American Sanitary Engineering.

PHILBRICK.

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BY

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PREFACE.

THE following lectures were recently delivered before the School of Industrial Science at the Massachusetts Institute of Technology, Boston. Parts of them have been printed at different times in the columns of *The Sanitary Engineer* and in the *American Architect and Building News*. A demand for their re-issue in a connected form, suggested their publication. They are intended to awaken interest in the subjects discussed, rather than to treat them exhaustively. Care has been taken to suggest the methods and to recommend appliances best suited to American conditions of climate.

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LECTURE I.

INTRODUCTORY.

THE practice of sanitation by engineers has of late attained to such a degree of importance, that a few words may be appropriate in explanation of the origin of sanitary engineering and its sphere of action. For, though there has been plenty of talent devoted at intervals to the general subject of the preservation of health ever since the days of Esculapius and his daughter Hygeia (who has bequeathed her name to the study), and although it is some thousands of years since the construction of many great public works for this end, it is to the recent great multiplication of human wants, and the complications arising under the present state of civilization, that we owe the late extraordinary development in this branch of the engineering profession.

Sanitary engineering has to do with any mechanical devices or works by means of which the complex conditions of modern society may be controlled by healthful influences. It seeks to eliminate from our homes and surroundings those effete substances which nature throws off from our bodies, for these matters when once excreted cannot be harbored near us without great risks.

Every race of men and every type of civilization has had its own standard of purity. The Jew is still governed by the Mosaic Law. The Arab and the Turk looks for guidance to the Koran, and is there taught to be a fatalist. Christian nations, whatever their former mistakes may have been, are now guided by a study of the natural laws which govern disease. We regard all those diseases which originate in the presence of filth as merely physical phenomena. They are the outgrowths of man's negligence and ignorance, for they may be made subject to human control through the causes which give rise to these consequences. We believe that physical phenomena are governed by *fixed laws;* that we can use those laws for the accomplishment of our purposes, 1st by making ourselves familiar with them, and 2d, by arranging such combinations as are known to produce definite and certain results. Other and different results may ensue through our ignorance and neglect. But these are just as much in accordance with *law.* No innocence or purity on the part of the individual will render him exempt from the penalties which are sure to follow certain conditions, over which that individual may perhaps have no influence whatever, but which may have been within the control of the social body or community of which he forms a part. Hence, each one of us is responsible, so far as his power is felt, not only for the harm that may come to himself from a violation of these laws, but for all harm that may come to other members of his household, or of the village or city in which he lives—responsible, in short, for the proper conduct of life in harmony with known laws.

If we fail of complete success, such failure can only be attributed to one of two causes:—either incomplete information of the laws of disease, or our own sloth and inefficiency in conforming our lives to them.

The tendency of man to aggregate in dense masses and form cities is nothing new, yet we are very slow in applying to our own life the experience of the thousands of years of which we have definite record. Accumulations of filth in the soil have rendered the site of many an ancient city untenable. Modern cities can only escape a similar fate by profiting from this lesson. In our newer States a large part of our population are now suffering from lack of settled homes and lack of organization in these newly formed communities, before the land has become so subdued and peopled as to enable them to avail themselves of fixed habits, comfortable homes, and the advantages of organized and combined effort for their mutual protection; while, in the older States, we are already hoarding within our midst accumulations of filth which may prove hot-beds of pestilence to future generations. Here in Massachusetts even, it is no uncommon thing to find (in rural homes) a well for water supply in close juxtaposition with collections of foul and putrifying matter in vaults of privies, cesspools, pig-styes or barnyards, while a city government erected within ear-shot of our oldest institution for learning, still compels every householder to hoard in the immediate vicinity of his dwelling, the vilest refuse of his family to ferment and decompose in the soil, on which his children may soon build a new house.

We must not forget, however, that we owe much to the example of ancient cities for the improved sanitary condition of our modern towns. Among the most important steps we are taking in this direction, is in the plentiful supply of pure water from unfailing sources, brought not only through the streets and public places, as was done in Rome 2,000 years ago, but into our very homes. It is to this purifying agency that many an old city owes its prolonged existence, while others, less fortunate, have been swept away by pestilence. Damascus, supposed to be the oldest living city of which we have record, has from the beginning had a pure and abounding water supply. It was not without some reason that Naaman called the rivers of Damascus "better than all the waters of Israel,"—for the Jordan, in which the great Syrian captain was told to bathe, was as muddy and repulsive as our own Missouri, while the Abana and Pharpar were clear mountain streams.

These rivers were at an early date diverted from their channels as they came from the melting snows on Mt. Lebanon to run to waste in the Syrian Desert, and subdivided in unnumbered rivulets, which to this day irrigate the whole city, gladdening and refreshing animal as well as vegetable life within its limits. They wash away its impurities to make fruitful and productive a belt of land along the base of the mountain, which is brilliant with perennial verdure. The city is not so dense as more modern ones. The vegetation follows the beneficent water to every house, which has its shady and fruitful garden, so that when seen from the high slopes on the west, the city appears as if embowered in a dense forest. This state of things has enabled Damascus to outlive all its old cotemporaries. It has kept up within itself that equilibrium of animal and vegetable life which modern science has shown to be in harmony with the greatest perfection of both, each using as food what is thrown off as effete by the other. The refuse of animal life gives a perpetual development to the forests of apricots and figs, which in their turn feed the population of Damascus. Hence, it still flourishes, a garden city on the borders of a desert, and an example of the beneficent effect of a pure and abundant water supply, even though now for many centuries peopled by a race of fatalists and polygamists, a race who know as little of personal cleanliness as the Hebrews whom they supplanted.

But there are very few cities which, like Damascus, have at the same time pure water in abundance, with rivers running through their streets so copious and permanent as to wash away their filth. Ancient Rome possessed such a supply through gigantic public works, such as no modern city can boast of. But Christian Rome of to-day has allowed these works to pass into decay, keeping up only such small portions of them as may supply the public squares with fountains, but not enough to *wash out* the whole city as of old. Modern Rome is therefore paying the inevitable penalty of soil pollution, till it is shunned by all strangers as well as by many of its permanent citizens during several months of every year.

Among the earliest of nations to establish a sanitary code were the Jews. Though by no means so advanced in many other branches of civilized life as their cotemporaries in Egypt, India, or Syria, the followers of Moses had this immense advantage. The perpetuation of the seed of Abraham to this remote age is a witness to the efficiency of the Mosaic code in this respect.

It would be well if our modern cities were more attentive than they are to many hygienic injunctions which may be found in the Levitican Law.

But, however important sanitary rules may have been considered by the old Jews, who respected the Mosaic code, or by the more modern civilization of pagan Rome, even these rules were lost sight of during the centuries that elapsed after the fall of Rome. During the gloomy period that for 1,000 years preceded the protest of Luther, *filth* was sanctified by the influence of even the Christian Church. Its votaries vied with each other in the neglect of personal cleanliness as a form of mortification of the flesh, by which their piety was to be measured.

The monastic orders, who cherished the half-smothered embers of literature during that dark period, scorned the practice of bathing and change of clothing, as marks of luxury, inconsistent with the austere code of morals that had been inaugurated by St. Francis of Assisi, or practiced still earlier by the Christian outlaws of pagan Rome, who were forced to take refuge and live in the Catacombs under the city to escape their persecutors. Hence, outward or bodily impurity, as we understand it, became the test of sanctity—a mark of self-abnegation and of "holy living." The love of cleanliness for its own sake and as an expression of moral purity was utterly lost sight of, and if the notion ever entered the head of a monk of that day he was, doubtless, branded as an epicurean and a backslider.

So long as the monastic orders were the only custodians of science and letters, it is not strange that these habits should have been repected by the masses. When a revival of civilization led to the accumulation of population in large cities, we find the monastic standard carried out to great perfection. The crumbling ruins of a conquered city were leveled off and built upon by the new-comers, burying the accumulated filth of one generation, or race of men, under the dwellings of those who followed. For many centuries predatory bands of lawless men under bold leaders drove the whole population of Europe within the limits of walled towns for protection. Here narrow streets and high buildings shut out the sunlight. Witness such towns as San Remo and Perugia, or Assisi, in Italy, or the older parts of Rouen and Paris. Public water supplies were never thought of in those days, much less were sewers or drains of any kind. Christian Rome pulled down the massive baths and aqueducts of the pagan emperors, and used the material to build churches and monasteries, while treading under their feet the accumulating nastiness of century after century.

There came in due time the inevitable result. Pestilence in various forms invaded Europe in the 14th century, and for two or three centuries following the devastation was horrible. Dr. Guy states that Europe is supposed to have lost 40,000,000 of lives by the first attack of the Black Death, as it was called. During its last visitation in London, in 1665, this city is said to have lost 75,000 lives by it. The poor and superstitious people who were thus stricken could not be expected to see as we now can the necessary sequence of natural laws. The truth was revealed only by slow and patient research. During the 17th century the study of anatomy and physiology took root upon scientific methods. Monastic superstition and filth gradually gave place to the study of disease and the laws of health, till, beginning with Harvey's discovery in the 17th century and ending with Jenner's, about the beginning of our own, we have reduced even small-pox to human control.

Modern habits of life have so far modified the attacks of pestilence that they rarely prevail now over any large extent of territory, even though the application of steam power to travel has rendered the old methods of quarantine and isolation much more difficult to enforce than before.

We have, however, various forms of disease, more or less contagious, which scientific research declares to be preventible. Though held in check, and rarely assuming the character of an epidemic, the seeds seem always present, whatever their form may be, ready to germinate whenever proper conditions combine. It is the business of the sanitary engineer to see that such conditions are not found among human habitations. So long as life was pursued in the simple ways of a farming population, who spent most of their time in the open air, the rules found in Deuteronomy xxiii. may have been sufficient for the purposes intended ; but just in proportion as we complicate the conditions of our lives by artificial surroundings we create new risks and invite new diseases. Here follow the weighty responsibilities of our situation. No new course of life can be undertaken without bringing such responsibilities. The effete matter must be gotten rid of speedily—at all hazards—and it behooves us as fast as we render such removal more difficult by our habits, to inaugurate new means and methods for overcoming the obstacles. The family that lives in a tent may be safely provided for with a minimum of care, particularly if they change their camp often enough to avoid soil pollution. But when man seeks a more permanent home, he must guard against rendering it a pest-house by avoiding accumulations of filth, whether within or around it.

The growth of Christian civilization during the past three centuries has introduced many sanitary reforms besides water supplies for towns. It has brought within the reach of all classes the possibility of personal purity to a degree that never existed before. Steam cotton mills have now it made possible for every man to provide a change of under-clothing at an insignificant cost, while 200 years ago linen and cotton garments were unknown except to the wealthy.

Among the most difficult, and still perplexing questions in sanitary work, is the removal of excreta from our towns and cities, and it is in the endeavors to solve this problem that many very important engineering works have recently been carried out.

In discussing such improvements, we often hear it objected that they are unnecessary, because, we are told, our fathers always lived well enough without such things, and what was good enough for them is good enough for us. This is an argument which can be opposed to every improved method of living with equal force. It rests upon the fallacy of taking it for granted that no real need exists for such improvement. The best way to meet such arguments is by facts which shows the fallacy of the supposition on which they are based.

We are told by Dr. Farr that "the mortality of the City of London was at the rate of 80 per 1,000 in the latter half of the seventeenth century, and 50 per 1,000 in the eighteenth century, against 24 at the present day." Moreover, the density of the population of London is steadily increasing, which would inevitably cause the death rate to *increase* if improved sanitary measures were not followed. But the fact is that in spite of this steady increase of crowding of the population, the death rate has steadily decreased, while the death rate by so-called zymotic diseases has kept stationary. All this is encouraging. Yet, an immense work remains to be done. In a recent London journal* we find the following statement: "The case of Graystoke Place School, in Fetter lane was discussed by the School Board at their meeting on Dec. 18th, 1879. From the report, it appears that the site was pestilential, and that the school had become a centre of infection for the whole adjacent neighborhood. Children had been taken in and kept in school while suffering from infectious diseases. The whole neighborhood was in a dreadful state in respect to water supply, etc., and yet this occurred within two minutes walk of Fleet Street, the chief thoroughfare of the City of London!"

The same journal goes on to say that: "Fortunately, our knowledge of sanitary law is increasing, but with this increase of knowledge an increase of difficulties also arises. All that has been done is only palliative work. The system of legal and practical patching in every department of sanitation is only creating greater troubles for ourselves or posterity. Engineering and chemical science may do much for our sewers, our drains and our houses. But sanitation, like charity, should begin at home, and until a practical knowledge of the requirements of health in the domestic circle is more largely diffused in the mass of the people, until in many cases their habits are changed, future progress must be necessarily slow and constantly impeded by the very persons whose interest science is endeavoring to protect."

It may, perhaps, be supposed that a profession which has been so long in reaching its present stage of development must have now gained a point where exact methods are agreed upon for the treatment of almost every case that may arise. But nothing could be further from the fact.

It must be remembered that so far as civil engineering is concerned, strictly speaking, it is commonly decided, in general terms, by some other party than the engineers, what sort of a structure is needed to supply a given want. After such a decision is arrived at, the engineer is called in to devise and construct a canal here, or railway there, a dock for this port, or a breakwater for that. The public

* *Engineering.*

need is generally manifest, and the way in which it is to be satisfied is determined by local circumstances, concerning which no great doubts can arise. The civil engineer is expected to look up his materials, reckon the cost, and plan the structure in sufficient detail to explain his methods to the mechanics who do the work. But in sanitary work the engineer has a far wider field of duty, and more varied responsibilities. He must first determine the character of the work which is to accomplish the desired end. Sometimes he is even asked to determine whether anything is needed, and if things are not well enough as they are. In short, his counsel is required to judge and condemn an existing state of things into which a community, quite unawares, may have been slowly drifting, as well as to devise a remedy for the evil.

The public is generally ready enough to see when it needs a new bridge over a stream that stands in its way; but the same public is not yet well enough educated in the laws of health to foresee all the needs of drainage, particularly if the same locality has, apparently, for generations before, gotten along very well without it.

The growth of population goes on insensibly, and people are very apt to think that what was well enough two years ago is well enough now, and if an engineer makes such a fuss about drains, it must be because he wants to get a job for himself, etc., etc.

Fortunately the recent organization of boards of health in various States of our Union is tending to awaken a more general interest than has heretofore existed, by a wide diffusion of the sort of information which the mass of people need on subjects connected with sanitary improvement. Still it will always be expected that the sanitary engineer will make himself familiar with the latest discoveries of the medical profession relating to the causes of disease, and the agencies which can most readily be brought to bear for their prevention or cure.

It is in making use of the forces of Nature that the greatest triumphs of the engineering profession have been achieved. In all the various specialties with which the engineer has to deal, his chief aim is to use these forces to do his work.

Our generation has witnessed great achievements of this sort. The atomic forces residing in a few jars of quiet-looking fluid, in which some equally quiet bits of metal are dipped, have recently enabled us to talk with all nations of the earth as if they were at our own door. It is hardly a century since Watt made practical the hitherto useless steam engine. Less than a year since (1878) Eads has caused the ungovernable torrent at New Orleans to dredge its own permanent path to the sea through four miles of slimy ooze, and thus opened a harbor that was before inaccessible to vessels of over fifteen feet draught.

In sanitary work the planning of sewers and the building of pumps are doubtless necessary details and indispensable in various places, but the direct use of the sunshine in some way or other may yet prove to be a more prompt and efficient method of curing many of the preventible diseases, or in checking their growth, than all the bricks and mortar in the universe, if we only knew how to use it at the right time and in the right manner.

We know that the sun's rays are the source of all the energy which we use to drive our machinery or our horses. Every form of motive power, and all animal life, draws its energy directly or indirectly from this single fountain head. If we could have more direct sunshine in many a dark place we could doubtless save many lives that are now waning.

The methods now pursued and advocated by the best sanitary authorities for dealing with many of the more difficult problems (notably the disposal of sewage), can be called at best only tentative. So long as we know of nothing better, we must needs use such as we have, but it would be very foolish to suppose they are not capable of continuous improvement. It will not do for us to lie idle. We should soon lapse into the condition of London in the seventeenth century, when the Plague was invited from the far East by the neglect of laws which we now know how to respect. It may be that the next generation will be able to see far more clearly than we can, how many things can be done where the best of us seem to be only groping in the dark. But we cannot sit down and do nothing. It behooves every earnest man to use all the light that is given, and do the best that he can, trusting to future generations to be lenient in their criticisms.

