this being so at these places on account of their proximity to large bodies of salt water and the opportunity thus offered for the removal and dissipation of the sewage by dilution and tidal currents.

At Worcester, Mass., is a good representation in this country of a well-managed chemical precipitation plant. Worcester is a city of about 110,000 people, the natural drainage of which is into a river which flows through the city. The plant for chemical treatment of the city's sewage was constructed largely in 1891, although additions have been made to it since, as the growth of the city and the increase in the volume of sewage to be disposed of have required. At these works there are sixteen precipitation tanks, about 100 feet long, 66.7 feet wide, and 7 feet deep. When the works were first put into use, the volume of sewage treated was about 3.83 million gallons per day, and in 1901 it was 9.76 million gallons per day. The sewage on its way to the tanks passes through screens, and is there mixed with chemicals. From these screens it passes through a mixing channel to the first precipitation tank and then continuously through the series of tanks, at the end of which it is discharged over a weir. Lime and sulphate of alumina are generally used for precipitation. The sewage, however, is of a rather unusual character owing to the discharge into the sewers of much waste from iron and wire works, in which large quantities of acid are used. On account of this the sewage is sometimes acid and contains sulphate of iron. When in this condition no sulphate of alumina is used, lime alone being added in sufficient quantities to decompose the sulphate of iron and allow precipitation. In the addition of the chemicals they are powdered and then passed through hoppers into agitators, where they are well mixed with a small amount of sewage. From these agitators this sewage containing the chemicals is discharged into the main body at the head of the mixing channel. About one ton of chemicals per million gallons of sewage treated is used. During 1901 the purification effected by this plant was shown by the following table:

TABLE IV.—PARTS PER 100,000.

	Sewage.	Effluent.
Ammonia—		
Free	1.7500	1.6260
Albuminoid—		
Total	.6210	.3180
In solution	.2390	.2620
In suspension	.3820	.0560
Chlorine	9.1800	8.9500
Oxygen consumed	8.6700	4.1000

This table shows that approximately forty-nine per cent. of the organic matter determined as albuminoid ammonia was removed, and about fifty-three per cent. of the organic matter determined by the oxygen-consumed method. By operating the plant in the manner followed at Worcester the volume of wet sludge produced amounts to about 1.5 per cent. of the total volume of sewage treated.

A series of experiments upon the removal of organic matter from sewage by means of chemical precipitation was made at the Lawrence experiment station, continuing from 1890 until 1898, and the results showed that generally about fifty per cent. of the total organic matter could be removed from the Lawrence sewage by this treatment, and a considerably greater percentage of the matters in suspension only. As good results were obtained with the normal alkaline sewage of Lawrence when using one thousand pounds of chemicals per one million gallons as when using a greater amount, and, of the various precipitants tried, sulphate of alumina gave on the whole the best results. The chemicals used in precipitation are of low cost per pound, but when a large volume of sewage is to be treated, this expense amounts to a serious sum. At Worcester during 1901 the cost of operating the precipitation plant was \$43,774 or \$12.27 per one million gallons of sewage treated, a very large portion of this expense being for the chemicals used and for treatment of sludge.

By chemical precipitation the amount of organic matter present in sewage can be reduced very greatly before the main body of sewage is allowed to run to waste, as the figures already quoted show. The organic matter in solution, however, is affected but slightly by this treatment, and this is really the matter which is in the proper condition to putrefy first—that is, it is the most offensive matter in the sewage as the sewage undergoes decay. On this account clarification by chemical precipitation is but a partial purification at best, and in order really to purify the sewage, a further treatment of the effluent of the precipitation tanks must be resorted to. That is, this is necessary if a stable or non-putrefying effluent is to be obtained. Up to the present time this has usually been accomplished by filtration through sand. Almost with the inception of the work upon chemical precipitation at the Lawrence experiment station sand filters were put into operation to receive the sewage clarified in this way. For example, the supernatant liquid from treating Lawrence sewage with sulphate of alumina, at the rate of one thousand pounds per one million gallons and allowing four hours for sedimentation after the addition of the chemical, was applied for over four years to a sand filter containing five feet in depth of sand of an effective size of 0.17 mm., and at an average rate of 200,000 gallons per acre daily. This rate was from two to three times as great as could have been followed successfully upon the area used if untreated Lawrence sewage had been applied. A well purified, well nitrified, clear, and stable effluent was always obtained, and at the end of the experiment the filter used was in good condition. The upper few inches of sand were somewhat clogged with organic matter at the end of this period, but no more so than was to be expected when filtering sewage at this rate.

