became stopped by the dirt from the water. On such an occasion, which perhaps happened every two years, the filter required to be cleaned and refitted, and this process was frequently delayed by the user owing to its cost.

Charcoal, with or without the use of the sponge, was then introduced as a medium. Vegetable charcoal was known to remove odours, animal charcoal to take away colour; the latter became the favourite, and a great variety of forms of charcoal filters were placed on the market and received "testimonials." The action of the charcoal was not merely mechanical: it also for a time softened the water by absorbing some of the lime; metals like lead and iron were removed, and it was supposed to be even capable of purifying from "sewage." By compressing the charcoal with some binding material, like resin, oils, silicates, &c., and then charring again in close vessels, the once popular blocks were formed; they were supposed to be capable of being cleaned by scrubbing and blowing water through in the reverse way. Only a few years ago the tests which were considered valid as applied to these filters consisted in adding water containing finely divided carbon or ultramarine, and noticing whether a clear filtrate was produced. In the same way, claret was poured in and came out colourless, solutions of lead and iron were added, tests applied after filtration, and none of the metal found. It need hardly be said that the filter must be fairly *new* for such tests to succeed, and that they have no sanitary value.

In 1876, the Royal Commission on Rivers Pollution pointed out that when the filtered water was allowed to stand, minute organisms, animal and vegetable, appeared, and made it unfit to drink and actually offensive; whilst, if the charcoal had not been burnt at a sufficiently high temperature—which is rarely done, as it involves a loss of carbon—some nitrogenous matter remained and became a breeding ground for organisms, which were also encouraged by the 70 per cent. of calcium phosphate and by the other mineral salts present. On the other hand, some of the products of the putrefaction of albumen—ptomaines, sulphides, enzymes—are oxidized by newly prepared charcoal. Spongy iron increases the ammonia. Fresh organic matter, like white of egg, was almost unacted upon.

It was common for these filters to be excessively foul internally, being green with confervæ and containing small worms and swarms of bacteria.

Dr. Drown's report of 1895 to the Massachusetts State Board of Health, laid it down that one of the chief objects of water filtration was, in most cases, the removal of the disease germs. However bright and sparkling a water may be, it has been repeatedly proved during cholera outbreaks that it may frequently convey germs. Such water is apt to be preferred by unthinking people when a water slightly turbid might be perfectly harmless. In 1888 Prudden and Ernst stated they had found typhoid bacilli in the domestic filters of houses at Providence, Rhode Island.

In view of this essential point, Dr. Sims Woodhead and Dr. Wood subjected existing types of filters to a bacteriological test by passing through them yeast cells and various pathogenic organisms (*Staphylococcus pyogenes aureus*, typhoid and cholera bacilli; see p. 304). They examined the filters of twenty-one manufacturers, including all the best known types, reporting that the only forms that did not admit the passage of disease germs were the candle filters known as the Pasteur-Chamberland, Berkefeld, and Aéri-Filtre-Mallié. They condemn all others as increasing the risk of acquiring infectious diseases. Even in regard to the two latter forms, their approval of the Berkefeld was based upon insufficient experiment, and of the Mallié on a non-commercial form (*British Medical Journal*, Nov. and Dec., 1894).

A report by Dr. Plagge, which has been issued by the Prussian War Office, mentions that in 1885 he tested all the then known filters, and found that the carbon, natural stone, gravel, sand, cloth, sponge, paper, and asbestos forms extant in Germany were entirely useless. In the few cases where he examined filters from England, made with spongy iron or some form of carbon, he obtained the same result. In a renewed investigation of modern forms of filters, conducted within the last few years, he came to a similar conclusion. With reference to a number of carbon filters, he found that they were all incapable of preventing the passage of disease germs, and he severely characterised the false claims put forward by the makers. The different forms of filter composed of a carbon preparation and asbestos, were also found to fail, as well as the well-known Austrian filter of Breyer, composed of "micro-membranes" of an exceedingly close felt of very finely-divided asbestos. With regard to this filter, Dr. Guinochet also says (*Eaux Potables*, J. B. Baillière, Paris, 1894): "It is not a perfect filter, as it allows microbes to pass; it proves, in fact, that the fineness of the filaments used in the construction of a filter does not play such an important part as has been said, since here is a membrane whose particles are not more than $\frac{1}{1000}$ millimetre (0·0004 inch) in diameter, while porcelain would be formed of grains much more bulky, besides leaving between them spaces larger than those of asbestos. It is not so necessary to obtain spaces smaller than the microbes, which is practically impossible, as to secure that the microbes arriving in the interior may be retained by molecular attraction." Dr. Guinochet concludes that the Breyer form does not filter so well as the Chamberland, that it is delicate, difficult to clean, and liable to leakage.

Dr. Plagge also condemned all filters made of paper, cellulose, and asbestos, whilst the Pasteur-Chamberland was described as satisfying all sanitary requirements. He then examined some of its imitations, which, while yielding water much more rapidly, are stated by the makers to be equally efficient. The Berkefeld filters were successively under observation during three years, thirty-seven specimens being used; of these, twenty-nine passed microbes almost immediately, within twenty-four hours, or before the end of the trials, which lasted three to eight months. Dr. Plagge is of opinion that it is indispensable for the Berkefeld filter to be boiled either once or twice in twenty-four hours, according to the extent of its use. He further draws attention to the fragility of the Berkefeld filter as compared with the Pasteur-Chamberland form.

Dr. Johnston, in a bacteriological examination of representative filters in 1894, obtained similar results, and states that "the Pasteur-Chamberland filter is the best and the only one on which reliance can be placed for permanently sterilising water." The results were obtained with the cylinders marked "B," which are intended for slow filtration, worked from a main tap at a pressure of from twelve to forty-six pounds to the square inch.

Guinochet, using the rapid Pasteur filters marked "F," working continuously under pressure for several weeks, found in the filtrate only a few bacterial colonies and moulds, which he considers were due to accidental contamination while making the cultures.

Unfortunately, therefore, the majority of household filters are worse than useless, since they do not remove the contaminating bacteria, and actually, by forming a nidus for their growth, contribute to their formation and multiplication in the water sought to be purified by their means. The extent to which the danger of a bad filter may go was calamitously shown at Lucknow, in 1894, when a particularly virulent epidemic of cholera among the East Lancashire regiment was traced to the pollution of the barrack-room filters. Out of a total of 646 officers and men there were 145 cases, of which 93 terminated fatally.

Hankin maintains (Report on N.W. Provinces of India, 1895) that domestic filters, except the Pasteur-Chamberland, are quite incapable of keeping back the cholera bacillus. P. Frankland obtained some unexpected results with Pasteur and Berkefeld filters, when Thames water sterilised by filtration was infected with the typhoid bacillus. The latter refused to grow, and in five days had disappeared. To ascertain whether any antiseptic substance had been communicated by the filter, it was washed with a large volume of pure water and tried again, with the same result, although in the same liquid ordinary water bacilli were found to multiply with ease, showing that the filtration removes some food substance necessary for the growth of typhoid germs. M. de Freycinet, French Minister of War in 1892, states that where the Pasteur filter was used, typhoid fever disappeared, even in the garrisons which were most often and the most cruelly attacked. His successor, General Zurlinden, strongly corroborated this statement, with the caution that "soldiers who have in their barracks a pure water are none the less exposed to typhoid fever in inns, restaurants, and other public places."

The candle filter is the outcome of experiments made by Pasteur, who found that plates of plaster of Paris were inefficient in sterilising bacteriological fluids. Chamberland afterwards suggested the application to drinking water of the tubes which Pasteur had found efficient for bacteriological work. Such filters do not merely strain off suspended matter, as many of the organisms are smaller than the pores. The action must therefore be due to some molecular attraction dependent on the material of the tube and its manufacture. It is stated that "it requires the highest skill in pottery to produce a uniform result as to sterilising capacity, and that some 30 per cent. of the finished tubes are rejected on test." Many other forms of porous porcelain have been tried, but none of them seem at present to give the same efficiency. Candle filters are manufactured by the Sanitats Porzellan Fabrik at Charlottenberg, and in this country several

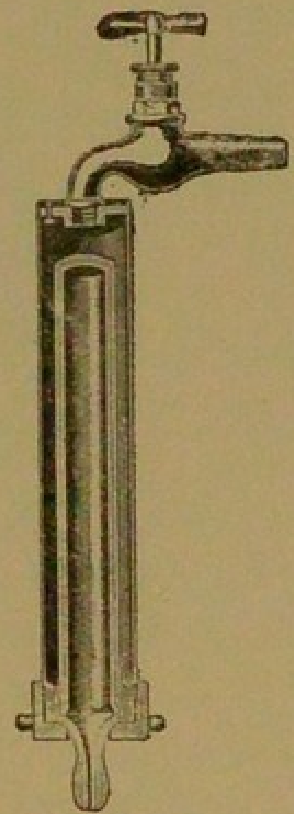

FIG. 33.
Standard Pasteur-Chamberland filter (pressure form).

English-made candle filters have made their appearance. At present, however, there is no sufficient evidence to warrant the belief that any of them give the protection against water-borne disease which is afforded by Pasteur filtration; and the assumption that they function similarly is a very dangerous one for the general public, who are unable to distinguish between the forms.

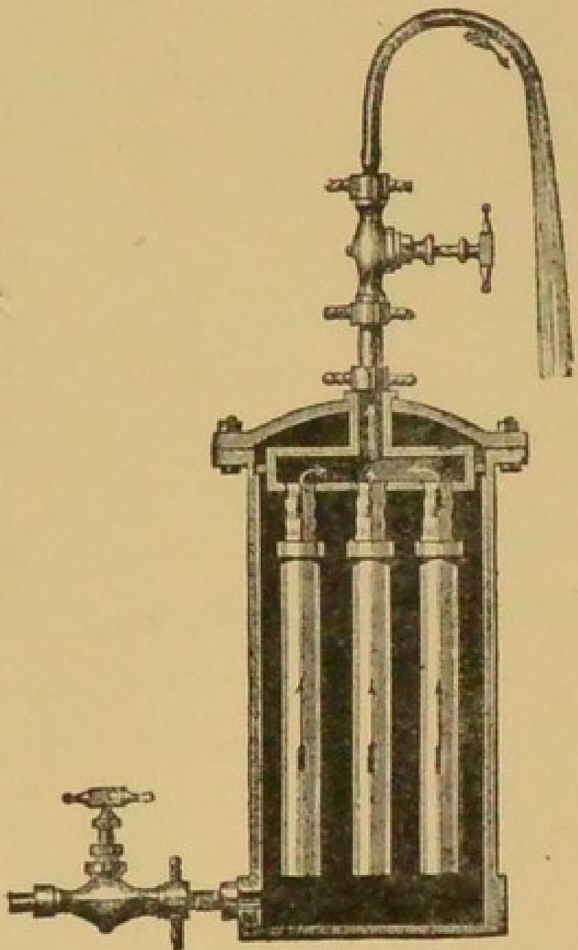

FIG. 34. Battery of pressure filters (English form).

In use the unfiltered water passes through the filter tube or tubes from outside inwards. This may take place under the pressure of a water main (Figs. 33, 34, 39) or of a pump, under suction of a siphon tube which may deliver into a separate filtered water

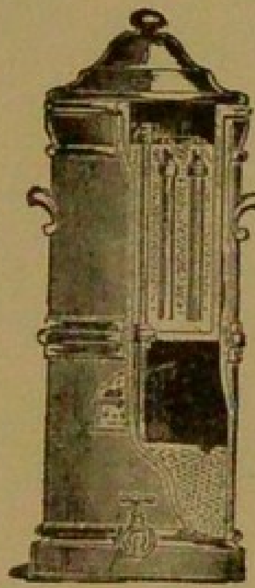

FIG. 35. — Pasteur-Chamberland filter for table use (without pressure).

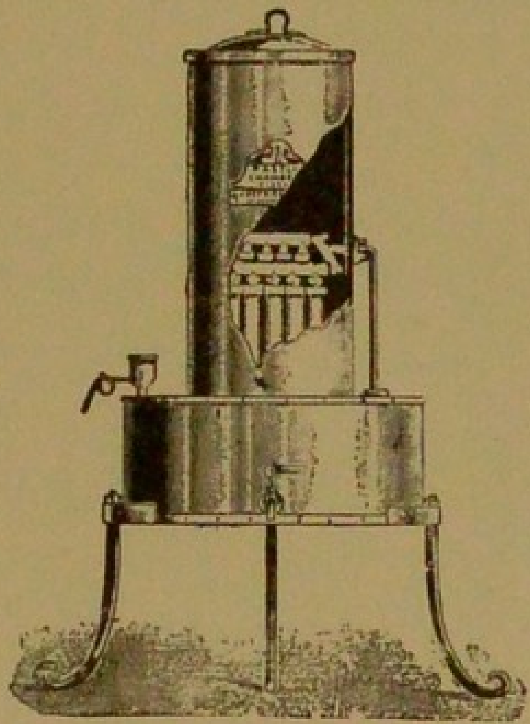

FIG. 35A. — Battery of candle filters for schools.

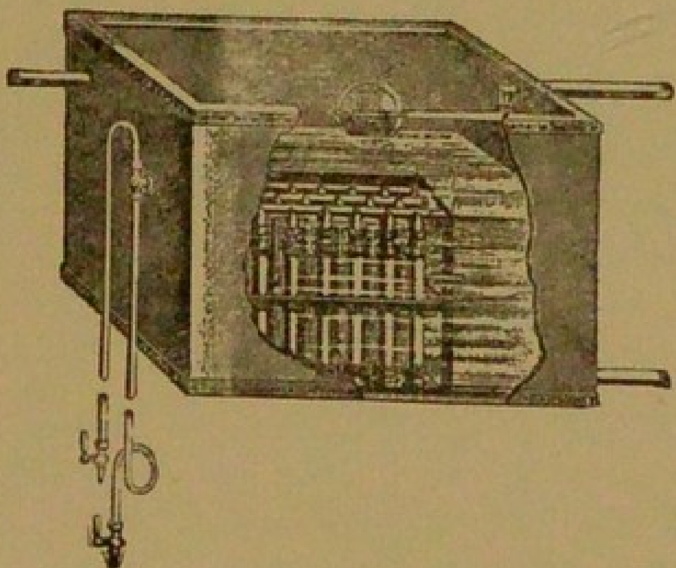

Fig. 35B.—Cistern form of filters with siphon tube.

chamber, as shown in Figs. 35 and 35A, or from the cistern by a long siphon tube to a lower room, as shown in Fig. 35B. Under some circumstances the head of water in the filter chamber above the candle can be used, but the yield is then slow. In Fig. 36, the candles are fitted into a closed reservoir, from which the filtered water is removed by a hand-pump, which creates a partial vacuum in the filtered water chamber and thus augments the rate of filtration. The filter may consist of one or any number of tubes delivering into a common reservoir made either in one with the filter or separate from it. In the latter case, care should be taken that the receptacle is dust-proof. The water can obviously be led by pipes and distributed over the house instead of unfiltered water. The average yield per tube is about half a gallon per day without pressure and eight gallons per day with pressure.

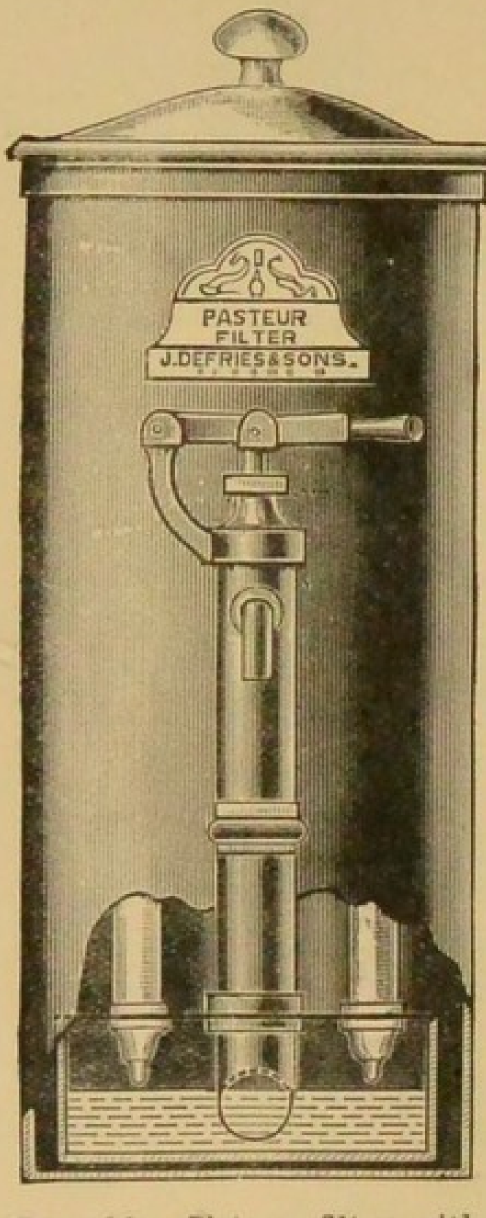

FIG. 36.—Cistern filter with hand-pump (Pasteur-Chamberland).

The Nordmeyer-Berkefeld filter (Fig. 37) is made of kieselguhr, or infusorial earth, in the same form as the Pasteur, but of much greater thickness. It is much more porous than the porcelain of the Pasteur-Chamberland, and allows the water to pass with about five times the rapidity, which would be a great advantage if it were not for the fact, as shown by the experiments mentioned above, that it is also more permeable to microbes, and allows them to grow through in a shorter though variable time, and therefore does not present an equal safety. It was nevertheless thought that it was sufficiently resistant to give protection against water-borne disease, and the entire British forces in the South African campaign of 1899 were equipped with it. They notwithstanding suffered enormously and constantly from typhoid fever, a result which, when contrasted with practical results obtained from Pasteur filtration, threw doubt upon the filter's capacity to arrest the microbe. This has since been

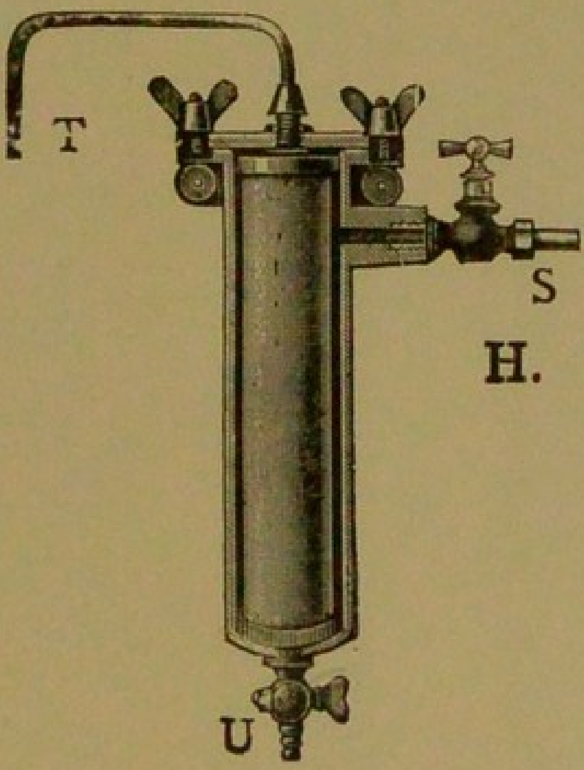

FIG. 37. Nordmeyer-Berkefeld filter (pressure form).

tested directly at the Hygiene Laboratory of the Royal Army Medical School at Netley, by Prof. Horrocks, and it has been found that the typhoid bacillus, even in water without any nutrient addition whatever, penetrates the Berkefeld filter in a few days. The same bacillus, whether in water or in nutrient broth, failed altogether to penetrate Pasteur filters during the several weeks over which the experiments lasted.

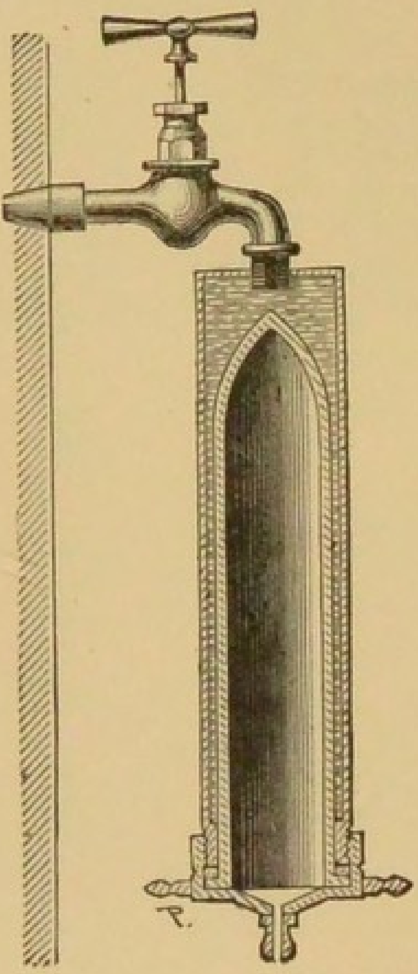

Fig. 38. Filtre Mallié (pressure form).

As to the rapidity of filtration or output of the Berkefeld filter, Dr. P. Frankland, who reported very favourably on this form, but tried it after too short a time (twenty minutes), using Loch Katrine water, found that the rate, which was at first about seven gallons an hour, had in one hour diminished to about half that amount, and in twenty-four hours' continuous running had come almost to a standstill. The matter removed was a dark brown layer of slime of a vegetable or peaty nature, containing also all the bacteria. He published no trial of the filtrate after the first twenty minutes mentioned above. The Manchester town supply also gives a coating of thick black mud one-eighth of an inch in thickness, swarming with bacteria and other organisms. The Pasteur filter with the same water required cleaning once a week, which seems the ordinary time for the Pasteur form.

If it were possible to subject Berkefeld filters to daily sterilisation, they would then be as safe to use as the Pasteur-Chamberland form, and the question would resolve itself into a choice between a battery of Pasteur-Chamberland filters, involving only a weekly cleaning and somewhat larger initial cost, and that of a couple of Berkefeld filters purchasable at a more moderate cost, but necessitating a daily sterilisation as recommended by Dr. Plagge. It would even then have to be remembered that the kieselguhr filters have to be handled with considerable care, as they are far more fragile than those made of porcelain, and the slightest flaw would render them quite useless; and in this way the renewal of tubes would become a large item of maintenance. There is, further, no certainty that the Berkefeld tubes are always initially sound, owing to the impossibility of reliable test other than bacteriological examination; and the process of cleaning inevitably destroys their soundness and renders the filtration illusory sooner or later. The initial efficiency of the filter, whatever it may have been, will therefore be liable to be reduced through these factors; and the impossibility in actual practice of getting a filter tube sterilised every day or

P 2

so with certainty and regularity makes it impossible for practical purposes to substitute Berkefeld for Pasteur filtration as a preventative of water-borne disease. The fact is unfortunate; but the military experience in South Africa shows that it is still more unfortunate that the fact should have been ignored or undiscovered for so long.

The "Aéri-Filtre Mallié" is constructed in a similar way to the Pasteur form, but is made of a porcelain paste of exceedingly finely-divided asbestos (Fig. 38). As described by Drs. Woodhead and Wood, it was so slow in filtration as to prevent it from ever coming into general use. Since the date of that examination it is being made of a different composition containing only a small amount of asbestos, and in this form there are no published data for estimating its efficiency in arresting microbes.

In case of a suspicion of failure from any cause, a sample of the filtered water carefully collected in a stoppered bottle, as described on p. 263, should be submitted to an expert for bacteriological examination. Whatever form of filter be adopted, the filtered water must of course be carefully guarded from subsequent pollution.

In India the use of the Pasteur-Chamberland batteries for large supplies has greatly extended. Those constructed for the Darjiling municipal waterworks (Fig. 39) are of the pressure type, and consist of thirty-eight cells of tough cast iron coated with an acid-resisting composition and arranged in four rows. Each cell contains 250 Pasteur filter tubes fixed into solid elastic bushes, and is connected by wrought-iron pipes to cast-iron mains, which deliver into cast-iron collecting mains, all protected by the acid-resisting composition. The cells are fitted with gun-metal valves, enabling any one cell or group of cells to be cut out for cleaning or other reason. The inlet and outlet pipes are controlled by sluice valves in the ordinary way. Cleaning of the tubes and cells is effected by means of a circulating pump, which forces through the tubes of any cell or group of cells a solvent—usually a diluted acid—by which the deposit in the pores of the filter tubes is removed; and it is claimed that at the same time the whole of the filtering system is sterilised. "This process only entails the passage of an inappreciable quantity of acid per gallon of filtered water during the day; and as the same acid can be used several times, it is accordingly both economical and free from objection." All the parts of the installation are interchangeable, and its nominal output is 150,000 gallons per day.

Similar cells are largely used in this and smaller sizes by some of the larger steamship companies for sterilising the drinking water. This is of considerable importance, as many ports of call are known to have inferior water supplies.

For military or travelling purposes exhaust filters are found by experience more suitable than the pressure forms, as they involve no joints which have to be broken for cleaning. During the late Ashanti expedition, a number of portable pressure filters were used in the field and caused trouble in this way. These were specially made, and were constructed of aluminium alloy, with gun-metal fittings, so as to reduce the weight to the utmost extent consistent with serviceable strength. The station where they were used was the only one which was free from dysentery, so that the efficiency of the filtration was thus again verified.

Exhaust filters are made with single tubes for personal use, or with batteries for the use of bodies of men. In view of the temptations offered by casual streams to men on the march, small pocket filters in a case, which could be used with or without a small hand force-pump, can be supplied to the men. Mouth suction filters are always objectionable, as it is hardly possible to prevent the saliva passing down the tube. The siphon form is useful if a suitable vessel is at hand. The portable form with hand pump is much to be preferred.

In conclusion, although a town supply may be of good chemical quality, comparatively free from bacteria, and well filtered, yet in its passage from the works to the consumer it may become contaminated with the bacillus of typhoid or cholera, or some other pathogenic organisms, brought in by leakage from the drains in the neighbourhood of the supply pipes or by infection of cisterns. There may also be a breakdown in the filter-beds, as occurred in 1894 at Altona, when a fresh outbreak of cholera occurred

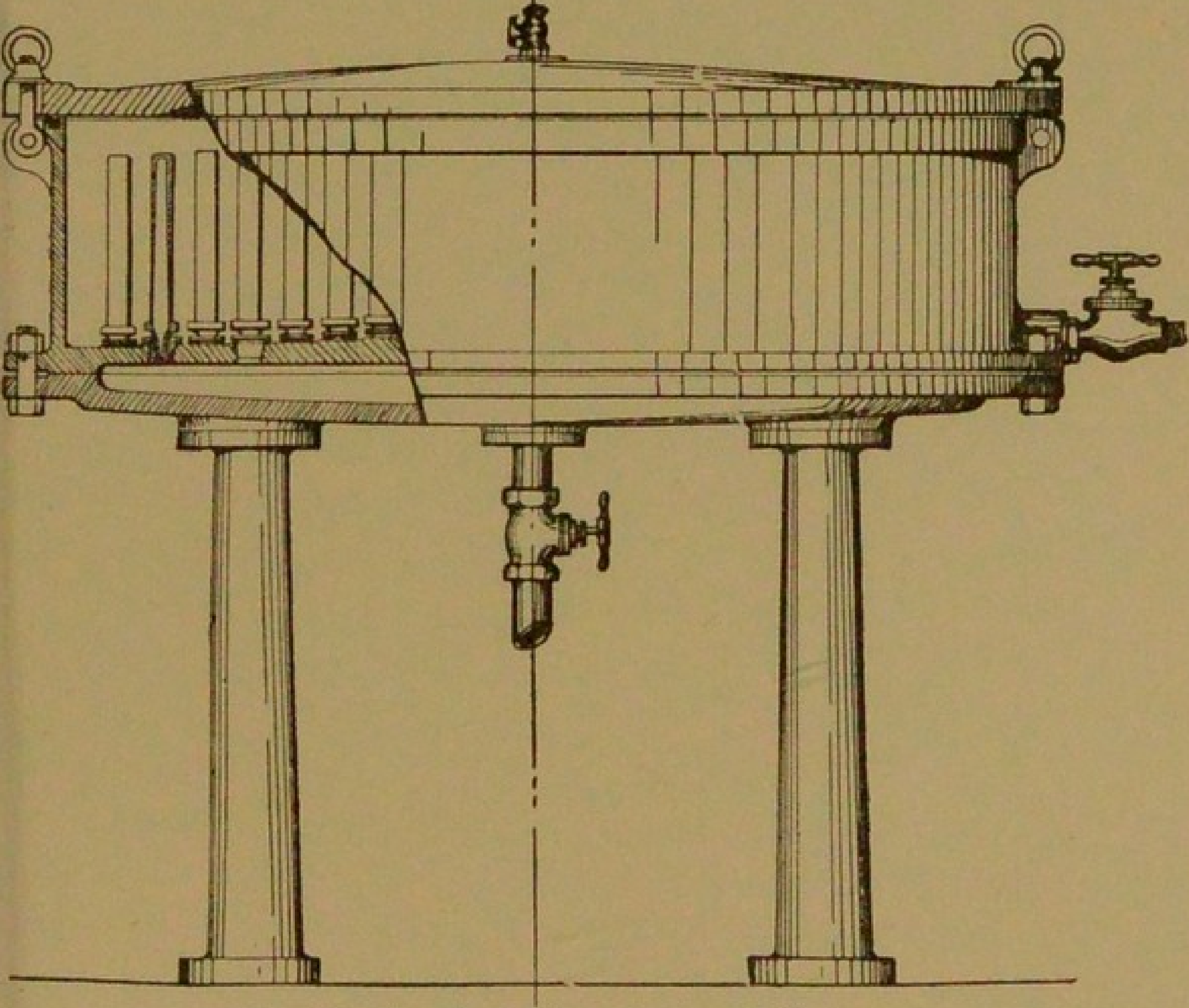

FIG. 39.—A cell of a large Pressure Filter.

through one of the sand filters becoming frozen and refusing to act, though in the previous year the filter had successfully resisted the epidemic. In the same way Dr. Klein has recently shown the liability of the London supply to pollution by sewage organisms, and Dr. Shirley Murphy attributes sporadic cases of enteric fever in London to the same cause. It is on these grounds chiefly that at the present time the sterilisation of water at the supply works is not advocated, and only the partial bacterial filtration aimed at. The possibility of subsequent pollution from some such causes renders it highly important that some adequate system of domestic filtration should be adopted by every householder. In many conditions, as on board ship and in country places, filtration on a smaller scale is the only purification practicable.