The close relations of the sanitary engineer with the medical profession have been referred to.

But in exploring the causes of disease, the general laws of vegetable as well as animal physiology must be studied. The intimate connection between the two was never understood in detail till explained by modern chemistry. We know not only that vegetation draws its support from unorganized matter, but also that it is chiefly from the air and such mineral salts as are soluble in water. The air contributes the great bulk of vegetable matter, viz., carbon, which plants have the power of appropriating, by help of the sun's rays, from the minute portion of carbonic acid in the atmosphere. They also decompose water and retain the hydrogen. From both these processes oxygen is thrown off. But animal life is unable to feed upon mineral salts, or upon air alone. Its existence pre-supposes that of vegetation, on which it may feed. Its food is partly assimilated by the digestive organs, but it cannot assume the proper functions of blood till exposed to the air through the delicate membranes of the lungs, where it absorbs from the air some 25 per cent. of its oxygen.

The boundary line between animal and vegetable life is difficult to recognize in many marine forms, but in nearly all the forms with which we are most familliar the distinction is quite pronounced. The distinguishing feature of animal life is voluntary motion and the power of doing work in its technical sense. Now, it is a universal law that no work can be done by the animal without a waste of tissue. It is during this waste of tissue, and the efforts to repair it, that the blood becomes charged with carbonic acid, a process of slow combustion, carried on by the oxygen it has taken up, evolving animal heat, and continually throwing off this carbonic acid into the air which is exhaled. Here the animal yields up the elements which it does not need to make use of, and which are a very important part of the food of the *plant*, as we have seen. Thus the two great kingdoms of Nature are constantly aiding each other's development. Not only does this interchange go on through the air, but the solids which help make up the bodies of animals, when decomposed after death furnish abundant plant food, as do their solid and fluid excretions during life. While, as we have before said, no animal life could exist without vegetable life to feed upon, the constituent elements of both are constantly moving in this cycle, and all these processes are in perfect harmony with each other, and consistent with the best development of both the vegetable and animal.

If the engineer keeps this law constantly in view, many opportunities will be afforded in practice for making use of it for the disposal of such effete substances as become detrimental to the health of cities. But even when circumstances forbid this direct application of animal waste, and where cost prevents us from accomplishing it, Nature does not allow of ultimate waste. The atmosphere is a great storehouse to which all decomposing matter yields up its gaseous elements, and from which vegetation can sooner or later appropriate these to its use.

The sewage of cities has often been used with success as a fertilizer for the soil. It has accordingly been argued by many that it must be a great waste for London, and on a smaller scale for Boston, too, to throw their sewage into the sea. But experience has proved that the value of sewage as a manure is not so great as was once supposed, while the cost of applying it to the soil is often too great to be thus recouped.

If thrown into the sea, the inhabitants of the particular district where this occurs may not profit by its value, but this is not lost to the world. It is soon decomposed by exposure and the elements of which it once consisted are stored in the air or water for the future use of either vegetable or animal life. The kelp is nourished and contributes to human wants, so do the various mollusks that fatten upon the mud in our bays.

But the architect also must be consulted by the engineer, or what is better, taken into partnership, for many of the most important sanitary works consist of those details in the interior of our houses which the architect has or should have under his supervision. Within the last generation our houses have changed their character to a very marked degree ; not only have their exteriors received artistic development, but their interiors as well. Meantime, the introduction of public water supplies in most of our cities and large towns during the same period has led to the almost universal use of the water closet in our houses. What was looked upon as a luxury thirty years ago is now regarded as a necessity, and even the cheapest class of houses now have this device. The introduction of waste pipes for drainage inside our houses, with a constant water supply, has led to a ramification of the system, and a multiplication of these appliances for the sake of convenience, with too little regard for the risks encountered. In fact these risks were at first hardly known by any, and if now known, do not seem to be understood by many of our builders. Large blocks of houses are constantly in process of erection where the owner wishes to spare the cost of the advice of an architect, except so far as he may need a draughtsman to formulate his plans on paper and thus enable him to obtain a competition of mechanics on a uniform basis. The architect, properly so called, has often been dispensed with by employing a mere draughtsman in his place, a course which precludes entirely any study of the sanitary aspects or details of the interior construction by persons who alone are qualified by their previous experience to give intelligent advice on the subject.

Its importance is brought to light in a painful manner occasionally, when too late to save valuable lives. But there is an unmistakable feeling of jealousy found among the majority of builders towards educated men as advisers. It may be wearing off, and is perhaps less noticeable in Western cities than in the East, where the conservative element is strong. The only way it can be overcome is by proving the superior competence of educated men. If they commanded respect as *men of affairs* as well as artists, theorists and draughtsmen, if they perfected themselves in all the branches of experience needed to assist the builder in investing his money, the architects and sanitary engineers would in a short time be sought for and appreciated. The former have had the same difficulty to contend with during the past thirty years, and they have succeeded in creating a certain popular demand for their services. The latter have but lately come upon the field, and must qualify themselves for their duties before claiming public confidence.

But the regulation of the details of drainage in houses has generally, till quite recently, been left by the architects almost entirely to the plumbers and masons who execute the work, without that supervision and control which intelligence and scientific acquirements ought always to exercise over ignorance and stupidity. It may be true that intelligent and experienced mechanics are able to advise architects about many details of construction, and with considerable advantage to the latter, especially where the education of the architect has not included a mastery of the theory and practice of the best methods of construction. But in listening to such advice, while crediting its author with sincerity and a certain amount of mechanical skill, it must be remembered that few men whose experience is limited to their own trade or craft, can grasp the various branches of study that are needed to have an intelligent comprehension of this important subject. Besides understanding the best means of preventing disease through an intimate knowledge of the hidden ways in which it is propagated, the sanitary engineer must know something of chemistry, and a good deal about physics, viz., the laws of hydraulics, pneumatics, and the theory of heat as a form of mechanical energy. These are subjects on which the best scientific talent of the world is now hard at work, continually making new discoveries of great value to society. The master plumber, or mason, however perfect he may be in the knowledge of his own handicraft, can hardly be expected to gather, and much less to comprehend and sift out for daily use, the crumbs of mental food which the engineer can utilize and combine from a variety of sources.

It is true we have of late many popular books on these subjects, but the authors do not always agree, and this disagreement gives an impression to the illiterate, if not to all their readers, that the writers are only half informed after all, and perhaps know but very little more than the plumbers themselves. The fact is this: the whole subject is so new and unexplored that no man has the time to write and publish a book about it, without considerable risk of finding his practice thrown out of date, and supervened by some new discovery in physiology or chemistry, or some new mechanical device, which the army of inventors have contrived while he has been writing. Yet much good has been done, and can be done, by such publications. Their trifling mistakes and omissions can readily be forgiven when regarding the influence they may have in educating the people how to live, and in awakening public attention and interest to a subject of such vital importance. The only danger is that too implicit reliance may be placed on any such publications as containing all that is known at the time of their publication, or as advising the best thing to be done under all circumstances. No general rule can be laid down for universal application in such matters as the details of drainage and ventilation with any better prospect of success than in the practice of medicine. It is true that our people, especially the partly illiterate, are prone to study family medicine books and administer their own remedies, but the more intelligent prefer to send for their family doctor, as in fact most of them actually do in cases of emergency. Those who wait too long before such action are very likely to regret the delay if anything goes wrong. It is important for the good of society that this distrust should give place to confidence, so that the community may readily avail itself of the best talent that may be found.

For this end nothing on the part of the professional man will tend to inspire public confidence so readily and so permanently as a thorough knowledge of his own business, and an earnest desire for *truth*, in study as well as in practice. He must show a conscientious faithfulness and a proper regard for economy in devising the best possible means of reaching the desired ends. It is not a subject on which superficial knowledge can be safely tolerated. No stone should be left unturned till *all* the facts that bear upon a case are thoroughly investigated, collated, and compared. If the sanitary engineer pursues this course the public will soon learn to have faith in him as a necessary member in the great social circle, and will heartily contribute to his support.

One of the most harassing experiences which the sanitary engineer has to meet with arises from the difficulty in deciding, off-hand, as to the relative merits of the thousand devices which an army of inventors have brought to his door. The ingenuity of our people and our age seems to know no bounds, and naturally enough every inventor considers his own patent the panacea for all evils. The method, or process, to be pursued in attaining some desired result is often a matter in which a good deal of study is needed. Moreover, every known method is supplemented by a variety of ingenious contrivances, and the comparative merits of the latter may have a good deal to do with sustaining or condemning the method itself. Thus in the rapid development of new inventions, pushed most industriously by their authors and their agents, we have a constantly varying field to survey, in which now this and now that method of proceeding seems to be preferable, according as it is represented by the most perfect and practical device for carrying it out. Moreover, the various circumstances arising in different places, one of which may be better adapted to this treatment, and another to that, serve to increase the apparent confusion of the whole subject. The only way to meet such questions is to be sure that you are thoroughly grounded in the governing principles, viz., the laws of Nature, whose aid you wish to avail yourself of in reaching your end. Without a thorough training in such matters the engineer becomes a mere quack and experimenter; for, however ingenious any device may be, and however plausible the man who promotes its use, it is the part of folly for anyone to seek to accomplish his ends if his processes are not in perfect harmony with physical laws. It is not only a wasted effort, but serves to bring into discredit, by its failure, the cause of education itself. The greater opportunities we have for acquiring knowledge, the greater is our responsibility for making the best use of it, and the greater the disgrace if we act on imperfect information, and are led astray by false lights. It is from considerations of this sort that we are led to appreciate the dignity of this profession, and its possible value to society, when disgusted, as at times we may be, by the petty annoyances of its minor details, the bigotry of men who have seen and studied only one little spot in the great field, and the ignorance, or want of light, yet existing upon many points which are yet obscure.

It is here, as in many other walks of life, that we should be careful to keep the attention fixed upon fundamental principles, as the foundation upon which all human effort must rest. We should not permit the mind to be obscured by details till the subjects in hand are thoroughly investigated in the broadest and most general way.

For this reason I shall often refer to physical laws somewhat in detail, for, however abstruse and uninteresting such subjects may be, so long as we build upon these foundations it behooves us to know all about them. Sand may have its proper uses, but it is not rock, and must not be used as rock. The difference may be easily distinguished sometimes, but not always. Nature is often coy, and not so readily understood as may be supposed. She seldom yields her secrets gratis. It was only after a century of patient effort, beginning with Franklin's discoveries, that Morse was able to utilize the subtle forces of electricity. The methods now in daily use would, if introduced two centuries ago, have led to the execution for witchcraft of men like Prof. Bell. His conquest would in fact have been impossible at that time, for such feats are not spasmodic sallies of genius; they are the result of years of patient plodding, taking nothing for granted, and holding fast to all that is proven, till step after step is gained. If we mounted the ladder by a single leap, or by wings, we should find the height too giddy to be of any practical use.

If, therefore, any of these details should appear tedious, I hope due compensation may be found in the firmness with which you will finally grasp the subject, the importance of which you can hardly fail to appreciate.

LECTURE II.

THE VENTILATION OF BUILDINGS.

THIS subject is inseparably connected with heating, for two good reasons, viz :—

First, In all cold climates the fresh air that is introduced must first be artificially warmed in some way.

Second, Heat as a form of mechanical energy is largely used as a motive force, in connection with gravity, to set in motion the air which we wish to move, whether outward from within buildings or for the introduction of a fresh supply from outside.

There are various sources of impurity inside of buildings, more or less prejudicial to health, many of which can be kept out and avoided in great measure, and should therefore never be allowed to contaminate the air within the walls.

Among these sources are the following :—

(*a*) Emanations from cast-off clothing of diseased persons, or soiled undergarments awaiting the laundress, even when they have been worn by persons in ordinary health, for such garments always contain effete matter in a somewhat volatile condition.

Shakspeare in the "Merry Wives of Windsor" represents even the coarse sensibilities of *Falstaff* as disgusted by these emanations—in an age much less sensitive than our own.

(*b*) Excreta of all kinds, whether fluid or solid, but particularly those of diseased persons.

(*c*) Dampness in cellars, mouldy heaps of rubbish, leaky pork-barrels, spilt food, and all kinds of vegetables stored in cellars.

(*d*) Cooking fumes of all kinds, for, however savory some may be, others are not only nauseating, but absolutely injurious.

(*e*) Gases from cooking or heating fires, and the products of combustion of illuminating-gas.

(*f*) All descriptions of filth in the soil, whether recent or old.

(*g*) Leaky drains, and accumulations of putrescent matter in cess-pools or drain-pipes.

All these and similar sources of bad air must be first eliminated by suppressing their cause, leaving for ventilation only the duty of removal of the volatile excreta from the lungs and skin of the inmates. Perhaps the treatment of cooking fumes and the products of the combustion of illuminants can be left for ventilation, but these gases should be specially provided for, and never suffered to diffuse themselves, as is generally done, all over a building. The quantity of contamination caused by illuminating-gas is enormous, and will be referred to hereafter.

After the elimination of all such foul agents as have just been alluded to, we shall find quite enough left to be done within the prescribed limits, without being encumbered with these substances, which I shall therefore suppose to have been excluded from the apartments which are to be treated by ventilation

The importance of having pure air is acknowledged by all intelligent persons. The chemical qualities of its constituent parts, and their effect upon the human system, are now tolerably well known to all who have paid any attention whatever to either chemistry or physiology. But the *standard of purity* is a subject about which a variety of opinion exists among different people. Nature has fortunately endowed us with a faculty of conforming to a certain amount of impurity without visible harm, if the system is sound and strong, though more delicate persons suffer from lesser quantities.

Thus we see, in various races of men, acquired powers of resistance, which enable them to endure conditions which would be very unwholesome to others. The extreme in this direction is attained by the Esquimaux. Dr. Kane, in his description of a night passed in one of their huts, buried in an enormous drift of snow, says he "crawled in on his hands and knees through an extraordinary burrow thirty paces long." He "soon found himself gasping the ammoniacal steam of some fourteen vigorous, amply fed, unwashed, unclothed fellow-lodgers. He had come, somewhat exhausted by an eighty miles' journey through the atmosphere of the ice-floes. The thermometer inside was $+90^{\circ}$, and the vault measured fifteen feet by six. Such an amorphous mass of compounded humanity one could see nowhere else : men, women and children, with nothing but their native dirt to cover them, twined and dovetailed together like the worms in a fishing basket," etc. But even the endurance of the Esquimaux is slowly yielding to the grim conditions by which they are surrounded. Their numbers are waning. Nature refuses to go beyond the limit reached in Greenland, in fortifying man against such influences. The children who live and grow up, do so by reason of their strength, by the stern rule of the "survival of the fittest," but their numbers do not replace those who have gone before them. The race is passing away.

In leaving the high latitudes and entering more temperate regions, man shows his appreciation of a fair allowance of pure air, while his physical development improves by the use of it. Yet the force of habit is strong, even with us—so much so that the reasoning powers and scientific data must be resorted to, in order to save enough pure air in our crowded cities to prevent positive harm. All are aware of the stifling air of a theatre gallery if entered late in the evening from a cool, northwest wind on the street. Yet if one goes in earlier, and takes the increase of impurity as it accumulates, by insensible degrees, it is only noticed by its secondary effects upon the system—dullness, headache or sleepiness. Thus the standard of purity must be a conventional and arbitrary one, fixed by experience, and adapted to the class of occupants by whom a building is to be used. If the conditions of climate do not favor a free circulation through open windows, and particularly when artificial heating becomes necessary for health and comfort, the problem soon becomes a difficult one, and must be solved independently for each particular case, according to its ruling conditions. The element of cost generally becomes one of these conditions; for where money has to be spent to get pure air, the higher the standard required, the more will be the expense of furnishing the supply.