At Worcester it has been recognized that the effluent from the filtration plant would not have the desired effect in rendering the river into which the sewage formerly flowed very much less objectionable unless further treatment was given the sewage, especially as the volume of sewage is increasing steadily as the population of the city increases. On account of this, sand filters are being constructed there, upon which a portion of the sewage runs after chemical treatment. At the end of 1901 the city had 14.5 acres of filter beds. These filters received during the year 220,000 gallons per acre daily of partially purified sewage, and when the chemical effluent alone was being passed to them, they were at times operated at the rate of 300,000 gallons per acre daily. Owing to the fact that the Worcester sewage is often slightly acid, the results obtained by these beds have not, of course, been as good as would have been the case if the sewage was alkaline. Nevertheless, they add very materially to the efficiency of the plant.

Mechanical Straining of Sewage.—In the process just described a large body of sludge is formed, this sludge consisting of the precipitated matters, chemicals and water—that is, it consists of about five to ten per cent. of mineral and organic matter, mixed with ninety to ninety-five per cent. of liquid. By filter-pressing the sludge can be further freed from the liquid until the weight of water and that of solid matter are about equal—that is, fifty per cent. of each. This is expensive, however. This fact being recognized, experiments were early inaugurated at the Lawrence experiment station, looking toward some method of freeing sewage so thoroughly from the organic matter in suspension in it, that this matter would contain but a small percentage of water; that is, investigations were made looking toward producing high rates of filtration through sand filters by removing the matters in suspension in sewage as well as or better than by chemical precipitation, and at as low or lower cost per one million gallons of sewage treated. These experiments seemed to indicate that coke strainers could be constructed which would accomplish this result. Accordingly, in 1894 a coke strainer was put into operation, containing six inches in depth of coke "breeze." This breeze is the screenings from commercial coke. Strainers of this sort and of a varying depth were kept in operation for seven or eight

years, and resulted in removing from the applied sewage nearly as much organic matter as is removed by chemical precipitation. The organic matter, moreover, removed in this way is left in a semi-solid mass upon the surface of the strainer or in the upper layers of coke, and can be easily removed, together with some of the coke, if necessary, when the strainer becomes clogged on account of its accumulation, and subsequently dried and burned. That is to say, instead of having the suspended matters in the sewage left in the bottom of a tank mixed with a large volume of water—so large, in fact, that it forms ninety-five per cent. by weight of this concentrated sewage—we have these matters practically freed from water.

Such strainers were operated at Lawrence at rates varying from 1,000,000 to 2,000,000 gallons per acre daily. A strainer constructed in 1895 was continued in operation for three years, and during this period the amount of coke removed from it amounted to one inch in depth for each 16,400,000 gallons of sewage strained. It was found later, however, that with a slightly coarser grade of coke as good a removal of organic matter from the sewage could be obtained and with an expenditure of not more than half as much coke as the figures given. As a result of straining through coke, about forty per cent. of the total organic matter in the sewage can be removed, and about sixty per cent. of the organic matters in suspension, varying, of course, with the different grades of sewage. The resulting effluent from a coke strainer can, of course, be purified at a rate of filtration much greater than can be attained with a sand filter receiving untreated sewage. At Lawrence a filter receiving strained sewage was continued in operation for a number of years at a rate approximating 300,000 gallons per acre per day, and the average effluent was about as follows, showing good nitrification and purification:

EFFLUENT OF SAND FILTER.

PARTS PER 100,000.

Color	0.1300	Nitrogen as—Nitrates	2.3800
Ammonia—		Nitrites	.0001
Free	.0145	Oxygen consumed	.2300
Albuminoid	.0207	Bacteria, per cubic centimetre	85.0000
Chlorine	7.0800		

A purification plant of this description has recently been constructed in the town of Gardner, Mass., where the sewage is first passed through a coke strainer with an area of one-half acre, and then to sand filter beds. Strainers of fine anthracite coal in operation at the experiment station have of late done better work upon an experimental scale than coke filters.

Filters of Coarse Material at Rapid Rates of Filtration.—Sedimentation, chemical precipitation, and straining are not, of course, in the true sense proper sewage purification. They are but preliminary methods taken to remove and concentrate a certain amount of the organic matter in sewage, and thus make it possible to filter the main volume at high rates upon sand or other filters. It is only in fortunate localities, however, that sand filters can be constructed at a low cost. In New England in most instances sandy areas are available. Throughout a large section of this country, however, areas of sand are not to be found, and sewage filters must be built on different lines. This is also the condition of affairs in England. Because of this, elaborate studies and experiments have been made of late years upon other means of purifying sewage than by sand filtration; all these methods having, of course, as their main feature the possibility of purifying large volumes of sewage upon relatively small areas. Sand filters are comparatively inexpensive of construction, costing in New England not more than from a few hundred to four or five thousand dollars per acre, according to the locality in which they are built and other conditions. All high-rate filters, however, are of necessity constructed of material, the expense of gathering which together or of preparing it for use varies greatly, and in some instances exceeds the cost of a like area of sand filter beds.