That such a system is attainable by simple means we have attempted to show. It would be a hygienic ideal, and probably will become a necessity, that the required apparatus be furnished as an integral portion of the ordinary water fittings, and that the duty of keeping it cleansed and in order be enforced by official inspection. The expense would bear no comparison with the outlay that is periodically occasioned in combating with diseases which are conveyed through the medium of impure water.

The reports of the French Minister of War in 1889 and 1892, demonstrated that a conspicuous diminution in the number of deaths from typhoid in the French army had followed the substitution of spring or filtered water for the water of rivers or wells. In the barracks of Melun, in 1889, the deaths from this disease had been 122; after the introduction of the Pasteur-Chamberland filter, the mortality of subsequent years fell to fifteen, six, two, seven, and seven. In one case the attacks were confined to soldiers lodged in the better rooms who had made use of water from troughs fed from the Seine, on account of the filters being frozen. The other battalions, who had drunk nothing but the regimental tea, had not a single case. Similar and quite as conclusive examples occur throughout the report in reference to typhoid and cholera, and still more striking results to the same effect are given in the report for 1894.

The slowness sometimes urged against this class of filter arises from the attempt to get a higher duty than the nature of the water allows, therefore the size and number of tubes must be proportionally regulated. Where slimy matter is present and power is available, a mechanical system of brushing might be devised; better still would be a preliminary straining through coarse sand, with a Pasteur filter as a final steriliser.

CHAPTER X.

SOFTENING OF WATER.

Although the carbonates of lime and magnesia are almost insoluble in water, in presence of carbonic acid they dissolve to an appreciable extent, forming bicarbonates, which though unstable, have been proved to be definite compounds. As rainwater and other natural waters contain free carbonic acid, partially derived from the atmosphere, which contains ordinarily 4 parts in 10,000, and partly from the oxidation of organic matter in the water, they exert a solvent action upon any carbonates present in the soil or rocks with which they come in contact, and thus most natural waters contain these bicarbonates in solution. Such waters are said to be *hard*, and, chiefly, the hardness is due to lime salts. Formations containing magnesium carbonate, such as the new Red Sandstone and the Permian, usually yield waters in which the hardness is due to magnesium bicarbonate.

The word *hardness*, implying the hard or harsh feeling to the hands in washing, is thus used in a purely technical and commercial sense. In very hard waters the curds which are formed before a permanent lather is produced by the soap are often considerable, whereas in distilled, or a very soft water, a lather will be obtained almost immediately, and little or no precipitate will be formed in the water. Natural fats are converted into soaps by heating with soda or potash. This process effects the decomposition of the fat into the potash or soda soap, or salt of the fatty acids which exist in the fat in combination with glycerine. The hard soaps contain soda, whilst soft soap contains potash; when dissolved in water they both yield a solution of the well-known soapy feel, frothing and forming a lather on shaking. The other metallic salts of these fatty acids are insoluble in water, so that when a soap solution comes into contact with a hard water it is decomposed, white curdy precipitates of lime or magnesia soaps are produced, and at the same time the solution ceases to have a soapy feel, and loses the property of lathering.

When a water containing earthy bicarbonates in solution is boiled, an escape of gas will be noticed, and gradually a white precipitate will be thrown down, with a corresponding loss of hardness. The white precipitate produced consists of the carbonates of lime and magnesia formed by the decomposition of the bicarbonates, and as this change takes place on boiling, when the hardness of a water is due solely to presence of these salts, it is said to be *temporary*. On the other hand, the sulphates, chlorides, and nitrates of lime and magnesia are soluble in water, even in the absence of carbonic acid, and are not precipitated on boiling. They, therefore, constitute what is known as *permanent* hardness, or hardness after boiling.

For purposes of comparison, both forms of hardness are recorded in terms of the amount of dissolved carbonate of lime that would decompose and precipitate the same amount of soap. A measured volume of the water, usually fifty cubic centimetres, is taken, and "Clark's soap-test" (a definite amount of soap dissolved in proof spirit) is added from a burette until a permanent lather is produced. Each cubic centimetre of soap solution used represents one grain per gallon of *total hardness* estimated as carbonate of lime. Another measured quantity of the water is then boiled for about half-an-hour, until the bicarbonates are decomposed, filtered, if necessary, and the soap test again added from the burette until a permanent lather remains. This second reading gives the *permanent hardness* in terms of carbonate of lime, and the difference between the two values is the *temporary hardness.*

Hardness is usually recorded in degrees, *i.e.*, grains of carbonate of lime per gallon, equivalent to the soap-destroying power of the water under examination. From this number the parts per 100,000 can be obtained by multiplying by ten and dividing by seven. Since a perfectly pure water requires a small amount of soap before it produces a lather, some analysts are accustomed to deduct one degree from the reading to correct for this consumption. It is, however, best not to do this, as the figure required is the actual soap-consuming power of the water. Hardness determinations by different analysts often show slight discrepancies, owing to the above correction and to variations in the time of boiling and other causes.

Statistics from a number of towns show that the hardness of the water supply does not produce any perceptible effect upon the mortality, notwithstanding the fact that it is commonly held that hard waters tend to induce gout and calculous disorders. It is, however, certain that a change of water produces frequently as much effect as a change of air, and that persons who are habituated to a soft drinking water experience slight derangements of the digestive system on partaking of hard water for a few days.

For industrial and general domestic uses, a hard water has very serious disadvantages. The waste of soap alone is generally stated to amount to twelve pounds per 10,0C0 gallons of water for every degree of hardness. From the author's experiments, and from calculation, the quantity is probably rather less than the above, but may be safely estimated as from nine to ten pounds per 10,000 gallons for every degree. Not only does a hard water cause this serious waste, but the curd produced occasions a greasy deposit in sinks, pipes, and utensils, and forms one of the difficulties in dealing with sewage. When soda is added in washing to overcome the hardness, the fabrics are more or less injured, and insoluble earthy soaps are left in the fibre. For most industrial purposes a soft water is indispensable, and, with the exception of London, all great manufacturing centres have soft supplies. The woollen trade of Bradford would be seriously affected if that town had a hard water supplied to it; and (as already mentioned) Glasgow is estimated to save £36,000 annually in the matter of soap since using Loch Katrine water.

In cooking, a hard water is objectionable, as a deposit of lime salts is formed upon the surfaces of tea-leaves, meat, vegetables, &c., which hinders their extraction or hardens their tissues. It has been asserted that "ten ounces of tea made with soft water is as strong as eighteen ounces brewed with hard water;" and M. Soyer, in his evidence before a Royal Commission, proved that in the making of soup more meat is required with a hard water, and the operation takes a longer time. Vegetables have their colour darkened by the action of the carbonate of lime. For these reasons, it is a common practice to add a little bicarbonate of soda to the water in culinary operations. In baking, the dough rises better, and bread is lighter in colour, when soft water is used.

Brewers and distillers find a soft water very desirable, as, when the water has a high temporary hardness, the refrigerators become coated with a non-conducting scale of carbonate of lime mixed with organic matter, which is often very thick and difficult to remove. The presence of a large quantity of carbonate of lime makes the water alkaline, and so hinders the fermentation and favours the growth of unhealthy organisms. Permanent hardness, on the other hand, seems a condition for the brewing of light-coloured ales, and Burton has gained its reputation from the sulphate of lime which is present in the water of the Trent and wells in the neighbourhood. So much is this the case that, in other localities, sulphate of lime, as gypsum, is added by the brewer when the water supply is deficient in this ingredient.

The fouling or furring of steam boilers is due to the deposit of earthy salts which is formed on boiling and evaporation. The reactions which take place in water heated to a high temperature under pressure are different to those which obtain in water boiling in an open vessel. The carbonic acid is less easily disengaged, and consequently the carbonate of lime is deposited more slowly. The incrustation given by supplies whose hardness is mainly temporary, such as Chalk waters, the Thames, and most other rivers, takes the form of warty, detached plates, or cauliflower-like masses, which are fairly friable, and do not adhere very strongly to the iron. Such boiler deposits, therefore, do not present any serious difficulties beyond the trouble and expense of cleaning the boiler from time to time. At the same time, careless removal of the scale by workmen may cause damage to the boiler-plates, and in most cases it is more economical to soften the water before use.

"Selenitic" waters, or those heavily charged with sulphate of lime, and magnesian waters containing magnesium chloride and sulphate, deposit a crust which is very hard and crystalline. When chloride of magnesium is present, the heat causes this salt to be decomposed, and hydrochloric acid is produced, which is given off with the steam in small quantities, and causes corrosive effects which may be of a serious character. Magnesium hydrate is at the same time deposited in the crust, according to the equation :—

$$MgCl_2 + 2H_2O = Mg(OH)_2 + 2HCl.$$

This decomposition is retarded in the presence of alkaline chlorides, like common salt, so that sea water, although it contains a large quantity of magnesium chloride, may be evaporated nearly to dryness without any evolution of hydrochloric acid, and even at the high temperature of boilers the decomposition is very limited. The addition of salt to such waters has therefore been suggested as a remedy for this pitting action, but in most cases it would be better to use a softening process before the water enters the boiler. The magnesium hydrate, which is invariably found in crusts from magnesian waters, owes its origin mainly to the decomposition of the magnesian salt by the carbonate of lime previously deposited, the carbonic acid escaping, as shown by the equations :—

$$CaCO_3 + MgCl_2 = CaCl_2 + MgCO_3.$$
$$CaCO_3 + MgSO_4 = CaSO_4 + MgCO_3.$$
$$MgCO_3 + H_2O = Mg(OH)_2 + CO_2.$$

Vivian Lewes points out that this explains the almost entire absence of calcium carbonate from marine crusts, and also that ferric chloride is not found in the water, which would be the case if corrosion or pitting were due to hydrochloric acid. At the same time, it is quite possible for both actions to occur, and some corrosion may take place before the calcium carbonate has time to take up the hydrochloric acid, the iron being afterwards precipitated. It will be noticed, that all the incrustations from marine boilers contain a considerable quantity of iron (Table B in Appendix).

Calcium chloride and nitrate, and also magnesium nitrate, although present in most hard waters, are so soluble in water that they are never precipitated, and are consequently not found in boiler crusts. Some soluble salts, like sodium chloride, form slightly soluble double salts with the magnesium chloride and sulphate, and are therefore occasionally met with in deposits. Magnesium sulphate is very soluble in water, but, in presence of calcium chloride and carbonate, reacts with them, and thus eventually is found as magnesium hydrate in the crust. Calcium sulphate is, as already mentioned, the most objectionable constituent of waters for use in steam boilers, as it yields a hard, crystalline scale, which is exceedingly difficult to remove. When first deposited it is hydrated in the form of gypsum, $CaSO_4 2H_2O$, but slowly changes into anhydrite, $CaSO_4$, which is still denser and more insoluble. At a temperature of 150° C. (300° F.), calcium sulphate is nearly insoluble in either salt or fresh water, and is therefore almost completely deposited under such conditions. If the water be heated under pressure above this temperature before entering the boiler the salts are deposited outside the boiler, but the difficulty is only transferred to the tubes of the heater, and Tilden has shown that the removal is imperfect.

Waters impregnated with sewage often have a considerable quantity of oily or fatty substances, with soda salts and ammonia, present in them. The last-named acts upon copper, and any dissolved copper will be subsequently deposited upon the iron of the boiler and cause local corrosion, or "pitting," by galvanic action. The scale under such circumstances often shows green spots, and such waters should be treated chemically before use. Moss or peaty waters are often valuable for boilers on account of their softness, and because the mud is easily *blown*. But if they contain much of the organic humus acids, they must be neutralised with lime before using, or the action upon the iron will be considerable.

Lefévre proved that the rapid pustular corrosion of steam-boilers used with some river waters was due to solid organic particles, which, by oxidation, developed pectic acid. He prevented this action with success by adding either alum or, better, ferric chloride, in quantities determined by experiment, followed by lime, to the feed-water. The purified water was easily decanted, and no longer acted on iron, and when ferric chloride was used deposited hardly any scale. In tidal rivers the proportion of admixed sea water is greatest at high tide, and as at low tide the water is generally too dirty for use in boilers, such a supply must be chosen with regard to these conditions. As a rule, however, the water of the lower part of a tidal river is quite unfit for use. Pit waters, especially from shale and coal, frequently contain acid sulphates of iron and alumina, which are most injurious to boiler-plates. Those that are not acid can be used with some advantage, as the coal-dust gives a scale which is much looser, and where such water is used on an old boiler it sometimes detaches the existing scale. Surface waters, on account of their hardness, are generally unfit for use in boilers. Some years ago, two 30 h.p. boilers, supplied from a well in Lambeth, gave such a deposit that nearly a ton of incrustation had to be removed monthly by cleaning and chipping.

An idea of the composition of boiler-crusts is given in the table (Table B, Appendix). Collet estimates the amount as follows:—" Condensing engines, when large and of very high steam economy, require about two gallons per hour per indicated h.p. for boilers, and generally twice as much for condenser water; small and inferior, but yet 'high class,' three to five; low class, in bad condition, six to fifteen gallons per hour. Three gallons is the average, equal to

3,000 gallons per day of ten hours for 100 h.p. If the water has fifteen degrees of total hardness, the deposit per working day will weigh six and a half pounds, or over a ton per annum, of which the larger portion will remain as scale, equal to thirty-five cubic feet of soft, or seventeen of hard scale." The order in which the deposition usually takes place is:— (1) Carbonate of lime; (2) sulphate of lime; (3) oxide of iron; (4) silica, alumina, and organic matter, with magnesium hydrate; (5) common salt.

These coatings are very bad conductors of heat. Rankine states that the resistance to heat of carbonate of lime is eighteen times, and that of sulphate of lime fifteen times, that of iron. The consequent waste of heat in urging the fire for steam-raising in a foul boiler is enormous. It is estimated that one-sixth of an inch of scale necessitates the use of 16 per cent. more fuel; quarter of an inch, 50 per cent.; and half an inch, 150 per cent. additional coal. These figures are probably in excess of the truth, but the loss is still very large. In addition to this, there is the damage to the boiler-plates by overheating, and a certainty of explosion if the coating should crack suddenly, and the water be admitted to the nearly red-hot iron. The scale evidently prevents a proper internal examination of the boiler. Chipping off the crust injures the boiler, and may start the rivets.

"Blowing off" for a short time at frequent intervals is always necessary, as only the deposit near the cocks is blown out. The cocks themselves are often worn out by the friction with the scale. When the whole boiler has to be blown, it should be cooled first by the very gradual injection of cold water, or any loose deposit will cake together as the water runs off. The loss of time, heat, and water, in frequent blowing off is very great. In marine boilers using salt water the neglect to blow out is often the cause of collapsed furnace crowns, the density of the water gradually increasing until it reaches the saturation point, when solid sodium and magnesium chlorides separate on the plates, even though there may be a copious supply of water; then the same non-conduction and over-heating occur as in the case with lime deposits. For this reason, condenser water (which is the spent steam condensed and used again, amounting practically to distilled water, and therefore perfectly soft) is returned to the boiler to dilute the salt water. Approximately, one ton of water per 100 h.p. per twenty-four hours is required to make up the condenser water to the right amount.

C. E. Stromeyer, at the Institute of Naval Architects (May, 1896), proposed to control the composition of water in boilers by chemical testing. At intervals a sample is withdrawn and tested by nitrate of silver, caustic soda, or carbonate of soda, to determine the salts it has acquired by concentration. The feed of condenser, distilled, or softened water is regulated in proportion. In all cases where condensed exhaust steam is used as feed-water, the boiler should never be blown out without first using the scum-cocks freely, so as to remove as much as possible of the grease and scum.

A large number of patents have been taken out for the prevention of boiler incrustations. Some of these are mechanical, introducing twigs, fibres, wires, chains, balls, or brushes to entangle the deposit, like the familiar marble in the kettle. One of the most modern, which appears to have a wonderful power of aggregating the sediment to itself, is in the form of a metal centre with radiating wires. Electricity has, of course, been invoked, the boiler being made the negative terminal, and suspended plates or chains the positive, in the hope that the hydrogen gas generated by galvanic action would protect the boiler from oxidation, hinder a crust from forming, or render it loose and friable if deposited, but the result has not answered the expectations. Spent tan, peat, moss, wheat bran, potato-pulp, chestnuts, peas (patent 3,395, 1883), and other solid materials acting mechanically, undoubtedly render the crust looser, but they clog the boiler, promote priming, and furnish so much more solid matter to remove. Treacle (patent 4,717, 1877) and glycerine (patent 4,236, 1881) are worse than useless.

Tallow and fat-oils are to be condemned, not only because they form greasy lime or magnesia soaps, which agglomerate into hard concretions, but because by the heat they are decomposed into glycerine and fatty acids, which are known to act vigorously upon iron plates. The scale where tallow is used has been found to contain 12 to 26 per cent. of iron from the plates. A sediment from a condensed steam tank where tallow was used as a lubricator contained 50 per cent. of ferric oxide, 41 of fatty matter, and nearly 1 per cent. of copper oxide from the fittings. This shows that the fatty acids, rising with the steam, penetrate the cylinder and pumps. In a great many cases considerable injury has been caused to a boiler by the presence of copper in the feed-water. For these reasons "cylinder oils" are used that consist mainly of mineral or hydrocarbon oils, not acid, and not decomposed by superheated steam. The main part of the fatty matter which always accumulates in boilers fed partially by condenser water is drawn off at intervals by the scum-cocks.

Paraffin oil, which is extensively used in America, causes the deposit to be thrown down in a pulverised form by incrusting the particles with a very thin oily coating. Such a deposit is easily blown, while in a singular manner the oil sinks into the scale already formed, and causes it to split up and be removed with facility. Indeed, it has been actually mentioned as a drawback that it so thoroughly cleanses the joints that it sometimes causes a boiler to leak. Its use is unattended by priming or frothing. But its action is only temporary, as it passes off with the steam and requires constant renewal. It should be free from solid paraffins, or "hard scale," or it will form concretions like tallow. It is recommended to be first introduced when the boiler is empty, to make an oily coating over the plates; afterwards it is added with the water, sometimes by an automatic arrangement. In buying a crude product, a careful test should be made for acidity by shaking up with distilled water and testing the water with litmus paper, since some sulphuric acid is often left behind from the purification of the raw petroleum; if any acid be found, the sample should be rejected, or the acid may be neutralised with soda.

"Soda-tar," from paraffin refining, containing caustic soda and carbonate of soda, is a well-known anti-incrustator.

Chemical incrustation-preventers have been numerously patented and advertised, and no doubt many of them yield a large profit to their manufacturers. The majority are, however, useless, and many injurious. Tannin, as contained in extracts of various barks, gives a loose and friable tannate of lime, but it attacks iron dangerously, and has no effect on the permanent hardness of waters. If tannate of soda be used, its virtue is little greater than the soda it contains, while its expense and the ease with which it decomposes are fatal defects. Any acid preparation designed to dissolve the scale will attack the iron of the boiler-plates also. Ammonium chloride has also this objection, as by dissociation with the heated steam it generates ammonia gas and hydrochloric acid, $NH_4Cl = NH_3 + HCl$, both of which originate serious local mischief to metal parts, either iron, copper, or brass.

Caustic soda and sodium carbonate are the most inoffensive members of the class, but if in excess they cause foaming and wet steam, especially in locomotives, and are apt to corrode the fittings, particularly asbestos packing. They are sold at very large profits to manufacturers, and are known under numerous fancy names. Sometimes they are coloured with litmus powder or aniline dyes. The scale from soda crystals is often very hard and difficult to remove. Borax and boric acid (3,721, 1878) have nothing to recommend them. The triple sodium phosphate, Na_3PO_4, is said to have given good results; the product, phosphate of lime and magnesia, has been proposed to be sold as manure. "Baudet's patent" is sodium hyposulphite, glycerine, and rainwater. Sulphite of soda ("Morgan's compound") has also been recommended, while in Germany barium chloride has been used to turn the calcium sulphate into the soluble calcium chloride, leaving a pulverulent precipitate of barium sulphate.

A. Nieske (*Wochenschr. f. Brauerei*, 1895, 215) employed chromates as incrustation preventers, stating that under the conditions of pressure in a boiler, calcium carbonate and sulphate are decomposed by a soluble chromate to form a light, non-adherent sludge of calcium chromate, readily removed by blowing off, the plates remaining clean even after protracted working, and showing no corrosion. For this purpose the waste of chrome-dyeing has been used with success at Rochdale (Tatton, *Proc. Inst. Civ. Engineers*, 1900, cxl., part 2).

Sodium Fluoride.—Doremus gives the following prescription for preventing scale: "Determine the lime and magnesia in the water; multiply the CaO by 1½ and the MgO by 2. The sum gives the amount of sodium fluoride required to throw down the lime and magnesia. One-fourth of this quantity suffices, as the earthy fluorides do not adhere, and form nuclei for the other hardening salts to deposit. Sodium fluoride is now manufactured for the purpose at a reasonable rate by the American Fluoride Company, New York. Two ounces per 1,000 gallons is the average quantity added to the feed."

Any chemical reagent is better added outside the boiler before the water enters. Even if used in the feed-heater it chokes up the tubes, and requires continual removal. In any case, an analysis of a compound, and of the water for which it is proposed to be used, should be obtained, and chemical advice sought, or heavy expense and injury to the boiler may ensue. Many large firms expend as much as £150 a year on incrustation-preventers, which amount would go a long way towards the cost of the far more preferable preliminary softening.

In works where large quantities of water are used, as the price charged for town's water is generally far above the cost of pumping, the saving through sinking a well, if a spring or river is not near, in large establishments often amounts to more than £1,000 a year. The water, if hard, must be previously softened. To show the importance of procuring analysis of the waters, we may mention that considerable changes in the composition sometimes occur owing to atmospheric conditions, to fresh strata being tapped, or to new factories being established on a stream. Clear water may be obtained at great cost from a well or other source, and may be unfit for use on account of its hardness, whereas turbid water from a neighbouring stream may, by simple filtration or deposition, furnish a suitable supply at a much cheaper rate.

Methods for softening Water.—It has already been mentioned (p. 219) that temporary hardness can be removed by boiling, but this method is costly, and causes a loss of water. Boiling is said to cost not less than 1*s.* per 1,000 gallons, while lime costs about a farthing. Professor Clark, about 1840, patented his well-known process of adding lime-water, so as to combine with the carbonic acid which kept the earthy carbonates in solution, with the result that both portions of carbonate of lime were precipitated.

Calcium Bicarbonate. Slaked Lime.

$$CaCO_3,CO_2 + Ca(OH)_2 = 2CaCO_3 + H_2O.$$

Thus cnly the permanent hardness was left, plus about two grains per gallon of carbonate of lime in solution. The precipitate was allowed to deposit in reservoirs or tanks, and the clear water drawn off, but the area required by these tanks was considerable, their sediment settled slowly, the finer particles were apt to remain suspended and render the water milky, and the carbonic acid of the air also re-dissolved some of the earthy carbonates.

The Porter-Clark modification mixes the lime with the water by paddles, and then passes it through filter presses of cloth, saving much time and space, and ensuring a clear product. The quicklime is preferably slaked first; a good quality should be employed (Buxton lime is reputed the purest), as far as possible free from stones and clinkers. Good lime ought to contain at least 90 per cent. of free CaO. The best generally is "stone lime" from limestone. Grey and shell lime from chalk often contains a large quantity of clay and stones. It should be almost entirely soluble in hydrochloric acid without much effervescence (which would show carbonate from underburning or exposure to the air), and not more than 4 or 5 per cent. should be insoluble in water. It should also give no smell of sulphur compounds, and should be kept away from air. Lime-water can be tested by blowing through it, when it should give a heavy cloud, or by nitrate of silver. Its strength is determined from time to time by sta dard acid.

In the softening process the undissolved lime is allowed to settle: the clear lime-water, containing about sixty to seventy grains of CaO per gallon, being agitated with the water. After the deposition of the main part of the precipitate, the still turbid liquid passes on to the filters. The process is made continuous by running the lime solution into the water as it passes through a mixing chamber. To ascertain the proper proportions, the lime-cock is at first turned on until the lime is in excess, as shown by withdrawing a sample of the softened water, and testing it with nitrate of silver, when a grey-brown precipitate of silver hydroxide is obtained. The cock is now turned off until a sample shows no brown, but only a white precipitate: the proportions are now correct. Another test is a drop of phenolphthalein solution: excess of lime produces a red colour. An automatic arrangement, worked by steam or water, maintains the supply of lime-water at the right proportion to the flow of the water. Further tests must be made from time to time, as waters change somewhat in composition from day to day.

An intermittent system without filtration consists of two lime-water tanks, in which the lime-water is prepared one day and used the next, and three softening tanks, of which two are for use on alternate days, and the third is for reserve while cleaning out, &c. The lime is run into one of the softening tanks and the hard water pumped in; next day the carbonate of lime has deposited, and the clear water is run off for use. For a moderate-sized town requiring 250,000 gallons a day, the two lime-water tanks should hold 40,000 gallons each, and the three softening tanks 300,000 gallons each, or a total of 980,000 gallons.

The objections to this system are (1) the imperfect mixing of the solution with the hard water; (2) the cost of construction of the tanks, and the large area of ground required; (3) the heavy working expenses.

Clark's process removes only the temporary hardness. Lime does not affect calcium sulphate; with magnesium salts, it indeed precipitates magnesia, but it leaves lime salts instead, so does not reduce the permanent hardness; although, under certain circumstances, it precipitates the bicarbonate of magnesia. Waters permanently hard, therefore, require additional treatment with an alkaline mixture, which will vary in composition and amount according to the character of the water.