The vitalizing or valuable element in the air for the support of animal life is well known to be the 21% of oxygen, which is diluted by about 79% by volume of nitrogen, the latter being practically inert. The injurious effects of foul air are two-fold: first, the diminished supply of the oxygen, which is felt in the loss of quality in the blood, followed by a lowering of tone throughout the system; and second, the increase of organic impurities, by which the blood becomes yet further deteriorated, or, if still continued, actually poisoned. It is these effete substances which nature is constantly excreting through the lungs and skin. It was formerly thought that the active injury, effected by breathing air which had been previously breathed, was due to the CO_2 exhaled, and this gas was made a great bugbear in all the earlier treatises on ventilation. But more recent physiologists consider this ingredient as nearly neutral, so far as the quantities ordinarily found even in crowded apartments, and impute the harm to organic effluvia which are so various in their nature, and often so subtle, as to defy ordinary chemical tests. But though these harmful agents cannot be so readily counted and weighed in any specimen of the air, it is generally accepted that they exist about in proportion to the *excess* of CO_2 in air that has been breathed. It is known that a certain small amount of CO_2 exists in the purest air, about four parts in 10,000 in volume; also that air exhaled from the lungs contains about a hundred times as much—say 4%. Now this change is readily detected and measured by simple chemical tests, with sufficient accuracy to enable us to use it as an index of the deterioration of the quality of the air which it has suffered by once being breathed. Dr. Angus Smith gives this test: That no precipitation of carbonate should be given when a 10½ oz. phial full of air is shaken in ½ oz. of clear lime-water. Assumming that the increase of CO_2 is commensurate with both the loss of oxygen and the amount of organic impurities, the excess of this gas over the standard quantity of four in 10,000 is therefore generally used as a test of the essential deterioration of air.

The standard of purity is stated by Dr. Parkes as six parts in 10,000, or 50% more CO_2 than existing in pure air. That is to say, this quantity cannot be exceeded without appreciable injury to persons of delicate organization, and should therefore be taken as a proper limit to be worked to as far as practicable. It may perhaps be considerably exceeded for a time, *i. e.*, 7 or 8, and even 20 parts in 10,000 will not be fatal, but will create certain discomfort and lassitude. An average pair of lungs is said to exhale $\frac{6}{10}$ of a cubic foot per hour of CO_2, while, according to Pettenkoffer, about 15 cubic feet of air are exhaled during the same time. The time required to vitiate a given volume, V, by one pair of lungs, then, to this degree (.0006), is $T = \frac{.0002\ V}{0.6} = \frac{V}{3000}$ in hours; hence 3,000 feet will keep a man comfortable only one hour, say in a room 10 feet high and 17.3 feet square, if hermetically sealed. If tight rooms were more easily got, we should suffer oftener; all rooms leak gas, by diffusion. CO_2 has a specific gravity of about 1.5, yet is not inclined to accumulate at the bottom of a room. Even though not chemically combined with air, the gas pervades the whole space. Gases of a different specific gravity never stand long in one another's way; they all have a harlequin habit of jumping through one another with great agility, each gas being, as it were, a vacuum to others, though somewhat obstructing their diffusion. This fact of diffusion was announced by Dalton, but its law was defined by Graham, thus: that each one of two gases of different specific gravity, when separated by a porous diaphragm, diffuses itself through the space occupied by the other gas, at a rate varying inversely with the square root of their relative densities. Thus, taking hydrogen and oxygen :

	Sp. Gr.	$\sqrt{\text{Sp. Gr.}}$	Coefficient of Diffusion.
H	1	1	4
O	16	4	1

The fallacy of some men is obvious, who talk about the CO_2 always settling to the bottom of a room, and needing ducts to take it away from thence.

Pettenkoffer relates that when on a visit to Marienbad, he noticed a spring from which a constant delivery of gas took place, consisting chiefly of CO_2. The spring was surrounded by a small wooden building, and walled in by a tank 23.7 metres long by 11.4 metres wide. The water was two metres deep. On one long and one short side of the tank extended a platform, near the level of the water surface, from which you could look down and see the gas bubbling up. He had no means of measuring this flow of gas, but estimated that it must exceed one millimetre depth on the surface, per second, equal to six centimetres per minute, or 3.6 metres per hour.

If this gas were not rapidly diffused, the building would soon be filled to a depth of three metres, and in an hour the air would become unbreathable. A man standing on the platform has his head only 250 to 260 centimetres above the water ; but no inconvenience arises from standing there for hours together. "*Man lebt darin wie in gewöhnlicher Luft.*"

Only beneath the platform are candles extinguished, near the water. Soap-bubbles blown by a man's breath, and allowed to fall towards the water, are checked only by the immediate approach to the water, where they float quietly on the stratum of gas. An aproximate analysis of the gas[1] showed it to consist of 70% CO_2; at 5 centimetres above water, 31% CO_2; at 25 centimetres above water 23% CO_2; at 100 centimetres above water, 2% CO_2; at 145 centimetres above platform, less than ½% CO_2.

So far as we know, the organic vapors which we wish to get rid of are subject to the same law of diffusion. The *vapor of water*, however, is supposed to possess an attraction for organic exhalations, and serves as a vehicle for their diffusion. Hence, and for other reasons, air that is saturated with vapor of water is more commonly complained of as oppressive, and is really more likely to be unwholesome than dry air, of which I shall have more to say later.

We have considered the case of a man enclosed with, say, 3,000

[1] See *Zeitschrift für Biologie*, vol. ix., p. 246.

feet of air, which would in an hour's time reach the proper limit of vitiation. The next question is, how fast to introduce fresh air in this apartment to prevent the increase of such vitiation. As the process is supposed to continue at the same rate, we must evidently supply an entirely new volume every hour, *i.e.*, 3,000 cubic feet, or fifty feet per minute.

Dr. Billings, of the Johns Hopkins Hospital at Baltimore, uses for hospital wards a somewhat larger figure than this, viz., one cubic foot per second per man—a convenient ratio to remember. Of course a still larger quantity is required for certain surgical wards and in cases of contagion ; while a smaller quantity must be accepted in many cases where the cost would be unreasonable, or inconvenient draughts would be occasion'ed by its introduction. From these considerations we see that although air contains some 21% of oxygen, we can avail ourselves in respiration of only a small part of this without suffering. When the quantity of oxygen is reduced by even $\frac{1}{20}$ of this amount, the air is unfit to breathe, representing essentially the same condition as an increase of 1% of CO_2 with a corresponding increase of watery vapor and organic exhalations.

In order to learn the effect of close air upon the system, within safe limits, Dr. Angus Smith says he constructed a closet, lined with lead, and containing, when a man was in it, 170 cubic feet of air. After remaining in this apartment one hour and forty minutes, the CO_2 had attained to 1%. The first change that his senses noted was that of increased moisture, making the air feel "soft." After one hour he perceived an unpleasant smell of organic matter, like that in a crowded school room, but made perceptible only when stepping about, and thus accumulating the effect of the successive portions of air coming in contact with his lungs. After one hundred minutes the smell became quite unpleasant, and he came out. Three other persons entered at once, and said it was "very bad ;" after one minute he entered again, and found it "extremely bad." The oxygen was reduced to 20%. "Was glad to escape, though not conscious of discomfort. The pleasure on coming out was altogether unexpected, like that experienced on walking home on a fine night after leaving a crowded room." His attention had to be called to the bad odor, however, while in the chamber, in order to perceive it, *i. e.*, it did not arrest attention. It took four hours for his lungs to recover their normal condition, *i. e.*, to work unconsciously, after coming out.

The second time he stayed inside for one hundred and sixty minutes. After the first one hundred and forty minutes he found a long breath was agreeable—the air felt close. On standing in a chair it seemed worse. The oxygen was then reduced to 19.61%.

He afterwards reduced the oxygen by burning candles in the room, and entered the closet with candles and a spirit-lamp. The candle was soon extinguished; he tried to light it, but the match would not ignite. He still breathed without difficulty; but gradually a feeling of discomfort came on, hard to describe. The breathing increased in rapidity. He afterwards lighted the gas, which burned brilliantly. After the gas had gone out he went in again, and stood up in a chair, but felt incipient faintness; yet the senses were not so unpleasantly affected by the smell, etc., as in a crowded school room. His lungs seemed to refuse to expand, but he could not tell why.

After opening the door the oxygen was tested and found 17.45%. He was satisfied from these experiments that badly ventilated rooms that contain less than 20.7% oxygen are very unwholesome. Even if a man lives where a candle will not burn, he does not think it proved that he is not injured.

The closet was tried voluntarily by a young woman, after the oxygen had been reduced to less than 19% by candles, and the CO_2 had reached 2.1%, but no organic matter from human breath. She stood for five minutes very well, then suddenly became white, and could not come out without help.

Again, having supplied CO_2 artificially in the closet to 3.84%, and reduced the oxygen to 20.19%, two men went in, and got headaches instantly. They were not able to stay over seven or eight minutes.

The same lead closet was used as a test of the amount of heat given off by a man in a given time, but as it was not surrounded by a good non-conducting medium, it is probable that considerable heat was wasted through the walls. One man, confined for one hour, was found, on a mean of five tests, to heat the 170 cubic feet of air 5.64° Fahrenheit.

Dr. Smith goes on to say that in the earlier stages of want of ventilation the organic exhalations are most injurious. These bad influences increase with the temperature, but those of CO_2 do not. So that we ventilate in warm weather more for getting rid of the organic matter than the CO_2. The increase of the vitiation to an injurious degree is so insidious, and makes so little impression on the senses, that he considers lack of ventilation worse than the fumes of vitriol: those would alarm the sense of smell, and notify us at once of their presence.

The relative quantities of oxygen and CO_2 in air, under different conditions and in different places, is given in the following table :—

TABLE A.

VOLUME OF CO_2 IN THE AIR. [From Dr. R. Angus Smith.]		VOLUME OF OXYGEN IN THE AIR. [From Dr R. Angus Smith.]		
Places.	Percentages.	Places.		Percentages.
Near Chambeisy,	0.460	London, North,	7 tests.	20.857
Lake Geneva,	0.439	" South and S. W.	16 "	20.883
Suburbs Manchester, (14 tests),	.0369	" Parks,	7 "	20.95
Pit of theatre,	.2734	" Metropolitan		
Stables,	.0833	" Railway tun'l,	10 A.M.	20.60
Study, at table,	.1177	" " "	7.30 P.M.	20.79
" at ceiling,	.1561	Manchester, wet day,		20.98
School-room,	.0970	" dry day,		20.91
" "	.0886	" dense fog,		20.82
In brewery,	.1214	" suburbs,		20.96
" near vats,	.1800	" sitting-room,		20.89
In a mill, with 400 people,	.2830 to .3000	Theatre pit.	11.30 P.M.	20.74
		Theatre gallery,	10.30 P.M.	20.63
		Scotch Mts., mean	24 places	20.98
Streets of Manchester, fair,	.0403	" lower, "	12 places	20.94
" " fogs,	.0679	Scotland, mean of	30 places	20.96
" " near privy,	.0774	Sea-shore on Heath,		20.999
" " in suburbs,	.0291	Manchester, front y'd,		20.943
" " in close blds.,	.1604	" near privy,		20.700

The higher the apartment is made, and the more cubic space per head, the easier it becomes to regulate the change of air without sensible draughts. It is found that if currents are established near the floor at the rate of over two feet per second, a perceptible and disagreeable effect is produced, particularly if the dew-point is low. The inlet ducts must therefore be so adjusted as to position and size as to have this limit observed as nearly as may be in practice.

A great deal of annoyance has been caused by the neglect of this precaution.

Supposing the inlet and outlet ducts to have been provided of sufficient size to change the air at the desired rate, we have still to see that the fresh-air inlets are so disposed that the air will be properly mixed with the air already in the room, and not pass directly to the outlets, as is too often the case. Such a result would of course leave the air in the room without the needed renewal, and it would fall below the desired standard in quality. Even after arranging all the apparatus with the greatest care, it will be found to work very irregularly under differing conditions as to wind and weather.

Strong winds on the exterior of a building always exert a powerful influence upon the movements of air in the interior, both by their action through the ventilation ducts, and through all the smaller orifices about doors and windows, and the pores of the walls themselves. Their sum total is often capable of admitting a large quantity of air in windy weather, or when large differences of temperature exist between outside and inside. These cracks do a great deal of work under such circumstances, when least wanted ; but in sultry weather, when ventilation is often most needed, they are quite inactive, and cannot be relied upon. Their action is therefore not to be regarded as an assistance, but rather as a disturbing element in carrying out any system of ventilation, often requiring a good deal of special attention to counteract or modify their action, and sometimes making all the difference between success and failure.

Diffusion through differences of temperature causes a good deal of change of air in buildings. It is called thermo-diffusion.

When air or other gas is divided by a porous diaphragm, and warmed on one side to a temperature above that on the other side, diffusion takes place from the cold side to the warm, though the pressures are equal. Pettenkoffer, of Munich (as quoted by Hartley), relates this interesting experiment. He had a room in his house with a tight German stove, of fire-brick. The capacity of the room was 265 cubic feet. The doors and windows being all closed, the temperature outside being 32°, and inside 66°, difference 34° Fahrenheit, he found the air was changed completely every hour. After putting a fire in the stove, the change of air arose to 3,320 cubic feet per hour. After pasting paper over all the cracks around doors and windows, the change was at the rate of 1,060 cubic feet per hour, through the walls. When the temperatures were 71° and 64°, difference 7°, the rate of change was reduced to 780 cubic feet per hour.

Mürke and Schulze state (Hartley) that with a difference of 40° of temperature air goes through one square yard of wall of different materials thus :

	Cubic ft. per hour.		Cubic ft per hour
Sandstone,	4.7	Tufaceous limestone,	10.1
Quarried limestone,	6.5	Mud,	15.4
Brick,	7.9		

This is a very important fact in regard to dwelling-houses, where the number of persons is often small in proportion to the area of outside wall, but paint upon the walls may modify this largely.

Let us now consider the influence of the common methods of illumination upon the character of the air.

TABLE FROM LUNGE IN DR. LINCOLN. (B.)

Kind of Light.	Used per hour.	Candle power.	CO_2 per hour.
	Litres.		Litres.
Petroleum, . . .	0.045	10.	56.8
Oil lamp, . . .	0.025	4.	31.2
Candle, ...		1.	11.3
Gas (flat burner), . .	127.	10.	86.
One man, . . .			17.0=0.06 cubic ft.

For equal light we get (Roth and Lex, Dr. Lincoln):

	CO_2 in litres per hour.
Street Gas, ...	155.
Refined Oil, ...	87.
Petroleum, ...	75.

Street-gas evolves 681 volumes CO_2 for every 1,000 feet of gas. (Lunge in Dr. Lincoln.) Hartley says, two of CO_2 to one of burning gas.

Thus we see that an ordinary flat burner, consuming 127 litres or about four cubic feet per hour of street-gas, consumes as much oxygen and delivers as much CO_2 as five men, while an argand burner, very commonly used on our parlor tables, is equivalent to at least eight men. It may be said that the burning of gas does not evolve the organic impurites that human lungs do. But unfortunately street-gas has its own impurities, which though not organic are possibly quite as noxious, viz., sulphur, which in burning in free air produces SO_2, which is often betrayed by the tarnishing of silver-plated surfaces exposed in the room where much gas is burned. At any rate, the depletion of oxygen is a positive loss, however pure the gas may be.

If due consideration were given to these facts in planning gas lights, we should soon find that the easiest way to deal with the products of gas-burners would be to provide special ducts to take them out of the rooms, whenever they are used in any considerable numbers, as they generally are in theatres, halls, etc., as well as in strongly illuminated parlors. Fortunately the amount of heat evolved by the burning of gas is generally sufficient to serve as a motor to expel the noxious products from the room, if we only provide suitable ducts for this purpose. The pure air will readily take the place of what is thus gotten rid of, if we give it a chance; for gravity assists—that is, the bad gases are so heated that their buoyancy helps them out of our way, while the considerable quantity of vapor of water which is evolved by the combustion of the hydrogen serves as a vehicle to take up and carry along the SO_2 and other impurities which the burning gas gives out.[1]

The influence of the vapor of water upon air for respiration is a very important subject. The following table shows the capacity of air for vapor, and the tension of the vapor in inches of mercury at different temperatures:

TABLE C.