Of the first attempts upon filtering sewage at high rates, the passage of this sewage through aerated gravel or broken stone filters, with nitrification aided by a current of air forced into the filters, appeared to be the most interesting and practical. Such filters were operated at the Lawrence experiment station as early as 1892, and at experimental plants in other places soon after this date. At Lawrence average rates of 500,000 gallons per acre per day were obtained by this method, covering a period of five years, and good nitrification occurred in the filters, the sewage being applied to these filters in small doses at frequent intervals. The effluents of the filters, however, contained much organic matter in suspension and in solution, and the purification obtained was considered only preliminary to sand filtration; or, in other words, it was simply a method for increasing the rate at which sand filters could be satisfactorily operated, but with an idea of destroying, more effectively than could be done by chemical precipitation or coke straining, the organic matters in suspension in the sewage. The highest average rate obtained at the station by this combination of aerated gravel filters and sand filters was 250,000 gallons per acre daily. Owing to the grade of gravel used and the lack of proper underdrainage, these filters clogged badly from time to time, necessitating the removal of filtering material, washing, and replacing. The sand filter also became badly clogged from time to time, necessitating the removal of surface sand. The cost of aeration by means of a forced current of air was considerable. Later studies at Lawrence, moreover, have shown that the method of filtration and aeration followed in the gravel filters, although causing nitrification and thus partially purifying the sewage, undoubtedly rendered the organic matters coming through these filters in suspension in their effluents of a more stable, less easily decomposed nature than when applied in the sewage to the filters. For this reason, when these effluents were applied to sand filters, although the liquid passed below the sand readily and was well purified, these stable matters, instead of being readily passed into solution and nitrified by bacterial action, accumulated within the upper layers of the sand. Disposal plants based upon this method of procedure are, however, in operation in several places in this country with more or less success.

Contact Filters.—Contact filters are sewage filters constructed of any coarse material such as coke, cinders, slag, broken stone, gravel, broken bricks, etc. The method of operating these filters is to close the gate at the outlet of their underdrains, gradually fill the open space of the filter with sewage, allow a period of standing full, then drain, rest for a more or less prolonged period, and again fill. In this manner the entire depth of the filter is brought into contact with the sewage applied each day; that is to say, the entire open space of the filter is filled with sewage daily or even several times daily, and a high rate of filtration obtained. It is evident that filters constructed of these materials and operated in the way outlined cannot produce the results given by good sand filters; in other words, they are not good strainers, and the sewage passes through them too quickly for prolonged bacterial action to occur. Nevertheless, very satisfactory purification results can be obtained by their use, especially if the system of beds is so constructed that double contact of the sewage is given—that is, a system of beds in two sets, all sewage passing through two filters.

In operating these filters the method of filling may be continuous or intermittent; that is to say, the sewage may be allowed to pass into the filter continuously until the entire open space is filled from the underdrains to the surface, or the sewage may be run in at frequent intervals. When the latter plan is followed and the sewage is well distributed, the method introduces more air into the pores of the filter than the continuous method, and better purification ensues. When the effluent flows from the filter, air is drawn into the filter again and fills the open space. It is evident that, if the action of the bacteria upon the sewage in the filter is to be that of oxida-

BIBLIOTECA

tion, the sewage should be withdrawn some time before the exhaustion of this oxygen occurs. When the filter is emptied, the oxygen drawn in causes a partial oxidation of the organic matter left within the filtering material, nitrification ensues, and we have a filter really working all the time, although flooded but a portion of the time. If the filter is constructed of rough material, such as cinders, coke, slag, etc., much organic matter is strained out from the applied sewage by being caught on this rough material, to remain in the filter and to become oxidized and nitrified when the filter is empty. Experiments with this class of filters were first made in England.

Long-continued investigations have been made at the Lawrence experiment station studying this class of filter. Filters of different materials have been in operation, different methods of flooding have been followed, and double contact has been compared with single contact. These studies have shown that the best results can be obtained with filters constructed of rough material, such as cinders and coke, that in such filters, when well operated, good nitrification occurs, and that fairly stable effluents are obtained. With filters of broken stone much poorer results are obtained. The rates of filtration followed have reached one million gallons per acre per day with filters of coke five feet in depth, and rates fully as great as this with filters of broken stone. In all these filters there is a tendency for the open space to become clogged more or less with the matters removed from the sewage, thus decreasing the rate of operation, and the prevention of this is the most serious problem presented in the satisfactory and permanent operation of contact filters. In fact, it is quite generally recognized at the present time that, if filters of rough material are to be used successfully in this way for any long period, a larger portion of the matters in suspension in the sewage must be removed as a preliminary to filtration. In the life of filters of this nature, but constructed of smooth material, this preliminary treatment is not so essential, as the material in the filter can be so graded and the underdrains left so open that much of this matter will pass from the top to the bottom of the filter and flow out from the underdrains. Such filters of smooth material, however, do not, as has been said, give as good results as the filters of rough material.