Caustic Soda, or sodium hydrate, NaOH, of commerce contains 50 to 70 per cent. of sodium oxide, Na_2O (theoretical 77·5), with water and some carbonate, chloride, sulphate, thiosulphate and insoluble matter. Only the hydrate and carbonate are useful, and sulphide must be absent. The 70 per cent. is generally used. As on opening it becomes moist and absorbs CO_2, a whole drum should be dissolved in the proper quantity of water in an unpainted iron tank, *kept well covered*, and the solution siphoned off as wanted, the strength being determined by gravity or by standard acid. It can be prepared direct by boiling sodium carbonate with its equivalent of lime and decanting from the carbonate of lime; or lime and sodium carbonate are mixed together and dissolved in the water to be treated.

$$Na_2CO_3 + Ca(OH)_2 = CaCO_3 + 2NaOH.$$

Sodium Carbonate.—The ordinary crystals have the formula $Na_2CO_3,10H_2O$, and contain only 37 per cent. of the anhydrous carbonate, with 63 per cent. of water of crystallisation. They are called "soda crystals," "Scotch soda," "washing soda," or simply soda. Brunner, Mond & Co.'s concentrated crystal soda is a sesquicarbonate, containing 70 per cent. of Na_2CO_3, in the form of small crystals readily soluble in water, and presents the great advantage of less weight and bulk, and therefore less freight than "soda crystals." The so-called "carbonate of soda" of the shops is *bicarbonate*, $NaHCO_3$, and is useless for softening.

The use of these three agents, lime, soda, and sodium carbonate, is often wrongly and imperfectly stated, and the solutions added by guesswork, hence the frequent failures in attempts at commercial softening. The total and permanent hardness of the water, and the strength of the reagents must first be known; these require simple operations in volumetric analysis by soap-test and by standard acid solutions. If the water be fairly constant in composition, and a sufficient stock of the solutions be made, the determinations need not be frequently repeated. But the softened effluent must be occasionally tested with nitrate of silver, or by the taste, to see that there is no excess of the chemicals, as such an occurrence would be injurious for many purposes. It is better in most cases not to carry the precipitation to its final limit, but to leave the softened water with about three to five grains of hardness. Sometimes a partial softening is easily and cheaply effected, where to go further would be costly. The following are the equations on which the calculations are based, taking calcium sulphate as the representative of permanent, and calcium carbonate of temporary hardness.

$$(a)\ CaSO_4 + 2NaOH = Ca(OH)_2 + Na_2SO_4.$$

$$(b)\ Ca(OH)_2 + CaCO_3CO_2 = 2CaCO_3 + H_2O.$$

The reactions are almost simultaneous, thus :—

$$(c)\ CaSO_4 + CaCO_3CO_2 + 2NaOH = 2CaCO_3 + Na_2SO_4 + H_2O.$$

The remainder of the temporary hardness will be removed in the usual way by lime :—

$$(d)\ CaCO_3CO_2 + Ca(OH)_2 = 2CaCO_3 + H_2O.$$

The result may be summarised thus :—

RULE I.—*For a water in which the temporary hardness exceeds the permanent, caustic soda must be added equivalent to the permanent hardness, and lime equivalent to the temporary hardness minus the permanent hardness.*

In waters of great permanent hardness due to lime salts, carbonate of soda must be used instead of caustic :—

$$(e)\ CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$

If it be necessary to remove also the temporary hardness, lime must be added *subsequently*, as in equation (*d*) above. We should then have:—

Rule II.—*For a water in which the permanent hardness due to compounds of lime, exceeds the temporary hardness, carbonate of soda must first be added in proportion to the permanent hardness, and then, if necessary, lime equivalent to the temporary hardness.*

Every degree of hardness, reckoned as carbonate of lime, whether as grains per gallon, or as parts per 100,000, is equivalent to 0·8 grains, or parts, of $NaOH$, to 0·56 of CaO or 0·74 of $Ca(OH)_2$, to 1·06 of the anhydrous Na_2CO_3, or to 2·86 of the crystallised $Na_2CO_3,10H_2O$.

For magnesian waters the case is different, and here it will be useful to correct a prevalent mis-statement. It is usually asserted that calcium *and magnesium* bicarbonates are precipitated on boiling. But magnesium carbonate is much more soluble than is commonly supposed; it is only partially thrown down on boiling, the main part remaining in solution *as a part of the permanent hardness*. On the other hand, magnesium chloride, if present in any considerable amount, is liable to be decomposed by the boiling, hydrochloric acid escaping, and a basic chloride of magnesium depositing. This portion of the magnesium salts would therefore figure in the soap-test as *temporary hardness*. Magnesium chloride also reacts with the precipitated calcium carbonate, as mentioned in speaking of steam-boilers (p. 224), yielding dissolved calcium chloride, and at first basic magnesium carbonate, and then, finally, insoluble magnesium hydrate. Magnesium sulphate can also interchange with sodium chloride, forming sodium sulphate and magnesium chloride, which then may undergo the above changes, although the presence of alkaline chlorides, by forming double salts, renders it more stable.

Lime decomposes magnesium salts, throwing down magnesia, and leaving a sulphate, chloride, or nitrate of calcium as the case may be. In neither case is the hardness reduced; in that of the sulphate it is rendered still more objectionable. The chlorides and nitrates of calcium, however, give no fur in steam boilers, as they are so soluble. Waters with much chloride or nitrate of magnesium are improved by lime for use in steam boilers, while those containing magnesium sulphate are deteriorated; the relation to soap is little changed. For an improvement in this direction caustic soda must be employed, but the separation of the magnesium hydrate is never complete. The soap-test is not a safe guide to the soda required; a chemical analysis must be made, and eighty parts of NaOH used for every forty parts of MgO, the lime salts being dealt with, if necessary, by the other reagents, as above described. The process is more difficult, but a considerable improvement may be effected. The magnesium present as carbonate is almost entirely thrown down by lime.

$$MgCO_3 + Ca(OH)_2 = CaCO_3 + Mg(OH)_2.$$

Davis (English patent 5,655, 1887) used tri-sodium phosphate, Na_3PO_4, especially for softening magnesian waters, under the name of "Tripsa," employing 2·5 grains for every degree of hardness. Besides sodium fluoride (p. 234), Doremus has patented the use of a double phosphate and fluoride, Na_3PO_4, $NaF,12H_2O$, in large crystals of definite composition and permanent in air, whereas Na_3PO_4 itself readily becomes damp and alters. The phosphatic precipitates have some value as manure. In waters which are not potable through the purgative action and bitter taste of magnesium salts, such as occur in the Permian and other formations (see Table D in Appendix), lime, by substituting calcium for magnesium, would probably in great part remove the objection, while in this case if soda were used, the sulphate of sodium formed would be little less objectionable than the sulphate of magnesium. Chloride of magnesium with soda would of course form common salt. It must be understood that the use of soda somewhat increases the total dissolved matter, as the corresponding soda salts are left in solution, therefore the softened water, if used for too long a period in a boiler without washing out, will cause priming and finally a hard scale. Permanent hardness costs about nine times as much to remove as temporary (Archbutt).

The calculation of the amount of reagents required will be simplified by the following scheme, which gives the weight in grains of the reagents required to be added per gallon :—

A.—When Temporary Hardness is more than Permanent

$\frac{8}{10}$ of the Permanent Hardness = Soda, NaOH, in grains per gallon.

And $\frac{56}{100}$ (Temporary Hardness *minus* Permanent Hardness) = Quicklime, CaO, in grains per gallon.

Or $\frac{74}{100}$ (Temporary Hardness *minus* Permanent Hardness) = Slaked Lime, $Ca(OH)_2$, in grains per gallon.

B.—When Permanent Hardness exceeds Temporary.

$\frac{106}{100}$ of the	Permanent	Hardness	= Anhydrous sodium carbonate, Na_2CO_3.
Or $\frac{151}{100}$,,	,,	,,	= "Brunner-Mond's concentrated crystallised soda."
Or $\frac{286}{100}$,,	,,	,,	= "Soda crystals," $Na_2CO_3,10H_2O$
Afterwards $\frac{56}{100}$,,	Temporary	,,	= Quicklime, CaO.
Or $\frac{74}{100}$,,	,,	,,	= Slaked lime, $Ca(OH)_2$.

The amount is given as quicklime, not because it is added in that form, but because it is easier to calculate the strength of lime and lime water as CaO.

C.—For Magnesian Waters.

$\frac{56}{40}$ of the MgO found by analysis gives the weight of Quicklime, CaO, required for softening one gallon.

Or $\frac{80}{40}$, or twice the MgO = Soda, NaOH.

The lime salts can be afterwards treated, if necessary, according to A or B above. When a hard supply is replaced by a softened water it is always found that the old scale begins to loosen and fall off, sometimes causing the boiler to leak. As it is not advisable to push the softening to its lowest limits, the above theoretical quantities of reagents should be reduced by from $\frac{1}{10}$ to $\frac{1}{5}$. If an excess of lime is used the liquid is often opalescent and will not filter.

By the softening process a water is rendered clear, its colour is usually diminished, and a large proportion of the organic matter, and sometimes all the bacteria, are entangled and removed. The palate soon becomes accustomed to the slight difference of taste.

In the Sixth Report of the Rivers Commission, Sir E. Frankland urged that the water companies ought to use Clark's process for softening their waters "before they were allowed to raise fresh capital."

In the case of clean water, the lime precipitate produced by softening can be used for commercial purposes, or can be re-burned to quicklime, but in dirty waters it is very much discoloured, and is usually thrown away.

Softening apparatus.—These are made in many distinct patterns, which aim at improving the process in different ways:—

1. *To economise space.*—Several forms consist of divided iron tanks, with cisterns affixed above for the regulated supply of water and chemicals. The mixture passes down one side, partially settles, and passes upwards on the other through filters of various construction, the cleared and softened water emerging through a pipe at the top. Some types are designed on a small scale for softening a domestic supply. The

softening solutions are generally soda or carbonate of soda; the powders contain lime, and are often sold at a large profit.

Many of these contrivances are exceedingly ingenious, but also particularly liable to get out of order. The regulating, and withdrawal of sludge, are delicate operations, and on the whole, except in remote neighbourhoods, where no other course is possible, private softening on a small scale by a machine cannot be recommended. It would probably be better to have a large iron cistern of known capacity, to add the chemicals definitely in known strength, to stir thoroughly, allow to subside, and dip out or siphon off the clear water as wanted.

In kitchen boilers, however, the use of a hard water occasions continual trouble and expense, and great danger of explosion. If rainwater apparatus cannot be obtained, or a softer local supply, some form of automatic softener will become necessary.

2. *To insure the proper proportions and mixing of the reagents.*—At the locomotive sheds of the London and North-Western Railway, at Camden Town, 7,000 gallons per hour of chalk well-water from Watford is continuously reduced from seventeen or eighteen degrees of hardness to four degrees, under a pressure of sixty pounds per inch (Porter-Clark process). The lime is churned in a horizontal cylinder, all the mixing and delivery being accomplished by a water-motor worked by the pressure of the water itself, therefore adjusting its

rate of supply to the current of water. Filter presses separate the sediment.

The Porter-Clark process is specially adapted for waters of high temporary hardness, like those of London. At Duncan's sugar refinery, Victoria Docks, it was found that the pipes were becoming rapidly choked by carbonate of lime, owing to the removal of carbonic acid by the vacuum in the sugar evaporation. Hence that process was adopted, and worked successfully. They found that "if the proportion of lime was too little there was great difficulty in filtration, but by arranging the lime valve so as always to have a slight excess, the difficulty was removed; the filtration was also much easier if the water was warmed (the deposit becomes crystalline). The slight excess of lime in the boilers did not cause any trouble. The water lost its yellow colour and became blue."

The following illustrations show different forms of the plant used for working the Porter-Clark process:—

Fig. 40 is an apparatus that treats continuously 1,200 gallons per hour. The square tank on the right contains the lime water, which is transferred to the central softening cylinder by a small feed-pump. On the left is the filter press.

A smaller apparatus for softening and filtering 350 gallons per twelve hours, and working under pressure from the main without any motive power, is shown in Fig. 41. The softened water passes upwards to the cisterns of the house.

Where motive power is not available, a modification is used called the "Industrial" purifier. A pair of upper tanks contain lime water and other solutions for working twenty-four hours daily. The hard water and the solutions are introduced at the bottom of the lower tank, and the mixing is completed by

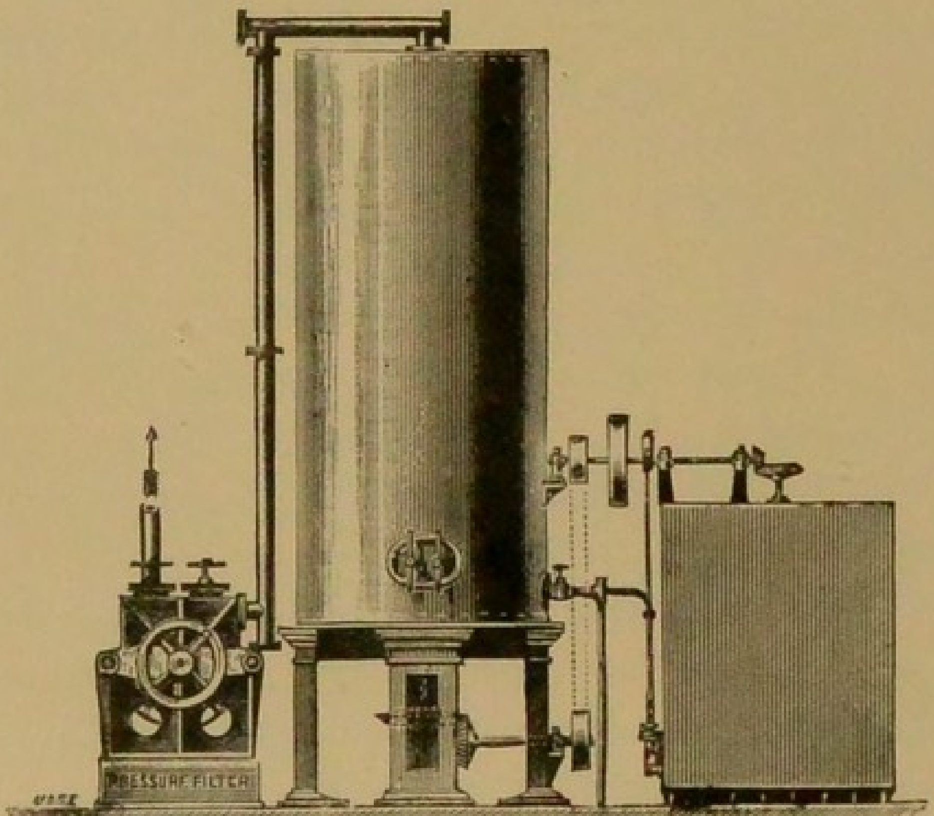

FIG. 40.—Porter-Clark Water-softening and Filtering Plant (1,200 gallons per hour).

causing the liquid to issue in a very thin stream over the edge of a trough fixed internally round the top of the lower vessel. The materials have to be carried up, and there is a corresponding inconvenience and loss of time as compared with working with a motor on the ground level.

Fig. 42 is a recent apparatus intended to reduce the cost of cleansing the filters daily. The longer tank consists of a mixing chamber and a filtering compartment. The water passes through a series of

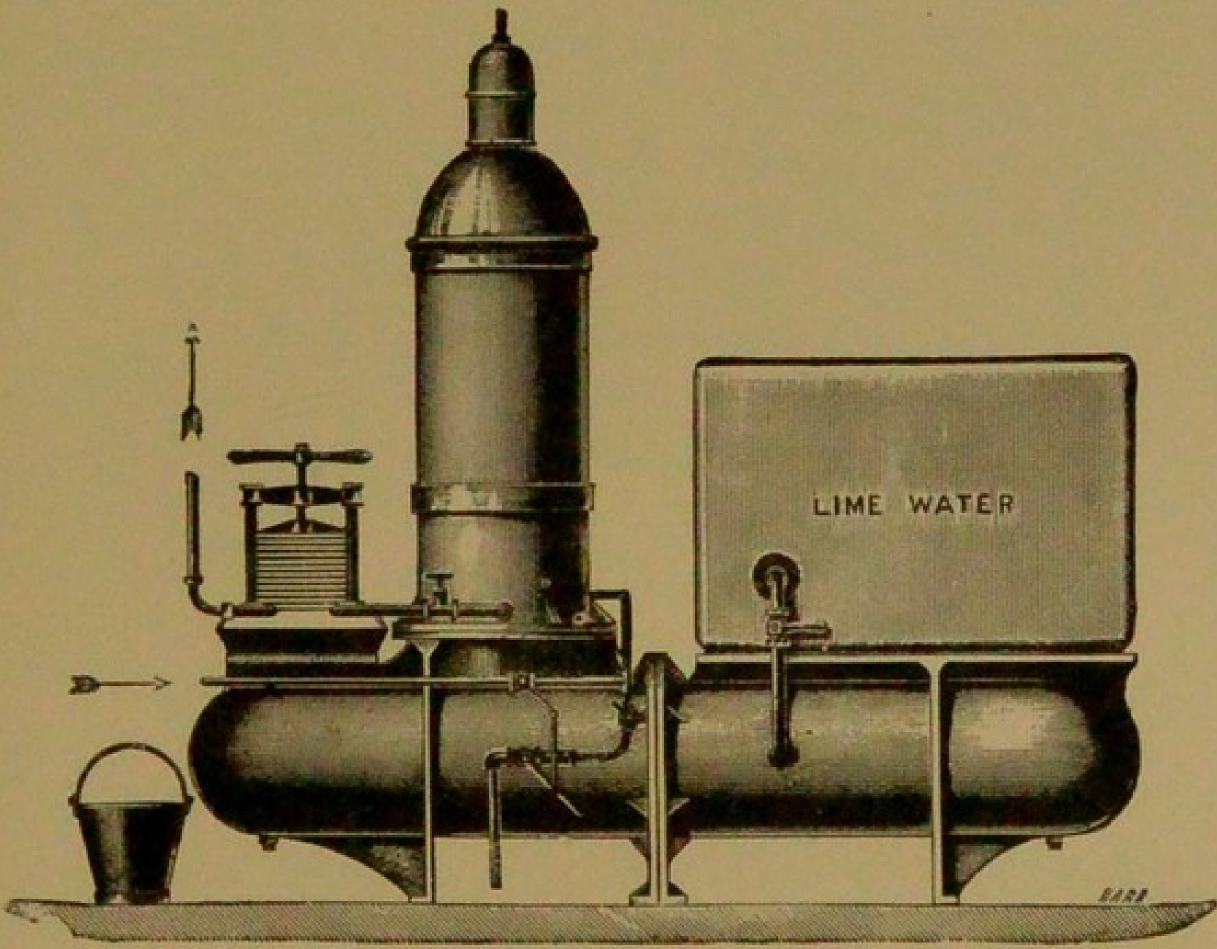

FIG. 41.—Porter-Clark Water-softening and Filtering Plant (350 gallons per 12 hours).

pendent filtering mats and cloths into perforated pipes and then into a main pipe connected with a suction-pump

Maignen uses a powder called "Anti-calcaire," of lime, carbonate of soda or caustic soda, and alum; the latter on dissolving gives aluminate of soda, which aids in the precipitation and clarifying. The powder is contained in a vessel over the cistern (Fig. 43), and its delivery is regulated by a kind of water-wheel worked by the incoming stream of water; the wheel also aids in the mixing; the resulting mixture is cleared by a filtering bed placed in a second compartment of the cistern. A constant supply of water is required, and the results are generally good, Maignen, and also Archbutt (*J. Soc. Chem. Ind.*, 1891, 519) state that the chemicals give practically the same result whether added together or separately.

I may here note that the soap test, with experience, gives rapid and useful results if (1) the sample is diluted with distilled water till the 100 c.c. taken have about 10 degrees of hardness: (2) at the end the titration is overdone to see that a strong lather is obtained, thus avoiding the mistake often caused by the "pseudo-point" of magnesia. But Hehner's method is now widely preferred. The alkalinity of 500 cc. of the water is determined by standard acid and methyl orange, and recorded as temporary hardness in terms of $CaCO_3$. The remaining lime and magnesia are now precipitated by boiling 250 cc. with a known volume of decinormal sodium carbonate, filtering and titrating with acid. The sodium carbonate consumed gives the permanent hardness. In important cases a mineral analysis is made; the CaO and MgO calculated to $CaCO_3$ give the total, and the CO_2 gives the temporary hardness. For softening, if lime equivalent to the total, and sodium carbonate to the permanent, hardness be used, more precipitate has to be removed than with soda and lime (p. 240).

3. *To remove the precipitate rapidly and completely.*—Settling reservoirs being slow in action and occupying much space, many other devices have been tried.

The Archbutt-Deeley process, as carried out at the Midland Railway Works, Derby, employs two tanks side by side. In one the water is mixed with lime, soda, and sometimes sulphate of alumina, in proportions determined by analysis. The solutions are injected through a rose by means of a steam blower. Since the particles of an old lime precipitate form

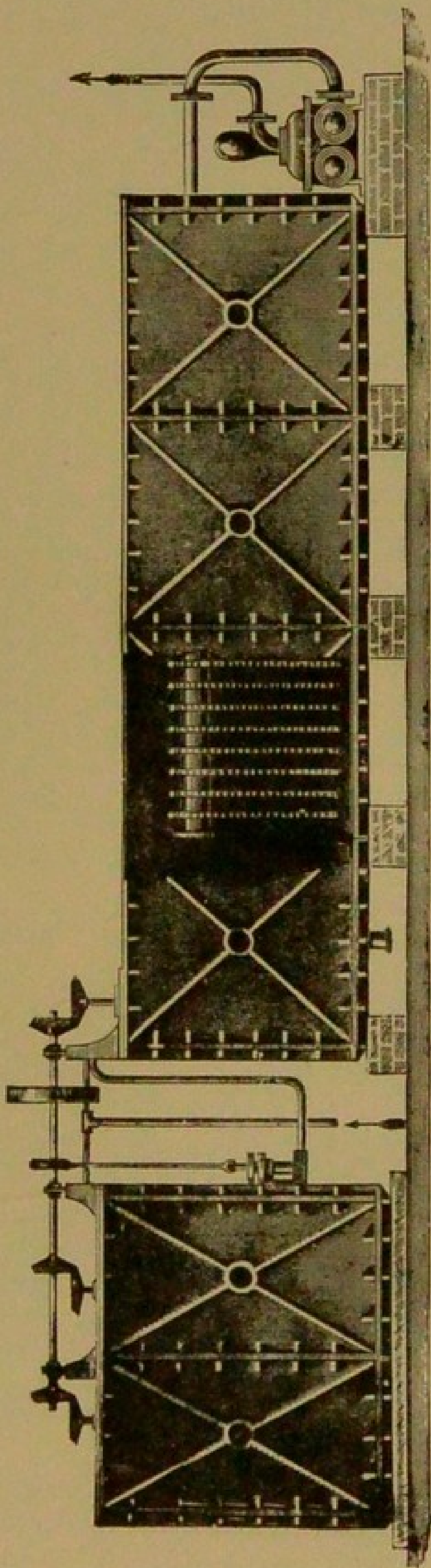

Fig. 42.—Porter-Clark Water-softening and Filtering Plant.

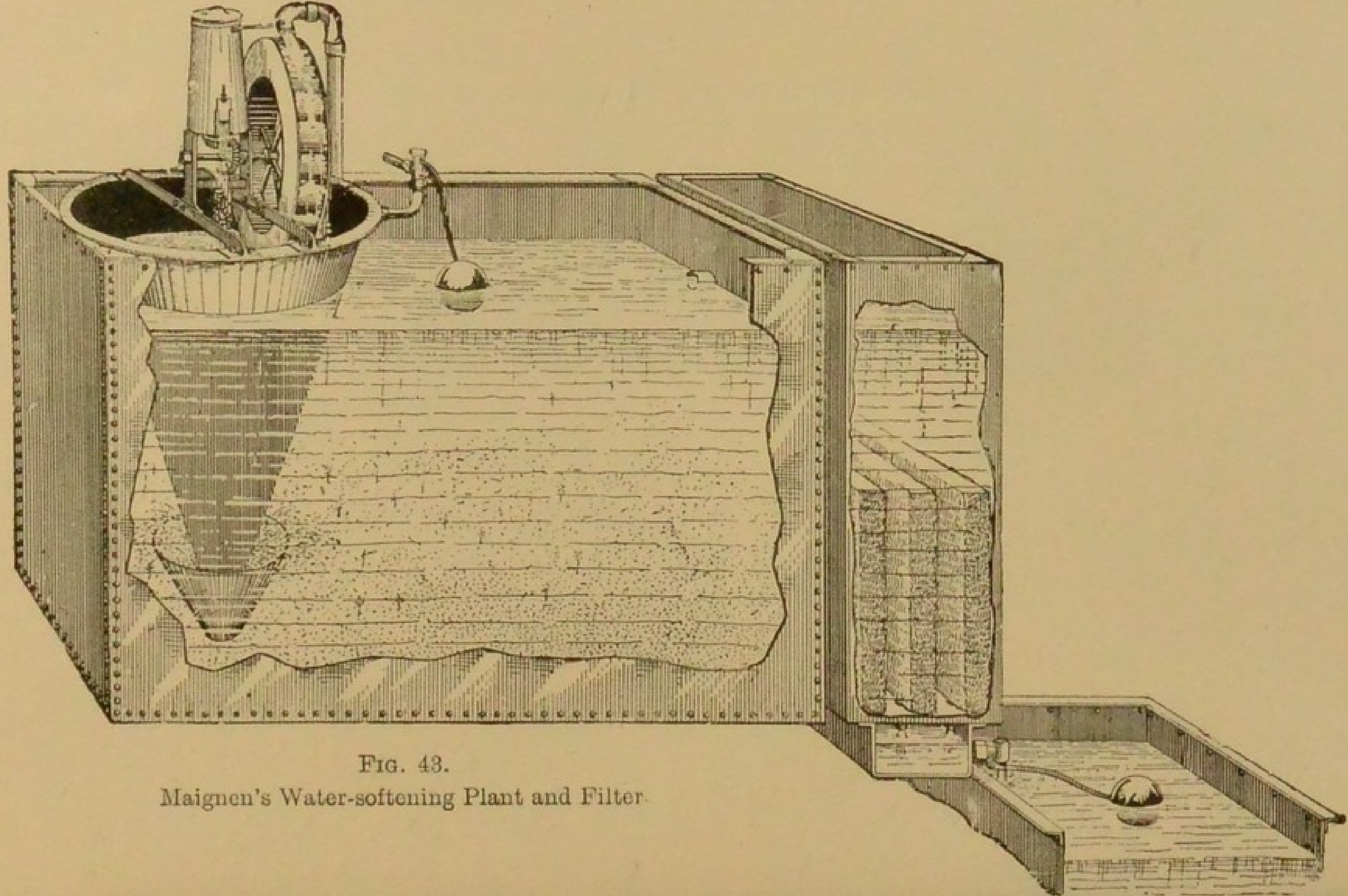

Fig. 43.
Maignen's Water-softening Plant and Filter.

nuclei, round which the new deposit aggregates, they are left in the tank to promote the separation. By means of a three-way cock, a blower injects air in bubbles through perforated pipes at the bottom of the tank, stirring up the old precipitate and mixing the two. The settling then takes place rapidly, the water, practically clear, is run off in from half-an-hour to an hour into the second tank. Magnesian waters are apt to deposit hydrate or carbonate of magnesia in the cocks and tubes. To prevent this, the water is re-carbonated after the process by forcing in carbonic acid gas generated by a small coke stove. The method seems in great favour with brewers and steam users.

Atkins's process, as carried out at Southampton waterworks, is mainly distinguished by the form of filter used to finally clean the softened water after settling. The filtering medium consists of an endless band of cotton cloth travelling slowly. It first passes round a perforated horizontal revolving cylinder with a hollow axle, immersed for nearly its whole depth in a cistern containing the liquid to be clarified, so that the water filters inwards, leaving the deposit on the outside of the filter cloth.