Temp. Fahr.	Tension of vapor in inches of mercury.	Weight in grains per cubic foot.			Volume of 1,000 cubic feet of dry air after its saturation.
		Vapor.	Saturated air.	Dry air.	
0°	.044		606.03	606.37	
5°	.054		599.40	599.83	
10°	.068	0.84	592.94	593.44	1002.3
15°	.086		586.55	587.18	
20°	.108	1.30	580.26	581.05	1003.6
25°	.135		574.08	575.05	
30°	.167	1.97	567.99	569.17	1005.6
35°	.204	2.48	561.99	563.42	
40°	.247	2.86	556.03	557.77	1008.3
45°	.299	3.44	550.19	552.24	
50°	.361	4 10	544.36	546.82	1012.0
55°	.433	4.87	538 60	541.50	
60°	.518	5.77	532.84	536.28	1017.3
65°	.617	6.81	527.14	531 17	
70°	.733	8.01	521.41	526.15	1024.4
75°	.868	9.39	515.60	521.22	
80°	1.023	10.98	509.97	516.39	1034.1
85°	1.203	12 78	504.19	511.65	
90°	1 410	14.85	498.43	506.99	1047.0
95°	1.646	17.18	492.56	502.41	

It will be seen, by the inspection of this table, that the quantity of vapor per cubic foot is nearly doubled with every 20° of additional

[1] The quantity of heat evolved by the combustion of a cubic foot of ordinary illuminating gas is estimated at 700 heat units: an ordinary four-foot burner would then evolve $4 \times 700 = 2,800$ heat units per hour, or 46.6 per minute. The specific heat of air is 0.238, nearly. A cubic foot of air at 60° weighs $\frac{536}{7000} = .0766$ pounds. So that to ascertain how many cubic feet of air at 60° would be heated 1° by burning a four-foot burner 1 minute, we have $\frac{46.6}{.0766 \times 0.238} = 25.562$, or 2,556 cubic feet, 10°, nearly. When we consider that air increases in volume $\frac{1}{490}$ for every 1° of temperature we see here plenty of motive power to carry off the heated air, and a disturbing element for heat of room if not carried off.

temperature. So that if we take air that is saturated, at any given temperature, and heat it to a tenperature 20° higher, we find it only 50% saturated.

Let us now look at the actual loss of heat by evaporation from the lungs :—

Air (as on the seacoast) at 60° Fahrenheit, and 80% saturated, contains 4.62 grains of water per cubic foot. Air (as in Arizona) at 70° Fahrenheit, and 40% saturated, contains 3.2 grains per cubic foot. The latter, though 10° warmer, as indicated by the thermometer, *feels cooler ;* because more than four times as much heat is lost by evaporation from the lungs, as in the former case, besides the excess of heat carried off by the skin. This is susceptible of actual proof as follows :—

The specific heat of air being 0.237 (nearly), and the air weighing about 536 grains in the first case, and 526 in the second case, as per above table : There being 7,000 grains in a pound, and 966 heat units being absorbed by evaporating a pound of water, the exhaled air at 90°, and saturated.

1st, In breathing air at a temperature of 60°, with a humidity of 80%, heat is absorbed from the lungs, thus : For one cubic foot there is absorbed by heating the air, $30° \times \frac{536}{7,000} \times 0.237 = 0.544$ heat units.

There is absorbed by evaporation as follows : Air at 60°, and 80% saturated, contains of vapor, . . 4.616 grains.

Air at 90°, and 100% saturated, as when exhaled, contains, ... 14.850 grains.

Supplied and taken up from the lungs, . . . 10.234 grains.

Now $\frac{10.234}{7,000} \times 966. = 1.412$ heat units :—

Total, $1.412 + 0.544 = 1.956$ heat units.

2d, If air is at 70° and 40 % humidity, there is absorbed by heating one cubic foot of it $20° \times \frac{526}{7,000} \times .237 = 0.356$ heat units.

Absorbed by evaporation ; air at 70°, and 40% saturated, contains, of vapor, ... 3.20 grains.

Air at 90°, and 100% saturated contains, of vapor, . 14.85 grains.

So the quantity taken up by the lungs is, . . 11.65 grains.

Now $\frac{11.65}{7,000} \times 966 = 1.608$ units :

Total, $1.608 + 0.356 = 1.964$ units ; or more heat than in the first case supplied by the lungs.

Now, what amount of the vapor of water is compatible with the greatest degree of comfort and health ?

Very vague notions prevail on this subject. We have on one hand a general distrust of *dampness.* Air that is nearly saturated with vapor is almost universally condemned in theory, whatever be its temperature. If it be lower than 40° or 45° Fahrenheit, it feels chilly and "raw," as we call it. It carries off the bodily heat rapidly by conduction or convection from exposed parts of the body; though, as we have just seen, the lungs may not lose so much heat as by saturating a drier air. Moreover, there are many humid climates like that of Ireland, which are by no means unwholesame. Any circumstances which occur in such a damp climate that tend to increase the dampness in dwellings, must, however, be much more carefully guarded against than here, where the natural condition of the air is relatively drier, and where such excess is readily absorbed.

We hear, also, a good deal about the need of supplying vapor to the air that is heated for warming our houses by closed stoves or steam pipes, and various devices are now in general use for that purpose.

In severe winter weather, the air supply for a furnace may be at 0° Fahrenheit, and therefore contain but 0.55 grains of vapor per cubic foot. This air is heated up to 100° or 150° perhaps; though 100° is hot enough, and after mixing with the air in the room we occupy, the whole is kept at about 70°. If no vapor be supplied, the 0.55 grains first found would be a very scanty supply for air at 70°, which can only be saturated by some fifteen times as much, or eight grains per cubic foot.

But even without artificial supply of vapor, this air would probably not remain in this condition. All surfaces with which it comes in contact yield more or less vapor, especially if the room be occupied. But let us suppose that by some artificial means this air at 70° has been supplied with vapor enough to bring it to a humidity of 70%. This is about the state of "summer air" in this climate, when abundantly supplied with moisture by expanses of water or recent rains on the soil. Such is commonly supposed to be the desired state of things; but even if it were possible to maintain it in our heated rooms at this season, the result would not be so comfortable as we might at first suppose

The difficulty of keeping the moisture consists in its considerable tension above the condition of things out of doors, so that the vapor would escape very rapidly through various cracks into the outer air by diffusion. Also, that wherever coming in contact with the window glass or outside walls of our buildings, the cooling influence of these surfaces would instantly chill the air below the dew-point, and the condensed vapor would stream down the glass, as we often see it do in a crowded hall under such circumstances. The discomfort or insalubrity of such a condition arises partly from the great contrast between such air and that out of doors, to which we may be alternately exposed ; but chiefly to the tendency of the organic impurities held in the air to decompose rapidly when in contact with vapor of water at high temperatures. They thus become offensive as well as injurious by their putrid state, which might in large degree be avoided in a drier air. Suppose a man to spend an hour walking or driving about the streets in a temperature of 0°. The respiration goes on actively, for a feeling of exhilaration always follows such exposure, if in health. The consequence is, as we have seen, that the air exhaled has not only to be heated some 80° or 90°, but supplied with water by evaporation to an extent that absorbs many times as much heat from the lungs as by heating the air ; yet no disagreeable effect is produced. If sufficient clothing is provided to keep the skin warm, the loss of heat there is not great, for no sensible perspiration occurs under such temperatures without violent exertion. The air that is inhaled and heated 80° by the lungs, is thereby rendered just as absorbent of moisture as if heated by contact with a stove, till the moist membranes of the lungs supply the water to it. The climate of high-table lands, such as exists in Siberia and Arizona, is considered, and in fact actually found to be, very conducive to health ; yet but very little vapor is found in the air in those places. The air is so dry that fresh meat dries up instead of putrifying in the open air, and certain tribes of Indians living in those elevated regions do not bury their dead, but dry their bodies on platforms, as we are told by Catlin.

I find the following quoted by Mr. Robert Briggs, from the Report of Dr. J. S. Billings, on the Hygiene of the United States Army in 1875.

Descriptions of military posts : Fort Yuma, California. "During the months of April, May and June, no rain falls ; then with the thermometer at 105° the perspiration is scarcely seen on the skin, and it becomes dry and hard, and the hair crispy, and the furniture falls to pieces—ink dries so rapidly upon the pen that it requires washing off every few minutes—a No. 2, Faber's pencil leaves no more trace on paper than a piece of anthracite, and it is necessary to keep one immersed in water while using another that has been standing in water some time.

"Newspapers require to be handled with care; if rudely handled, they break; 12 lb. boxes of soap, when re-weighed, gave but 10 lbs. Hams lost 12%, and rice 2% of their original weight. Eggs that had been on hand for a few weeks lose their watery contents by evaporation; the remainder is tough and hard—this has probably led to the story that our hens lay hard-boiled eggs.

"This post, though not the most southerly, is the hottest military post in the United States—a temperature of 100° at Fort Yuma may exist for weeks in succession, and there will be no additional cases of sickness in consequence. We have none of the malarial diseases. The average rain-fall during four years was a little over two inches each year."

The influence of a dry climate as a preventive or cure for lung diseases is fully set forth in the Report of the Massachusetts Board of Health, by Dr. H. I. Bowditch, who seems to have established it beyond dispute. Actual observation confirms the impression that no bad result follows the breathing of air in hospital wards as dry as that of Arizona. Dr. Cowles, of the Boston City Hospital, says there is no discomfort arising from a humidity limited to 15% to 21% in his wards.

The small amount of humidity in our climate as compared with that of England is given by Mr. Robert Briggs, as a reason why a higher temperature within doors is needed here for comfort than in damper climates. The Englishman expresses surprise at the heat of our houses. A temperature of 70° to 75° appears excessive to a man who is accustomed to live in one of 55° to 60°. But the difference in humidity is a sufficient cause. If our air contained the same quota of moisture that the air of England does, we should not need the high temperature. It is the dryness of our air that absorbs heat by forcing evaporation, as has been explained, so that the system loses as much heat in our dry rooms heated to 75°, as in an Englishman's parlor at 65° with its moderate evaporation. If the damp air of England were heated to the high temperature to which we are accustomed, it would be extremely uncomfortable, if not unendurable. Dr. De Chaumont has stated—(Proceedings of Royal Society, V. N. 1877, p. 495)—that the amount of CO_2 in air when vitiated to certain degrees perceptible to the senses was found to be as follows: First, fresh air, % 0.1943; second, rather close, % .4132; third, close, % .6708; fourth, extremely close, % .9054. He therefore adopted 2 in 10,000 as the limit of respiratory impurity in an air space well ventilated, being the same standard as adopted by Parkes.

Dr. De Chaumont also estimated that an increase of 1% of humidity has as much influence on the condition of an air space, when judged of by the sense of smell, as a rise of temperature of 4.18° Fahrenheit. For this reason extreme heat in England, when it occurs, is much more oppressive than in drier climates. The surrounding ocean nearly saturates the air with moisture at all seasons. When the temperature is above 70° or 80°, comfort requires that the heat of the body be reduced, to which end a dry air that evaporates the perspiration conduces most rapidly. Hence the most uncomfortable weather we have in our own summers, occurs when extreme heat is accompanied by the S.W. trade wind, that comes laden with vapor from the tropical seas, and is not capable of absorbing more. We call it "dog-day weather," and it is associated with a feeling of suffocation, arising from the plethora of vapor, and the inability of such air to remove the accumulated animal heat by evaporation of perspiration on the skin. The least exertion covers us with moisture, though the temperature may be several degrees lower than on other days when a dry north-wester carries off the water as fast as it comes through the skin, with the corresponding cooling effect. In short, the damp air when above 60°, always feels hotter than the thermometer shows it to be, while the dry air often feels cooler than it is.

When below 50°, an air nearly saturated with watery vapor becomes disagreeably chilly, not by promoting evaporation, but by the capacity for heat existing in the water, the specific heat of watery vapor being over twice that of air, and the loss occurring by convection through contact with the skin. This effect is therefore partly checked by warm clothing, till the clothing itself becomes dampened, when its effect is rather worse than that of the damp air. Every one knows the danger of wearing wet clothing. Mrs. Brassy says (voyage in the yacht Sunbeam), the rains are so frequent in Polynesia that the natives are said to be much more troubled by pulmonary diseases since their civilized habits have taught them to wear clothes, because they had not learned the importance of keeping them dry. When naked, the skin dried quickly after a shower, while now they wear wet clothing till it becomes dry, a much longer process, demanding a large supply of heat from within to carry on the evaporation.

Although it is not desirable to provide for the saturation of the air in our houses in winter to a standard near to that of summer air, and although a comaratively dry air is not found unwholesome, the addition of a small quantity of water, such as is now generally done in most of our house furnaces, is for some reason or other apparently necessary, both for comfort and the preservation of ordinary wood-furniture, which tumbles in pieces in a very troublesome way if kept in an air with less than 10% or 15% of humidity. In a paper read before the American Institute of Architects by Mr. Robert Briggs, he discusses this question very clearly and fully. He speaks of the discomfort arising from rooms heated without any artificial supply of water, and attributes it to the lack of humidity simply. But Dr. John S. Billings attributes the discomfort to a lack of fresh air, or to a temperature in the air that is supplied that is too high for comfort, if enough be admitted to keep the quality good. The exposure of water and its consequent rapid evaporation absorbs this surplus heat, and allows the proper amount of fresh air to be admitted without the sense of over-heating. If it be argued that the dry air, even at the higher temperature, would call for an amount of evaporation in the lungs to cancel the surplus heat, the answer would be that the presence of any considerable number of inmates would tend themselves to over-heat the room. Thus, when we come to consider large halls for the accommodation of hundreds of people, artificial evaporation is unnecessary, for the lungs of the inmates supply more vapor of water than is actually needed, and it becomes an evil.

The heating of theatres, large halls, court rooms, etc., combined with a proper amount of ventilation, is a difficult problem. We have two very different conditions to provide for; first, the heating of the vacant hall to a degree consistent with comfort, say 60°, which is simple enough; second, the maintenance of this or any other comfortable temperature after the hall is filled with people, which is far more difficult. We have then to supply fresh air for breathing, and diffuse it over the space without disagreeable drafts, at the rate of some 30 or 40 cubic feet per minute for every person in the hall, and carry off the same quantity of vitiated air. We have also to take into account the heating capacity of the inmates, rather an indefinite quantity, concerning which no reliable data can be had, and which we must estimate as best we may. The amount of heat imparted by the human body to the surrounding medium must vary largely with the state of activity, vigor of the circulation, and the difference of temperature between the body (standard 98°), and that of the surrounding medium. Comfort requires a constant escape of heat, so we may suppose the surrounding medium to be cooler than the body, *i. e.*, that the conditions are such as we wish in order to produce comfort. It has been variously estimated under such conditions, that an adult gives out from 150 to 470 heat units per hour. The greater amount is about the same as that produced by the burning of a sperm candle.

But if we take a moderate estimate, say 200 heat units per hour, for people at rest in a comfortable room, we shall have for the number of cubic feet of air thus heated 1° per minute for each adult, as follows: The weight of a cubic foot of air being .0766 lbs., and its specific heat being .238, then $\frac{200}{60 \times .238 \times .0766} = 1,810$ cubic feet of air heated from 60° to 61° in one minute by an adult.

The capacity for emitting watery vapor from the lungs is, as above stated, sufficient to relieve us from any need of an artificial supply of vapor. The excess is rapidly diffused and carried upward with the vitiated air. This vapor has the convenient quality of seizing upon and carrying with it many noxious organic vapors and dust which we can thus get rid of. The failure to remove these is, in fact, the most frequent cause of trouble. Another complication is met with here. These organic vapors arising from the exhalations of an assembled audience are mostly in a putrescent condition to begin with. The loading of the air with vapor of water tends to hasten this decomposition, so that after being heated, steamed, and sent upward by their buoyancy, mingled, perhaps, in the upper gallery of a theatre, with the products of several hundred gas burners, each emitting as much heat, watery vapor, and CO_2, and consuming as much oxygen as half a dozen men at least, we have a state of things sufficiently repulsive to make the strongest man succumb.