Contact filters are being adopted and constructed in many places, especially in England. At Manchester, England, a plant for the purification of 30,000,000 gallons of sewage per day upon contact filters is now being built, the sewage first being treated in septic tanks which will be spoken of later. To show the purification results obtained by this manner of filtration, the following figures are quoted, giving the average analyses of the effluents of two coke contact filters at Lawrence, operated during 1901 at rates of 910,000 and 850,000 gallons respectively. To the first filter sewage was applied which had first been passed through a coke strainer, and to the second filter sewage just as pumped from the sewer.

TABLE V.—PARTS PER 100,000.

	Filter No. 1.	Filter No. 2.
Color	0.5200	0.5500
Ammonia—		
Free	1.6400	1.7200
Albuminoid—		
Total	.1716	.1842
In solution	.1238	.1250
In suspension	.0478	.0592
Chlorine	11.4600	10.1300
Nitrogen as—		
Nitrates	1.3400	.8900
Nitrites	.0197	.0096
Oxygen consumed	1.0500	1.0600
Bacteria per cubic centimetre	131,500	397,000

The effluents here averaged are somewhat better than can be obtained, generally speaking, by contact filtration. The purity of these effluents, however, does not compare favorably with those which can be obtained by sand filtration. The organic matter present in them is nevertheless, often oxidized to a more or less stable condition, thus rendering them well enough purified to run to waste at many places.

Septic Tanks.—A septic tank is simply a brick or concrete tank, covered or uncovered, through which sewage passes slowly, allowing time for sedimentation and for the action of those bacteria which disintegrate, hydrolize, and by this means destroy or change organic matter by passing it into solution in the liquid or causing it to escape into the air in the form of gas. On a previous page a statement has been made regarding the difference between fresh and stale sewage. To carry on even further the bacterial action causing this change is the theory of the septic tank treatment. In many instances, however, of so-called septic tanks, the sewage when entering is so fresh and the period allowed in the tank so short that little more occurs toward changing the sewage than that which occurs when the sewage passes through a considerable length of sewer before reaching the filtration area. To explain the action of the tank in other words, we can say that, when oxygen is exhausted from sewage, bacterial life continues active and putrefaction ensues, following the process of decomposition, which occurs in the presence of oxygen. All of the organic matter in the effluent from a septic tank is supposed to be changed by the action of the bacteria to a condition in which it is more easily oxidized by the aerobic bacteria in sand or other filters.

While several claims to the first installation of a tank of this kind have appeared, it was in modern times and under modern studies probably first put into operation in Exeter, England, and soon adopted in other places in that country. Its success or failure as an addition to a sewage disposal or purification system appears to depend largely upon the nature of the sewage to be treated. It is evident from long-continued experiments in Lawrence and elsewhere, that with some sewages passage through the tank is of undoubted advantage in connection with the disposal of sludge, and that the sewage is as easily or more easily purified than without the tank action. Other experiments at Lawrence have shown that there is danger, in the treatment of some sewages in the tank, of so oversepticizing them, so to speak,—that is, of carrying the work of the anaërobic bacteria to such an extent—that the effluent of the tank can be filtered only with considerable difficulty and after good aeration. A small tank has been in operation for five years at the Lawrence experiment station, treating the sewage pumped there, and after these years of use the accumulated sludge within the tank amounts to about thirty per cent. of the tank capacity, the tank not having been cleaned out during the course of the experiment; and further than this, the effluent of this tank has contained only about one-half as much crude organic matter as the sewage entering. The time of passage of the sewage through the tank has averaged about sixteen hours. At a filtration area in Massachusetts a tank was continued in operation for several years, and the sewage reaching this area was really more difficult to filter after treatment in the tank than before. The reason was that the sewage was very rotten when entering the tank, and when issuing from it was of a character which seemed to retard nitrification within the filter, unless thoroughly aerated preliminary to filtration.

TABLE VI.—PARTS PER 100,000.

	Septic sewage.	Sand filter.	Coke filter.
Rate—gallons per acre daily	......	300,000	800,000
Ammonia—			
Free	4.5200	0.7867	1.4021
Albuminoid—			
Total	.4300	.0807	.1480
In solution	.2700	......	......
In suspension	.1600	......	......
Chlorine	11.2500	10.4800	11.1500
Nitrogen as—			
Nitrates	......	2.9200	1.1500
Nitrites	......	.0046	.0093
Oxygen consumed	2.8500	.6900	1.0500
Bacteria per cubic centimetre	1,020,000	69,000	221,000

The effluent from the septic tank at the Lawrence station has been applied for the past five years to two experimental filters, one of these being an intermittent sand filter and the other a coke contact filter. High rates of filtration have been maintained with each filter. During 1902 the rates and the average analysis of the septic sewage applied to and the effluents from these filters were as shown in the preceding table.