More or less of a vacuum is maintained in the cylinder by pumps or by a fall in the outlet pipe, so as to aid the filtration by the pressure of the air. The cleared water passes out through the hollow axle. The cloth as it emerges is passed through a second part of

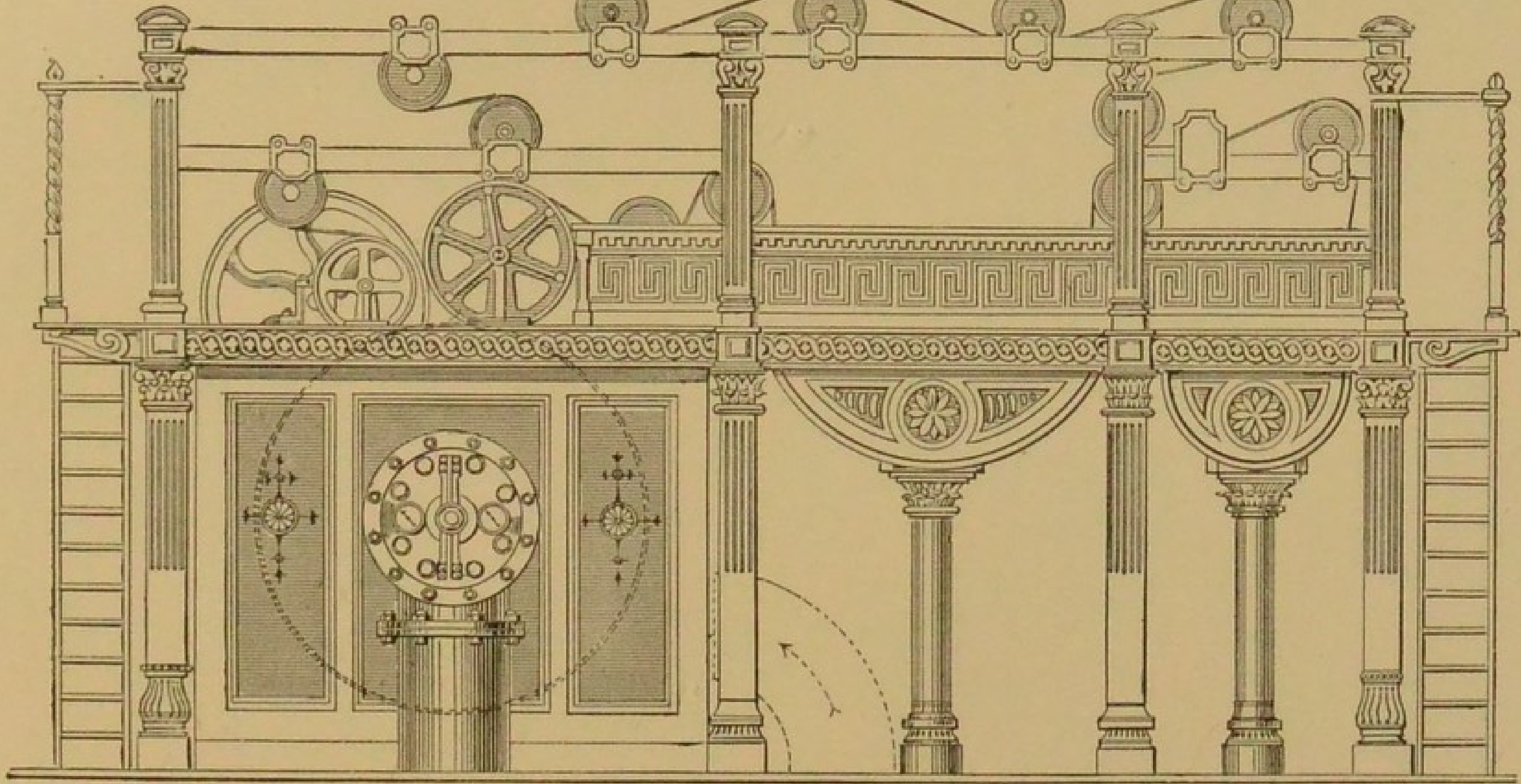

FIG. 44.—Atkins's Water Softener and Filter.

the machine, where it is rinsed, boiled, steamed, and returned overhead by a series of rollers to the filtering tank. By this ingenious arrangement, the filtration and cleaning is made continuous, and it is claimed that a machine will soften 2,000,000 gallons per diem, at a cost of one farthing per 1,000 gallons (Fig. 44).

The "Stanhope Tower" (Fig. 45) has a series of sloping perforated shelves through which the water, mixed with lime and soda, ascends. In one form these take the shape of a series of funnels,

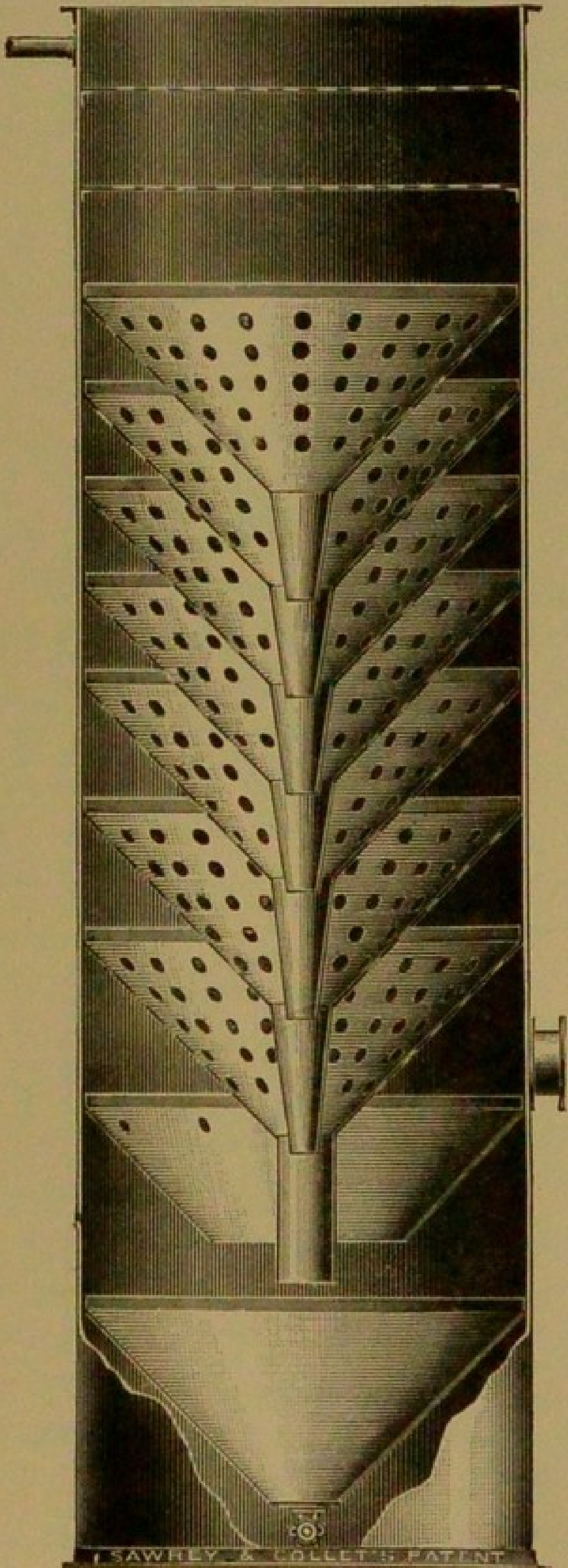

FIG. 45.—The Stanhope Tower.

on which the precipitate collects and slides down through a central tube to the base of the tower below, where the water enters. The deposit is drawn off by a sludge cock. The original form was patented by Gaillet and Huet. The towers are made rectangular or cylindrical, in various sizes, and are constructed to soften from 500 to 5,000 gallons per hour, "at a cost of one halfpenny per 1,000 gallons."

Wright's Patent Heater Condenser Company manufacture a form of apparatus (Fig. 46) in which the water is softened under pressure. This is said to be more applicable in cases of towns' supply, large institutions, or mansions, where the water has to be delivered at some distance from the softener, or where the tank is a considerable height above the outlet. A small reagent pump for the lime, or lime and soda, is fitted to the main pumps, so that every time they make a stroke the reagent pump makes one also. The incoming water passes over a small water-wheel working the lime-mixer. The deposition takes place on inclined plates. The filters, of charcoal, or of cloth if the water contains grease or matters that carbon will not arrest, are designed to work under a pressure of eighty pounds to the square inch. They are cleaned by reversing the current. The usual cost of chemicals is stated to be about 1*d.* per 1,000 gallons.

Another form of the apparatus specially intended for boilers combines a heater with the above pressure-softener (Fig. 47). It removes both temporary and permanent hardness down to three degrees, and

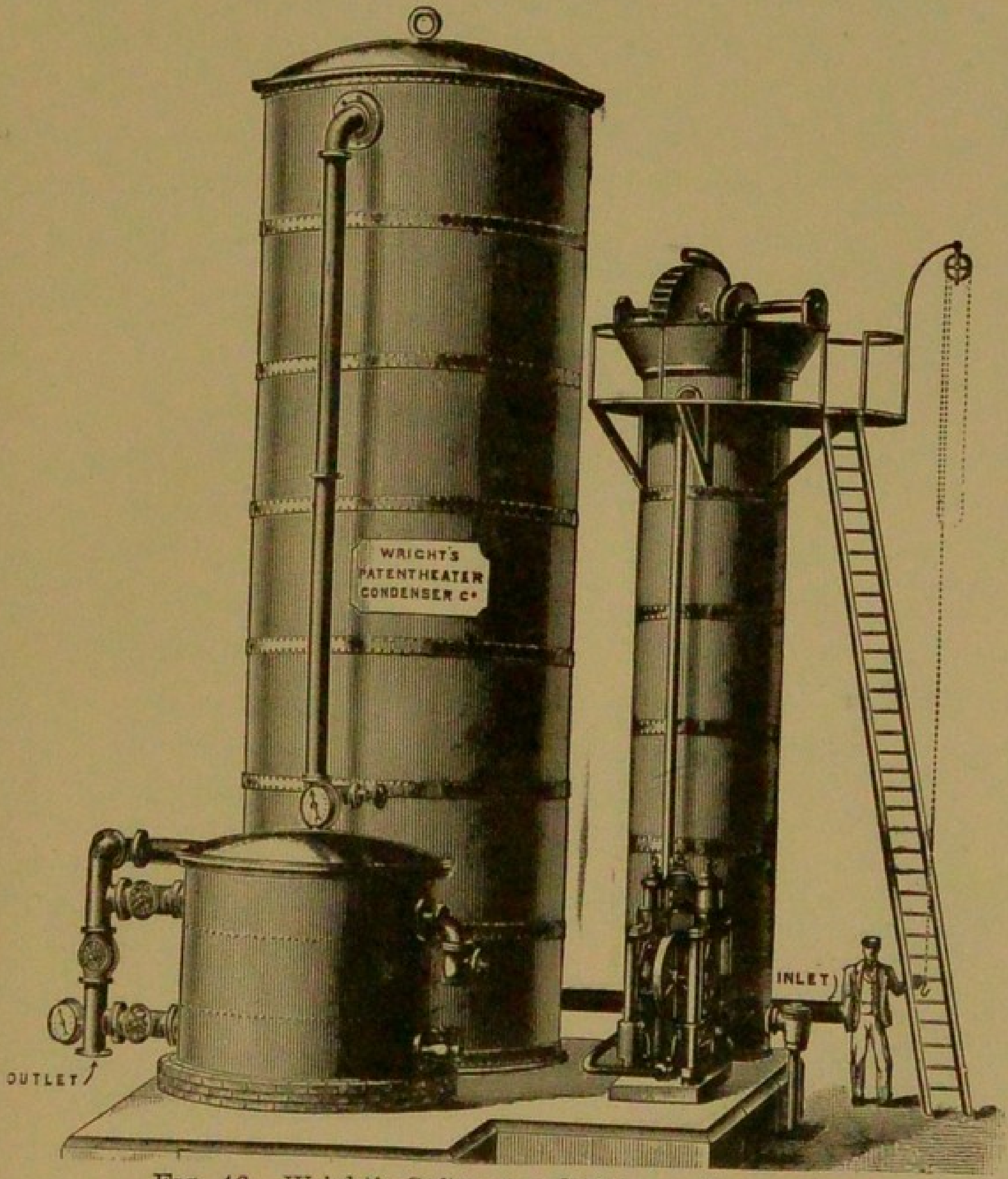

FIG. 46.—Wright's Softener and Filter under pressure.

raises the temperature to 210° F. before entering the boiler.

As to the economy of softening there can be no doubt. It is estimated that "a farthing's worth of lime saves about 30*s*. worth of soap." On the small

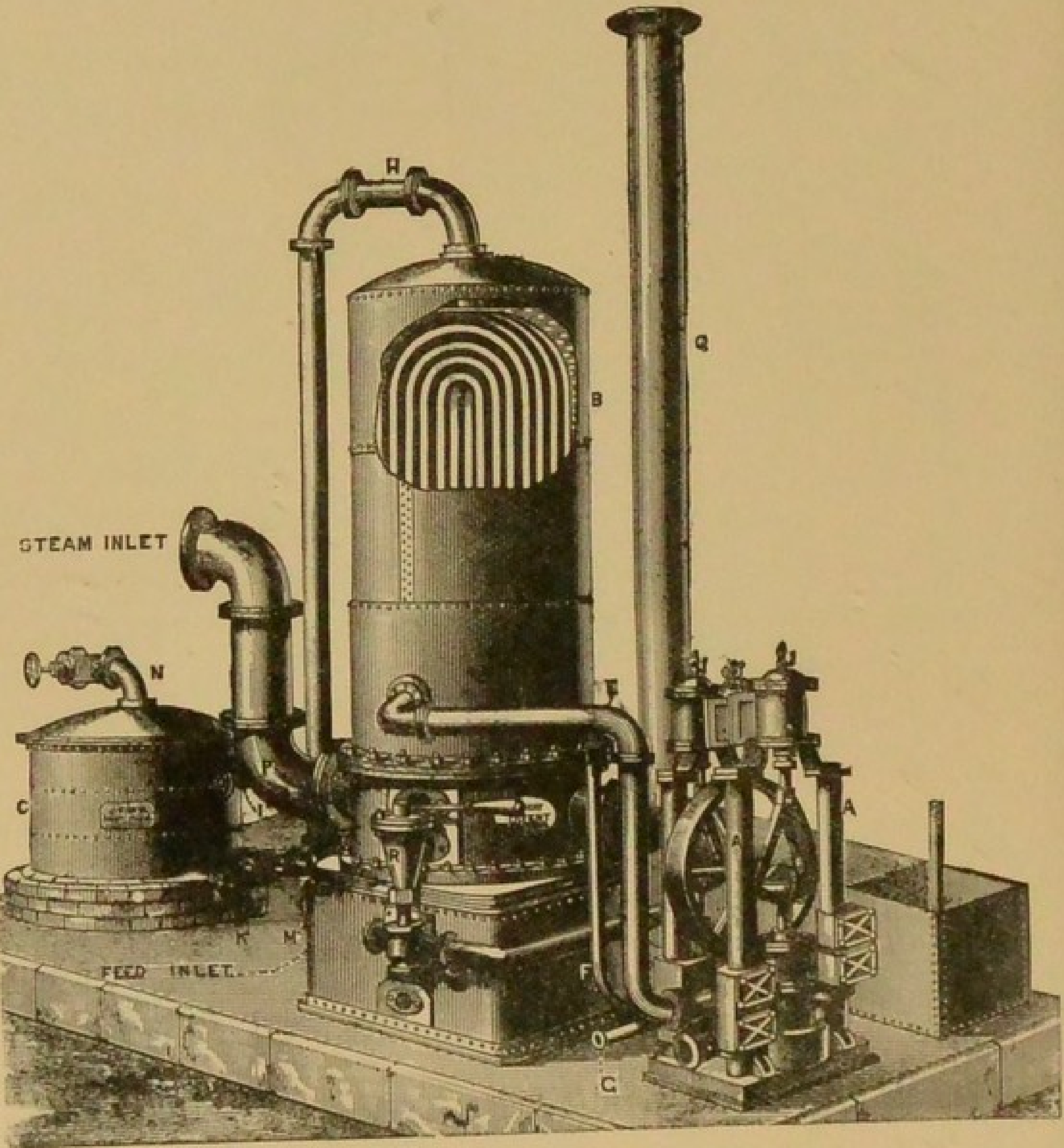

Fig. 47.—Wright's Combined Softener and Heater.

scale this would be about 1*d*. per 1,000 gallons under favourable conditions. Frankland considered that a town supply could be softened for £1 per 1,000,000 gallons.

Some analyses by the author, given in a report by Mr. Aldwinkle, the architect to the Metropolitan Asylums Board, February 6th, 1896, show the practical results obtained by some of these processes :—

		Hardnesses in grains per gallon after softening.		
Process.	Place.	Total.	Tempy.	Permt.
1. Porter-Clark ..	Brookwood Asylum ..	3·1	0·7	2·4
2. Ditto ..	North London Railway Works, Bow ..	11·3	2·45	8·85
3. Atkins-Clark ..	Lambeth Workhouse ..	6·35	5·7	0·65
4. Ditto ..	Darenth Asylum ..	8·3	6·15	2·15
5. Archbutt-Deeley	McMurray's Paper-mills, Wandsworth ..	6·2	2·4	3·8

This table shows, as has been already explained, that lime effects almost a complete softening of a water like No. 1, which owes its hardness to calcium bicarbonate; whereas with No. 2, a magnesian water (this water had the original composition, total hardness, 16·4 ; permanent hardness, 10·8), little improvement is effected.

The same report gives interesting information as to the cost of the three processes, as applied to the special conditions at the Brook Hospital.

Hard waters, as a rule, are furnished by the following formations : Calcareous strata of Silurian, Devonian, and Coal Measures, Mountain Limestone, Lias, Oolites, Upper Greensand, Chalk.

Soft waters, by Igneous, Metamorphic, non-calcareous Cambrian, Silurian, Devonian, and Coal Measures, Lower Greensand, London and Oxford Clay, Bagshot Beds (hardness one to nine, average four), and non-calcareous gravel. Water from Gault Clay varies very much: some of it is soft and pure, some "of fair quality," hardness nine to eleven degrees; in Bedfordshire it often contains much lime and iron, derived from pyrites and coprolites. Lower Greensand and shale waters are frequently very ochreous. Water from Oxford and Kimmeridge Clays contains much vegetable matter, and is sometimes bituminous; other clays often include much sulphate of lime, and give waters of high permanent hardness. The New Red Sandstone waters are generally briny and quite unfit for drinking, besides containing much sulphate of lime and magnesian salts. Magnesian limestone also yields usually a bad supply. The water in porous strata below the central portions of clay basins is usually bad, containing much alkaline chloride and sulphate, and also sodium carbonate, due to the rain having percolated laterally through a large body of soil before reaching the spot, and having dissolved and accumulated the soluble constituents: from the presence of alkaline carbonate the lime is generally low, and there is often little organic matter.

A detailed description of the strata in their relation to waters will be found in the Appendix.

CHAPTER XI.

ANALYSIS AND INTERPRETATION OF RESULTS.

THE results of a bacteriological or chemical analysis of a sample of water are necessarily expressed numerically and in a technical way. It is possible, however, without discussing the details of the various processes used by chemists and bacteriologists, to understand the figures and the deductions which may be drawn from them. The minute proportions in which some of the most significant impurities exist in drinking waters render the analysis exceedingly difficult and delicate. The difference between a pure and an impure water may only be indicated by fractions in 100,000; and the problem is further complicated by the fact that, as animal and vegetable substances contain practically the same elements, it is often difficult for the chemist to decide whether the pollution is of animal or vegetable origin. As the quantities are so small, it is very rarely that their exact nature can be ascertained, so that usually the decomposition products only are determined. There is hardly any test sufficiently delicate to indicate with certainty whether an organic impurity in a natural water be poisonous or innocuous. On the other hand, the information furnished by an analysis gives valuable suggestions as to the quality of a water, especially if its source be known and the data of its normal composition have been previously ascertained.

The results of an analysis are still commonly expressed in grains per gallon of water, *i.e.*, in parts per 70,000. The method of stating the results in parts per 100,000 is, however, far preferable, inasmuch as being founded on a decimal system, they are at once comparable with analyses made in other countries. Continental results are sometimes stated in grammes per litre (parts per 1,000), whilst occasionally parts per 1,000,000 (milligrammes per litre), have been adopted. Results expressed as grains per gallon can be converted into parts per 100,000 by dividing by seven and multiplying by ten, whilst multiplying by seven and dividing by ten converts parts per 100,000 into grains per gallon. A Committee of the British Association recommended that all water analysis results should be expressed in parts per 100,000, and many authorities have since adopted that plan, which is the one used in this book.

Samples of water for analysis should be taken in the stoppered half-gallon bottles known as "Winchester quarts," which are obtainable at most chemists. They should be free from any adhering dirt and washed out with concentrated sulphuric acid when purchased, then filled up with common water and rinsed several times, finally with distilled water.

In collecting the sample the precautions mentioned on p. 27 should be observed. The bottle should be filled to the top with the water, then rinsed out with it, filled, and the stopper rinsed and inserted. Except when the gases dissolved in the water are to be examined, it is best to leave a small air space below the stopper. If possible the temperature of the water should be observed at the time of collecting the sample. Any surrounding circumstances—distance of dwelling, &c., nature of soil, depth of well, presence of plants, &c., —should be noted. After the sample is collected it should be despatched as quickly as possible to the analyst, as many waters change very considerably on keeping.

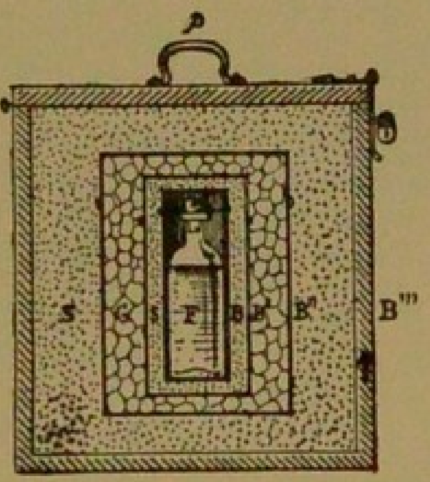

FIG. 48.—Ice Case for Bacteriological Samples.

Samples required for bacteriological examination should be separately taken in sterilised bottles, about two ounces in capacity, and immediately packed in ice (Fig. 48) and forwarded for examination. For an ordinary chemical analysis one Winchester quart of the water is sufficient, but when a mineral analysis is required two or three times this amount will be found necessary.

The interpretation of results of analysis is often a matter of considerable difficulty, as the analyst judges of the purity or otherwise of a water upon all the factors presented to him, and not on any single constituent. Some authorities insist upon withholding from the analyst particulars as to the source and possible contaminating influences of a water sent for analysis, thinking that by so doing his opinion will not be biassed in any way. Such procedure is, however, most undesirable, as it must obviously be to the interest of the senders to arrive at the truth, and any circumstances which may give rise to suspicion may be very helpful to the analyst as explaining some of the figures which he may obtain, which otherwise he might consider not sufficiently condemnatory to warrant his pronouncing against the supply.

The deductions to be drawn from the general appearance, colour, and odour of a water have already been mentioned in Chapter I.

The total solids are obtained by carefully evaporating a measured volume of the water, drying the residue at 120° C., and weighing it. The solids in a good drinking water should not amount to more than thirty or forty parts per 100,000, and should be white and crystalline, or finely granular, and not coloured in any way. Frequently a water sample contains matter in suspension, and it becomes a question whether the suspended matter should be included in the total solids or separately recorded. As a water sample is taken usually by inexperienced persons, it is exceedingly unlikely that the suspended matter collected in a Winchester quart represents fairly the average amount of matter in suspension in the water, so that, in most cases, the analyst prefers to separately estimate this amount. The total solids are therefore determined upon a sample of the water taken from the bottle after it has been allowed to stand for some time, when the grosser particles will have subsided to the bottom of the bottle.

The loss on ignition represents the amount of loss which the total solids undergo when the dish containing them is heated to low redness. If there is much organic matter present the solids blacken under this treatment, and if this organic matter is of animal origin an odour of burnt feathers, indicating the presence of much nitrogenous matter, is noticed. The ash may be coloured brown if iron is present in the water, but is usually white, and consists of the mineral salts present. Many mineral salts, *e.g.*, magnesium chloride, lose acid on being heated in this way, so that the loss on ignition is not an absolute measure of the amount of organic matter present in a water. To overcome this difficulty some analysts add a known amount of sodium carbonate to the solid residue before igniting, in order to fix any such acids which might otherwise be evolved.

The total amount of chlorine as chlorides is very important and is determined volumetrically by a standard silver solution. The result is returned as chlorine, sometimes also as sodium chloride. It must not be forgotten, however, that waters naturally contain other chlorides, as those of calcium, magnesium, and potassium, so that the calculation into sodium chloride is only for convenience. A high chlorine, however, usually raises a suspicion of contamination with sewage, as urine contains about 1 per cent. of sodium chloride. About 1·5 to 3·0 parts of chlorine per 100,000 is a normal amount; but in districts where there are salt deposits, as in Cheshire, or in wells in the New Red Sandstone or in proximity to the sea, the water may normally contain a higher amount without indicating sewage pollution. In the United States the influence of the sea on land water has been carefully studied, and Dr. Drown, in his reports to the Massachusetts State Board of Health, has shown that it is possible to map out the State by lines which are practically parallel to the coast line, in which the ground water shows equal amounts of chlorine. Such lines he terms "isochlors," and in his hands they have proved of considerable value, as any excess of chlorine found in any well water above the natural "isochlor" shows at once local contamination.

The amount of chlorine found in a water can be converted into its equivalent amount of sodium chloride, NaCl, by multiplying by the factor 1·65. Although chlorine as chlorides thus gives a measure of the amount of sewage pollution that the water has received, it does not give any information as to when such pollution took place, since, by filtration and oxidation, the organic matter of the sewage and the pathogenic organisms formerly present may have long since been entirely removed from the water.

By the term *oxygen consumed* by the organic matter in a water is meant the reduction which an acidified solution of permanganate of potassium undergoes when brought into contact with a known volume of the water. This test is conducted in various ways, and different analysts use solutions of permanganate of different strengths, and allow it to act on the water under various conditions of time and temperature. The red colour of the solution is gradually destroyed, very polluted waters removing the colour almost instantaneously. By using a solution of permanganate of ascertained strength, the amount of reduction is determined by adding excess of potassium iodide, and titrating with a standard solution of thiosulphate. The method most commonly followed in this country is to determine the amount of oxygen consumed at 80° F. in two stages :—

1. *In fifteen minutes:* this figure includes the nitrites and any ferrous salts, sulphides, and any very easily reduced organic matter.

2. *In four hours:* after this time the whole of the organic matter will have been oxidised from most waters, but with very bad waters a longer time is still required to finish the oxidation. In Germany it is customary to boil the water with the acidified permanganate for one hour; whilst the author is in

the habit of keeping the water and permanganate for three hours in a stoppered bottle at a temperature a little short of boiling, so as to get a maximum amount of reduction.

Attempts have been made to calculate the relation between the amount of oxygen required and the amount of carbon present in the water as found by combustion, but no definite relation seems to exist, since the factor varies with waters of different characteristics. Where, however, consecutive determinations have to be made on the same supply, the oxygen absorbed approximately represents the carbonaceous matter, and varies, like the albuminoid ammonia and the chlorides, with the fluctuations of the seasons, so that any abnormal deviation at once points to some new source of pollution.

The condition in which *the nitrogen* derived from animal organic matter exists in a water is one of the chief points which a full chemical analysis determines. A water contaminated with sewage will contain a definite amount of chlorides and nearly all nitrogenous matter with which such chlorides were originally associated. If, after pollution, the water has been under the influence of bacteriological action, the nitrogen may have been converted into oxidised forms; and, therefore, in most cases a water contains nitrogen in the several forms of organic compounds, ammonia, nitrites, and nitrates. Fresh sewage is practically free from nitrates, whilst a deep well, or well-oxidised river water, contains the nitrogen almost entirely in the form of nitrate. The ratio of the oxidised to unoxidised nitrogen in a water, therefore, gives a measure of the amount of purification which has taken place, and the total nitrogen of all kinds the absolute amount of pollution which the water has sustained. Under certain conditions, however, some of the nitrogenous compounds are so completely destroyed by bacterial agencies that nitrogen gas and the lower oxides of nitrogen are evolved, and a loss of total nitrogen is therefore caused. When the quantities of nitrogen in a water are compared with the amount of chlorine, it is found that the chlorine is largely in excess, although in urine the amount of nitrogen is slightly greater than the amount of chlorine. This difference between theory and the amount found is partially due to the absorption of nitrates by plants, and only in raw sewage do we find that the amount of nitrogen at all approaches the amount of chlorine.

