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.

In the ordinary process of boiling water in a kettle, most of the accompanying phenomena escape our attention; but if a thin glass vessel be used it is noticed, as the first effect of the heat, that bubbles of gas arise from the bottom and ascend through the liquid. This is due to the fact that gases are more soluble in cold liquids than in hot, and the first gases to be liberated are oxygen and nitrogen, derived from atmospheric air which has dissolved in the water. As the liquid gets hotter, bubbles of steam will form on the lower surface in contact with the flame, will rise a short distance and then be condensed and collapse with a crackling noise, which, echoed by the metal, is the cause of the "singing" of a kettle. These bubbles will rise higher and higher as the heat increases, till at last they rise to the top, the steam escapes, and the liquid is said to boil. It will be seen that steam itself is absolutely transparent, and only becomes visible when it condenses to a cloud of minute particles of water. Thus the moisture in the air is invisible until it condenses on a cold surface as dew, or is naturally chilled into mists or clouds. Whenever, then, the steam impinges on a cold surface, it changes again to water. 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. The contrivance is called a still; the process is distillation, and the product is distilled water (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 the water. The solid bodies in water are not volatile at

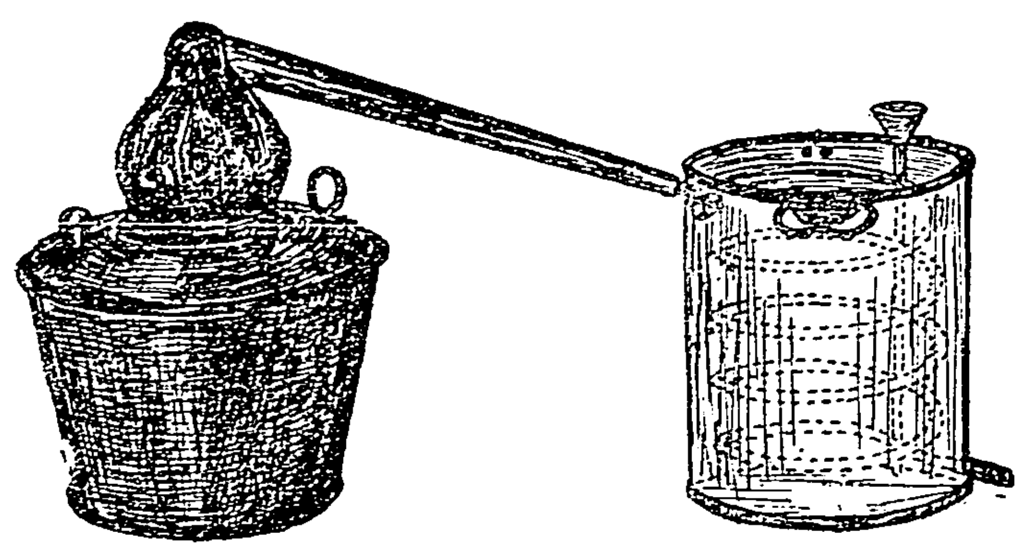

FIG. 17. Apparatus for distillation.

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. It would seem

easy to purify water for drinking purposes by distillation; but, apart from the cost and time, the product has a flat, mawkish taste, and sometimes a burnt flavour 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.