At Manchester, England, very extensive experiments were carried on for two or three years, investigating this process. Tanks with a capacity of 500,000 gallons per day were operated, both covered and closed tanks being used, with little difference in the results obtained, and the city of Manchester is now building a sewage disposal system whereby the sewage will first be treated in septic tanks and then upon double contact filters. At this city in 1900 the volume of sewage to be disposed of reached 30,000,000 gallons per day. From the operation of their experimental tanks it was estimated there that it would be fair to assume that fully thirty-five per cent. of the sludge would not become liquefied in the tanks, but would have to be removed from time to time. That is to say, where they were in 1899 carrying 237,000 tons of wet sludge to sea per year, it was estimated that only about 75,000 tons would have to be carried to sea after the construction of the system; the remaining organic matter being disposed of by bacterial action in the tanks and on the filters.

At Worcester, Mass., this method of treatment has been experimented with for several years, a tank of 350,000 gallons capacity having been used. Through this, sewage has been made to flow at a rate varying from 300,000 to 500,000 gallons per day. The sewage at Worcester is generally acid, but this has not interfered entirely with the tank action, as about twenty-five per cent. of the total solid matter has generally been removed by the tank. The odor from this tank has been very considerable, and also from the beds when this sewage has been applied to them.

Plainfield, N. J., among other places, has recently adopted this system of sewage disposal. This is a city of about 16,000 people, and has the so-called separate system of sewers. It formerly disposed of its sewage on sand filters, but these were not particularly successful owing to the extreme fineness of the sand. Hence a change was made. Two septic tanks have been constructed, fifty feet wide, one hundred feet long, and six feet deep, both being under one roof. The sewage, after it passes from these tanks, goes to a double set of contact filter beds. The average flow of sewage per day at the present time is about 800,000 gallons, and it reaches the disposal plant through a fifteen-inch pipe. At this place it enters a small influent chamber, where the flow may be diverted to either tank. The sewage enters the tanks about two feet above their floor level. In front of the inlets to the tanks are baffle walls, to deflect the flow of sewage and distribute it evenly across the whole width of each tank. The sewage flows from outlet openings, twelve in number in each tank, placed below the surface of the sewage and above the floor of the tank. In leaving the tanks the sewage passes upward over a weir into a channel to the first set of contact beds. Air and light are excluded from the septic tank, but the sewage is supposed to be aerated after passing from the tank by flowing into and through a channel extending the full length of each tank. The gate-house and roof over the septic tanks are of wood, with tar and gravel covering, all the remainder of the construction of the tank and weir being of stone, brick, or concrete. The contact beds are in two sets of four each, the first set being 5.42 feet above the level of the second set. Each bed is ninety-two feet wide, one hundred and six feet long, and five feet deep. On the concrete floor of each bed fourteen lines of four-inch horseshoe tiles are laid, radiated from the gate-chamber, and coarse stone is spread beneath and over them six inches deep. The first set of beds contain, above this coarse stone, three and one-half feet in depth of trap rock, the pieces of rock varying in size from one-fourth to one and one-half inches in diameter. The second set of beds are of practically the same depth, but slag and cinders are used as filtering materials instead of the broken stone. Distribution pipes are laid in the upper foot of the material, through which the sewage is distributed over the surface of the beds. The sewage runs continuously from the septic tank through a twelve-inch pipe, built in the top and middle wall of the gate-chamber at the intersection of the division walls. Here it is diverted by wooden gates to each of the four beds in succession. After one bed is filled the sewage is turned on to the next, and so on; the height of the sewage in the beds being indicated by tell-tale balls above the roof of the gate-chambers. The sewage remains in each bed an hour or more, is drawn off through a sluice-gate and passes through a pipe to the gate-chamber of the second set of beds, from which it is discharged, after a period of contact, into a brook. Each bed is at rest an hour or more between fillings. Sludge can be drawn from the tanks through eight-inch pipes to sand filters. In a year's operation of this system it was necessary to remove sludge from the septic tanks several times. The price of construction of this system of disposal is said to have been about $40,000.