The power of dry air to delay the putrefaction of solids has been before alluded to in connection with the drying of meats in Arizona; but here we have the reverse of all those conditions; plenty of heat, plenty of vapor, and the organic impurities, already corrupt when given off, and in that gaseous or finely-divided condition which is most conducive to rapid decomposition. The only wonder seems to be that we ever are able to spend half an hour in such an atmosphere without seriously impairing our health. That we do not, is only a proof of the native vigor which resists such influences.

It is a case of almost daily, or at least nightly, occurrence, to find such halls provided with the same influx of heated air, hour after hour, with the seats all filled, that was provided before the people came there. The temperature of the air introduced through the heating apparatus, which was found necessary to bring the vacant hall up to 60° and keep it so, is largely in excess when a thousand people are breathing in it, while the quantity of air coming in is rarely enough under these new conditions. In short, we want not only a much less supply of heat to produce a given temperature in a filled hall than in an empty one, but we want to keep the actual temperature lower when filled than at first, owing to the increase of humidity. To accomplish this with success, and at the same time furnish the required supply of air, is the thing which is rarely done. Of course it requires a degree of intelligent supervision to regulate the heat of the fresh air while keeping up the influx in volume. Regard must also be had to the condition of the weather. A change of 10° or 15° in the outside temperature during two hours, affects the case not only by loss of heat through the walls, windows, doors, etc., but by requiring so much more heat to be applied to the fresh air that is introduced, in order to produce the same effect, *i.e.*, bring it to the desired temperature when taken from the outside and admitted to the room.

I have thus far tried to describe the *amount of work* to be done in changing the air inside of buildings. I shall, in the next lecture, try to show *how* this work can best be done.

LECTURE III.

THE VENTILATION OF BUILDINGS.

IN my last lecture I attempted to show the need of ventilation, the quantity of work to be done, *i. e.*, of air to be moved, and some of the difficulties and complications arising in effecting the purpose. I will now describe some of the methods pursued in accomplishing this work, and how they may best be adapted to the ends in view.

Three distinct methods for moving the air within buildings are in use:—

1st, By *perflation*—*i. e.*, opening doors and windows, and allowing the wind to blow through the building. This method is of course limited to mild weather, or in cold weather to short periods of flushing, as in bed-rooms, after leaving them in the morning.

2d, By *aspiration*—*i. e.*, the application of heat to move vertical columns of air in chimneys and pipes, by help of the greater specific gravity of the air outside of such pipes, etc., aided by wind.

3d, By mechanical force applied through rotary fans or blowers of any kind.

This last is sometimes called artificial ventilation, from the sole reliance upon motor machines of some sort. This power or force is generally applied in the form of compression, *i. e.*, by pushing the air along forcibly, while the second method is generally considered akin to a process of exhaustion, the heated column being in a flue called an "aspirator." Yet, strictly speaking, the motive force here is gravity, and the upward movement is really produced by the excess of pressure through the bottom of the flue from the weight of air outside, as compared with the pressure through the top of the flue. The latter includes the lighter air and gas inside, and therefore fails to balance the outside column.

Taking up these methods in the order above named:—

The process of *perflation*, though limited as I have said, is by no means to be ignored. All buildings in warm climates, and dwelling-houses everywhere, should be so planned as to take advantage, as far as possible, of this cheap method of changing the air.

In houses situated within densely peopled cities, the temptation to neglect this means is the greatest, for it becomes a question of cost. The compactness of city houses, when in continuous blocks, renders frontage valuable, and a majority of such houses have less than one-half their perimeter exposed to the air. Yet many devices may be resorted to by the architect to increase this perimeter by offsets and projections, such as have now become so common, beginning with the old-fashioned "swell-fronts" and blossoming out to-day in a great variety of oriels and niches. It enables us to invite every wind of heaven within our walls at pleasure. Such a breaking up of lines is susceptible, too, of æsthetic treatment, and is to be encouraged for that reason also. The extreme development of such an outline is seen in the modern field fortification, which by its re-entering angles and bastions is ready to receive the enemy in every possible direction. For the same reason it gives the best chance for a friend to get in, if not resisted by gates, moats and glacis—*vi et armis*.

But besides the exterior outline, the inside arrangements of a house should conform to the need of a direct access to the winds. In country houses the problem is simple enough, but in cities there is a constant pressure to avoid cost by devoting a large space in the interior, half way from front to rear, to various purposes which demand more fresh air than they often get. The result is generally an entire abandonment of perflation in this region, and the substitution of inefficient devices for aspiration. This is one of the greatest evils of a modern city house, and an argument of no small force in favor of spreading out the domicile in stratified "flats," on the French method, so that each house can have its outside exposure better arranged for the access of fresh air than if built on a ground plan of 18 by 80 feet, and five stories high. On the other hand, the "flat" system exposes a family to the unpleasant fumes of cooking, or other smells evolved by the family or families below them, which may be a worse evil than the one before alluded to. The parts of a house which should be best provided with outer air at will, are the sleeping-rooms, bath-rooms, and kitchens. The modern habit places the kitchen at the bottom of the pile, almost buried in the ground, and sometimes with so little light that gas must be used for a good part of the day. The result is that it becomes next to impossible to exclude the fumes of the cooking, and as a large number of houses have no device whatever, for carrying these off, or an inadequate one at best, one can hardly enter a city house on a winter afternoon without becoming aware, with the first breath, of all the most prominent dishes that are to be served for dinner. Such houses do not lose the odor of one dinner before the next is in progress, and the result is an accumulation in all the carpets, upholstery, and even in the blankets and wall-papers, of a nondescript flavor of past cookery. The odors of food are very good things when fresh and in their places, but quite otherwise when thus become stale and hoarded up in one's furniture.

The kitchen should and generally can be located in a projection at the rear, so that two sides at least can have light and air from the outside, and should be isolated as far as practicable from all communication by air draughts with the rest of the house, through dumb-waiter shafts, stair-wells and passages. Where this projection is difficult or impracticable, the most ample provision should be made for carrying off the fumes by a large and separate flue in the chimney, devoted exclusively to the purpose all the way up.

I have been called upon this very week to apply relief to a housekeeper whose chamber was invaded early every morning by the dense odors preliminary to breakfast. I found a large flue opening over the kitchen fire, well arranged for relieving the kitchen, but as the *same* flue had an opening in the lady's chamber, above which the duct was partly obstructed, the result was the ventilation of the kitchen into the chamber by a very efficient draught.

The bath-rooms and water-closets, too, should, wherever practicable, be so located as to get access to fresh air; but as this is rarely possible in the city, except at a large cost for ground-room, other devices are generally resorted to, instead of perflation, for changing the air in these apartments. As the sleeping-rooms are generally used only for the night, time can more easily be taken to get the wind through them than in the kitchens; but whenever located in the *interior*, and removed from the outside walls, the doors and openings should be so arranged opposite one another as to make it easy to get a draught through them at will.

In the planning of hospitals, school-rooms, halls for assembly, court-rooms, and other public buildings, particularly when to be used in mild weather, regard should be had to establishing these through currents, and in such a way that the draughts may be under control, as to the height above the floor. The warmest weather, with moist air, such as prevails near the sea coast for many days in summer, and sometimes with but very little wind, requires the currents near the floor, and if the windows are all high we suffer for lack of the refreshment that a perceptible draught would give us; but in cooler or dryer weather we may need *some* air, but directed upward, so the draught may not be so perceptible. Tilting shutters above windows, or tilting sashes, hinged at the bottom, and held at different angles at will, are used with much success at such times for public buildings.

It is very important that ample openings should be provided for the escape of vitiated air from near the top of rooms where it accumulates in warm weather, as I have explained. Many business offices, factories and public buildings have windows that do not extend within several feet of the ceiling. Although these windows may be made to open at the top, as all windows should, there will still be a reservoir of foul air above them which it is very difficult to remove, and which renders all efforts to change the air unavailing without a high wind to help us in doing so.

A simple piece of apparatus is used on all sea-going vessels, particularly steamships, called the wind-sail, by means of which the fresh air is forced down a vertical pipe into the hold by an open funnel or bell-mouth at the top, kept always facing the wind. Such a device, or a modification of it, with a vane attached, might often be of use to force air into the inner regions of many large buildings, at times when the sultry condition of the weather renders some special effort worth while in this direction.

With a proper regard for the considerations here referred to, the method of perflation is all that is needed for the ventilation of most buildings in this climate during several months of the year, and for the whole year in tropical climates. In hospitals and other large establishments where fresh air is of great importance, the other methods, which are generally provided for the cooler months, can also be called into activity upon any emergency during the summer when the need is felt.

An excellent method of admitting a slight current of fresh air in a sleeping-room, even in winter, is to provide a bit of wood about two inches square and the same length as the width of the sash. By shutting the bottom sash on to this piece, we leave a space between the meeting-rails where the air enters and is deflected upward by the glass, so that no draught is felt.

The law of diffusion of gases is a great help in ventilating sleeping-rooms. Hartley gives the following instance, showing the amount of work done by the combined effect of diffusion and leakage through cracks, etc.:

"A bed-room 12½ x 12½ x 10 feet high, net contents 1,500 cubic feet, with a dressing-room on one side of 560 cubic feet capacity, and two walls against the open air. The windows and doors were all shut, but the chimney open. One person occupied the room for nine hours. It was found the CO_2 had increased one part in ten thousand. Taking the exhaled CO_2 at 5.4 cubic feet for the nine hours, the change effected was equivalent to 54,000 cubic feet, changing the whole contents of the room every fifteen minutes, if nothing is allowed for diffusion."

This goes far towards indicating the power of natural methods of ventilation in private houses, where the exposed surfaces are quite large in comparison with the number of persons occupying the house. But it is not applicable to rooms in the interior of buildings, nor to those which are occupied by many people.

The second method (by means of heated columns of air) is the one generally used for all weather that requires the windows to be closed, both in dwelling-houses and public buildings.

A great variety of conditions are here met with, which complicate the case and call for special attention. Economy and convenience both point to the plan of using the heat required for the comfort of those occupying the building as a motor to do the work of changing the air, and this can generally be managed with success in dwelling-houses, school-houses, hotels, and most buildings used for commercial purposes. But the penurious character of many builders, with the great lack of information and attention to the subject, have produced a result very various and unsatisfactory. For rooms in dwelling-houses where chimney openings can be provided and where there are one or more sides of the room having openings to the outer air, no further provision is generally needed, provided always that the gas-burners, if many are used, have special vent-pipes. But in city houses that have bath-rooms and water-closets remote from the outer walls, some special provision is generally needed. The interior of such houses is often provided with a sky-light well, which can be used for an up-cast shaft to deliver air through the roof. If the top of this shaft is provided with a ventilating cowl, of which the common truncated cone, surmounted by a double conical cap (Fig. 1), is a good type, we can get a tolerable draught in windy weather or while the house is artificially heated, but during damp, sultry weather, precisely when most needed, the pipe is quite inert.

Although such appliances are generally worth while, and may do much good, it is also advisable to call in the aid of the kitchen-chimney flue, which is rarely without a fire even in summer, the heat of which can be used to create a draught. A common method, and a mistaken one, is to pierce the fire flue with a metal pipe for this purpose. If this pipe is large enough to do any real service, say six to eight inches diameter, it will be likely to spoil the fire draught. So the better way is to build a round pipe into the chimney, of cast-iron, eight inches or more in diameter, exposed to the heat of the fire flue, and extending quite to tne top. Branches can be led off from this, of tin or galvanized-iron pipe, to the bath-rooms and water-closet seats, urinals, etc., taking care that the sizes of these pipes diminish as they ramify, like the roots of a tree: otherwise those nearest the chimney will be the only ones to get a draught, or the reverse. This ventilation-pipe should never on any account be connected with any drain, waste, or soil pipe, the vents of which ought *never to enter any chimney*. I have applied this system to some old houses with excellent results, though it is much easier to apply it when they are built.

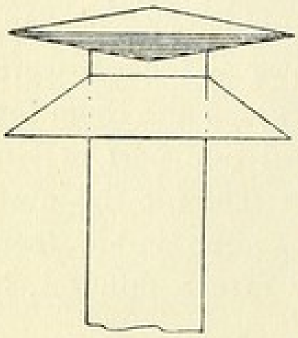


FIGURE 1.

When providing up-cast shafts for removing air from public buildings, special apparatus must be constructed and often furnished with special heating by steam-coils or otherwise. When working on such a large scale it is necessary to compute the proper capacity of the apparatus and to proportion it to the amount of work to be done. Let us, then, investigate the cause for the upward motion of heated air, and ascertain how great a force we have to depend upon.

The motive force is gravity, acting by means of the greater weight of the air outside, compared to the weight inside the shaft. We have a normal pressure outside of some 14.6 lbs. per square inch, tending to force air in at the base of the shaft. If the temperature inside were the same as outside, this pressure would be exactly balanced by that coming down through the top of the shaft, and no motion would result. If the inside air be heated, the pressure at the base through the top would be thereby diminished to the extent of the difference in weight of the heated column as compared with the air outside.

Now, air expands about $\frac{1}{490}$ of its volume for every degree, Fahrenheit, additional temperature. So if we have a shaft forty feet high, and heat it fifteen degrees hotter than the outside air, the air inside would lose in weight by an amount represented by a column $40 \times \frac{15}{490} = 1.224$ feet high. The velocity with which the outside column would try to get in at any orifice at the base of the shaft would be governed by the same law as that of a body falling through the space of this excess of height. Now the formula for the velocity of falling bodies is $V = \sqrt{2gh}$, where h represents the height or space through which the fall is made, and g the force of gravity or the velocity at the end of the first second. This force at this latitute is about 32. Substituting this value for g, and the value 1.224 for h in the above general formula, we have :—

$$V = \sqrt{64 \times 1.224} = 8\sqrt{1.224} = 8.848 \text{ feet per second.}$$

This is the theoretical velocity. We must then make such an allowance for friction as circumstances demand.

The co-efficient of friction is seldom less than 0.5 to 0.3; but the friction is largely increased by the roughness, length, the crooks, or other disadvantages of the pipe.

The product of the velocity by the sectional area of the flue will of course give the volume of discharge.

In making all such computations we have some elements of uncertainty—first, in the actual heat of the rising column, as it can be maintained; and second, the co-efficient of friction, which in small flues is quite uncertain.

Since the introduction of fresh air in cold climates demands artificial heating, the hot air so introduced is in small buildings buoyant enough to find its own way out when vitiated, if a path is given it. In dwelling-houses and all buildings where no large numbers of people gather, the heating apparatus, if proportioned for this purpose, gives all the motive power that is needed to change the air during the period when the weather requires the windows and doors to be closed. But care must be taken to so adjust the influx of warm fresh air and the efflux of the vitiated air as to accomplish the purpose intended, and in a way not to produce disagreeable draughts. In the first place, the air should be taken from a place where it is not liable to be contaminated. A too frequent practice is to supply it from the back yard, close to the ground, often within a few feet of a cesspool with grated cover, or unsavory heaps of rubbish that are apt to collect in such places. Dr. Angus Smith says, "Disease crawls along the ground." The cold-air duct should always terminate, in cities, some six feet or more above the surface, and it is much better to have it debouche on the north or north-west side of a building in this climate, so as to receive the winds that prevail here in extreme weather. It is found difficult to make air move in such ducts against the direction of a strong wind, and it is not an uncommon thing to find the air-current inverted if the inlet faces the leeward side of the house. It is found to pass down from the rooms on the windward side of the house, supplied from cracks or cold chimney-flues, and thence through the heating apparatus into the street or back yard! Not only is much heat wasted in this way, but great risk of fire incurred by forcing heated air through wooden boxes intended only for cold air. Another very common mistake is made by placing the cold-air ducts in sub-basement spaces almost inaccessible for inspection. They should be accessible through their whole length, and for this reason it is much better to keep them above the basement floor, and construct them of galvanized-iron rather than wood. I have during this month inspected a house near this building, one of a block of fine stone fronts, where the cold-air duct was made of brick sides and rough board covering, the bricks being laid directly on the ground under the basement floor. The rats had honeycombed the sand beneath it in great numbers, apparently nesting there, and stowing away their hoards of garbage. A drain-pipe suspended to the floor near by had a leaky joint, from bad workmanship, so the foul air from the drain circulated freely, and was drawn into the cold-air duct through its numerous rat-holes and cracks in the covering, to be warmed and distributed all over the house. A man had recently died in one of the chambers with typhoid fever, but the owner seemed loath to believe that the house was not in perfect order.