The term *albuminoid ammonia* is given to the quantity of ammonia which can be obtained from a water after the removal of the saline, or free ammonia, when such water is boiled with an alkaline solution of permanganate. The process was first devised by Wanklyn and Chapman, who showed that, although the total organic nitrogen was not obtained in this way in the form of ammonia, all polluted waters gave off a fraction of the nitrogen in this form, so that the relative amounts of albuminoid ammonia fairly represent the amounts of unoxidised organic or polluting matter actually present. Before determining the albuminoid ammonia, it is necessary to remove the free ammonia, so that a determination of the amount of free ammonia is first made.

Free ammonia and albuminoid ammonia.—For this determination about half a litre of the water, made alkaline with carbonate of soda, is distilled until the free ammonia has passed over, and the amount estimated by the brown colour given by Nessler's reagent. To the remainder in the retort a solution of potash and potassium permanganate is added, and the distillation continued until the "albuminoid ammonia" has all come over; the amount is estimated by means of Nessler's solution, as in the case of the free ammonia. A large quantity of free ammonia is generally indicative of recent sewage contamination, as it is frequently formed directly from urea by bacteria. Vegetable matter gives rise to little or no ammonia on decomposition.

As already mentioned, the albuminoid ammonia is only a relative quantity, and does not give the absolute amount of organic nitrogen present in a water. In many of the recorded cases of water-borne typhoid the amount of albuminoid ammonia found in the water was so extremely small that the supplies would seem from the chemical analysis alone to be of high organic purity. It has been shown that *Bacillus typhosus* actually flourishes better in a water which is pure and free from other matter which has undergone nitrification (p. 53). In an inoculated water Pearmain and Moor found no less than 900,000 bacteria per cubic centimetre, but the amount of pollution produced by adding the broth culture to the water was so small as not to appreciably raise the amount of albuminoid ammonia.

Nitrites are usually looked for qualitatively by colour reactions, and are returned as strong or slight, according to the intensity of the colour produced. They are generally regarded as a bad sign when present to any appreciable extent, as they either indicate that the organic matter is only then undergoing oxidation, and is therefore recent in character, or point to a reduction of nitrates present in the water by reducing organisms and fresh contamination with organic matter. In this way a river water containing a large quantity of nitrates may suddenly lose them owing to admixture with fresh sewage, but the change is usually detected by the simultaneous production of nitrites. The presence of nitrites, therefore, indicates temporary or unstable conditions of the nitrogen contents of the water, and points either to incomplete nitrification of the ammonia, or to a reduction of the nitrates previously present.

Nitrates are present in rainwater to a very slight extent, and are derived from the air, being produced probably by the direct combination of atmospheric oxygen and nitrogen during thunderstorms. Mainly, however, they are the product of nitrifying organisms. Dr. E. Frankland's original description of nitrates as "previous sewage contamination" is thus to a great extent justified, as moorland waters and those containing vegetable *débris* are almost free from nitrates. In deep well-waters from the chalk the nitrates are often high; here the water, originally derived from the surface, has passed through a perfect natural nitrification and filtration. But nitrification may take place in a polluted water so rapidly that nitrates may accumulate after transit through a layer of soil quite inadequate to remove the germs of either typhoid or cholera. Therefore a water which contains over 0·5 or 0·6 parts of nitrogen, as nitrates or nitrites, in 100,000 may be certified as dangerous, even if for the time the free and albuminoid ammonia are not excessive, especially if the chlorides are also present in undue proportion. The results of nitrate and nitrite determinations are usually recorded as "oxidised nitrogen."

The results obtained as above, with a microscopical examination, constitute in most cases sufficient data for an opinion on the quality of a drinking water. But as germs of disease are so excessively minute that they may be actually present, and yet give no weighable or measurable quantities to chemical analysis, the latter alone can never certify that a water is perfectly safe. A chemical analysis, however, gives valuable information, and for the following reasons should never be omitted:—

1. Changes in the chemical composition of a water reveal the presence of active bacteria.

2. When pathogenic organisms are present in small numbers, their detection by bacteriological methods is exceedingly doubtful.

3. Bacteria do not thrive without nitrogenous food, which is at once detected by analysis.

4. Their entrance into a water supply is almost always accompanied by sewage products, which reveal themselves to the chemical examination, and in cases of doubt the chemical analysis should always be supplemented by a bacteriological test.

For domestic and industrial purposes the *hardness* of water is an important item. It also gives an insight into the mineral composition of the "total solids," whether the water contains much lime or magnesia, and whether they are present as carbonates (temporary), or as sulphates, chlorides, or nitrates (permanent hardness). The chlorine and nitrates ("oxidised nitrogen") will have been already determined; the sulphates can be tested for by comparison with a water of known composition, *e.g.*, the tap water of the place. If the total hardness be deducted from the total solids, we have approximately the amount of sodium and potassium salts, which in some samples are a leading feature, and when excessive render the water laxative, of a bad taste, and unfit for drinking (see Table A in Appendix). The presence of *potassium* is significant in suspicious cases. Urine contains sodium salts, fæces yield mainly potassium compounds; hence the latter in large quantity point to pollution by solid excreta. *Phosphoric acid*, as a rule, is practically absent from pure waters, though traces occur where the strata contain coprolites. As phosphates are a characteristic ingredient of both urine and fæces, "heavy traces" condemn a water; "traces" are suspicious. In sewage effluents which have been treated with alum and lime, phosphates are usually absent, having been precipitated as the insoluble phosphate of alumina. They may sometimes also be low in sewage effluents and undoubtedly polluted waters, if aquatic plants have had time to remove them in their growth.

Organic carbon and nitrogen, or combustion process (Frankland and Armstrong).—The water is evaporated with certain precautions to remove the nitrates, and the residue burnt with oxide of copper. The product consists of carbonic acid and nitrogen, which are measured, and the former calculated into "organic carbon," the latter into "organic nitrogen." The relation between them reveals whether the contamination is of animal or vegetable nature, since animal matter has, as a rule, a greater percentage of nitrogen. Unfortunately, the process is liable to numerous errors, the chief of which are:—

1. During the prolonged evaporation (twelve to

twenty-four hours), destruction of the organic matter and loss of volatile compcunds occur.

2. Ammonia or dust may be absorbed from the atmosphere.

3. The nitrates, especially if high, are not always completely destroyed. Any remainder would figure as "organic nitrogen."

4. Uncertainty as to how much ammonia is retained by the acid.

5. Introduction of nitrogen from the copper oxide during the combustion, of occluded hydrogen from the metallic copper, and thence the formation of carbon monoxide, either of which, if not tested for, would be returned as nitrogen.

6. Leakage of air into the pumps, &c.

7. The fallacy of deducting the amount of gas (CO_2 and N) obtained in a "blank" experiment, as a correction for air-leakage, impurity of reagents, &c., since this is an exceedingly variable quantity. Many analysts who have obtained the apparatus have consequently discontinued to use it.

Kjeldahl process, as modified by Drown and Martin. —The water is boiled down with concentrated pure sulphuric acid to near dryness, a little permanganate added, and gentle heat continued until the brown colour has almost disappeared. By this means the nitrates and nitrites are first expelled, and the remaining nitrogen is converted into ammonia, which remains as ammonium sulphate. The residual liquid is distilled with pure soda, and the ammonia determined by the Nessler test or otherwise. After deducting the free ammonia, the rest is calculated into "organic nitrogen" (Kjeldahl). The process is a useful one: the results are about double those of the albuminoid ammonia (see p. 269).

No method at present devised yields with certainty the *whole* of the organic carbon and nitrogen in a water, and any that did so would still furnish little certain information as to its composition. Isolation of definite compounds from larger quantities of water is the direction that future analysis must take, and a few attempts have already been made.

H. Fleck (*Zeitschrift für Angew. Chem.*, 1889, 580) evaporates one or two litres to dryness with tartaric acid, extracts with absolute alcohol, evaporates, and moistens with potash solution. With polluted waters he obtained a distinct odour of fæces (*skatol*?).

M. Baudrimont extracts the original water with ether: on spontaneous evaporation of the solvent characteristic odours, fatty residues, &c., are left.

Zune concentrates the suspected water at a gentle heat until a few cubic centimetres are left, then extracts with warm alcohol. In the case of pollution by urine or fæces, he finds urea and biliary matters in the alcoholic solution, and uric acid (by the murexide test) in the insoluble portion. Such a discovery would, of course, be proof positive of admixture with fresh sewage. But these methods only apply to recent and extreme contamination. Odours are liable to great divergence of opinion.

Products of manufacture occasionally find their way into drinking water. Soap, petroleum, various fibres, traces of metals and chemicals have been detected in domestic supplies. These occurrences have sometimes been of service, as pointing to a leakage into wells or pipes that might also admit pathogenic organisms (see p. 89). Poisonous metals, like lead, copper, and zinc, should be entirely absent. Not more than a trace of iron is admissible. Arsenic, barium, manganese, &c., have been occasionally recorded.

In a paper on Fermentative Changes (Royal Dublin Society Transactions, September, 1895), W. E. Adeney has proved that it is important in the examination of a water to show (1) the absence of easily fermentable matters of all kinds; (2) that it has been subjected to efficient natural or artificial filtration. The first condition will have been established if the water contains no free ammonia, or only slight traces, since of the easily fermentable substances present in waters it is the last to be fermented. The second is satisfied if traces only of fermented organic matter are found. To determine the rate of progress of the natural purification of polluted waters by bacteria and oxidation, he estimates the oxygen, carbonic acid, ammonia, nitrite and nitrate, present in the water, kept out of contact with air, at various stages.

The *determination of dissolved oxygen* is seldom made.

It is valuable in showing the purification or pollution of rivers during flow and in filtration experiments. Gérardin has shown that diminution in the amount of oxygen dissolved in a water indicates low *vegetable* life, and usually results in an unpleasant odour and taste, besides retarding natural purification. A fully aerated water will contain about 7 c.c. of dissolved oxygen per litre, the amount, however, varying with the temperature from about 6 c.c. in summer to over 8 c.c. in winter. A sewage or badly polluted water contains little or none. (See Chapter I., p. 19.)

The following are fairly valid inferences:

Free ammonia.	Albuminoid do.	Chlorine.	Indications.
High.	Moderate.	Small.	Sewer gas.
High.	Very high.	High.	Sewer water.
High.	Rather low.	Very high.	Urine.
Rather high.	Low.	Very low.	Vegetable matter, perhaps marshy.

Dr. Smart has pointed out that, in the albuminoid ammonia process, fermenting vegetable matter gives a yellow colour with the carbonate of soda, and a greenish with the Nessler test. This, coupled with the oxygen consumed and the rate of evolution of the albuminoid ammonia, led to the following discrimination:—

NH_3 evolved slowly = recent organic matter.
Oxygen consumed low = animal.
" " high = vegetable.

NH_3 evolved rapidly = decomposing organic matter.
Oxygen low: Nessler colour, the normal brown } = animal.
Oxygen high: Nessler greenish, Na_2CO_3 yellow } = vegetable.

The above differences of colour have been for a long time observed, and have been attributed to different causes. Water containing notable amounts of sewage always gives a peculiar aromatic odour in the first albuminoid distillate.

Wanklyn's standards for albuminoid ammonia are :—

High purity, 0 to ·0041 parts per 100,000.
Satisfactory, ·0041 to ·0082.
Impure, over ·0082.

In the absence of free ammonia, he does not condemn a water unless the albuminoid exceeds ·0082, but a water yielding ·0123 he condemns under any circumstances. This would frequently, and with justice, condemn the waters of the London companies.

Frankland and Tidy's standards for oxygen consumed are :—

High organic purity, ·005.	Medium, ·05 to ·15.
Doubtful, ·15 to ·21.	Impure, over ·21.

Tables of hard and fast limits for waters are, however, useless and misleading. So much depends on the locality. A number of typical analyses will be found in the Appendix.

In a research on the different actions of sodium peroxide and of permanganate on the organic matter in water (*British Association Reports*, 1893), I have shown that different kinds of "albuminoid ammonia" are possible, remarking that waters containing fresh sewage which has been partially oxidised by the peroxide yield the remainder of their ammonia to the alkaline permanganate much more rapidly than when the water had not been so treated, and suggesting the presence in waters of organic nitrogenous matters which, when partially oxidised, are then in a condition to be completely broken up by the stronger reagent. When the albuminoid ammonia process was introduced it was well known that there was a varying relation between the quantities of albuminoid ammonia and the amounts of different kinds of organic nitrogenous matter. The works of Preusse and Tiemann, Mallet, Leffmann and Bean, P. Frankland, and others, have confirmed the inference that, although a useful indication, too much importance must not be placed on this item of the analysis.

Barnes (*J. Soc. Chem. Ind.*, 1896, 83) compared the effects of acid permanganate and of acid bichromate on different bodies, and showed that the latter was far more energetic towards starch, glycerine, sugar, and gelatine; that with albumen and its congeners the permanganate used increased, while in solutions containing tannin or peaty matters the amounts of permanganate and of chromate consumed approached equality. Woodman (*J. Amer. Chem. Soc.*, 1898, xx. 497), has applied Barnes' ratio to the discrimination of the nature of the organic matter in waters. The process is described in the above papers.

For equal volumes of water, the number of c.c. of permanganate used, divided by that of bichromate, gives the "oxygen ratio." For example:—

I. PEATY WATERS, with high "oxygen consumed," but known to be free from sewage—

	Colour.	Ratio.
Boston tap-water, July, 1897	0·3	0·656
" " January, 1898	0·7	0·646
" " March, 1898	0·48	0·649
Dark swamp water diluted	5·0	0·833
" "	1·8	0·689
Reservoir, Orange, Mass.	0·58	0·659
" Athol (full of algæ)	—	1·132
" " (filtered)	1·7	0·750
Infusion of dried leaves	10·0	0·656
Solution of humus in ammonia	—	0·692

II. SEWAGES.—

Sewage from Marlboro' (filtered, old) ..	—	0·543
" Boston (decanted, fresh) ..	—	0·389
Filtered sewage, Boston	--	0·470
Same, diluted with 5 vols. distilled water..	—	0·490
" " 10 " "	—	0·460
Well, contaminated with sewage	—	0·449

Peaty waters, therefore, give a ratio above 0·600, whilst sewage and waters polluted by it are below that limit, although urine alone, according to Barnes, gives ·621.

A well water suspected from the high "oxygen consumed" gave a ratio of 0·957; hence it was concluded that vegetable matter, and not sewage, had entered, which was confirmed by examination of the site.

Bacterial Examination.—Bacteria are divided into groups, based upon their appearance under the microscope (Fig. 49), as follows :—

1. *Micrococci*, or rounded forms, seen under ordinary powers as simple dots. These may be single, or micrococci proper; double, or *Diplococci;* in fours or cubical packets, as *Sarcina* (one form of which is common in the human stomach); in bunches, like

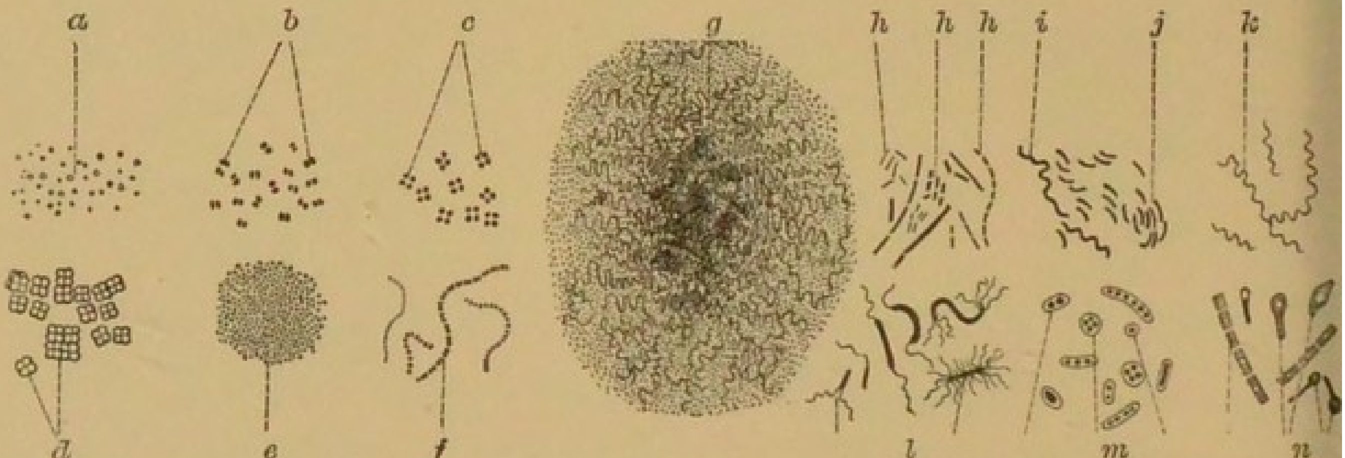

Fig. 49.—Forms of Bacteria: *a*, Micrococci; *b*, Diplococci; *c*, Tetracocci; *d*, Packet cocci (Sarcina); *e*, Staphylococci; *f*, Streptococci; *g*, Zooglœa colony; *h*, Bacilli; *i*, Spirilla; *j*, Comma bacilli; *k*, Spirochœtæ; *l*, Ciliated cells; *m*, Cocci with capsules; *n*, Bacteria showing spores.

grapes, as *Staphylococci;* or connected in chains, as *Streptococci*. Often they are collected in jelly-like "zooglœa" masses.

2. *Bacilli*, or short rods, often connected end to end to form a conferva-like line, or grouped side by side. The ends of the rods sometimes widen into dumb-bell shape, and spores may form in clear vesicles in the middle or at the ends. The rods are, in a

few species, curved into "comma" or short spiral forms, which are then considered as belonging to group 4.

3. Longer unsegmented threads, straight or undulating, often matted and interlaced into flocculent masses. *Crenothrix* (Fig. 50) develops in water-pipes and in covered tanks, under the influence of darkness and of deficient aeration, sometimes to such an extent as to communicate a bad odour and taste to the whole supply. It imparts a reddish tint to the liquid, owing to the oxide of iron which it assimilates and then excretes; it increases very rapidly by spores. At Lille and at Berlin it has caused very great trouble and expense. *Cladothrix dichotoma* also occasions great inconvenience by blocking pipes, especially if the water is periodically stagnant, as in intermittent supplies, and when it is rich in organic material. In large numbers it gives rise to whitish flocculent masses; threads of it are easily identified under the microscope, and indicate that the water is not in a

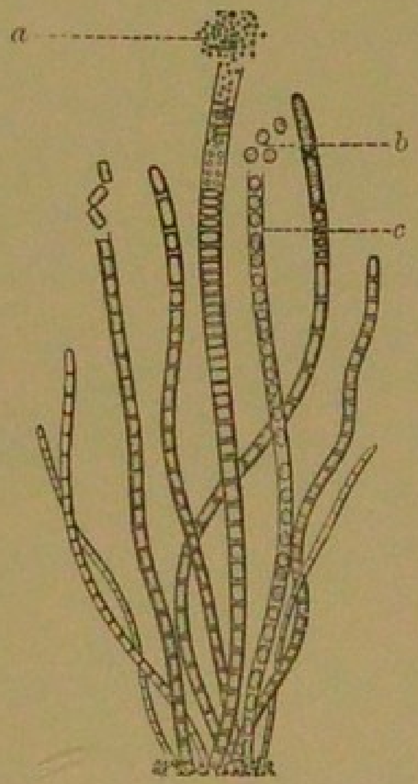

FIG. 50.—Crenothrix Kühniana (×600). *a*, Arthrospores; *b*, single segments; *c*, common sheath surrounding the separate spores.

proper state, or that the filtration is inefficient. It develops a strong mouldy smell, and precipitates carbonate of lime round its filaments, so that if treated under the microscope with hydrochloric acid it shows bubbles of carbonic acid gas. *Beggiatoa alba*, "the sewage fungus," occurs as whitish or grey threads, or large flakes (Fig. 51), by the sides of effluents, and sometimes finds its way into polluted drinking waters. At the extremities of the filaments highly refracting granules will be seen under the microscope; these are sulphur in a liquid state secreted by the plant, and formed either by a reduction of sulphates to sulphides or from sulphuretted hydrogen produced by putrefaction; in either case the water is obviously unpotable. This fungus is frequent

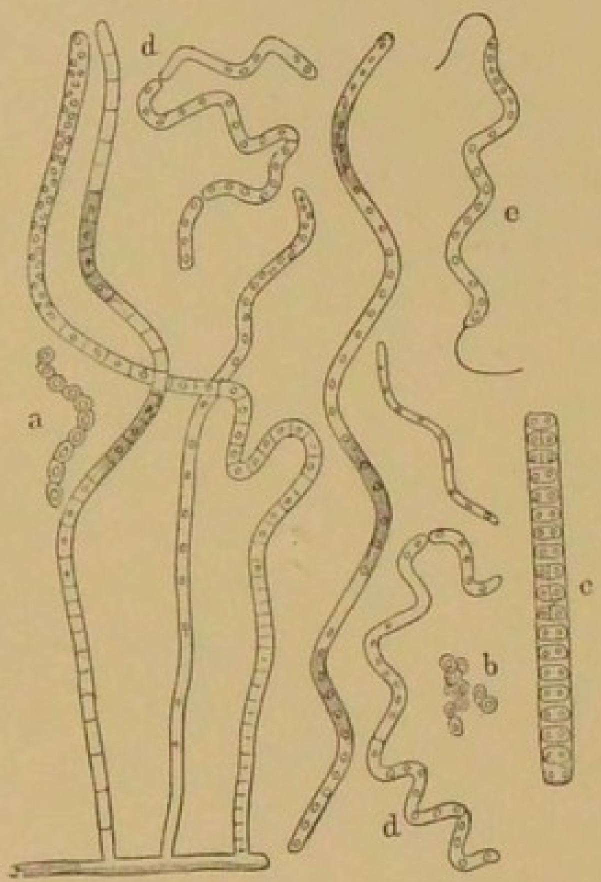

Fig. 51.—Beggiatoa alba, showing attached, free, curved, and spiral forms. *a*, chain of spores; *b*, free spores (motile); *c*, portion under a higher power, showing transverse and longitudinal division; *d*, filaments breaking up (the small dark circles are granules of sulphur highly refracting); *e*, free motile segment with terminal flagella.

in drain-water, and is also found in sulphur springs. *Leptothrix ochracea* is one of the "iron-bacteria," growing sometimes luxuriantly in ferruginous waters containing very small quantities of organic matter. It occasionally leads to rust-coloured flakes and crusts in decanters, and shows that the water contains too much iron to be wholesome, and indicates that the water should be previously treated by lime and deposition or filtration (p. 18). *Fusarium aquæductuum* (*Fusisporium moschatum*), the "musk fungus," was found by Lagerheim in the tap-water of Upsala as long greyish masses hanging down from the orifice of the pipes. Its presence has been suspected in many waters having a musky odour; it is believed to be pathogenic (Heller). I have found the inodorous *F. solani* in London water.

4. Screw-shaped or spiral bacteria. *Vibrios* are short, undulating forms; *Spirilla* are longer, and in a distinct helix or screw; *Spirochæta* is a long, thin thread, with numerous short turns of the spiral (see Fig. 49). The comma bacillus has been variously referred to Vibrio or to Spirillum, as both forms occur. This variability of shape of the same species renders it necessary to supplement a simple microscopic examination by cultivation experiments. Certain identification of a special organism depends on:—

(*a*.) The microscopic appearance at different stages of growth.

(*b*.) The presence of capsules, spores, flagella, &c.

(*c*.) Motility. Some bacteria are sluggish or almost immotile; others exhibit rapid changes of position. In this case minute, whip-like processes, called *cilia* if short and numerous, or *flagella* if few and lengthened, should be looked for by careful staining.

(*d*.) The production of substances recognisable by chemical tests, such as indol (p. 302), &c., and of characteristic colours by chromogenic bacteria, of fluorescence, of odours, of phosphorescence, of liquefaction, turbidity, precipitates, or gases.

(*e*.) Whether the bacterium can live without oxygen. The larger number are incapable of multiplying in absence of air, and are called *aerobic*. Such as cannot grow in the presence of oxygen are termed *anaerobic*. Both of these are described as *obligate* aerobes or anaerobes. If an organism can thrive under either condition it is said to be *facultative*.

(*f*.) The results of cultures in different media and at various temperatures.

(*g*.) Experiments by inoculation on animals. These can only be carried out under a licence, and are not necessarily conclusive as to man.

Cultivations are made with various media, such as nutrient gelatine, agar-agar, meat broth, milk, blood serum, potatoes, albumen, &c. The most important of these is the nutrient gelatine, which consists of meat broth containing 10 to 15 per cent. of gelatine, 1 per cent. of peptone and 0·5 per cent. of common salt. It is rendered neutral or very faintly alkaline and clarified with egg-albumen. While hot, quantities of about 10 c.c. are run into test-tubes fitted with cotton-wool plugs, the cotton-wool and tubes having been previously sterilised by heat. These tubes are then fractionally sterilised by steaming for half an hour on three successive days. When properly prepared the jelly is quite bright, should not melt at 22° C., and undergo no alteration on keeping; as the cotton-wool plugs, while admitting air, exclude the micro-organisms floating in it. Nutrient agar is prepared similarly to the above, 2 per cent. of agar-agar being used in place of the gelatine; this remains solid at blood-heat, and is therefore used for cultures at the higher incubation temperatures. These tubes of gelatine and agar are always stocked, and they are used for the following cultivations :—

1. *Plate cultures.* — This method was originally devised by Koch, and is almost invariably resorted to for the isolation of bacteria. The gelatine is gently warmed until perfectly fluid, one cubic centimetre or less of the water, according to its purity, is then added from a pipette graduated into $\frac{1}{10}$ths of a cubic centimetre. The tube is then carefully shaken and the contents poured into a shallow glass dish with a close fitting lid—this "Petri's dish" and the pipette are previously sterilised by heat. The gelatine is then allowed to set, which can be hastened by placing the dish on a block of ice, and is subsequently incubated at a definite temperature not exceeding

22° C. and examined from day to day. If germs are entirely absent, the gelatine will remain quite clear, but this very rarely occurs in nature. Deep well waters after a time show a few isolated specks; other waters, according to their quality, show greater or less numbers of centres of growth (Fig. 52). These "colonies," which are due to the multiplication of

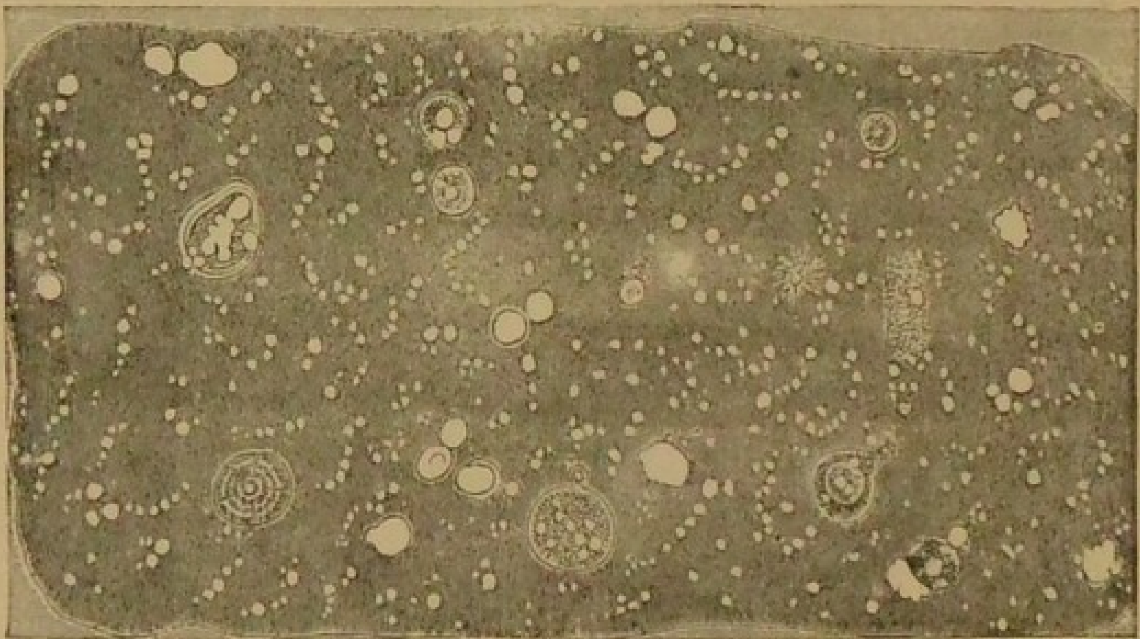

Fig. 52.—A Koch-plate culture, showing colonies.

scattered organisms, are almost invariably pure cultures of the original germ, and soon exhibit characteristic differences. Some form cup-shaped depressions of liquid gelatine, others refuse to liquefy the medium. The colonies are either raised above the surface or penetrate deeply into it; the outline may be ragged or circular; branchings from the centre or concentric circles may appear; they may remain white or develop peculiar pigments. Many bad waters cause the gelatine to rapidly liquefy and to emit an unpleasant putrefactive odour. If there is no guidance as to the purity of the water, several plate cultures with varying quantities have to be made at once, as they cannot be repeated; sometimes the sample has to be diluted with sterile water. A maximum of about 100 colonies should be obtained on a plate, and even then if a number of rapidly liquefying bacteria is present the plate will be useless in one or two days, according to the temperature, before other colonies have developed sufficiently to be visible. Owing to the rapidity with which bacteria multiply, especially in the presence of organic matter, it is sometimes preferable to start the plate cultures at the spring or other source of supply, the operator being provided with a spirit-lamp and a case for the safe transit of the plates to the laboratory.