Intermittent Continuous Filtration.—In the continuation of studies upon rapid methods suitable for the purification of sewage, filters of coarse material have been constructed, through which sewage is passed in a practically continuous stream. The coarseness of the material used in these filters is so great, however, and the rate of application of the sewage to them so regulated, that the surface of the filter is always practically free from sewage, and a large portion of the open space in the filtering material is always filled with air. Such filters may be constructed either of rough material such as coke, slag or cinders, or of smooth material, such as coarse gravel or broken stone. By the method of operation the sewage applied passes in thin streams or layers over the filtering material, and is in contact with air from its entrance at the surface of the filter until it passes away in the underdrains. With a filtering material of such a coarse nature, operated under conditions which assure an abundance of air within the filter, wonderful activity of the oxidizing and nitrifying bacteria is induced, and the production of nitrates is exceedingly rapid. Filters constructed in this manner, containing from eight to ten feet in depth of filtering material, can be operated, on an experimental scale at least, at rates approximating two million gallons per acre daily, and produce a highly nitrified effluent. Much of the organic matter in suspension in the sewage when it enters these filters passes away in suspension in their effluents, but in a very different and inoffensive condition from that in which it exists when applied to the filters. That is, if the filter is well constructed and properly operated, a large portion of this matter adheres for a considerable period to the filtering material throughout the entire depth of the filter, and its more easily decomposed constituents are either passed into solution, or disappear as gas, while the remainder is oxidized to a more stable form. Effluents of successful filters of this class contain organic matter in such a stable form that they are little subject to putrefaction even under adverse conditions, except after a considerable interval, and more often than otherwise they improve in character after issuing from the filter. Their steady improvement is assured if they run into a considerable body of water containing free oxygen. Filters of this class were first put into operation at the Lawrence experiment station in 1899, and have since been studied quite extensively there. Studies upon their operation and the results produced by them have also been carried on in England of late years upon a considerably larger scale than at the experiment station. They have not as yet, however, been installed on any considerable scale for the practical treatment of the sewage of a town or city. Such a filter was operated at Lawrence during 1903 at a rate, at times, of 2,250,000 gallons per acre per day, and produced an effluent often turbid, but

BIBLIOTECA

always well nitrified and fairly stable. The average analysis of this effluent is shown in the following table, of many analyses made during the year:

TABLE VII.—PARTS PER 100,000.

Rate—gallons per acre daily	1,820,000
Color	.5700
Ammonia—	
Free	1.7400
Albuminoid	.1392
Chlorine	8.6100
Nitrogen as—	
Nitrates	2.7600
Nitrites	.0071
Oxygen consumed	1.0800
Bacteria per cubic centimetre	46,000

Résumé.—In the preceding pages nine methods of sewage disposal or purification have been described, covering the most important methods in use at the present time. They include those methods by which sewage is purified by natural means—that is, by bacteria and air—and which have promise of such developments in the future as adequately to cover all sewage purification problems. The methods are as follows:

1. Disposal by dilution.
2. Sewage farming or irrigation.
3. Filtration through intermittent sand filters.
4. Chemical precipitation, followed by filtration.
5. Mechanical straining, followed by filtration.
6. Filtration through gravel or other filters of coarse material, with forced aeration.
7. Contact filters.
8. Septic tank treatment, followed by filtration.
9. Intermittent continuous filtration.

Summarizing these methods, it can be said that disposal by dilution is extensively practised and entirely satisfactory at such places as those mentioned in the previous text.

Sewage farming is successful in many places, especially with a concentrated English or European sewage.

Filtration through intermittent filters of sand or other fine material is a process which is already extensively used and is certainly destined to be used very largely in the future wherever such filters can be built at a reasonable expense. They are entirely successful wherever used, if the material of which the beds are constructed is suitable, and if such beds are properly operated.

Where a large amount of sewage must be taken care of upon a small area, or where some clarification must be made before sewage is disposed of by dilution, chemical precipitation is of undoubted value and will be used for many years in meeting such problems.

Straining sewage through coke or other materials of a like nature is undoubtedly successful on a small scale, and the future will show whether it can be applied to larger problems.

Forced aeration and filtration through gravel is hardly entitled to serious consideration in this connection, but as it was really the first step in the various processes of rapid filtration, it has been included in the previous text. It can undoubtedly be made practical and of use where the volume of sewage to be purified is small, and where cost is a secondary consideration.

The use of contact filters will increase undoubtedly at places where sand filters cannot be easily or inexpensively constructed. If they are properly built and properly operated, good results can be obtained by their use.

Septic tank treatment is also a proved success in some cases, and will undoubtedly be used much in the future. It must never be considered, however, as it is sometimes now considered by those ignorant of the subject, that the septic tank treatment is a purification. It is simply a clarification, and a preliminary treatment whereby sludge may be destroyed and the sewage may be so changed that either purification is made more easy by subsequent filtration, or the rate of filtration made greater than could be secured without this treatment.