I was recently consulted by the owner of a house on Beacon Street, as to the position of his cold-air duct. It was located, as usual, under the basement floor, and though comparatively tight, was subject to the percolation of ground-water which stood in pools in it whenever the ground was saturated by rains. An examination of this water showed it to contain considerable quantities of sulphuretted hydrogen, arising from soil pollution in some form or other. The air-duct was abandoned and replaced by a galvanized-iron one suspended to the kitchen ceiling, made double to avoid the condensation and drip of moisture on the outside during cold weather.

The various methods of heating buildings which are in general use in this country have each their special uses and advantages. A proper selection or combination for any particular place requires some attention to be given to these different methods. Open fireplaces are very wasteful of heat, and as a sole dependence are in this climate entirely inadequate for any purpose except single rooms of a limited extent. When used in connection with other methods of heating, they become a valuable auxiliary. The heat is imparted from them by radiation, which does not heat the air at all, except by first heating the walls and surfaces with which the air comes in contact; thus a degree of comfort is attained without over-heating the air. The sun heats the atmosphere in a similar way—by first heating the surface of the earth, which imparts heat to the air by contact. Moreover, the open fire is a valuable help in removing vitiated air from a room, and is therefore particularly useful in hospitals and other sick-rooms. In a room that is occupied by women and children, and by men of sedentary occupations, and is heated by hot water, steam, furnaces, or stoves, a higher degree of temperature is required for comfort than if a small open fire is used in connection with the other means. Moreover, all rooms that are heated exclusively by currents of warm air that have passed through heating apparatus give a higher degree of temperature near the ceiling than near the floor, tending to heat the head warmer than the feet—a very unsatisfactory state of things, which is partly corrected by the open fire.

If without an open fire, we demand in this climate that the air should be heated to 70° or higher, while if supplemented by a radiating fire it is equally comfortable and much more conducive to health to keep the air about 10° cooler, *i. e.*, if the fire shines on us, the desired heat of the body is maintained without heating the air above 60°. When wood fuel was abundant, fifty years ago, scarce any other means were employed for heating dwelling-houses. The result was not satisfactory, for the influence of the fire was hardly felt beyond the room where it was kept. The fire might be too hot for comfort near by, while on the opposite side of the same room ice might be forming. When wood became more scarce and anthracite was first introduced in our houses, a regard for economy led to the invention of various kinds of close stoves, which, while very saving of fuel, overheated the air without providing for its renewal. The result was a detestable degree of closeness, with loss of vigor, pale faces and dyspepsia among the family. Later came the furnace in the cellar, which is only a large stove for heating rooms above by a circulation of hot air through pipes. The advantages of this method as compared with detached stoves are chiefly in the introduction of a constant flow of fresh air, if taken from a proper place, supplied to various apartments at will, heated to a comfortable degree, and a saving of labor by concentrating the fires in one place.

This was a considerable advance on the detached stove system, provided the air was allowed a way to get out of the room after being vitiated. In fact, for dwelling-houses of small capacity this method, when properly regulated and proportioned, and supplemented by small open fires in the rooms that are constantly occupied, leaves little to be desired. The whole house can be thus kept at a temperature of about 55° or 60°, while the rooms most occupied are heated to about 65° and thus made quite comfortable by small open fires of wood or soft coal. These heat the inmates without heating the air as above explained. There is but little doubt about the lower temperature being most healthful, provided comfort is attained, for the breathing of cool air is far more conducive to physical vigor. Even invalids gain strength and can be made quite comfortable out of doors with the thermometer at 50°, if well clothed and exposed to the sunshine while sheltered from the wind. In order to get good results from a heating furnace, regard must be had to the following: *First*, ample size for the fire-pot, and extended heating surface, so that the needed volume of air can be warmed without the iron becoming red-hot and overheating the air. It should never be over 100° to 110° Fahr. when introduced into the rooms. *Second*, ample sized pipes, proportioned to the sizes of the rooms. No definite rules can be given for these sizes, which should be adjusted to the exposure of the room as well as to its size, particularly in a country-house.

The management of the fire demands more judgment and foresight than is often bestowed upon it in the changeable weather of our climate. Anthracite fires are very convenient in this respect, that they do not need frequent attention to keep them alive; but if an equable temperature is to be maintained in the house, this fuel is so slow to ignite, and so slow to burn away, that some foresight must always be exercised in controlling the draught. A great variety of patterns for such furnaces are offered in our market. Their relative merits depend more upon the quality of workmanship and their strength, than upon the particular kind of material. The strength and conductive power of iron render it almost the only material, though soapstone is used to a small extent. It is desirable to keep the joints tight, of course, to prevent the diffusion of the gases of combustion into the hot-air chamber that is to supply the house.

For this end it is found that horizontal joints are better adapted than vertical ones in cast-iron. Wrought-iron has been considerably used of late, with tightly riveted joints. When new, it is doubtless a tighter material than cast-iron ; but it is more perishable, and quite as likely to change its form and work its joints open by alternate heating and cooling, so that its superiority is not yet fully established by experience. The permeability of cast-iron to the passage of gases is due more to the quality of the metal than to its fusibility. There is no more difficulty in making cast-iron impermeable to gases of combustion than to steam, and it is used universally for steam-pipes for the supply of engines without leakage, and to some extent for boilers also, under a thousand times the pressure that can ever exist in a stove with an open smoke-pipe. In order to avoid the chance of furnaces leaking gas, the exit for smoke and gas to the chimney should be ample in size and unobstructed by dampers. Such dampers should be forbidden by the Board of Health. If the draught is to be checked to reduce the heat of the fire, the smoke-pipe should never be reduced in capacity. The proper way is to close the orifices *below* the fire, and exclude the air from the grate. In order to accomplish this more effectually, the fittings for doors below the fire should be made heavier and firmer than they now are to avoid working, and carefully fitted by planing the joints, so as to control the flow of air into the fire.

It is found to be difficult to get satisfactory results in distributing heated air by horizontal pipes to a greater length than ten or twelve feet from their origin, particularly when the room to be heated lies to the windward of the furnace, in extreme weather. When houses are expanded in size beyond the limits that can be thus served, two furnaces serve the purpose better than one. But in larger mansions, and in large stores and public buildings, the practice of heating by steam or hot-water pipes has many advantages. The heat can thus be carried horizontally for long distances, the only limit being the loss on the way by escape from the pipes to the surrounding medium. This is checked by "lagging," *i. e.*, covering the pipes with a non-conducting material like felt or asbestos. The process of heating buildings by steam has had a considerable development here of late, but without a proper regard, in most cases, for the provision of fresh air that is needed in the rooms to be heated. The process known as that of *direct* radiation ignores the introduction of fresh air entirely, leaving it to the chance cracks and openings and pores in the walls. Of course this cannot be recommended, and if exclusively used will be productive of much discomfort and ill-health.

It is cheaper, doubtless, to conduct the steam by small pipes directly to the room which is to be warmed, and there to deploy it by pipes or other forms, to give the desired surface for radiation—as it is erroneously called—and omit the introduction of fresh air. We accordingly find all the earlier attempts to heat buildings by steam were on this principle, this building included. But more recently the demand for fresh air reached the ears of the manufacturers of the apparatus, and we have now what is called the indirect method, which, though not quite so economical of coal, is more conducive to health. The ordinary process is to ramify the steam-pipes in the basement at some convenient point under the room to be heated, to introduce outer air around the coil in ducts, and thence up into the room. A large amount of fresh air can thus be introduced and propelled to the desired place. If more heat is needed after supplying the desired quota of air, this heat can be supplied by placing a steam-coil in the room. The terms radiator and radiation are misapplied, because the pipes are rarely heated so much above the surrounding air as to impart much heat by radiation ; moreover, radiant heat passes *through* air without heating it. The air in contact with these pipes becomes heated by such contact, and, being expanded, rises to be replaced constantly by other air, keeping up a circulation till all the air within reach is warmed. This process is sometimes called convection. It has generally been supposed that steam-pipes cause no risk of setting fire to wood, since the steam is rarely used with much pressure, 5 lbs. per square inch being a moderate limit, and 10 or 12 lbs. being rarely exceeded. The temperature of steam at a pressure of 5 lbs. per square inch is 228° Fahr., while at 12 lbs. it is 244° Fahr. But it has been found that even this temperature, if constantly applied for long periods, will partly burn the wood—reducing it to charcoal so void of moisture that it is very combustible. Whether or not actual ignition has occurred without further stimulus is not definitely known. But since it is not desirable to char the wood in any part of our buildings, the steam-pipes should not be placed in contact with it.

Concerning the best height in the room to introduce the fresh air and to remove the foul air, much difference of opinion exists among experts, and some heated discussion is to be found on the subject. I can only say that there are plenty of examples where fresh warm air is introduced near the bottom, and the foul air removed above ; and other examples with the flow of air in the reversed direction. For ordinary use in private houses, the introduction of the fresh air near the floor is the simpler method. The extraction of the foul air near the floor can only be effected by special apparatus contrived for the purpose, with some aspiratory or mechanical force to move it; while, if the foul air be taken from the top of the room, its higher temperature as compared with the outside air will generally provide for its motion. In the Annen Real Schule at Dresden (described by Dr. Lincoln in "Buck's Hygiene") the upward movement is used in summer, when the heat imparted to the air by the children assists, and the downward movement in winter, assisted by aspiration chimneys. In the Hall of Representatives at Washington and in the Boston City Hospital are found two quite successful examples of the upward movement, and in the *grand salle* of the Trocadéro at the Paris Exposition is a good example of the downward system. This hall seats five thousand persons. The air is furnished by a fan, at the rate of 40 cubic metres per hour for each person, or 200,000 cubic metres in all per hour—about 2,000 cubic feet per second. To avoid throwing the whole burden of movement upon the propelling fan, however, which might produce an inconvenient compression, the duty of movement is shared by an exhausting fan, that draws the foul air from five thousand openings in the floor.

Concerning the comparative merits of heating by steam and hot-water pipes, there is some difference of opinion, but the facts seem to be as follows: That hot-water apparatus may require a more costly plant, but is more economical of fuel when used for buildings of considerable size. Moreover, since water is not usually heated above a temperature of 200° or thereabouts in the boiler, the heating surfaces are limited to 160° or less, which is better than the higher temperatures generally used for steam-pipes, a greater surface being used to do the same work. The hot-water apparatus is simpler, and the quantity of heat needed in any particular apartment is controlled by valves in the pipes, that check the flow without entirely stopping it; while with steam we must have the whole or none, and the whole, with a temperature of 212° or more, is often hotter than we wish. The regulation of temperature where steam is used is therefore effected by providing for a supply of cool air, to be mixed with the warm air in the pipes before coming into the room. This system requires very careful adjustment, and is not easily managed.

Dr. J. S. Billings, in a report on the ventilation of the Johns

Hopkins Hospital, says: "From practical trial with the hot-water method, I am perfectly sure that for heating purposes it is entirely satisfactory, and is probably cheaper than steam. My attention has been called recently, however, to a very successful application of steam-heating in the new wards of the Boston City Hospital, according to the plans and under the direction of Dr. Cowles, the superintendent. From information furnished by Dr. Cowles, and from my own observations, I believe that this method gives satisfactory results: results, so far as temperature and ventilation are concerned, as good as, but no better than, the hot-water system."

Dr. Billings quotes the following from a report of Surgeon D. L. Huntingdon, U. S. A., upon the heating and ventilation of the "Barnes Hospital," at the Soldiers' Home in Washington:

"The total space to be heated is about 310,000 cubic feet. The heating is effected by a low-temperature hot-water apparatus, consisting of two tubular boilers, each nine feet long, and forty-two inches in diameter, with connecting mains, pipes and coils.

"The heating coils, composed of cast-iron pipe, are placed in brick air-chambers in the basement, at the sides between the windows. At the point of entrance of the supply to each coil is a valve, by which the supply may be diminished to any degree, and the temperature of the coil regulated accordingly.

"From the above coils, pass the flues for fresh-air supply. These flues are of terra-cotta pipe, built into the walls. In the lower wards the flues are so arranged that the fresh air can be admitted either near the floor or near the ceiling. After a fair trial, it appears that the lower registers are to be preferred. When the air is admitted at the top, the ward is heated unequally; a series of observations showing a difference of from 10° to 12° between the floor and ceiling, and the patients complain of cold feet and discomfort, for which reasons the upper registers are not in use. The apparatus has given great satisfaction, has maintained a pleasant, even temperature of about 70° in the coldest weather, and permits of changing the temperature at any locality, easily and rapidly. Many such changes are made each day by the engineer, to meet the varying circumstances of winds, changes of temperature, etc."

When providing for the ventilation of large buildings used for halls of assembly, theatres, legislative halls, etc., it is often found that the amount of heat needed for comfort is inadequate to give motion to the quantity of fresh air needed for the number of persons who breathe it, particularly when we consider the heating power of the persons themselves, and the quantity of vapor given off by their lungs, which, as mentioned before, renders a lower temperature desirable than in a dry air. Moreover, in halls that are to be occupied for many hours, as for legislative bodies and courts, there are many days in the year when scarce any heat is needed beyond what is imparted by the inmates, and when the outer air is too cool to allow a free circulation through windows, etc. There are also many more days, in summer, when there is too little wind to effect the necessary change without artificial help, and when the supply of air is needed for its cooling effect upon the overheated assembly. In all these cases, artificial propulsion must be resorted to, either by aspirating shafts, to remove the air from the room forcibly, allowing the fresh air from the outside to take its place; or by *pushing* in the latter by fans or other blowing apparatus. Both of these methods are sometimes used together.

The use of the aspiratory and propulsory systems, separate and combined, is fully set forth in the report of Surgeon D. L. Huntingdon, before alluded to, and I will close the subject by liberal extracts from this report, describing one of the most successful attempts at ventilation of which we have record.

"At all times when the building is not thoroughly ventilated by natural means (open windows), fresh air is supplied by means of a vertical air-shaft, placed at the west of the hospital building, at a distance of seventy-four feet. This shaft is thirty-eight feet in height, with a diameter of eight feet, open at the upper part, and protected from the weather by louvre blinds. A large weather-cock or vane placed above it turns a hood or cowl within the shaft, which tends to throw the current of air forcibly downward." This shaft seems to serve the same sort of purpose as the wind-sails on steamships, while its height secures an undoubted purity of the air. "This shaft at its lower extremity connects with a brick air-duct 286 feet in length, which passes under the basement of the building through its entire length, giving off, at intervals, lateral branches, which pass into brick air-chambers, within which are placed the coils connected with the heating-apparatus, and finally terminating in terra-cotta flues distributed to the several wards and rooms above. At its throat this air-duct is eight feet high and five feet wide, but steadily decreases in size in its passage under the building, until at its extremity it is reduced to two and one-half feet in height by two feet in width.

"At the throat, the amount of air passing into the duct, and thence into the building, is regulated and measured by folding-leaf doors.

This duct is kept perfectly clean and pure, and arrangements exist by which moisture may be supplied to the air in its passage." The quantity of air passing into the building through the duct varies, of course, with the direction and force of the wind, and with the greater or less activity with which the air in the interior is removed by natural or artificial modes of ventilation. Repeated anemometrical observations show the velocity of the air current through the throat of the duct to average from 50 feet to 800 and 900 feet per minute, the latter quantity during the prevalence of high westerly or northwesterly winds. The removal of foul air from the interior by aspiration is effected by means of two large chimneys in the main building. Each chimney has an elevation of ninety-six feet, four feet four inches by five feet eight inches area inside, and is protected from the weather by a cap with open sides. A boiler-iron flue two feet in diameter passes up the centre of each chimney to a height of three feet above the cap. Into these flues pass all the products of combustion from the several furnaces, range, and other necessary fires, materially assisting the upward draught in the chimneys. At the base of each flue is placed a fire-grate for the purpose of producing an upward current when from natural causes the chimneys fail to act. Into these chimneys open all the ducts which receive the foul air from the wards; these ducts, or foul-air boxes, fifty feet in length, 3 feet 3½ inches wide, and 12 inches deep, are placed above and below each ward, and communicate above and below with the ward, by means of accurately closing registers. These foul-air boxes are lined with tin, and are cleaned daily. In each ward, and above each gas-burner, is fitted a three-inch tube, terminating in a funnel-shaped cup through which all air rendered unfit for respiration by the burning gas is discharged into the above-named ducts. Each ward contains twelve beds, is fifty feet long, twenty-four feet wide, and fifteen high, equal to 18,000 cubic feet. Both fresh and heated air are introduced into the wards by a similar set of inlets. In each of the lower wards these inlets are sixteen in number, eight of them being placed ten inches above the floor, and the other eight ten inches below the ceiling. This double set was arranged for experimental purposes, to determine, if possible, the best position for warm-air registers for heating and ventilating. The ventilation of the urinals and water-closets of each ward is effected by connecting them with the chimneys seventy feet high, at the end towers, and in which a constant current is maintained by fires used for heating water.