As a rule, the colonies on the surface of gelatine plates grow more rapidly and are easier to diagnose than those in the depth, which often remain mere dots; when typical colonies are required, "surface cultures" are prepared. The sterile gelatine is poured into the Petri dish and allowed to become quite solid. About 1 c.c. of the liquid to be examined is then run on to the jelly and carefully spread over the whole surface. After a few hours the water is absorbed and the bacteria are deposited superficially.

The number of colonies on the plate is counted with the aid of a magnifying glass, and when they are numerous by placing the culture over a glass plate ruled in centimetre squares (Wolffhügel's apparatus). As each colony originates from one individual, a factor is obtained which represents the number of organisms per cubic centimetre. But it is obvious that the *number* of bacteria alone furnishes very imperfect information unless their *nature* is also known. It is, however, of great value in controlling the efficiency of filtration or the carefulness of storage, as where innocuous organisms can penetrate, disease germs can also find a way. For this reason, Koch prescribes for a good drinking water a maximum limit of 100 micro-organisms per cubic centimetre. The following is Miquel's experience of the numbers found in different classes of water:—

	Number of organisms per cubic centimetre.
Exceedingly pure water	0 to 10
Very pure ditto	10 to 100
Pure water	100 to 1,000
Mediocre water	1,000 to 10,000
Impure ditto	10,000 to 100,000
Very polluted ditto	100,000 to many millions.

There is no doubt that these limits are too wide, and Koch's figure, 100 per cubic centimetre, is now generally looked upon as easily reached by good filtration. Delépine has employed a comparative method, taking as a standard of purity the water from one of the feeders which is known to be free from contamination ; he finds that the number of organisms may be increased 300 per cent. by wet weather. In river waters, Kibrehl states that the number of bacteria normally increases with a rising tide and decreases with the falling tide. Deep well waters, as a rule, contain less than ten, while P. Frankland found that out of sixty-one samples of filtered water collected at the London companies' works, only one contained more than 100 colonies per cubic centimetre, the average being twenty-nine. But the water as delivered to the consumer frequently contains a much larger number, as is shown by the table of analyses in the Appendix.

The number, and nature, of organisms present in a water, which multiply at blood-heat, can be determined from an agar plate culture, prepared similarly to the gelatine plate, and incubated at 38° C. for forty-eight hours; as a rule no further growths appearing after this time.

The colonies on the gelatine plates are organisms capable of multiplying at room temperature, and may include many water-bacteria, which are killed, or at least inhibited, at the temperature of the body; but pathogenic forms, and the majority of organisms present in fæces, develop rapidly at blood-heat. In the author's laboratory gelatine and agar plates were prepared from tap water previously infected from a pure culture of *B. typhosus*—the agar plates showed numerous colonies of the typhoid bacillus after twenty-four hours at 38° C., but the bacillus could not be recognised on the gelatine plates, even after six days' incubation at 15° C., the gelatine being then almost entirely fluid owing to *B. fluorescens liquefaciens* and other rapidly liquefying bacteria originally present in the tap water. Agar plates are therefore very valuable for detecting any pollution of a natural water. The number of colonies obtained at room temperature may be within Koch's limit of 100 per c.c., and yet an excessive number of "blood-heat" organisms may be present; or the water may exceed Koch's limit, whilst few or no blood-heat colonies are obtained. In other words, the *ratio* of blood-heat organisms to those obtained at room temperature has always to be considered.

For example, in a London water, regularly examined by the author, the ratio of blood-heat colonies to those obtained on the gelatine plates varied at different times from 1:68 to 1:2, while the average ratio of nearly a year's weekly examinations has been 1:12. The average number of blood-heat colonies per c.c. after forty-eight hours' incubation of the plate was 7; that of the gelatine colonies, five days' incubation at 15° C., was 83.

Deep well waters should be entirely free from "blood-heat" organisms, and the presence of even a few must be regarded as suspicious.

To identify an organism, as soon as the colony is sufficiently developed it is microscopically examined, minute portions transferred with a sterilised platinum wire to various culture media, and the development of these sub-cultures watched as already described.

2. *Streak cultures.*—A tube of melted gelatine (Fig. 53) or agar is allowed to solidify in a slanting position, so as to expose a long surface; the tube is then inverted, the plug carefully removed and the surface of the jelly lightly scratched with the infected platinum needle, the cotton-wool plug is then singed and quickly replaced. Streak cultures are specially adapted for the development of pigments which generally require free access of air for their production.

3. *Stab cultures.*—The tube is held horizontally, the inoculated wire plunged steadily nearly to the bottom (Fig. 54), withdrawn, and the wool plug at once replaced. Certain ramifying growths show themselves better under this method. Moreover, the occurrence of

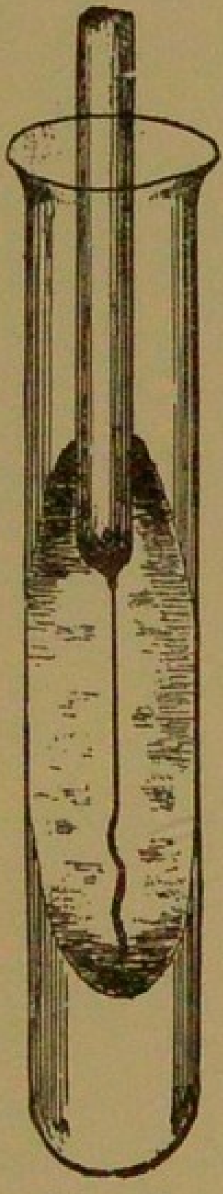

FIG. 53.
Streak cultivation.

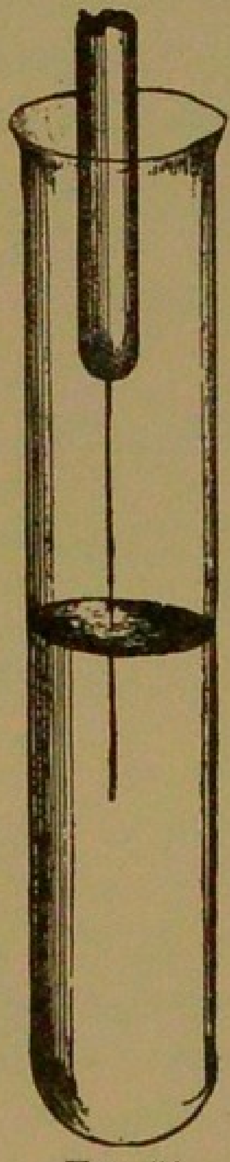

FIG. 54.
Stab culture.

a growth in the deep layers will often reveal the presence of anaerobic organisms, which can afterwards be specially cultivated as described below.

4. *Shake cultures.*—The fluid gelatine or agar is inoculated with the organism, gently shaken, so as not to produce air-bubbles, and then allowed to solidify. If the organism produces gas during its growth, the jelly will become impregnated with small gas bubbles, which gradually increase in size and number. *B. coli communis*, a non-liquefying bacterium

FIG. 55.—Roll culture, showing lines drawn on glass to facilitate counting.

present in large numbers in sewage and polluted waters, gives the "shake reaction" after six hours' incubation at 38° C.

5. *Roll cultures.*—These can be employed instead of gelatine plates when it is required to start the cultures at the water source; but they must be kept cool, and are soon spoilt by liquefying bacteria. Quantities of about 10 c.c. of nutrient gelatine are sterilised in wide test-tubes; these are inoculated in the usual manner, and a rubber cap is drawn over the cotton-wool plug. The tube is then held horizontally in cold water, and rotated with the fingers till an even layer of

the gelatine has set round the walls of the tube (Fig. 55).

6. *Anaerobic cultivations.*—A wide test-tube fitted with two narrow tubes, as shown in the drawing, is sterilised, and the inoculated gelatine is introduced. Hydrogen is now passed through the liquid, kept

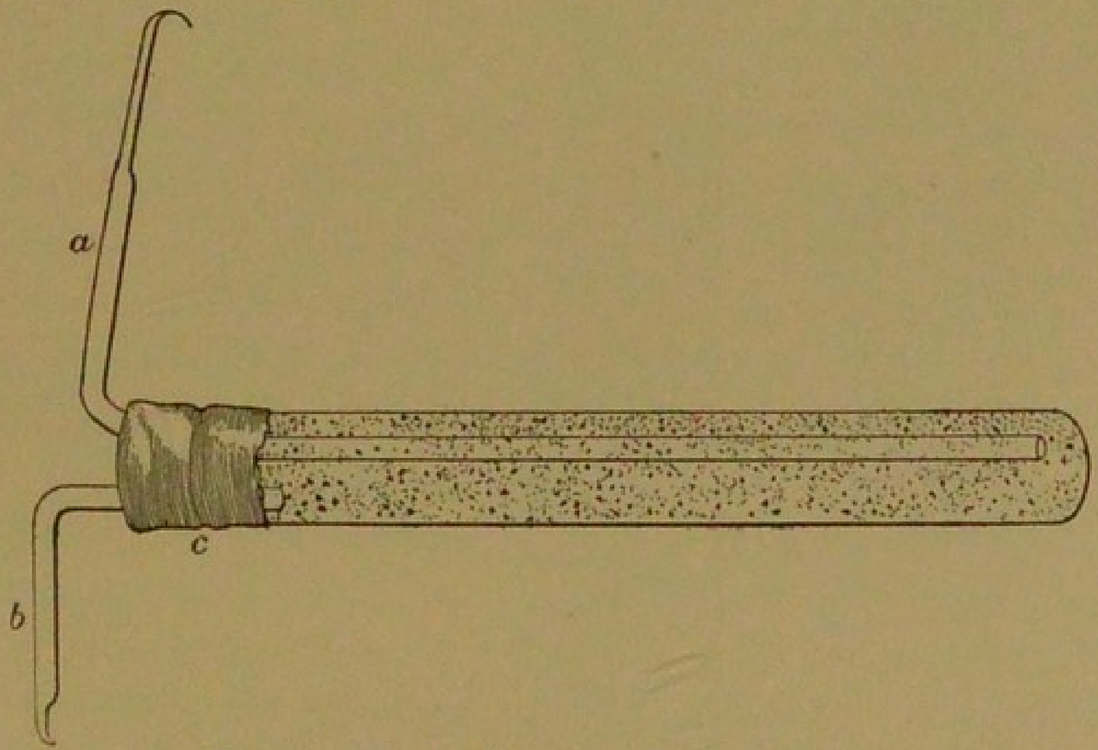

FIG. 56.—Anaerobic culture in hydrogen.

warm, until the air has been completely displaced; then the two glass tubes are rapidly sealed at the blowpipe, and the caoutchouc stopper covered with melted paraffin wax. The tube is now rotated horizontally in water for a roll culture, as above (Fig. 56). Or the culture is mounted in a closed jar containing a layer of pyrogallic acid and potash to absorb the oxygen (Fig. 57). The air may also be exhausted by

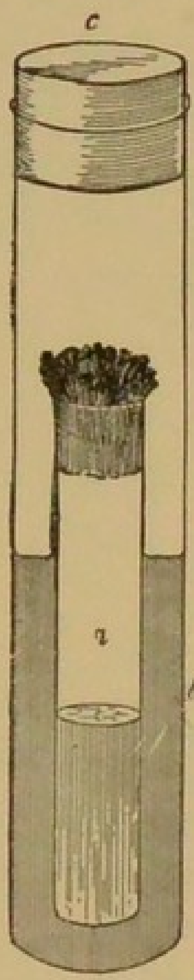

Fig. 57.
Anaerobic culture in jar.

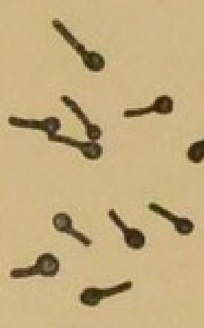

Fig. 58.
Tetanus bacilli with terminal spores.

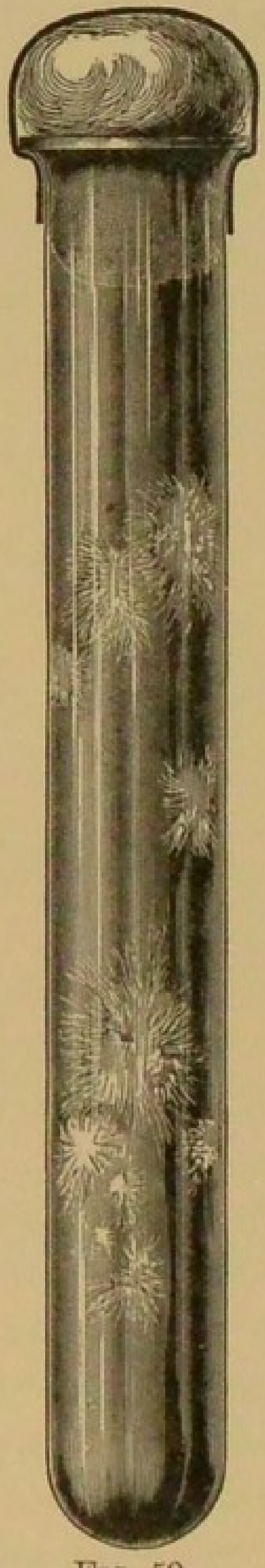

Fig. 59.
Tube culture of Tetanus bacilli (anaerobic).

an aspirator and the apparatus sealed. In this way Roux isolated the Tetanus bacillus (Figs. 58 and 59) from the filtering galleries at Lyons (p. 195), and Miquel from the waters of the Seine and Marne.

Special additions are sometimes made to the nutrient gelatine, such as litmus, to demonstrate the production of acidity or alkalinity, lead carbonate for sulphuretted hydrogen, magenta to detect any bleaching action. Many bacteria grow luxuriantly on a particular medium, their development on other materials, if any, being poor and not characteristic ; the nitrifying bacteria only will grow in the absence of organic matter, and have to be isolated from a silica jelly plate. Some species, like *B. coli communis*, coagulate milk; the majority do not. *B. lactis viscosus*, first found by Adametz in the water of brooks in the neighbourhood of Vienna, is a widespread infector of milk, rendering it slimy and foul. Butter made with such milk quickly spoils. *B. butyricus* and *B. lacticus* can be carried by water, as well as many others which set up peculiar fermentations.

Sterilised slices of potato are of great value for the distinction of several pathogenic forms, such as typhoid and others, and the production of pigments. *B. prodigiosus*, found in air and water, often loses its characteristic blood-red colour after repeated sub-culture in gelatine, but it can be restored with metallic brilliancy by cultivation on potato.

Microscopical examination and staining.—The suspected colony is examined at first with a low power, about 1 inch, the Petri's dish being inverted or, if necessary, the cover is removed. A minute portion of the growth is then mixed with a drop of pure water on a cover-glass and dried by a very gentle heat, and it is fixed by rapidly passing twice or thrice through a flame with the residue upwards. A drop of the stain is then spread over the preparation, or it may be floated face downwards on the staining solution, which sometimes requires warming, and after a few minutes the specimen is carefully rinsed with water, dried, and examined under the microscope with a $\frac{1}{12}$ inch immersion lens. For such rapid work methyl blue is a most useful stain—fuchsine, gentian violet and other dyes are also used, sometimes with a mordant for demonstrating flagella, spores, &c. Many bacteria do not stain readily, some are easily bleached again, and the manner in which an organism takes up a stain often helps in its identification Details of different processes, and the morphology of the bacteria occurring in water, must be sought in special treatises on Bacteriology.

The size of organisms is recorded in micro-millimetres = $\frac{1}{1000}$ of a millimetre (about $\frac{1}{25000}$ of an inch), commonly abbreviated μ. In the absence of a scale, a comparison may be made with bodies of known size, such as red-blood corpuscles.

To study the growth of an organism and to decide whether it is motile or not, a "hanging drop" examination should be made. A portion of the fluid culture is transferred by a platinum loop to the surface of a thin cover-glass held by forceps. This is then inverted over the well of a hollow slide, round which a ring of vaseline has been painted, so as to fix down the cover-slip. The edge of the drop must be first focussed with a low power, and then with a higher.

An "impression" preparation is made by gently pressing the cover-glass on the colony, which must be on the surface and not too advanced. The cover-glass is then removed with the aid of forceps, and, after being allowed to dry, the preparation is fixed, stained and mounted. Many bacteria show their natural grouping when examined in this manner, which is not so clearly defined in the usual cover-glass preparation.

Sterile distilled water is frequently required, and can be obtained by a Pasteur-Chamberland or Berkefeld filter (p. 201). Apparatus, cover-glasses, &c., must be carefully freed from grease or dust, and all vessels for cultures must be sterilised before use by heating for some hours above 100° C. Perishable articles, like rubber corks, are soaked in a one per 1,000 solution of mercuric chloride (or preferably formalin) and then *thoroughly* washed with hot sterile water.

The identification of all the species of micro-organisms in a natural water would usually be an extremely laborious, if not impossible, task, and the results when obtained would not be of equivalent value in our present limited knowledge of the subject. The bacteriologist therefore confines his attention to the number of organisms present, the nature of the predominant species and the significance of their presence, and a search, by special methods, for any pathogenic forms that may be suspected.

To determine the "pathogenicity" and the presence of surface organisms, Blachstein conducts animal experiments with broth cultures from the water.

One cubic centimetre of the water is introduced into a tube of sterile broth, and this is incubated at blood-heat for two days. Animals, usually guinea-pigs or rabbits, are then inoculated, either subcutaneously or intraperitoneally, with 2 c.c. of the broth culture. If other than harmless water organisms are present, the subcutaneous inoculation excites a more or less violent local action, and the animal infected intraperitoneally loses weight, and in some cases death rapidly ensues.

A water which contained 668 bacteria per c.c., of which 106 rapidly liquefied gelatine, was examined by the above method. Two guinea-pigs were inoculated with a forty-eight hours' broth culture from 1 c.c. of the water; subcutaneous and intraperitoneal injections were made respectively. The former produced a large indurated swelling, but the animal did not lose weight. The guinea-pig inoculated intraperitoneally died in three days, and had lost seventy-five grains in weight. This water therefore contained a large number of putrefactive and noxious bacteria.

The organisms found in natural waters are for the most part bacilli. Houston considers streptococci as indicating recent pollution: I have occasionally found them in deep well waters of undoubted purity. Moulds sometimes develop on the gelatine plates; they are rare except in waters that have been improperly stored, and have usually got in during manipulation. Protean forms, such as *Proteus vulgaris* or *mirabilis* are occasionally met with, but their presence is objectionable, as they are typical organisms of advanced putrefaction.

Koch's "Comma-Bacillus," *Vibrio* or *Spirillum Choleræ Asiaticæ,* first found by him in the water of a tank at Calcutta, readily multiplies in sterilised and pure waters, but in river water is soon crowded out and starved by the ordinary water bacteria, hence it has been discovered on comparatively few occasions. It appears as curved or undulating rods, mostly short, but sometimes lengthened into threads of spiral form, very motile, and ciliated at one end (Fig. 60). It is best stained by fuchsine. On gelatine the colonies are circular, with a rough, irregular, scintillating surface and indented margins. The medium liquefies very slowly, cavities being formed by the evaporation. A stab culture in gelatine gradually grows as a loose, white thread, without branchings. A globular depression is produced, after some days, at the point of inoculation, and eventually the whole becomes fluid. Since it is easily killed by the presence of free acid (see p. 164), all media must be made slightly alkaline by carbonate of soda. On potatoes thus prepared it forms at 30° to 40° C. a greyish-brown layer.

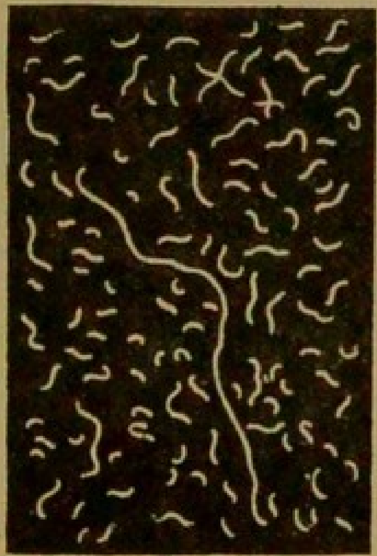

FIG. 60.—Cholera bacillus. (× 1,000.)

In dilute peptone water the cholera spirillum multiplies with great rapidity, forming a pellicle on the surface, even after twelve hours' incubation at 38° C. Advantage is taken of this fact, first noticed by Durham, in the examination of waters. A quantity of the suspected water is treated with 1 per cent. peptone and 1 per cent. salt, rendered faintly alkaline and incubated at 38° C. Microscopical examinations are made every few hours from the surface of the culture, and plate cultures are prepared. A portion of the peptone culture is tested for the "cholera-red reaction" by adding a few drops of hydrochloric or sulphuric acid (free from nitrous acid), when the rose colour of nitroso-indol appears. This reaction depends upon the fact that the cholera spirillum produces indol, *as well as nitrites*, whereas nearly all those that resemble it do not show the same chemical action. *B. coli communis* also forms indol, but not nitrites, consequently it does not give the colour unless nitrite is also added, whilst *B. typhosus* does not form indol.

Gruber uses a comparative method. He prepares a number of tubes containing cholera spirilla in peptone grown at 38° C., then sterilises them by heating for ten minutes to 65° C. A number of such tubes are inoculated with the suspected water, and kept at 38° C. for twenty-four hours. One is tested for cholera-red; if it gives a deeper colour than a tube that has not been inoculated, it proves that the water contains an organism similar to that of cholera, which has continued the indol-formation which was interrupted by the death by sterilisation of the previous cholera vibrios. Other inoculated tubes are examined under the microscope and by cultures. Klein says that it is possible to give a definite opinion in from eighteen to forty-eight hours.

Agar plates are placed in the incubator face downwards, so that the condensed moisture does not fall on the surface of the medium. Gelatine cultures are maintained at 22° C. The colonies show their characters in thirty-six to forty-eight hours. Koch also relies on the pathogenic effect on guinea-pigs (*cobayes*), which are affected by the cholera vibrios, but apparently not by the allied forms. It is believed, however, that there are a number of different organisms which at stages of their development can produce in man the symptoms of cholera, some of them giving the "cholera-red" reaction.

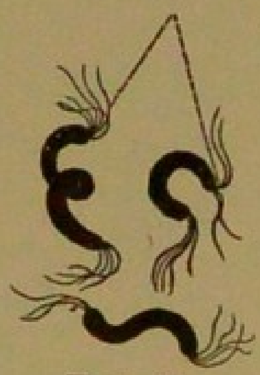

FIG. 61.
Spirillum undula.
(× 800.)

In a search for cholera organisms in water, the sample must be examined at the earliest possible moment after it is taken, and light should be excluded.

Other spirilla are frequently present in stagnant waters, and are characterised by their rapid motion, due to the flagella with which they are provided. Some of these may be pathogenic. *Spirillum undula*, the common form, according to Schenk, is shown in Fig. 61, stained to show the flagella.

The *B. typhosus* of Eberth appears as short, plump

FIG. 62.—Typhoid bacilli. (× 800.)

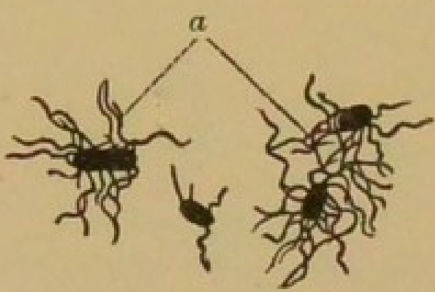

FIG. 63.—Typhoid bacilli (showing flagella). (× 1,200.)

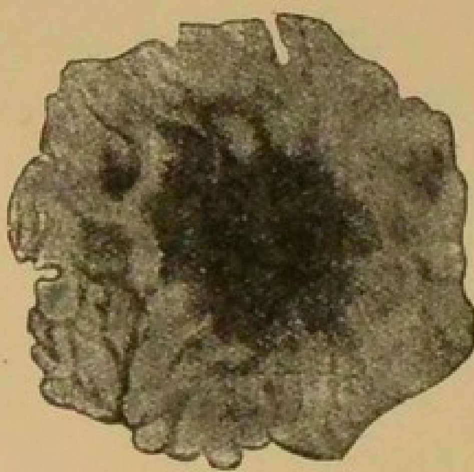

FIG. 64.—Colony of B. typhosus on gelatine plate, five days old.

rods with rounded ends, growing sometimes in cultures into long threads bent at an obtuse angle, which are characteristic. (Fig. 62). They are extremely motile, surrounded on all sides by a great number of flagella, which, however, are not rendered visible by the ordinary stains, requiring a special process, such as Löffler's, when the bacillus presents the appearance shown in Fig. 63, the cell appearing larger owing to its envelope taking up the heavy stain. Colonies on the surface of gelatine plates are whitish, with indented margin, becoming yellowish-brown; the gelatine is not liquefied.

B. coli communis is constant in the intestines of man and animals, and will always be present in waters contaminated with typhoid. In some forms it greatly resembles the typhoid bacillus, and was frequently mistaken for the latter by earlier observers. It does not liquefy gelatine, but produces gas, which the typhoid bacillus does not, and they can, therefore, be distinguished by shake cultures (p. 294). Further distinctions are, that *B. coli* when grown in peptone broth produces indol (see p. 302), and also coagulates milk in twenty-four to forty-eight hours at 38° C., whilst *B. typhosus* does not.

The typhoid bacillus is capable of growing in the presence of small quantities of phenol and hydrochloric acid (Parietti's solution), while comparatively few other organisms, including *coli*, are capable of multiplying in such a medium; the rapidly liquefying bacteria in particular, which spoil a plate before the typhoid colonies can appear, being entirely inhibited. The absence of typhoid colonies on a few plate cultures, from such quantities as one or two cubic centimetres of the suspected water, would obviously not prove that the water was innocuous, especially in view of the fact that *B. typhosus* is rapidly crowded out by other bacteria, particularly when the water is contaminated with sewage. Therefore the following method is adopted for its isolation :—

A litre or more of the water is drawn by a filter pump through a sterilised Pasteur or Berkefeld filter (Fig. 65). The "candle" is then removed, and the film of bacteria, &c., carefully cleaned off into a beaker, employing a small sterile brush and about 10 c.c. of the water. Carbolised gelatine plates, containing 0·05 per cent. phenol and 0·05 per cent. hydrochloric acid, are then prepared with 1 c.c. of this liquid and incubated at 22° C. Any suspicious colonies are then examined and sub-cultures made with gelatine, streak, shake and stab cultures, milk, potato, and broth tubes for indol reaction. Widal's, or the serum reaction, is also used as confirmatory of *B. typhosus*.

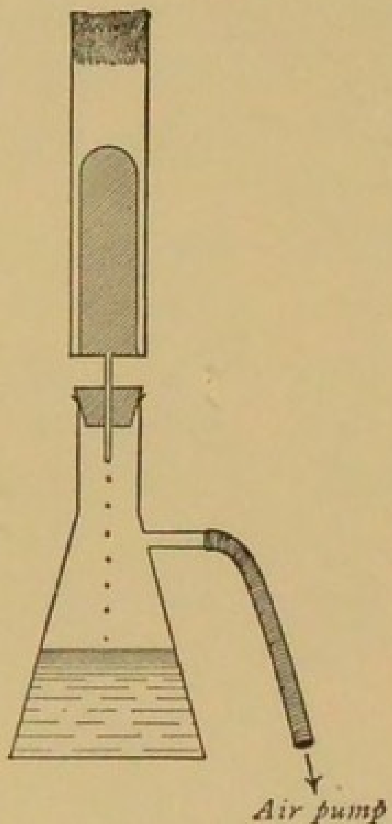

FIG. 65.—Diagram of bacterial filtration.