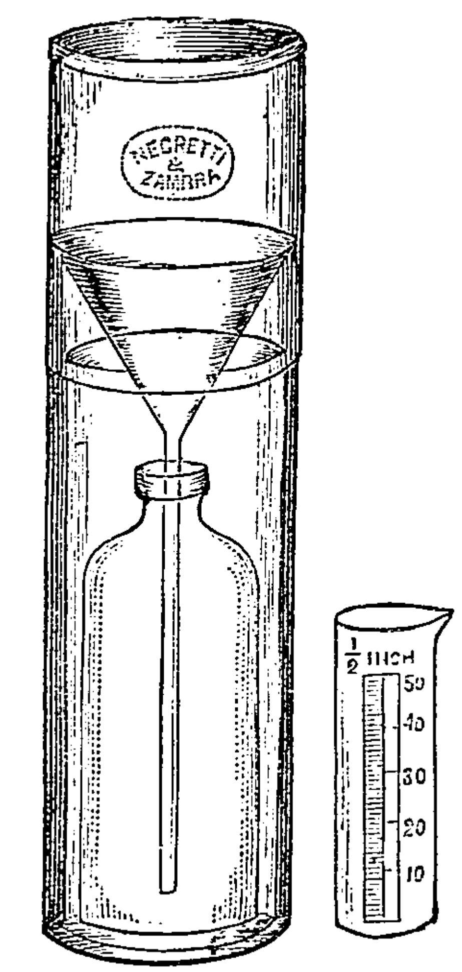

FIG. 18.
Standard rain-gauge.

For measuring the amount of fall, the English Meteorological Office have adopted a form of rain-gauge (Fig. 18) having a circular metal funnel eight inches in diameter, the whole being protected from dust and evaporation by a metal cylinder, open at both ends and reaching about six inches above the funnel, round which it closely fits. The simpler form in the diagram has a rim directed inwards to prevent loss by splashing. A diameter of eight inches would give an area of about fifty square inches if round, or of sixty-four if square. The height above the sea must be recorded, as gauges placed at the top of a building always collect less rain than those placed at the bottom, owing possibly to the lower layers of the atmosphere being generally more saturated with moisture than those above.

The water which is collected in twenty-four hours is transferred to a specially graduated jar, in which the height in inches is measured. This gives directly, or by calculation, the depth of the layer of rain that would form over a whole level country, provided that none were lost by evaporation or by sinking into the soil. It is clear that the amount of all the days added up would give the *annual* rainfall. This varies very much in different localities, 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. It also varies from month to month, being greatest generally in November. If the

whole were collected there would be from two and a half to three gallons per day for each person. As about twenty gallons per head per day are supplied in most cities, it will be seen that, even if the present waste were reduced, the rain would only yield a small portion of the consumption. 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 or by any source too impure to be of use for finer purposes. Moreover, one of the great difficulties in sewage disposal is the needless volume which is received at the works in periods of rain, especially when the whole has to be lifted by pumping and taken on to the land. The dilution should be effected, not by the uncertain rainfall, but by properly arranged flushing tanks, in which sea water or any common surface water could be used for the purpose.

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 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.

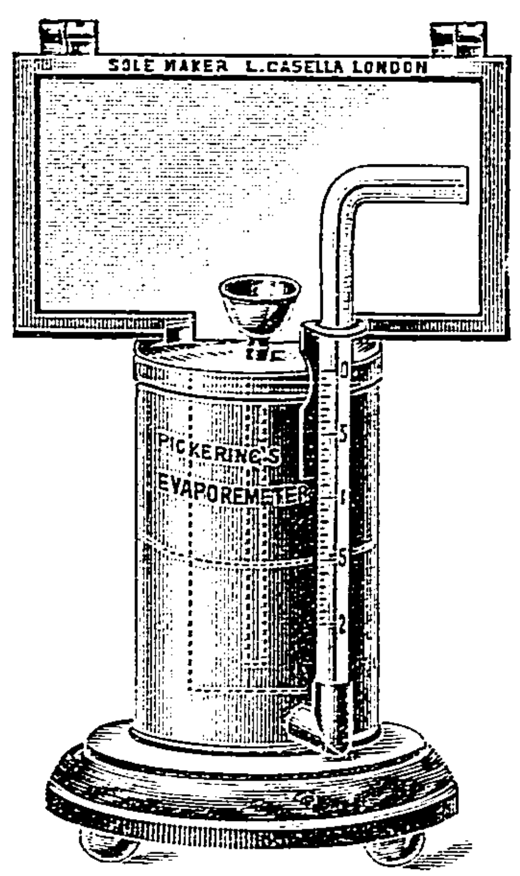

Fig. 19.
Pickering's Evaporometer.

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 impurities, 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 $1\frac{1}{2}$ 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 for some time past the policy has been pursued of buying up the farms on the watershed wherever possible, with the result that "analyses of samples of the water have never shown any ingredients which rendered it other than a good potable water." 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.