Intermittent continuous filters seem to have very much of promise in them, and they will undoubtedly be adopted more and more at places where sewage must be disposed of upon a small area and where the climate does not interfere with their efficient operation. *H. W. Clark.*

SEX.—In the life history of nearly every multicellular organism there is a time when a new germ (oöspermium, or *zygote*) is formed by the union of two cells (*gametes*) of different aspect. The larger, less mobile of the two cells, is the *macrogamete*, egg, or ovum (*q.v.*), and the smaller more active one is the *microgamete*, spermatozoon (*q.v.*) or its equivalent. The ability to produce a macro- or microgamete constitutes the essential distinction of *sex.* The individual which produces the latter is said to be of the *male* sex, the individual producing the former is said to be of the *female* sex. In most of the higher plants and in a few of the lower animals both sexes are included in a single individual, which is then said to be *hermaphrodite.* The union of dissimilar gametes is the essential feature of sexual reproduction (see *Impregnation*). In many of the unicellular animals, Protozoa, there is a temporary union, or *conjugation*, of similar gametes, during which there is an interchange of part of the nuclear substance. In other Protozoa the gametes are of different size and the union is complete and permanent. Thus in these lowly forms we see foreshadowed the sexual process of the higher organisms.

If our definition of sex be correct, it follows that the quality of sex cannot be an attribute of the gametes, but only of the parent organism, except in so far as the sex of the offspring may be determined by some characteristic of one or both of the gametes. This view is borne out by what is known of the history of the germ cells, which has been shown elsewhere to be identical in all essential features in the two sexes (see *Reduction Division*). The differences between the gametes of the male and those of the female are confined to the cytoplasmic structures, and are associated with a physiological division of labor; the cytoplasm of the egg being more or less laden with food yolk and unprovided with locomotor apparatus, while the spermatozoon has practically all of its cytoplasm modified into a locomotor apparatus, by means of which it may actively seek the egg. This explanation is not in accordance, however, with the views of Geddes and Thomson, who see in the visible difference between egg and sperm evidence of the same differentiation of sex that is found in the adult. They regard sex as a quality of protoplasm. It is for them a question of metabolism. In the female the anabolic processes are predominant, while the katabolic processes are predominant in the male. These characteristics are passed on to the eggs and spermatozoa respectively, and fertilization "restores the normal balance and rhythm of cellular life."

It is difficult to follow the physiology of this conception of sex, for, if the male is predominantly katabolic, one would think it might be hard for him to grow; one might almost expect him to shrink. Havelock Ellis (1894) has gathered the published data in regard to the differences in metabolism of men and women, and he finds differences in certain phases, but the general result is inconclusive. Thus, men have a larger percentage of hæmoglobin in the blood and greater lung capacity in proportion to stature; but, on the other hand, women have a higher pulse rate. It is very probable that in the period of early maturity in women there is less katabolic activity than in men as is shown by the greater tendency to store up fat. But, if the words mean anything, a predominant condition of katabolism is inconsistent with increase of weight or with life itself beyond a very limited period, and therefore can hardly be accepted as the essential feature of "maleness."

We may follow Ellis in dividing the characteristics that distinguish the sexes into primary, secondary, and tertiary. The primary characteristics are those associated with the organs concerned in the production and union of the gametes. And these organs may be divided again into the essential and the accessory reproductive organs. The former are the gonads, called ovary and testis in female and male animals respectively. In low

forms, like the jelly-fishes, there are no other reproductive organs. But we need to go very little higher in the scale to find developed accessory organs that assist in the discharge and union of the gametes. Such are the oviducts, the vasa deferentia, and the appendages of these organs. Morphologically these tubes may be modified nephridea, or they may be newly developed structures. In all strictly terrestrial animals and in many of the higher groups of aquatic forms fertilization takes place within the oviduct. This is associated with a marked structural differentiation of the sexes. The male is usually provided with a special organ for the introduction of the spermatozoa. This may be a prolongation of the sexual orifice, forming a penis, or, as in the rays and higher crustacea, it may be in part a modified limb. In the female, on the other hand, the oviduct is either provided with glands to secrete a protective covering for the egg, or is modified to shelter the developing embryo, or even, as in the placental mammals, to nourish it during its fœtal life.

The secondary sexual characters are those that clearly distinguish the sexes without being directly concerned in the reproductive function. Among these characters we may distinguish clasping organs, weapons, ornamentation, voice, and appliances for the shelter or nutrition of the offspring. In a large number of animals, especially among the crustacea and insects, there are to be found special modifications of one or more limbs of the males which serve to hold the female in firm embrace during coitus. Many males are provided with weapons, as tusks, horns, spurs, or the like, which are employed in fighting with other males for the possession of the females. Often the males alone are provided with such weapons, and when they are possessed by both sexes, they may differ in the two sexes. Thus the cow has long, pointed horns adapted for defense against carnivorous enemies, while the bull has shorter, thicker horns, probably more useful for fighting with rivals.