B. coli communis, although rather widely distributed in nature, is essentially a sewage organism. Houston and Clowes, in their report to the London County Council (First Report, 1898) on the Bacteriological Examination of London Crude Sewage, frequently detected the colon bacillus in as little as ·000025 c.c. of crude sewage.

"The *B. coli communis* is perhaps the most characteristic, and is one of the most abundant of the different species of sewage micro-organisms, and sewage is the chief and most dangerous source of pollution of potable waters. The *B. coli communis* is not present, at all events in any numbers, in pure waters, and it is evident that sewage may contain at least 100,000 germs of this micro-organism per cubic centimetre. It is obvious, then, that there exists a bacteriological method of detecting the pollution of water with minimum quantities of sewage, which is of very great delicacy."

But, besides the typical *B. coli communis*, there are closely allied bacteria, forming the "coli group," which are only distinguished by minor differences,

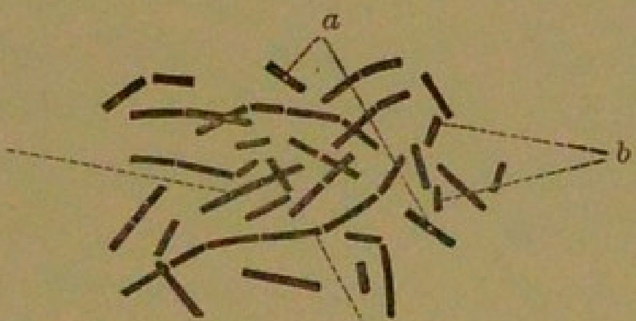

FIG. 66.—Bacillus anthracis. *a*, Spores; *b*, detached short rods. (× 800.)

such as degree of motility (*B. coli communis* is sluggishly motile) and the rate of production of indol, and also by their pathogenicity.

The isolation of the typical coli would undoubtedly condemn a water, but opinions vary as to the significance of the presence of atypical organisms, although these, if present in numbers, say sufficient to be isolated from the blood-heat colonies from 1 c.c. of the water, would be condemnatory.

Dr. Sims Woodhead defines the *true coli* bacillus as essentially "pathogenic to the lower animals, and producing indol *rapidly* in broth cultures."

Dr. Klein has found *B. coli* present in one week in four out of the eight London companies, and in two other weeks it was found in two. The Southwark, the East London, and the Lambeth all yielded it, in two weeks out of eight, in the early part of 1895. It has also been repeatedly isolated in the author's laboratory from London water supplies.

B. enteritidis sporogenes (Klein) is a pathogenic anaerobe, producing resistant spores which are abundant in sewage, Houston and Clowes finding 100 to 1,000 and more per c.c. in the London crude sewage. They are not found in pure waters. The spores are detected by heating for ten minutes to 80° C., to kill other organisms, and preparing anaerobic milk cultures. Examinations of London waters in the author's laboratory gave negative results with ordinary quantities, but by filtering 50 litres through a Pasteur candle their presence was proved.

B. anthracis, which has been identified in one or two cases in water, has the appearance shown in Fig. 66.

Staphylococcus pyogenes aureus is pathogenic, and is found in soil and occasionally in sewage and polluted waters. It liquefies the gelatine, producing a yellow to orange coloration.

APPENDIX.

RECENT EPIDEMICS CONNECTED WITH WATER SUPPLY.

Occurrences at Maidstone, King's Lynn, Worthing, Camborne, and Belfast have attracted a large amount of public attention. The Local Government Board issued in 1898 the following circular-letter to the Clerks of Town Councils and other authorities, on the subject of the supply of water in districts *which are not within the limits of Water Companies* :—

"The importance of a wholesome supply of water need not be emphasized, in view of the serious epidemics of enteric fever which have of recent years been brought about by specific contamination of water supplies in different parts of the country. It is true that this disease, which formerly prevailed somewhat generally in endemic form, has during the last twenty-five years been largely reduced as a cause of death. But, on the other hand, there is now a recurring tendency to sudden localized epidemics, in which the typhoid infection is distributed to large populations by means of the contamination of water delivered from public works of water supply.

"The Council are the body responsible under the Public Health Acts for securing to the inhabitants of their district a proper and sufficient supply of water; and the Board desire to impress upon them the importance of taking the matter into their serious consideration, with the object of guarding their district against dangers the gravity of which has been sufficiently shown by recent examples.

"Where the Council have themselves constructed or purchased any water-works, it is their duty, in pursuance of section 55 of the Public Health Act, 1875, to provide a supply of "pure and wholesome" water; and in order to fulfil this obligation, it behoves them to exercise every precaution to secure that the water which they deliver to the consumers shall be protected from risk of contamination, whether in connection with the sources from which it is derived or during the course of its storage or distribution, and that where means of filtration are necessary these should be adequate, and maintained in a thoroughly efficient condition. Not only are the Council thus under a responsibility for the wholesomeness of the water which they themselves supply, but they should, by careful inquiry, make themselves acquainted with the sources, nature, and quality of the various supplies in all parts of their district, and, in every case in which the result of their inquiries is unsatisfactory, should take all such steps as may be within their powers with the view of supplementing or improving the supplies.

"The Board would observe generally that accurate information should be procured, if not already available, in such matters as the following: (1) *Where water is derived from gathering-grounds or from springs*, whether drainage from human habitations, farmyards, and the like, finds its way, directly or indirectly, into the reservoir or to any part of the water service; and whether risk of access to the water of human excreta and similar refuse is likely to arise. (2) *Where water is derived from deep wells*, whether surface or other water, liable to be contaminated by drains, sewers, cesspools, and the like, reaches, or is liable to reach, the wells. The existence and direction of fissures in the strata deserve especial consideration in this respect. (3) *Where water is derived from shallow wells*, whether the wells are so circumstanced that they run risk of contamination by reason of drains, privies, cesspools, or middens, or by deposit of manure (whether derived from human excreta or not) in or on the ground in the neighbourhood of the wells.

"The Board trust that the Council will not fail to give their most careful attention to this subject, and that, where it may appear that further works which may be within the powers of the Council for the improvement or protection of existing supplies are needed, the Council will forthwith, with the assistance of such skilled advice as the circumstances of the case may require, execute the necessary works."

Water companies, which although private concerns, are established by Act of Parliament, seem to be specially exempted, by the opening clause, from the above responsibility.

It has been observed that careful attention to the points mentioned above would prevent the sickness and suffering of some 50,000 people every year in this country alone, and save some 4,000 lives.

In a recent paper by Dr. Vivian Poore, at the Royal Medical Society, he states that the contagion of typhoid or enteric fever is contained in the excreta, and may gain access to the bodies of the healthy in drink or food or air. When epidemic, it is generally through contamination of the drinking water, and sometimes through the water of the milk and other beverages. Short records were given of 46 instances within the last 30 years of contamination of public water supplies; and in 29 instances in which the figures were given the cases amounted to 16,486. Of the sources, 8 were streams and rivers, 11 were wells, 3 were upland gathering grounds, 7 were deep wells in the chalk, which were polluted by various leakages. Plumbers who attend to drains and sewers ought not to touch water pipes and cisterns without complete washing and change of raiment.

With reference to the causation of typhoid from the soil, as by leaky water mains (p. 136), &c., it is known that other diseases, such as malaria, cholera, yellow fever, dysentery, tuberculosis and summer diarrhœa may originate from this source, and may be transferred to water. Dublin is supplied from a purer source than London (p. 148), but the gravel soil is more polluted by leaky drains, and typhoid is far more prevalent.

However, at Buda Pesth, Draschke showed by elaborate statistics that improved water supplies, and not otherwise improved sanitary conditions, were the chief instruments in lowering the typhoid mortality. At Vienna, the temporary re-introduction of Danube water was followed by a rise of typhoid mortality in the parts where it was used many times greater than that in parts where the Hochquellen water (high springs) was supplied. Similar evidence was given from Naples, Bremen, Buda, Lemberg, and Fünfkirchen.

Maidstone Epidemic, 1897.—This is a remarkable instance of culpable negligence in the protection of portions of a water supply, and of its consequences. Population about 34,000. A fairly healthy town on the Lower Greensand, with a substratum of clay. Death-rate in decade preceding 1897, 14·54 per 1,000, as compared with 18·57 for the corresponding average of England and Wales. Typhoid, ·077; England and Wales, 0·175. Water supplied by a company from springs rising in three districts—Cossington and Boarley, both chalk; and Farleigh, surface springs, nominally in Lower Greensand, over Atherfield clay. The latter springs are said to be "derived from more or less shallow sources in the Ragstone, which is liable to be fissured; the gathering grounds of some of them are covered with hop or fruit gardens, which are heavily manured, and on which great numbers of persons are employed at certain seasons of the year. *The land on which the springs are situated does not belong to the company, who apparently have no control over the surface.*" According to the evidence of the manager, "it had never occurred to anyone that it might be expedient to exclude labourers from the vicinity of the springs, or to protect them in any way," although "on one occasion some petroleum which had been spilt on the surface of the ground found its way into the catchpit." (See p. 92.) The storage reservoirs were also liable to risks of pollution by surface water, and had not been cleaned out for two years, while the filter-beds were only used four or five times a year, when after heavy rains the water became turbid.

In the early part of September, 1897, a violent outbreak of typhoid fever, involving nearly 1,700 cases in about two months, and a total of nearly 2,000, suddenly appeared. Some of the above particulars are taken from the detailed report of the Local Government Board inquiry, lasting for eight days from January 31st, 1898, which, however, was not published in entirety till the following August. The official decision was that "on a review of the whole of the epidemic we have no hesitation in coming to the conclusion that it was caused by pollution from the Farleigh sources. . . . The sudden and simultaneous outbreak over a wide area, and the rapidity with which the epidemic grew, cannot be accounted for by the existence of defective conditions of sewerage and drainage." Although "many of the typhoid cases in the borough were due to defects of drainage and sewerage, with consequent pollution of the soil underlying the town," yet "the cases of typhoid were confined to the Farleigh area to an extent which quite precludes the possibility of mere chance." The percentages of incidence in the three areas were, as to persons attacked: Cossington, 0·86; Boarley, 0·97; Farleigh, 5·60; at the same time the most insanitary parts of the town escaped.

The examinations, bacteriological and chemical, were undertaken *too late*. *B. typhosus* grows freely at blood-heat, but disappears rapidly in ordinary water, starved out by the large numbers of common water organisms. It is true that it has been recently proved to be capable of living, under certain conditions, for one or two months or more, in *soil* containing organic matter.* But even here vegetation interferes with its growth. As the period of incubation of typhoid is fourteen to sixteen days, all the organisms that had caused the epidemic might have died or been washed away before the samples were taken. Even *B. coli*, which is much more robust, would suffer the same fate. Dr. Washbourne found sixty *coli* per cubic centimetre in the Tutsham spring on September 21st; the infection is supposed to have occurred about August 17th, the outbreak about September 9th. Drs. Durham, Foulerton and Tew found both typical and atypical *coli* in considerable numbers. But Dr. Sims Woodhead, at a later date, November 5th, did not discover *typical*, *i.e.*, intestinal, *coli*, although a number of soil organisms were present, proving surface pollution.

* Dr. J. Robertson, Medical Officer of Health, Sheffield, has found that during the warmer months typhoid bacilli, placed in the soil, continued to multiply, this multiplication lasting apparently for at least 143 days. When, however, the cold weather came on, and the soil was left untreated, at the end of 181 days none were found. If various organic matters were added at intervals, the bacilli lived through the winter, and were discovered after 315 days. These experiments have been confirmed by Dr. Sidney Martin, of the Local Government Board.

The chemical analyses suffered under the same disadvantage. Dr. Adams had calculated a "local standard" for the water of the district, founded on a large number of analyses extending over a lengthened period. He had formerly executed fortnightly analyses, which would almost certainly have given warning in time of any dangerous deviation from the normal. But from motives of economy, the local authorities had ordered that the water should only be examined quarterly. The water company had no examination at all, "except when fresh springs were added."

The analyses of September showed, in many cases, no great excess of albuminoid ammonia, but the increase in hardness, in phosphate, and particularly in nitrates, proved that the ammonias had been acted on by the soil. The chlorine was not high, a feature denoting fæcal, rather than urinous, contamination.

Dr. Adams, in his paper at the Society of Analysts, June, 1898, attributes the epidemic to the long drought having cracked the loamy clay, so that on the falls of rain which immediately preceded the outbreak, and, as is shown by his tables, coincided with the maxima of cases allowing for the period of incubation, the surface pollution, from hop-pickers or otherwise, was washed through the fissures into the springs. It is well known that typhoid and some other epidemics have usually followed on a dry period succeeded by sudden rains, and this may very well be the explanation. He also illustrates and explains the effect on the ground-water level. He considers the "premonitory diarrhœa," which in this as in other cases, gave the first warning of danger, to be due to ptomaine poisoning by soluble products of the incubated bacteria, washed through before the organisms themselves had time to be transported. It was pointed out that it might also have been caused by another bacillus (such as Klein's *B. enteritidis*) with a shorter period of incubation.

In the conclusion of their report the Commissioners observe that, "the general order of the Board of 1891 prescribes that the Medical Officer of Health shall inform himself as far as may be practicable respecting all influences affecting or threatening to affect injuriously the public health within his district. . . . Section 7 of the Public Health (Water) Act, 1878, imposes upon Rural Sanitary Authorities the duty of taking such steps as may be necessary to ascertain the condition of the water supply within their district." Yet it was stated at Maidstone that "when analyses were made, and the water was reported bad, no action was taken," also that "if the Medical Officer of Health visited the springs to take a sample, he was trespassing, and taking that which did not belong to him."

So that we have, as costly lessons of this disaster—

1. Protection of gathering grounds, which as far as possible should be public property and free from habitations.

2. Right of access for inspection and for taking samples.

3. Analyses at frequent intervals. A partial examination, chemical and bacterial, undertaken once a week, is more useful than complete analyses at longer periods.

On October 16th the reservoir, mains and pipes that had received Farleigh water were sterilised with chloride of lime solution of 1 per cent. strength, the hydrants and house taps being left open until the reagent was running freely at the outlets. The disinfection occupied forty-eight hours, and the system was then washed out. No corrosion of the pipes was observed, and all bacilli, except perhaps anthrax spores, which are not in question, would be destroyed.

The Maidstone Town Council decided to promote Bills to compulsorily acquire the undertakings of the water company, and also to obtain additional sources of supply, but the scheme was rejected by the ratepayers. The expense of the epidemic is estimated to have been over £18,000.

King's Lynn.—In 1897 there was a sudden epidemic of typhoid in this town, with a general distribution of the fever. The water was supplied from the Gaywood river, rising from springs polluted by foul surroundings. Fæcal matters were washed into the stream by the heavy rains, while the earthen pipes at the intake leaked freely at the joints. These pipes were bedded in clay covered by heavily-manured garden mould. The "filter-beds" were really only straining tanks. The total number of cases noted up to the end of 1897 were 461. New waterworks are in progress, supplied from deep wells in the chalk near Grimstone.

Worthing.—The official report on the outbreak in 1893 stated that the water supply was contaminated through a fissure in the chalk which conveyed sewage matter to a new well sunk shortly before. 1,411 cases occurred. Prof. Kelly considered that the water was infected by labourers employed on the works. Klein found *B. coli* and *typhosus* in water from the main. With the object of sterilising the pipes, they were filled with milk of lime, which was allowed to remain for three or four days and then washed out. It has, however, been proved by experiments on sewage that lime does not necessarily *kill* the bacteria, but merely carries them down, so that if any deposit were left, they might still re-diffuse. Chloride of lime, as used at Maidstone, is far more effectual.

Camborne.—The first case was notified on December 5th, 1897, and during the month there were eighty other cases, besides seventeen in the adjoining parish of Illogan. The only factor in common in these cases, which are distributed over a wide area, was that they were all supplied by the Camborne Water Company, while no case has occurred in neighbouring districts supplied from a different source. Periodical examinations of the drinking water were ordered to be made.

Belfast: Population 350,000.—During 1897 an epidemic of typhoid broke out in this city, and reappeared in 1898. In one week in August, 1898, 100 fresh cases were received into hospital. The disease at first attacked only the upper classes. The cause of this was stated to be that the better houses were provided with cisterns, and the overflow pipes were frequently connected with sewers. The gathering grounds were exposed to contamination, but the water, as supplied to the people, appeared on chemical analysis to be pure. Bacteriological examinations were made of the different sources, active disinfection was carried out, and the inhabitants were instructed to boil all milk and water before use. It was said officially that "the apparent want of exclusive association with either source of water supply, and the fact that there has been a prevalence of fever for many years, point to an origin from a general fouling of the soil."

Carnarvon: Population 10,000.—These wide-spread outbreaks naturally led to investigations as to the danger in other districts, since many towns drink water quite as unsafe as Maidstone, and only escape fever by mere accident. The sources of the Carnarvon water supply having for some years been subject to pollution, Dr. S. W. Wheaton reported to the Local Government Board on the subject. At the intake from the river Gwrfai, 6½ miles above Carnarvon, the water was screened through copper gauze, and then flowed directly to a reservoir, from which it was issued *without filtration* to the town. The river received the whole of the liquid refuse from the village of Rhyd-ddu, of 150 inhabitants, besides the drainage from farms of bad sanitary surroundings, situated on a tributary. The local authorities of the vicinity had failed to come to an arrangement as to a joint system of sewerage. Dr. Wheaton doubted greatly whether filtration, as ordinarily carried out, would render such water safe, and expressed a preference for a new supply from Lake Dywarchen, which was not then used for any purpose.

A severe epidemic of typhoid fever occurred in Philadelphia in 1899, there having been 4,880 cases and 490 deaths between January 1st and March 24th. This condition is consequent upon a defective water supply, and for more than fifteen years repeated small outbreaks have given warning of the danger. The water supplying the town was drawn from the Schuylkill River, and was much polluted, unfiltered, and deficient in quantity. From the fact that the general death-rate was not increased in any notable degree, that children were chiefly attacked, and that the incidence of the disease was so unevenly distributed, it appeared that the general sanitation was not satisfactory, the outbreak being partly due to overcrowding and defective drainage. The death-rate from typhoid fever in Philadelphia was 60 per 100,000; that of towns supplied by pure mountain spring water, *e.g.*, Berlin and Munich, is 4; and of towns supplied from proper filter-beds, *e.g.*, London and the Hague, is 8·3 per 100,000.

London (see p. 121).—The London County Council, at a meeting on October 12th, 1897, agreed to the following reference: "That it be referred to the Public Health and Water Committees to inquire and report whether the causes which have led to the typhoid fever epidemic at Maidstone have any parallel in the conditions of the London water supply, and what steps, if any, should be taken to prevent the propagation of the disease in London."

The report was issued in 1899, and was unfavourable to the present supplies from the Thames.

Although the typhoid rate in London is undoubtedly low, the fever is always present in the area. Hence considerable anxiety exists as to the security of the Metropolis against a widespread outbreak, especially as the Thames and Lea valleys furnish constant pollution to the river waters. In times of flood both rivers become turbid, and charged with the filth of all the districts drained: then, nothing but efficient filtration stands between London and water-borne disease. And yet, even the filtered water of some companies is occasionally turbid.

Neither the water companies who supply the water, nor the Local Government Board who are responsible for its analysis, nor the County Council, which represents those who drink it, have control over the river—only the Thames Conservancy—which is chiefly concerned with navigation. The County Council have not even the right to send to see if the filters are clean. Yet there is no city in the world where such minute and incessant care is taken daily, and almost hourly, to detect and report on the slightest deviation from purity in its water supply. Specific tests are often made for the presence of pathogenic organisms, besides the daily bacteriological examinations of the clear water wells of the companies. In view, however, of the well-known fact that, in the present state of bacteriological science, the detection of typhoid bacillus in waters which have caused the disease, has only been effected in a very few recorded cases, the statement in the reports of the Local Government Board that "the most minute microscopic examination of the water as it reaches the intakes of the various companies has hitherto failed to discover in it a single pathogenic organism," loses much of its presumption of safety. Moreover, bacilli of the *Coli* group, at least some of which are probably pathogenic, have been repeatedly found in the water supplied by certain companies. When it is observed in a report that, say, 93 per cent. of the bacteria have been removed, it is possible that the 7 per cent. left in may either have passed through the filters, or may represent a corresponding percentage of water that has actually not been filtered. Some of the companies run all their filtered water into a general receptacle from which the samples are taken for examination, so that a fault of the kind would be masked by an average. The anguillulæ, cyclops, infusoria, and various *débris* which have on many occasions been extracted by the micro-filter (p. 26) from the public supplies could hardly have originated in the mains, which are dark: they could not nave escaped efficient filtration, and their presence requires explanation as throwing suspicion on the efficiency of the subsidence and sand filtration. This process, if conducted with great care, undoubtedly effects an immense reduction in the number of organisms (p. 187), while the intensity of infection which may arise from a well or small supply is practically impossible with larger volumes like the Thames and Lea.

At the same time, Shirley Murphy has shown that an abnormal distribution of typhoid in the part of London supplied from the Thames has followed exceptional floods in the Thames valley. The legal power of constant inspection, of taking samples, and of stopping a supply when the arrangements are defective, is at present wanting, and yet is urgently needed. The powers and procedure would be similar to those at present in use under the Food and Drugs Acts. Even with all precautions, however, apart from the question of a future deficiency in the amount of water owing to the observed progressive shrinking of the Thames, London cannot be considered secure while drawing from polluted rivers. "Our only real safety lies in selecting a pure supply, and in keeping it so" (see p. 123).

In December, 1898, unfavourable reports were issued by Mr. Cassal on the water supplied by some West End London companies. Sir E. Frankland had reported that "owing to heavy floods and insufficient storage, the water sent out by all the water companies, except the West Middlesex, contained an excess of organic matter, which was, however, almost entirely of vegetable origin." Crookes and Dewar's official analysis found that the "oxygen consumed" figures were for the Grand Junction Company 0·071 grn. per gallon, and for the Chelsea 0·063, whereas in September they had been 0·025; an increase in December of about three times. Dr. Corfield remarked that this impurity during winter is constant, and that enteric fever at the same period was unusually prevalent and fatal in London.

The examples are numerous of local epidemics being caused by—

(1) *Disregard of regulations or warnings against using crude water.*—Two instances may be cited. At the Chicago Exhibition of 1893, the employees, numbering 15,000, used water sterilised at 100° C. by an ordinary feed heater. No diarrhœal troubles were reported. But on a few occasions when for a short time unsterilised water was used, intestinal troubles and even typhoid fever resulted. In September, 1897, a localized outbreak of typhoid occurred at Hamburg. It was traced by the medical board to the drinking of raw river water from the harbour, notwithstanding the frequent notice boards cautioning against its use.

(2) *The accidental breakdown of plant* (p. 182).

(3) *Contamination in transit.* — Besides the examples of leakage which have been described (p. 136), convictions have been repeatedly obtained for bathing in public aqueducts, notably in East London in 1898.

The first and third causes are common to all systems, but the second is the peculiar weakness of methods attempting to purify polluted waters, which therefore, even with the best appliances, demand continual watching and effective scientific control.

At a meeting of the Sanitary Institute in March, 1898, after a paper on "Water-borne Typhoid," by Dr. C. Childs, the following resolutions were passed as suggestions for legislation:—

(1) All local sanitary authorities shall have free access to the water supplies—from source to distribution—which are distributed within their districts, whether the source and course of the water so supplied be within their district or not. That the sanitary authorities provide for the thorough and regular inspection of the water supplies distributed within their districts, and for the regular analysis of such water, as often as may be deemed sufficient, and that the results of such inspections and analyses shall be regularly recorded and published.

(2) That the waterworks companies shall prepare and publish records of their water supplies; such records containing a full account of every source and tributary of the water supply, and a full account of all reservoirs, conduits, filter-beds, mains, and pipes by which the water which they supply is collected, stored, or conveyed, to the houses supplied; such records also being fully illustrated by maps, plans, and sections, showing the relation of all houses, drains, sewers, cesspits, and all deposits of organic refuse in the immediate neighbourhood of any part of the water supplied by them, and that all such records, maps, plans, sections, &c., shall be freely accessible for the purpose of inspection to the sanitary authority within whose district the water is supplied, and to every customer of the waterworks company.

(3) That the waterworks companies shall be required to make regular constant and thorough inspection of all parts of the water supplied by them—from source to distribution—with a view to preventing wilful, careless, or accidental pollution; also to make regular analyses of the water supplied by them, so often as may be considered necessary; and to make and publish reports of all such inspections and analyses.

(4) That waterworks companies shall be made responsible for the consequences of the pollution of water supplied by them, if such pollution could reasonably have been prevented.

(5) That wilful or careless pollution of any water supply shall be regarded and treated as a penal offence.

(6) That authorities, representative of the interests concerned, be appointed for each watershed of the kingdom, who shall have the general care and supervision of the waters within each respective watershed; shall take prompt measures to prevent any threatened pollution, and to arrest any detected pollution of any water; and shall be responsible for the due and effective administration of the laws respecting the protection of water within their districts.

In several Water Bills recently introduced, clauses embodying some of these resolutions have been inserted, and new water powers will probably not be granted in this country without similar protection being legalized.

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TABLE A.—EXAMPLES OF WATER ANALYSES.

Parts per 100,000.