"The experience gained by daily observations continued over rather more than one year, on the subject of the practical working of the aspiratory system, goes to show that the movements of air currents are exceedingly diverse, and that the conditions presented at one time and those at another give widely different results. A high barometer and a low relative humidity, with either high or low temperature, seem to be the first essentials for satisfactory unassisted aspiration. As the relative humidity increases, the aspiration flags, and on days with the barometer below its normal average it becomes necessary to employ assistance to the aspiration. The direction and force of the winds have shown themselves to be important factors in the matter. * * * *

"Under the conditions of unassisted aspiration, the upward movement of the air in the chimneys, as determined by the anemometer, has ranged from a barely perceptible current to 387 feet per minute.

"With brisk fires at base of the chimneys, and an average temperature within same of 82° F., the highest recorded observation is 700 feet per minute.

"As a practice only one set of ventilating outlets is kept open in each ward, and under these circumstances each chimney will remove about 138,000 cubic feet per hour from the two wards connected with it.

"For the main inlet-duct for fresh air it has been found in practice that an average flow of 60 cubic feet per minute gives the most satisfactory results, and it is the endeavor to maintain about this velocity by the natural movements of air, if possible, or if this fails, by mechanical means, as by the fan or assisted aspiration. The average rate of movement into the inlets of the wards is about 130 feet per minute.

"About 250,000 cubic feet of fresh air are passed into these four wards per hour, or about 5,200 cubic feet per man per hour. With the above-named velocity the air passes into the rooms well broken up by its passage through the ornamental gratings of the registers, and is diffused without draught. * * * *

"Propulsory ventilation is effected by means of a fan placed in a separate building 74 feet west of the hospital. The fan is an iron disk, 8 feet in diameter, with twenty-four blades 12 inches wide, driven by a six-horse-power engine. It is supplied with air only through the air-shaft. The boilers and furnaces are separated from the air-duct by two close doors, rendering it impossible for any smoke or coal-dust to enter the general circulation. The consumption of coal, when in use, is 140 lbs. coal per day.

"At this hospital we have made no continuous use of the fan, using it in summer during the warm stagnant mornings and evenings to create a draught throughout the buildings, and during the cooler weather to 'blow out' the building, and to assist in the ventilation of the wards. It is also used to regulate the temperature of the wards, as by its means we can speedily cool off overheated rooms, or in dull, damp, and cool weather it is usefully employed forcing warm air through the building. * * * *

"From what has already been said it will readily be seen that one system blends almost imperceptibly into the other. The three methods may be put in operation at the same time. A very common combination is that of propulsion with aspiration, and the end attained by such combination is still better ventilation than is attained by either alone.

"For more than a year the ventilation of this hospital has been closely watched. Almost daily observations have been made upon the practical working, and the best methods of regulating the machinery have been carefully studied. It is my belief that a very close approach has been made to perfect success.

"Simple and natural as are the laws upon which the supply of fresh and the discharge of foul air are based, and little complicated as is the apparatus, intelligent oversight cannot be dispensed with. I cannot help again expressing my satisfaction with the fan. By its means I hold the power, as it were, of deluging the house with fresh air at any moment ; and I am convinced that were the provision for the discharge of foul air far inferior to what it is, the use of the fan for a few minutes hourly would maintain a very satisfactory condition of ventilation."

Thus we see that the ventilation of our dwelling-houses is a matter governed by laws that are readily understood by all. It should therefore be removed from the realm of mystery where it has been kept so long, and dealt with by a little common sense. Nature has made the aeration of our blood one of the highest and most important functions of life, giving to the organs concerned in that process the monopoly, or at least the lion's share, of space in the whole bust, and defending them by an arm on either side. Man should respect this function by lending it all the coöperation that intelligent attention can afford. Architects should study the subject, housekeepers should give it their interest, for none of us can live for even five minutes without the active exercise of this function.

LECTURE IV.

THE DRAINAGE OF TOWNS.

THERE are three kinds of material to be removed by drainage :—

First, Subsoil-water, or that part of the rain-fall which soaks into the ground, and which may, if not drained off, remain too near the surface for health.

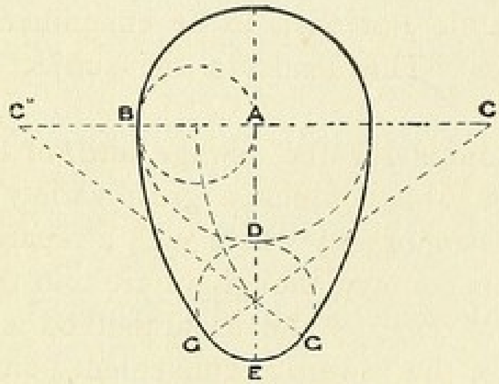
Second, Surplus rain-water which runs on the surface.

Third, Sewage, or the fluid and water-borne refuse of houses, stables, and manufacturing establishments.

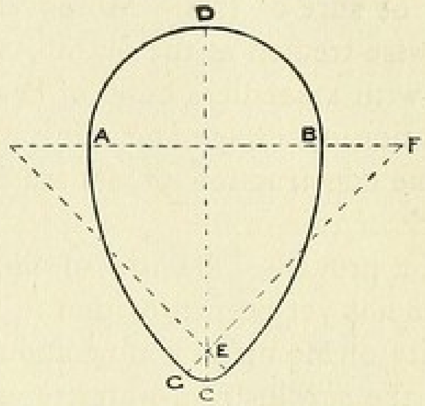
Previous to the beginning of this century, and even later, the large cities of Europe provided drains chiefly for the surplus rain, or surface water, which was discharged into the nearest water-course. It was illegal, says Baldwin Latham, to drain fecal matter into the London sewers prior to 1815, and only in 1847 was such drainage made compulsory. [Boston and other American cities, as far as I am informed, have not made it compulsory to this date.]

The sewers of the last century were nothing but rain-water culverts. Their faulty construction to act as conduits for sewage, or even for street wash, is plain enough when viewed in the light of modern experience. They were generally formed with flat bottoms, often having side-walls of rough stone, and with very little attention to uniform grades. The result was a large accumulation of solid matter, sometimes to such an extent as not only to block the opening, but to create very offensive exhalations by the decomposition of this detritus. Soon after the admission of water-closet and other house drains into the sewers, this evil became so aggravated that the matter was taken in hand by engineers, and proper attention has since been given to these details. The annexed figures from Latham's work show the modern forms of brick sewers.

The drainage of subsoil-water, to avoid saturation near the surface, is effected to a considerable extent in modern brick sewers, owing to their being constructed with somewhat porous walls. The importance of keeping the ground-water several feet below the bottoms of cellars is not fully appreciated, so that very little attention



Old Form of Oval Sewer.



New Form of Oval Sewer.

has been given to this subject in practice. Except by the adventitious drainage through the pores of brickwork, just alluded to, scarce anything has been done for this end in cities. All cities and towns that are built upon clay-beds or other impervious soils should consider this subject more fully. If the subsoil is gravel or sand, and sufficiently raised above the valley bottoms, it may take care of itself, but many cities are not so underdrained by Nature. If the sewers act as subsoil-drains, through their porous walls, they will also be liable to allow the fluid portion of the sewage to *leak out* into the soil whenever the ground-water is reduced below their level by a drought. Two evils result from this, viz., the pollution of the soil by such leakage, and the choking of the sewers themselves from the lack of fluids to wash along the more solid parts of their contents. The following method for taking off a part of the subsoil-water has been adopted in Oxford and some other English towns, viz., to provide a pipe of twelve inches diameter, or less, with open joints for the admission of ground-water to be laid directly below the sewer. This is a necessary adjunct in the construction of sewers through very wet ground, serving to gather the ground-water to the sumps from which it can be pumped out. Such pipes are often much encumbered with sand during the construction of the works, but if this can be avoided, and if the sewer is made tight enough not to leak into them, the same pipes can permanently serve a useful purpose as subsoil-drains. The true method in such cases would doubtless be to provide a separate system of subsoil-drains. But very few, if any, cities have yet done so. The ordinary way is to build the brick sewers so as to let the water in, not so much from intention as because it is very difficult to make them tight in wet ground, though they *can* and *should* be made so. If the ground were *always wet*, there would be no danger of outward leakage, but we can rarely be sure of this. Moreover, if the sewage is to be pumped or otherwise treated at the outfall, we do not wish to be encumbered there with a needless bulk of water. This leads to the subject of separation of sewage and rain-fall.

The construction of separate ducts for the sewage and for the surface or rain water is a question about which a great variety of opinion prevails. I know of no town or city where such a separate system has yet been provided in this country, though we are told that the city of Memphis is now about to do so. The usual method is to allow the surplus rain-water to enter the sewers at convenient points, with the view of assisting the flow of the seweage by its scouring effects. Of course, if this plan be followed, the capacity of the sewers must be proportioned to the duty imposed upon them. In most temperate climates the volume of such surface-water to be dealt with is many times that of the house-drainage, generally from ten to twenty times as great, so that the volume of *sewage* has had but little to do in governing the capacity of the sewers. It was necessarily controlled by the rain-fall.

But even when dealing separately with the rain-fall, it is conceded by all to be best to allow a small portion of it to enter the sewage-pipes; viz., at least such portion as may fall upon the front roofs of buildings. If *any* portion is so taken, due regard must always be had to it in adjusting the size of the conduits to the duty. The house-drainage alone can never exceed in volume that of the water-supply, for the solid matters added to the water are less bulky than the portion of water lost by evaporation. The flow of house-drainage is, however, not uniform, but concentrated mostly during the working hours of the day, and reaches its maximum during the forenoon. Hence allowance must be made for this maximum, which is sometimes fully double or nearly three-fold the average rate of flow.

The arguments in favor of separating the bulk of the rain-water from the sewers are of the greatest weight in a scattered population, such as often occurs in suburban towns, and the objections increase in force as the population becomes more dense. A few English towns have recently been provided with sewers on this principle, among which is Oxford, where it has been in use some two years, and is said to be quite satisfactory so far. The chief reasons in favor of the separate system are as follows:—

1. Economy. The separation avoids the construction of long

lines of large mains, because the rain-fall is conducted by short conduits to the nearest water-course, it being rarely found necessary to collect the whole discharge at any one point for a whole district. But it is not proper to discharge *sewage* in this way; so that, if both are mixed, we have either to transgress this rule, by discharging the mixture where it ought not to go, or build long mains of large size for its collection at some one place where the sewage can with propriety be delivered.

This combination of rain-water with sewage becomes a very serious encumbrance whenever the sewage requires either an artificial treatment of any kind at the outfall, or even pumping alone; for the works adapted to handling the sewage alone would be increased in capacity very largely if required also to handle surface-water. Moreover, the volume of the latter is so exceedingly variable that a large part of the plant provided for the maximum must necessarily lie idle for a greater portion of the time. If the sewage is used for irrigation of land, as is now becoming a common method in Europe, the trouble is not then avoided, for the same rain-storm which gorges the sewers to their full capacity has also the effect of saturating the soil to be irrigated, thereby rendering it less capable of absorption, and likely to become sodden and noxious to the crops.

2. The sanitary considerations arising from the better "self-cleansing" qualities of small pipes, carrying a more uniform flow. The variable volume of the rain-water requires large conduits to be provided for occasional storms, while for most of the time they are charged with an insignificant flow, not enough to render them "self-cleansing" by scour. The dry-weather flow, in fact, occupies but such a small part of the large sewer, that it does not move with sufficient velocity to avoid deposits.* If such deposits occur, the end is defeated for which the sewer was intended; viz., the complete and rapid removal of all the sewage to its ultimate destination. This is one of the axioms of the profession—a point upon which all modern sanitarians are agreed; for it is admitted by all that great harm must result from the delay and consequent putrefaction of the matter deposited by sewage, while, on the other hand, if it is kept moving, very little change need take place in its condition while it remains within the conduits, and the noxious character as well as the quantity of the gases of decomposition would be kept at a minimum.

* Since the above was written a Report has been made by Col. Geo. E. Waring, Jr., to the National Board of Health, giving the actual gaugings of the maximum flow of dry-weather sewage in several sewers of cities and public institutions, from which the following abstract is taken. The

I copy the following from the London *Engineering*, of January 16, 1880: "The subject of separating the rain-fall from the sewage of houses in passing through the sewers, has received much attention. Generally speaking, engineering authorities are agreed as to the desirability of such a separation. In London the amount of road refuse which enters the sewers is enormous, continually blocking them, and consequently sending the sewage and sewer-gases into the houses."

It may be argued by the advocates of a combined system that the rain-fall scours out such deposits, but it must be remembered that we have in this climate such long droughts that several consecutive weeks often pass during which no considerable rain-fall occurs; and this is likely to be during the hottest part of the year. The result would be the collection of deposits at such times, just when the heat renders the changes by decomposition most rapid, and its effect upon the health of a community most powerful.

The flow of sewage is, as above explained, comparatively uniform, being subject to only daily variations, and always within certain definite limits. It can therefore be definitely and cheaply provided for by such sizes of pipes as are needed, and which will for these reasons be so far filled every day as to insure a sufficient scour to keep them free.

For such small towns as can readily take care of their rain-water on the surface, the above reasons are certainly strong ones in favor of separating the sewage flow. In such towns the street traffic is so moderate that the street water is not very foul, and can therefore be

gaugings were generally carefully taken by civil engineers detailed for the purpose by the local authorities, and in the most important cases were taken at intervals of an hour or less, during the parts of the day when the greatest flow occurred:

LOCALITY.	Length of sewer above gauging.	Number of houses drained.	Population served.	Actual diameter of sewer.	Diameter of pipe running full to carry the actual flow.
Madison avenue, New York..	7,000 feet.				4" by 3½"
Providence, R. I............	1,391 "	41	267	12"	1.84-100"
Burlington, Vermont.........	2,790 "	54	325		2¼"
Sewers in Milwaukee........		368	3,177	42"	6"
N.Y. Lunatic As'm, P'kpsie.			301	12"	4¼"
Street in Poughkeepsie......	2,766 "	39	426	15"	3"
Insane Hosp. Taunton, Mass.			659	10"	4.58-100"
Street in St. Louis, Mo.......		1,370	8,200	87"	9" ‡

‡ This last instance showed a delivery of over a million gallons per day, from a population of 8,200, being 130 gallons per head. Hence it is inferred a considerable part of the flow came from ground-water leaking into the sewer.

These data are referred to with some force by the advocates of a separate system of pipes for sewage alone in such places as do not require sewers for carrying off the surface water.

discharged with impunity into the natural water-courses. Such towns, too, are precisely the ones that will find the saving of capital by the separate system an important item in their finances, and on whom the burden of constructing large and long main sewers would be found oppressive if not prohibitory.

But grave objections are found in various places, viz., in most large towns, to the plan of separate ducts for sewage and surface-water. First, the liability of polluting the brook-channels and even larger water-courses by the discharge of street wash into them. Very few towns remove the horse-manure from their streets so thoroughly as to prevent the more soluble parts from being washed away by every rain, with whatever other organic matter or loose material happens to be lying about in the shape of dust. If the surplus rain-water from the streets be delivered to the nearest natural stream, unless this be a large one, there will be a constant accumulation of silt in its channel, containing such a quantity of organic matter that it could hardly fail to become offensive in warm weather. The variable character of the flow, dependent on the rains, would favor the continual deposit of banks of foul silt in such channels, which cannot be self-cleansing. The result would be very unsatisfactory in all small brooks and streams of insufficient volume to largely dilute and carry off such impurities.