In some cases structures that probably arose as weapons are now developed as ornaments. The most notable examples of this are the antlers of the deer family. In most cases, however, the ornamentation has arisen independently of the weapons, and consists of the most varied forms of coloring and modification of structure. Ornamental secondary sexual characters are found widely distributed among the insects, amphibia, reptiles, birds, and mammals. They are especially conspicuous among the birds. They are usually possessed by the adult males only, and reach their highest state of perfection during the mating season. After this season the deer shed their antlers, and many male birds, like the bobolink, exchange their bright plumes for the sober protective coloring of the female. This exuberance of growth and coloring in the males, together with the song of male birds, and other instances of greater activity, like the superior eagerness of the male in courtship, are taken by Geddes and Thomson as evidence for their conception of maleness as a preponderance of katabolic activity. But they leave out of consideration the fact that these conditions are not always characteristic of the male sex. In the species of phalarope—birds not uncommon on our shores—the female is the more brightly colored, the more pugnacious, and more ardent in courtship; in short, she has all characteristics usually found in a male, except that she lays eggs. The male, on the other hand, is relatively dull colored, is courted by the female, incubates the eggs, and takes entire care of the young.

The characters that we are considering are called ornamental, not because they appear beautiful to us—often they are quite the contrary—but because, according to Darwin's theory of sexual selection, they are supposed to have been developed through the choice, conscious or unconscious, of the courted sex (see *Evolution*).

In man we find ornamental secondary sexual characters in both sexes, which would seem to indicate that the courting is not all done by one sex. The chief of these characters in men is the beard. While women have longer hair on top of the head, and this is associated typically with an entire absence of visible hair on other parts of the body, except on the axilla and pubes. The layer of subcutaneous fat that develops in young women upon reaching maturity, and gives them the characteristic rounded contours of that period, may have become a fixed character of the species by the action of natural selection, owing to its value as a provision for the nutrition of prospective offspring; but, at any rate, it now forms one of the chief ornaments of women.

Sexual differences in the voice or in the method of using it are common, as every one knows, in amphibia, birds, and mammals. Witness the piping of the frogs, the song of birds, and the deep voice of men. Usually the modification of the voice is found in the males, and first appears, as in man, at the beginning of maturity. In fact, it is a general rule that when the male possesses special weapons, ornaments, or peculiarities of voice, these characteristics are not developed until about the time of the first ripening of the spermatozoa, and the immature males resemble the females. For this reason it has been inferred that the female, at least so far as these characters are concerned, represents a more primitive type than the adult male.

Devices for sheltering eggs or young are developed after different patterns in various groups of the animal kingdom, and they are usually confined to the females. Thus in most species of crustacea the female is provided with some means of carrying the eggs until they hatch. The female marsupials have a fold of the skin forming a pouch, in which the imperfectly developed young are placed at birth and are carried there until they are able to run about. The most characteristic organs of the mammalia and the ones from which the group has received its name, the mammæ, or milk glands, are possessed by the females of all species from monotremes to man. While functional only in the females, these organs are present in a rudimentary condition in the males also. Their importance as a means of rearing the young is so great that it has been questioned as to whether they should not be regarded as primary rather than secondary sexual organs. That they are essentially secondary, however, is shown by the practices of civilized women, who have largely relegated them to the position of ornaments—to the detriment of the best races of the human species.

In addition to the well-marked secondary sexual characters that distinguish males and females, there are other usually slight differences that Ellis classifies as tertiary sexual characters. We know very little in regard to these differences in the sexes of the other animals, but, thanks to Ellis, we have in his book, "Man and Woman" (1894), a very interesting and complete summary of these characters, anatomical, physiological, and psychical, in men and women. It would be impossible to summarize even his summary in the limits of this article. We can notice only a few of his conclusions and must refer the reader to the book for more.

Among the anatomical differences women show a greater youthfulness of physical type, as is common among females generally; but they show another anatomical peculiarity not found in other female mammals, and that is an enlargement of the pelvis. This, in the higher races of men, might be regarded as a secondary sexual character. A study of the brain and of the intellectual process in men and women gives the impression that the observed intellectual differences may be as much due to differences of training as to any innate differences between the sexes. In their senses women appear to be less discriminating, but more irritable, and in their emotions they show a greater affectability. Ellis thinks that women are more variable than men, but that this is true for all characters is denied by Pearson.

It is a general rule that in most species the two sexes are approximately equal in number of individuals, but in a few forms in which parthenogenesis is common there may be a large preponderance of females. From the records of 59,350,000 births in European countries Oesterlen (1874) calculated that the normal proportion of

BIBLIOTECA