WATER.	Source or Locality.	Physical Characters.	Total Solids.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates and Nitrites.	Nitrites.	Total combined Nitrogen.	Percentage of Nitrogen Oxidised.*	Phosphates.	Total Hardness.	Permanent Hardness.	First Oxygen Consumed.†	Second Oxygen Consumed.‡	Organic Carbon.	Organic Nitrogen.	REMARKS.
Rainwater from Tank	Guildford	Inodorous, nearly colourless, not clear.	2·9	0·55	·045	·0256	No nitrate.	Trace	·082	Trace to nitrite.	None	Slight	..	..	..	..	..	A fair sample of rainwater as ordinarily collected.
Average of 71 Rainwaters	Rothamstead ..	.. .. ..	3·42	0·33	·049	..	·007	..	·068	10·3	..	0·5	..	..	..	·095	·021	Solids ranged from 0·62 to 8·58.
Rainwater, Land's End	Cornwall	Slightly turbid ..	42·8	21·8	None	..	·020	..	·054	37	..	10·0	..	..	..	·131	·034	Mixed with sea-spray.
Town Rain	London	Slightly sooty ..	3·8	0·6	·110	·032	·008	Distinct	·148	5·4	..	1·5	1·5	..	..	·383	·040	Trace of free sulphuric acid. Arsenic ·020 (Frankland).
London Waters. §																		
River at Sunbury (intakes)	Thames	Turbid	31·24	1·8	·002	..	·305	Distinct	·356	86	..	..	..	..	..	·314	·049	
River at Hampton (,,)	,, ...	Brownish turbid ..	29·74	1·9	·012	·0280	·273	,,	·335	81·5	Slight	21·5	5·0	·064	·140	·258	·052	Microbes per c.c. 18,330.
Chelsea Water Co.	,, ...	Clear, pale yellow	29·92	1·8	None	·0098	·236	V.F.T.	·276	85·5	Very slight	23·0	4·6	·040	·094	·177	·035	,, ,, 278.
West Middlesex Water Co.	,, ...	Clear, pale amber	30·1	1·8	,,	·0124	·254	None	·272	93·4	,,	22·4	4·4	·069	·160	·150	·018	,, ,, 38.
Southwark ,, ,, ...	,, ...	Clear, straw-coloured.	29·58	1·8	Trace	·0100	·225	V.F.T.	·241	93·4	,,	22·4	4·5	·090	·126	·170	·040	,, ,, 56.
Grand Junction ,, ,, ...	,, ...	Clear, pale amber	27·96	1·9	·003	·0060	·211	None	·237	92·8	,,	21·7	4·1	·077	·099	·179	·026	,, ,, 270.
Lambeth ,, ,, ...	,, ...	,, ,,	29·1	1·9	None	·0074	·237	,,	·261	90·8	,,	22·1	4·4	·020	·086	·162	·035	,, ,, 160.
Intake New River Co.	Lea	Turbid, pale yellow	32·3	1·7	·002	·0216‖	·324	V.F.T.	·344	94·2	,,	25·0	6·5	·030	·144	·099	·018	,, ,, 8,660.
New River Co.'s Supply	,, and wells ..	Clear, nearly colourless.	28·5	1·8	·0003	·0050	·287	None	·295	97·3	,,	24·0	6·0	·053	·077	·056	·008	,, ,, 28.
Intake East London Co.	Lea	Turbid, pale brown	40·9	2·3	·030	·0221	·255	,,	·346	78·7	Slight	26·6	6·4	·043	·150	·295	·066	,, ,, 23,010.
East London Co.'s Supply	,, and wells ..	Clear, very pale yellow.	32·24	2·1	·004	·0140	·285	,,	·309	92·2	Very slight.	23·6	6·1	·047	·077	·135	·024	,, ,, 214.
Kent Co., New Cross	Wells in Chalk ..	Clear, bluish ..	32·9	2·4	None	·0006	·227	,,	·235	96·6	None	24·5	7·0	·004	·009	·067	·008	,, ,, 8.
,, ,, ,, ...	,, ...	,, ..	39·0	2·0	,,	·0010	·450	,,	·461	97·6	Trace	..	..	..	..	·072	·011	
,, Deptford	,, ...	,, ..	38·8	2·3	,,	·0015	·329	,,	·345	95·4	None	29·2	7·1	·006	·013	·069	·016	,, ,, 11.
Midstream, Crossness (average) ..	Thames	Turbid, brownish	..	..	·102	·0394	..	..	..	..	..	..	..	..	·274	..	..	"Organic elements" 1·221.
Sewage Effluents.																		
Average London Sewage	.. .. ..	.. .. ..	..	10·5	4·52	·547	None	..	4·26	0	..	..	..	..	4·30	..	..	
Raw Sewage	Yeovil	Very turbid and fetid.	80·6	12·64	9·00	1·135	,,	..	9·39	0	Very heavy.	..	..	...	5·86	..	..	A blackish flocculent sediment.
,, ...	Weybridge ..	Cloudy, strong smell.	84·6	10·0	10·15	1·05	..	..	10·21	..	..	..	..	..	4·00	..	..	
,, (after treatment with Alum, &c.).	Coventry ..	Turbid, rather offensive.	63·6	7·01	0·34	0·104	No nitrate.	Strong	·460	Distinct to nitrite.	Heavy	..	..	..	1·87	..	..	Sewage diluted, and partly oxidised.
Fish Manures Factory Effluent ..	Wembley ..	Brown colour, very offensive.	245·8	16·7	52·0	2·50	None	None	47·1	0	,,	..	..	..	9·36	..	..	Contained trimethylamine and fish-oil.
Sewage Farm Effluent	Wembley ..	Blackish, turbid, and fetid.	133·4	12·6	0·85	0·63	0·75	Very strong.	1·54	48·7	..	..	..	..	1·79	..	..	From sewage farm. Nitrification in progress.
Sewage Effluent	Aylesbury ..	Cloudy, strong sewage odour.	80·0	8·9	4·4	1·3	0·08	Trace	5·95	2·3	..	..	..	..	7·83	..	..	A bad effluent. Nitrification very sluggish.
Sewage Farm Effluent	Croydon	Nearly clear ..	46·0	3·25	·455	0·07	0·88	Very strong.	1·40	63	..	..	..	..	1·29	..	..	Shows active nitrification in progress. A good effluent.

* This column has reference to the remarks on p. 249. In rainwater, the oxidised nitrogen has mainly been derived from the air.
† The "First Oxygen consumed" indicates the loss from permanganate in a short time (5 minutes or 15 minutes, as the case may be).
‡ "Second Oxygen consumed," the maximum amount obtained under the conditions used by the analyst.
§ These vary from time to time. For complete series, see reports of Metropolitan Water Examiners, also London County Council Report, 1896.
‖ This and the next furnish a good example of the improvement effected by subsidence and filtration.

[See continuation of this Table on following sheet.]

TABLE A.—EXAMPLES OF WATER ANALYSES—Parts per 100,000—*continued.*

WATER.	Source, Locality, or Date.	Physical Characters.	Total Solids.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates and Nitrites.	Nitrites.	Total combined Nitrogen.	Percentage of Nitrogen Oxidised. *	Phosphates.	Total Hardness.	Permanent Hardness.	First Oxygen Consumed.†	Second Oxygen Consumed.‡	Organic Carbon.	Organic Nitrogen.	REMARKS.
Sewage Effluent, Ripley Green, Guildford.	January 13, 1896	.. .. ..	39·5	9·11	·300	·086	None	Very strong.	·414	To nitrite only.	Heavy trace.	..	..	..	1·18	..	..	Nitrification not satisfactory.
Farm Effluent, Ripley Green, Guildford.	,, ,,	Distinct sewage odour.	59·9	8·48	1·42	·128	,,	None	1·41	0	Very strong.	..	..	..	1·52	..	..	In bad condition. No nitrification.
Sewage Farm Effluent	.. .. ..	.. .. ..	77·7	7·05	·380	..	·441	..	·908	48·5	..	..	..	..	..	·980	·154	Suspended matter: organic ·28, mineral ·76. Nitrification active.
Fresh Sewage: average from 16 Water-Closet Towns.	(Frankland) ..	.. .. ..	72·2	10·66	6·70	..	·003	..	7·80	0·04	..	..	..	..	..	4·70	2·20	Suspended matter: organic 24·2, mineral 20·5.
Fresh Sewage from 15 Midden Towns	.. ..	.. .. ..	82·4	11·54	5·43	..	None	..	6·50	0	..	..	..	..	..	4·18	1·97	Suspended matter: organic 17·8, mineral 21·3.
River Avon, Coventry	February 6, 1896 ..	Turbid, marshy odour.	51·6	2·2	Trace	·032	·025	Strong	·079?	31·6	H.T.	..	..	..	·240	..	..	Polluted with sewage, altered by flow and vegetation.
UPLAND SURFACE WATER.																		
River Exe above Town, May 28, 1895.	Exeter	Clear, very pale brownish.	9·0	1·3	None	·011	·107	V.F.T.§	·133	80·5	V.F.T.	4·21	4·14	..	·270	·400	·063	Peaty matter.
	Millstone Grit ..	Brownish, slightly turbid.	7·9	0·95	Trace	·009	·035	None	·060	58·3	None	3·5	3·0	..	·380	·250	·025	Very peaty.
Lower London Tertiaries, &c. ..	Bagshot Beds ..	Nearly clear ..	8·4	2·06	·004	·010	·007	V.F.T.	·059	11·8	V.F.T.	3·8	3·5	..	·220	·379	·048	Very little nitrification.
	Mountain Limestone.	Brownish, clear ..	17·7	1·24	·001	·006	·011	None	·059	18·6	None	12·7	7·0	..	..	·370	·047	Peaty.
	Magnesian Limestone.	Slightly turbid ..	17·8	1·40	·001	·004	None	..	·037	0	,,	14·7	8·3	..	..	·172	·036	
	Calcareous Soil ..	Turbid, brownish, faint odour.	110·4	12·75	·030	..	1·005	..	1·337	75·2	H.T.‖	67·3	42·1	..	..	1·34	·307	Highly polluted with manure.
	New Red Sandstone.	Clear, nearly colourless.	38·5	2·30	·001	..	·449	..	·466	96·3	..	31·3	10·9	..	..	·040	·016	Probably polluted with surface drainage.
DEEP WELLS.																		
Bore Hole, 575 feet, Coventry (see also Kent Waters above).	Red Sandstone ..	Clear, nearly colourless.	796·9	117·7	·100	..	·119	..	·239	49·8	..	151·5	36·3	..	..	·041	·036	Example of a saline and undrinkable water.
Artesian Well	Chalk under London Clay.	Clear, nearly colourless.	106·7	38·8	·118	..	·645	..	·681	94·7	..	48·5	25·4	..	..	·195	·067	High mineral constituents. Shows the difference mentioned at p. 327.
SPRINGS.																		
From Granite and Gneiss Rocks ..	.. .. ..	.. .. ..	5·94	1·69	·001	..	·106	None	·115	92·2	None	3·0	2·6	..	..	·042	·008	
Lower Greensand and Gault Clay ..	Shefford, March 13, 1896.	Clear and colourless.	99·4	12·4	Trace	·0022	·90	Trace	·904	99·5	Trace	..	..	..	·105	..	..	A bad water from its mineral constituents. Shows some signs of organic pollution.
Tideswell Spring, Derbyshire	Mountain Limestone.	Clear and colourless.	28·5	1·4	·001	·005	·25	..	..	..	..	24·0	..	..	..	..	..	
Weald Clay	Charlwood ..	Brown sediment ..	428·6	40·0	·020	·080	Trace	None	·157	Trace	Trace	21·8	..	..	·200	..	..	Alkaline, unfit for drinking.
Oolite	.. .. ..	Clear, colourless ..	30·3	1·55	·001	·003	·402	,,	·414	97	None	24·4	6·2	..	..	·043	·011	A good water.
A SHALLOW WELL	.. .. ..	Deep yellow brown, clear.	112·0	8·8	·252	·013	4·61	Abundant	4·85	95	H.T.	57·0	33·0	0·84	·112	..	..	Badly polluted.

* This column has reference to the remarks on p. 269. In rainwater, the oxidised nitrogen has mainly been derived from the air. † The "First Oxygen consumed" indicates the loss from permanganate in a short time 5 minutes or 15 minutes, as the case may be). ‡ "Second Oxygen consumed," the maximum amount obtained under the conditions used by the analyst. § Very faint trace. ‖ Heavy trace.

TABLE B.

COMPOSITION OF BOILER INCRUSTATIONS FROM DIFFERENT WATERS.

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Source.	Sea Water.				Brackish Water.	River Water.				Wells.		Town Supply—Edinburgh.	Spring—Slough.	Pits & Surface—Prestonpans.	Quarry—Granton.	An Acid Water.
							Carlisle.		Thames.	Dunbar.	Slough.					
Pressures in lbs. per sq. in.	5	10	20	25(?)	...	...	...	60	80	...	...	...	...	...	...	...
$CaCO_3$	2·00	3·44	0·34	0·97	43·65	75·85	75·92	8·20	81·45	32·16	25·62	62·95	50·04	1·22	17·31	2·20
$CaSO_4$	34·00	69·77	72·85	85·53	34·78	3·68	3·16	85·01	1·63	5·64	55·92	20·80	29·76	78·32	53·76	...
$Mg(OH)_2$	58·00	22·50	18·83	3·39	4·34	2·56	...	4·36	8·10	...	...	...	...	...	...	...
$MgCO_3$	...	...	...	...	...	...	10·16	...	...	20·04	5·56	7·24	10·84	10·36	18·04	None
Na salts	...	...	...	...	...	...	0·84	...	...	3·31	...	0·86	0·86	0·64	0·54	...
NaCl	Trace	0·99	2·16	2·79	0·56	0·45	...	Trace	Trace	...	0·22	...	...	...	...	...
Fe_2O_3, Al_2O_3, and $Ca_3(PO_4)_2$...	1·33	1·36	2·40	0·32	3·44	2·96	2·96	0·52	2·44	7·46	5·04	2·48	2·36	4·64	2·88	83·80
SiO_2	Trace	0·16	0·80	1·10	7·52	7·66	4·94	1·91	0·87	16·94	5·26	3·76	4·28	3·22	4·36	5·28
Organic matter }	4·67	1·78	2·62	Trace	1·55	3·64	0·49	Trace	4·65	7·67	1·04	0·69	0·64	0·88	2·33	8·72
Moisture ... }				5·90	4·16	3·20	1·53		0·86	6·78	1·34	1·22	1·22	0·72	0·78	

NOTES.—These analyses are only comparative in a general sense, as they were done under different circumstances. They, however, furnish good examples of the effects of varying conditions.

Nos. 1, 2, 3, 4 show the increasing proportion of calcium sulphate precipitated with an increasing pressure, and therefore temperature.

In Nos. 6, 7, 9, 10, 12, the waters were of the carbonate of lime class, in which the temporary hardness is predominant.

In Nos. 8, 14, 15, the waters had a high permanent hardness, due to sulphate of lime.

No. 10 is a magnesian water. The high amount of silica is remarkable, also the action on iron.

No. 16 shows the action of a soft and acid water on iron. The small quantity of carbonate of lime has probably been protected by the iron scale.

The proportion of organic matter is seen to vary greatly.

As boiler crusts usually contain magnesium hydrate only, the magnesium carbonate found in some of the above analyses must be due to the absorption of carbonic acid from the air by the crust after removal.

TABLE C.

TABLE OF THE COMMON ELEMENTS AND THEIR COMPOUNDS OCCURRING IN CONNECTION WITH WATER.

	Symbol.	Atomic Weight.	Chief Compounds and their Synonyms and Formulæ.
Gases.			A.—NON-METALS.
Oxygen	O	16	Free oxygen, O_2, in air, and dissolved in water, H_2O. Basic oxides, oxy-acids, and almost all organic matter. Ozone, O_3. Peroxide of hydrogen, H_2O_2.
Hydrogen ..	H	1	Product of putrefaction. Water, H_2O. Hydrates. All acids.
Nitrogen....	N	14	Free, N_2, in air, and dissolved in water. Product of some bacteria. Nitric acid, HNO_3, and nitrates. Nitrous acid, HNO_2, and nitrites. Ammonia, NH_3, and its salts. Nitrogenous organic matter, animal and vegetable.
Chlorine	Cl	35·4	Free, Cl_2, only artificially, as a disinfectant. Common salt, sodium chloride, NaCl; hydrochloric or "muriatic" acid, "spirits of salts," HCl; chlorides of all metals.
Solids.			
Sulphur	S	32	Sulphuretted hydrogen or hydric sulphide, H_2S. Ammonium sulphide, NH_4HS. Ferrous sulphide or protosulphide of iron, FeS. Sulphates. Organic sulphur compounds, including albumen, &c.
Carbon	C	12	Free in charcoal, coke, soot, &c. Combined in "carbonic acid," CO_2, more correctly carbon dioxide or carbonic anhydride. Carbonates (see lime, magnesia, &c.). All organic matter. Marsh gas or methane, CH_4, among products of putrefaction.
Phosphorus	P	31	Never free in nature. Phosphuretted hydrogen, PH_3, from putrefaction. Phosphates (see the metals).
Silicon	Si	28	Never free in nature. Silica, SiO_2, in waters, and along with silicates in rocks and soils.
			B.—METALS.
Sodium	Na	23	Caustic soda, sodium hydrate, or "soda," NaOH. Anhydrous sodium carbonate, the neutral or normal carbonate, Na_2CO_3. Crystallized sodium carbonate, "washing soda," "soda crystals," often simply called "soda," Na_2CO_3, 10 H_2O. *Soda ash, black ash,* or *ball soda*, very impure Na_2CO_3. Sodium hydrogen carbonate, acid carbonate, hydrocarbonate, or bicarbonate, often called "carbonate of soda," $NaHCO_3$. Sodium chloride, common salt, NaCl. Sodium nitrate, $NaNO_3$. Nitrite, $NaNO_2$. Sulphate, Na_2SO_4. Bisulphate, or acid sulphate, $NaHSO_4$. Sulphide, Na_2S. Disodium phosphate, common phosphate of soda, Na_2HPO_4, 12 H_2O. Tribasic phosphate, Na_3PO_4. Fluoride NaF. Biborate, borax, $Na_2B_4O_7$, 10 H_2O.

TABLE OF ELEMENTS—*continued.*

	Symbol.	Atomic Weight.	Chief Compounds and their Synonyms and Formulæ.
			B.—METALS—*continued.*
Potassium ..	K	39	Caustic potash, the hydrate or hydroxide, KOH. Carbonate, "pearlash," K_2CO_3. Chloride, KCl. Nitrate, nitre, or saltpetre, KNO_3. Sulphate, K_2SO_4.
Calcium	Ca	40	Oxide, quicklime, CaO. Hydrate or hydroxide, slaked lime, $Ca(OH)_2$ or CaH_2O_2. Carbonate, chalk, marble, limestone, $CaCO_3$. Bicarbonate, $CaCO_3 CO_2$ or $CaH_2 2 CO_3$, only known in solution. Chloride, $CaCl_2$. Sulphates: anhydrite, $CaSO_4$; gypsum or selenite, $CaSO_4$, $2 H_2O$. Nitrate, $Ca(NO_3)_2$. Phosphate, $Ca_3(PO_4)_2$.
Magnesium	Mg	24	Oxide, magnesia, MgO. Hydrate, $Mg(OH)_2$ or MgH_2O_2. Carbonate, $MgCO_3$. Chloride, $MgCl_2$. Sulphate, $MgSO_4$: crystallized or "Epsom Salts," $MgSO_4,7H_2O$. Nitrate, $Mg(NO_3)_2$.
Aluminium	Al	27·3	Oxide, alumina, Al_2O_3. Hydrate or hydroxide, gelatinous alumina, $Al_2(OH)_6$. Sulphate, $Al_2(SO_4)_3$, 18 H_2O. "Alumino-ferric," mixture of the sulphates of iron and alumina. Potash alum, $Al_2(SO_4)_3$. K_2SO_4, 24 H_2O. Ammonia alum, $Al_2(SO_4)_3$. $(NH_4)_2SO_4$, 24 H_2O. Chloride, "chloralum," Al_2Cl_6. Clay, impure silicate of Al containing iron.
Iron, Ferrum	Fe	56	Ferric oxide, peroxide of iron, Fe_2O_3. Ferric hydrate, $Fe_2(OH)_6$. Ferrous carbonate, $FeCO_3$. Bicarbonate. Ferric chloride, perchloride of iron, Fe_2Cl_6. Ferrous sulphate, protosulphate of iron, green vitriol or copperas, $FeSO_4,7H_2O$. Ferric sulphate, $Fe_2(SO_4)_3$, 9 H_2O. Ferrous sulphide, FeS.
Manganese..	Mn	55	Manganous oxide, MnO. Potassium manganate, "Condy's Green Fluid," K_2MnO_4. Potassium permanganate, "Condy's Red Fluid," "Crimson Salt," $K_2Mn_2O_8$. Peroxide or dioxide, MnO_2.
Lead	Pb	207	Hydrocarbonate, white lead, $PbCO_3$, $Pb(OH)_2$ (soluble as bicarbonate). Sulphate, $PbSO_4$ (insoluble). Hydrate, $Pb(OH)_2$ (somewhat soluble). Chloride, $PbCl_2$ (soluble).

The molecular weight of a compound is obtained by adding up the atomic weights of the elements in its formula.

TABLE D.

ORDER OF THE ROCKS AND CHARACTERISTICS OF WATERS DERIVED FROM THEM.

Period.	Group.	Sub-divisions.	Waters.
TERTIARY ..	Recent ..	Made Earth .. .. Vegetable Soil.	Waters from vegetable soil and from made earth are polluted and highly dangerous.
		Blown Sand	Waters from sand are sometimes almost pure rain water, but are often brackish.
		Alluvium	Surface waters, p. 69.
		Peat	Peaty and moorland waters are described at p. 71.
	Post-tertiary or Pleistocene.	Glacial Drift.	Shelly sands, marls, and gravel, usually too porous to allow of proper filtration of the surface water that soaks into them. In some places beds of peat affect the character of the water. In the west of England open shallow wells in the drift sometimes form the chief supply of villages, but are gradually being superseded by less dangerous sources.
	Newer Tertiary or Pliocene.	Norwich Crag, Red Crag, &c.	
	Middle Tertiary or Miocene.	Coralline Crag.	
	Lower Tertiary or Eocene.	Barton Clay	Absent in the London Basin. In Hampshire its sandy layers yield a good water, though not abundant.
		Bagshot Sands ..	Water mostly very soft, but often of bad taste and colour through fossil remains, lignite, &c.
		London Clay ..	Impervious to water.
		Woolwich and Reading Beds.	Pebble beds, sand, loam, and plastic clay. Water very various in quality, and not usually regular nor abundant in yield.
		Thanet Sands ..	Occur only in the London Basin. Water often abundant and soft, but wells liable to great fluctuations and to surface infiltration.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
MESOZOIC or SECONDARY.	Upper Cretaceous.	Upper Chalk, with flints. Lower Chalk, without flints.	These strata, as is well known, owing to their fineness of grain, yield water of great organic purity, but of considerable temporary hardness. They form large underground reservoirs of water resting on the chalk marl. Far-extending fissures have occasionally been known to convey surface pollution, but the water is usually almost free from organic matter and life. Artesian wells are frequent, as those of the Kent Company. The water from the chalk, where covered by the London clay, is not, however, good. See p. 260.
		Grey Chalk	Contains organic matter, water often ill-tasting.
		Chalk Marl	Contains clayey and silicious matter and iron. Water usually inferior in a mineral sense. Arrival at these beds indicates the termination of a boring in the chalk.
		Upper Greensand ..	Derives water partially from the chalk, stopped by the gault. Supply not large, often turbid and hard, sometimes ferruginous. Its organic character varies.
		Gault Clay	A blue tenacious clay with pyrites and phosphatic nodules. Springs yield a scanty and inferior water.
	Lower Cretaceous.	Lower Greensand ..	Contains much oxide of iron, therefore water ferruginous, and often full of sand. Strata partly marine. Beds of clay intervene. A few wells yield, however, a soft and pure water, but in limited quantity.
	Wealden (fresh water or fluviatile strata, specially developed in the south of England).	Weald Clay	No available water.
		Hastings Sand ..	Water good where in sufficient quantity.
		Purbeck Beds ..	Mainly limestone without water. The "dirt beds" convey much vegetable organic matter and an objectionable taste.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.		Waters.
MESOZOIC OR SECONDARY.	Jurassic ..	Upper Oolite.	Portland Stone ..	Owing to the porosity of the water-bearing beds of the Oolite, the water is frequently turbid, and surface water is rare. Limestones, with hard and scanty water.
			Portland Sand ..	Water abundant, and usually good.
			Kimmeridge Clay	About 600 feet deep. Much bituminous and vegetable matter. When this stratum is reached further boring is generally inadvisable.
		Middle Oolite.	Coral Rag and Calcareous Grit.	Water commonly free from organic matter, but of high *temporary* hardness and not plentiful. Fissures frequent, leading to danger from surface drainage.
			Oxford Clay ..	Stiff blue and brown clay, occasionally bituminous and pyritous, attaining in some places a thickness of 600 feet. The water is scanty, impregnated with Ca and Mg sulphates, and sometimes medicinal. This stratum, like clay beds generally, yields water above and below it.
			Kellaways Rock	A calcareous sandstone containing little water.
		Lower Oolite.	Bath or Great Oolite (calcareous with sandstones and clayey seams). Fuller's Earth (clay).	On the whole the Oolite consists of four masses of partially permeable strata separated by thick deposits of clay, the limestones forming the ridges and the clays the valleys:— (1) Portland Oolite Limestone and Sand, Kimmeridge Clay; (2) Calcareous Grit, Coral Rag, Oxford Clay; (3) Bath Oolite, Fuller's Earth; (4) Inferior Oolite, Lias Clay. Hence springs are numerous and abundant from the porous strata under the beds of clay. The water is usually hard, and varies from clear and palatable to very turbid. In some cases a saline taste from chloride and sulphate of sodium.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
MESOZOIC or SECONDARY.	Jurassic ..	Lower Oolite. Inferior Oolite (calcareous freestone and grit).	Northampton Sands contain ironstone, and the water is ferruginous. Deep wells at Gloucester and Cheltenham are impregnated with sodium sulphate and chloride. At Bath they are gypseous, but not often saline. Some springs in the Mendip Hills are good and copious. Oolite waters of Yorkshire are much softer than those from the southern Oolite.
		Lias. Alum Shale ..	Usually acid and loaded with mineral matter.
		Lias. Marlstone. Lower Lias.	Waters of fair quality where not medicinal.
	Trias or Upper New Red Sandstone.	Rhætic or Infra-Lias	The Rhætic includes the "Bone-bed," giving ill-flavoured water containing organic matter and phosphate of lime, therefore peculiarly apt to develop organisms.
		Upper Trias or Keuper. Middle Trias or Muschelkalk. Lower Trias or Bunter Sandstone.	The Muschelkalk is a limestone unrepresented in England. When cut off locally by thin beds of clay or by clay-filled faults the Bunter Sandstone yields excellent water, as at Wolverhampton and other places. More rarely good water is obtained from the Keuper. But, as a whole, the Trias, being a marine formation, including deposits of gypsum, rock salt, and oxide of iron, yields water unfit for drinking on account of its saline constituents (analysis, Table A).
			The Lower Keuper nearly always contains water and is generally known as "Waterstones." At Stockport there are many private deep wells of very good quality in the Trias and Permian rocks.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
PALÆOZOIC or PRIMARY. (These, from their hardness, form usually mountainous districts, and are important "gathering grounds.")	Permian or "Dyas."	Magnesian Limestone or Dolomite.	Furnishes an abundant yield in places, but the water shows high permanent hardness, from the presence of lime and magnesium salts, and is apt to be salt, bitter, and unwholesome. The thickness of the strata and, therefore, depth of sinking vary very greatly, and there is also great interference from faults.
		Lower New Red Sandstone.	Water organically good, but often saline and ferruginous. The beds contain large quantities of water, and yield copious springs, but the rock being extremely porous, surface contamination is frequent.
	Carboniferous	Coal Measures (hot springs occur at Matlock, Buxton, and Clifton).	Water mostly scanty in quantity, and of bad quality, often ferruginous and acid. Mine waters are generally very inferior, even if treated with lime. (See p. 147.) In many cases, however, it would be desirable to economize them in reservoirs for small towns and villages, as the draining of mines sometimes dries up the wells of a district. Storage would effect considerable improvement.
		Millstone Grit ..	Supplies excellent water to large towns in Yorkshire and Lancashire.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
PALÆOZOIC or PRIMARY.	Carboniferous	Carboniferous or Mountain Limestone.	The black limestone gives a water of an earthy and sulphurous taste, due to the presence of organic matter. The lighter limestones yield water organically pure, and of moderate temporary hardness (p. 244). The water is plentiful from fissures, but may then be mixed with much unfiltered surface water. In Mendip and Derbyshire rivers often disappear in "swallow holes." There is a regular business of stopping up these holes to prevent loss of water in dry seasons (Hughes). Mineral veins of lead and zinc sometimes contaminate the water, which always needs a chemical examination.
	Devonian or Old Red Sandstone.	Quartzose Conglomerate. Cornstone (clays and marls).	Waters usually good, but scarce. There are no wells for large supply, but where clay beds occur there is abundance at no great depth for private houses. Sometimes bituminous schists occur, containing remains of fishes; these give undrinkable water.
	Upper Silurian.	Tilestone (sandy). Ludlow Shales. Wenlock Limestone.	Tilestone water is good. The shales and limestones often give very inferior turbid and hard waters.
	Lower or Cambro-Silurian.	Caradoc Sandstone. Llandeilo Flags.	Usually very soft and pure waters of granitic character.
	Laurentian ..	(Chiefly in Canada)..	Like granitic waters, but of greater hardness, owing to the presence of crystalline limestones.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
IGNEOUS and METAMORPHIC. (May be of any age, but more common in the primary.)	(Mineral veins are frequent, and may cause metallic contamination of the waters with iron, lead, zinc, or copper, and also acidity.)	Granite, Gneiss, Quartz Rock, Mica Schist, Slate.	Very soft waters, containing potass. salts and silica, but little lime or magnesia. Usually bright and clear, and slightly alkaline. From very rapid streams there may be a white turbidity. Organically of great purity. Slaty waters often contain iron from decomposing pyrites, and are acid, and of a bad taste and earthy odour.
		Crystalline Limestone or Marble.	Hard, from bicarbonate of lime, otherwise pure.
		Trap and Basalt ..	Vary, often acid, alkaline, or ferruginous from decomposing minerals. Organically pure.
		Volcanic Ash or Tufa. Trachyte.	Alkaline and silicious, or may be acid or sulphuretted from presence of sulphur. Springs from volcanic rocks are frequently medicinal, but seldom potable. The temperature is usually high.
		Serpentine	When decomposed may give magnesian waters.

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