There is a second reason which operates with a good deal of force against any attempt to separate sewage and surface-water in our older cities, viz., the complications arising from an increase in the number of underground pipes in our streets. Most cities now have already gas-mains and water-mains under the pavements, while some cities have more than one system of gas-mains and steam-heating pipes as well. If we add to these not only one set of sewers, but two, one for house-drains and one for street gullies, with pipes for subsoil drainage besides, we have to consider how all these systems are to cross one another at every street corner, and how the small house pipes from either side the way are to cross the mains with which they do not connect, and still preserve the continuous slope for both mains and branches, which is indispensable for drains, and quite important for gas, steam, and water-supply pipes. Of course each system of mains could be laid at a different depth below the pavement, to provide for this crossing; but the grades of sewers often depend upon other things besides the level of the pavement. A long sewer must have often but a very slight descent, and cannot vary in inclination as the surface of the street may. So its depth cannot in such cases be a constant one. So long as we have only one set of sewers, acting also as drains, we can put them deeper than the gas and water-mains, which are usually laid at successive levels above the sewers, and nearly of uniform depth below the pavement; but, if we must have two systems of drains, their slopes or grades may often clash with one another and create much inconvenience. Of course such intersections and superpositions can be made feasible and practicable, but not without cost and continual trouble, —a matter that should be duly taken into account in considering such a change. If the day should come, as it may, when we have sub-ways under our pavements, in which all these pipes can be laid and repaired without taking up the pavement so often as is now done, then the putting in of an additional pipe would not be of so much importance as it is under the present condition of things.

Moreover, we must remember in connection with this discussion that the old-fashioned wide or flat-bottomed sewers, which favored the accumulation of sediment when but a small flow occurred in a large sewer, are no longer built in these days. The modern forms are like the long section of an egg with the small end down, so that the invert, even though covered with only six inches of flowing sewage, is narrow and smooth, and unlikely to collect any considerable quantity of deposit, even when the sewers are ten or twenty times as large as required for the dry-weather sewage alone.

It is evident that the circumstances of the locality which happens to be under consideration must be carefully considered in relation to this question. Thus the separate system of pipes for sewage and rain-water may not only be well adapted to many towns or districts with a somewhat scattered population, but also even in larger towns, perhaps, where the rain-water can be discharged into rivers of considerable size, that would not become polluted thereby. Still, if the town had within itself the elements of an indefinite increase, as many American towns have, the village of to-day may be a crowded city in the next generation, losing all the rural characteristics of both streets and brooks. In this case any provision which might have been suitable for a suburban population would cease to be so when the conditions had changed.

Previously to developing a scheme for sewerage for a new locality, a careful study of its local topography is absolutely essential. For this purpose a map should be prepared on a scale not less than two hundred feet to an inch, or one to twenty-five hundred, on which the elevation of the streets above datum may be noted in figures at their intersections and at such points as define a change of inclination. Also levels of the water-courses where crossing the streets, and the high-water levels of the streams. Contour lines for every five feet of elevation should be drawn from actual survey over the whole district, and the area and character of the water-shed of any small streams that are to be provided for should be definitely ascertained. The rain-fall should be studied by consulting the observations at the nearest station where such a record has been kept for a term of years, and a decision arrived at as to what portion, if any, of such rain-fall it is best to take into the sewers. We must also consider the present and prospective population of the place during such period as it is thought best to provide for, with a view to having the works conform in capacity as well as in their general scheme, as far as executed, to a plan that would, when more fully developed, meet the wants of the propable increase in population.

Even when providing for sewage and rain-water together, it is not customary to carry the whole volume of rain-water of violent storms throughout the whole length of the main sewers. When any natural water-course is crossed or found in the immediate vicinity of the main sewers, the overflow of the sewer into such water-course is generally provided for. It is readily seen that when a sewer is gorged with rain-water, flowing with a volume ten times as great as that of the dry-weather flow or *sewage* alone, the whole of this sewage is so far diluted that its discharge into the water-course is not likely to be of any inconvenience or harm in a sanitary point of view, for the stream into which such discharge takes place would, even if small before, be now swollen by the freshet, and carry along all such occasional impurities with the mud and silt that are always taken into streams at such times. If the sewer had before the rain become slightly foul for want of flushing during a period of drought, the first effect of the accession of storm-water would be to rinse out the sewer, while the freshet is rising, so that the whole length would be likely to be tolerably clear of previous accumulations, some time before the point of overflow is reached.

The quantity of storm-water that is to be provided for is a question to be determined in each separate street for itself. The quantity in the main sewers will depend upon, first, the amount brought in by the laterals or branches, and, second, on the opportunities afforded on the route for the overflow of the surplus.

DISPOSAL OF SEWAGE.

Among the first questions to be entertained and decided in planning a system of sewers is that of the *ultimate disposal* of the sewage. This is a question upon which a great amount of money has been expended in carrying out the various schemes that have been from time to time devised for the utilization of sewage. The quantity of organic refuse thrown off in the sewers of a large town is so large that it cannot with impunity be absorbed and carried along by small streams without danger to the health of the population residing on their banks. Even the tidal estuary of the Thames was so polluted by the sewage of London a few years ago that the further discharge along the banks where the sewers debouched was abandoned, and enormous intercepting-sewers were built to carry it along downstream to Barking, on the north or left bank, and Crossness on the right bank, some twelve miles below London Bridge. These intercepting-sewers are about eighty-five miles in length, and cost upwards of four millions sterling. Even after all this expenditure the sewage is not entirely gotten rid of, but is wafted up and down the estuary by every tide. Its lesser specific gravity causes it to float upon the sea-water brought in by the tide, and its manifest presence in some twenty miles of the lower Thames has given rise to a good deal of discussion during the past two years.

In a report by Capt. Culver to the Thames Conservancy Board, published in London (*Engineering*, for January, 1878), I find the following: "Capt. Culver finds that while we have to some extent relieved the river westward of Blackwall up to the bridges, in some of the lower reaches the Thames is worse than it was before the main-drainage scheme came into operation. Close to the two outfalls there is a large collection of offensive mud, arising from the deposit of sewage matter. This we can fully verify from the fact of having taken samples last August from the banks of the Thames, near Barking. The matter was about as thick as, and of the color of, moistened paste blacking, and the odor horribly offensive—far worse, in fact, than the worst specimen we ever saw at Hungerford Bridge in 1855–'7." Capt. Culver states further that the sewage which passes out of the outfalls at Barking and Crossness rolls up and down with each tidal flow within a reach of eight miles. The solid contents are deposited in all the bays and creeks where the water is still, and they fall to the bottom during the time of low water. On the return of the tide they are carried up with it, even so far as Charing Cross.

The above seems to indicate that tidal estuaries are not the best places in which to discharge sewage when in such large volumes as is the case at London, and points to either the further extension of these main sewers towards the sea at some future day, or the utilization of the sewage upon the land. A portion, though a small one, of the sewage delivered by the great main at Barking, being the sewage of about twenty thousand people, has for some years past been used experimentally on a farm, where the crops are irrigated by the crude sewage, but the experiment has not proved to be a profitable one.

The value of sewage to the farmer has been for many years considered in theory as sufficient to warrant its collection for chemical treatment and evaporation of its water, retaining the solid parts for sale as manure. Thousands of dollars have been spent in England in futile efforts to devise a method of doing this with a profit. But every company that has undertaken it in England has failed, so far as the value of the residual products goes. Such processes are continued only because they may afford, in many cases, the cheapest method of getting rid of the sewage for the community, and regardless of the profit by sale of products. The following is from the London *Engineering*, of January, 1878. After referring to the successive failure of various methods of precipitation, etc., the editor says: "Other chemical processes are being tried at Leeds, etc., but we have not heard of a single case in which so much success has been arrived at as to encourage any hope that chemistry will help us out of the sewage difficulty. It is evident that both this science and engineering have hitherto been baffled by the sewage question." This, of course, refers to the attempts at converting sewage to use as a manure with a margin for profit. There is no doubt about the necessity of disposing of it regardless of profit, the only question being how to do so with the least cost, and in a manner which will give good sanitary results.

A proper regard for the welfare of the population residing along the banks of many streams into which the bordering towns have always drained their surface-water has led to prohibitory legislation in England, enforced by the courts, where these same towns began by developing systems of sewerage, to pollute these streams to an appreciable degree. The result has been that many towns are treating their sewage chemically for the purpose of avoiding such pollution, even though the residuary products are not of sufficient value in the market to recoup the cost of the process. The various methods of chemical treatment have been described at some length in the Seventh Annual Report of the State Board of Health of Massachusetts. If they had been attended with more success as measures of public economy, it would perhaps be more worth while to describe them here in detail, but their whole history has been either experimental and disastrous to their promoters, or tolerated in other cases as the lesser evil of the two which were presented to the particular town which adopted them.

The most successful method, commercially considered, which has hitherto been tried for sewage utilization is that of applying it directly to the soil. Two methods are in use for this purpose. The first is by irrigation of a surface which had been previously prepared by underdrainage so as to grow a succession of crops of some commercial value, giving rise to the name of "sewage farms." As the value of the crop has generally been regarded as one of some considerable importance, for sake of economy, the sewage can only be applied to this land at such times as are consistent with the conditions of the growing crop, and since there are many times when its application would be an injury, rather than a help to the crop, much inconvenience is met with, unless an ample area is devoted to the farm. In many cases an acre is required for the sewage of every one hundred or two hundred of the population, so that in providing for large towns it is often difficult to find land enough for the purpose, which combines the necessary physical characteristics as to porosity, facilities for under-drainage, and cheapness. This has led to the economizing of the breadth of surface treated, by using certain crops of somewhat inferior value, which would endure a more frequent soaking of the soil, and the choice of very porous material where very deep and rapid drainage was feasible. Mr. J. Bailey Denton, of England, has found by applying to such land a discharge of sewage at comparatively short intervals, having several fields for successive treatment in rotation, that the pores of the soil are capable of oxidizing or burning up, as it were, a vast amount of organic matter, by means of the fresh volume of air that was made to enter these pores from above, following the downward flow of the sewage as it percolates through the soil.

This is therefore called the method of "intermittent downward filtration." Mr. Denton tells us that an acre of good porous material can thus be made to absorb the sewage of at least one thousand persons, and yield at the same time from the under-drains a water that is sufficiently pure to be admitted to the natural streams without detriment. But if this method were to be applied to many large towns, it would require a considerable surface—nearly a square mile, for instance, to dispose of the sewage of Boston, even supposing we could find within a reasonable distance the proper quality of soil for the purpose. If the ordinary sewage-farm method be pursued, Boston would require some five or six square miles, or over three thousand acres, to absorb her sewage, even with the most porous soil, and some six or seven thousand acres with an average soil.

The feasibility of using sewage on the land is therefore a local question, depending on the topography of the surface, the character of the soil, and the market value of the land for other purposes.

In 1876, a committee was appointed by the Local Government Board of England to inquire into the several methods of treating farm-sewage. This committee arrived at the following conclusions :

"1. That the scavenging, sewering and cleansing of towns are necessary for comfort and health, and that in all cases these operations involve questions of how to remove the refuse of towns in the safest manner and at the least expense to the rate-payer.

"2. That the retention for any lengthened period of refuse and excreta in privy cess-pits, or in cesspools, or in stables, cow sheds, slaughter-houses, or other places in the midst of towns, must be utterly condemned ; and that none of the so-called dry-earth or pail systems, or improved privies, can be approved, other than as palliations for cess-pit middens, because the excreta is liable to be a nuisance during the period of its retention, and a cause of nuisance in its removal ; and, moreover, when removed, leaves the crude sewage, unless otherwise dealt with by filtration through land, to pollute any water-course or river into which such sewage may flow. We have no desire to condemn the dry-earth or pail system for detached houses, or for public institutions in the country, or for villages, provided the system adopted is carefully carried out.

"3. That the sewering of towns and the draining of houses must be considered a prime necessity under all conditions and circumstances, so that the subsoil-water may be lowered in wet districts, and may be preserved from pollution, and that waste water may be removed from houses without delay, and that the surfaces and channels of streets, yards and courts may be preserved clean.

"4. That most rivers and streams are polluted by a discharge into them of crude sewage, which practice is highly objectionable.

"5. That so far as we have been able to ascertain none of the existing modes of treating town sewage by deposition and by chemicals in tanks appear to effect much change beyond the separation of the solids and the clarification of the liquid. That the treatment of sewage in this manner, however, effects a considerable improvement, and when carried to its greatest perfection, may, in some places be accepted.

"6. That so far as our examinations extend, none of the manufactured manures made by manipulating towns' refuse, with or without chemicals, pay the contingent costs of such modes of treatment ; neither has any mode of dealing separately with excreta so as to defray the cost of collection and preparation by a sale of the manure been brought under our notice.

"7. That town sewage can best and most cheaply be disposed of and purified by the process of land irrigation for agricultural purposes, where local conditions are favorable to its application, but that the chemical value of sewage is greatly reduced to the farmer by the fact that it must be disposed of day by day throughout the entire year, and that its volume is generally greatest when it is of the least value to the land.

"8. That land irrigation is not practicable in all cases, and therefore other modes of dealing with sewage must be allowed.

"9. That towns situated on the sea coast, or on tidal estuaries, may be allowed to turn sewage into the sea or estuary, below the line of low-water, provided no nuisance is caused; and that such mode of getting rid of sewage may be allowed and justified on the score of economy."

Signed by ROBERT RAWLINSON,
CLARE SEWELL READ.

It appears, then, that sewage can best be disposed of, according to circumstances, in one of the following modes:—

1. By discharging it into the sea or other bodies of water large enough to dilute it to such an extent that it will not be likely to again become a nuisance.

2. Where the conditions do not admit of the above, and where porous soil, capable of underdrainage, can be found convenient, to apply the sewage directly to the soil by irrigation, to be absorbed by the crops.

3. Where land is more limited in extent, and the soil still porous, the process of intermittent downward filtration is a safe method, though not so likely to give crops of any value on the land as the second method.

4. Where neither of the above methods is available, the sewage may be treated by chemicals, precipitating the solids in suspension, and so far modifying the impurities in solution as to render them harmless when discharged into small rivers and streams.

Past experience does not, however, justify us in expecting any profit to accrue to the town from any of these processes of disposal.

We have thus seen that before maturing the plans for sewers for any district, we must have the following points well studied, and the facts presented in a clear form:—

1. The topography of the surface.
2. The average and the extreme rain-fall.
3. The physical characteristics of the soil, and the character of

the surface; whether more or less steep, and more or less covered with buildings and pavements, which would favor a rapid surface-drainage.

4. The denseness of the population and its future prospects of growth.

5. The disposal of the rain-fall, and how much shall be taken into the sewers, if any.

6. The ultimate disposal of the sewage itself.

LECTURE V.

DETAILS OF SEWERAGE.

IN laying out a system of sewers for a town, the first point to be settled is the location and level of the outfall. If the town happens to be on the banks of a deep river into which the sewage can be discharged without fear of contamination, as at St. Louis or Cincinnati, several outfalls can be had at convenient points, but if the sewage is to be delivered to the sea, or to be disposed of by irrigation or other artificial treatment, or if it be necessary to lift it by pumping, as is often the case in low-lying districts, then it becomes necessary to collect it as far as possible at one locality, where it can be treated as a whole. The location of the larger mains will generally be determined by the courses of the natural valleys, wherever the slope of the surface is considerable, while the lateral sewers will enter these mains at the intersection of streets, with such ramifications as may be suggested by the contour of the ground.

Modern practice requires all sewers which are too small to allow a man to pass through them for inspection to be built in straight lines, broken by angles where change of direction is necessary, and these angles are always provided with either a man-hole for access, or a lamp-hole into which a lantern can be lowered. By this means any collection of sediment or other obstruction in any form can be readily located and removed. Changes of inclinations should, for the same reason, be made at these holes; but in sewers of three and one-half feet height and upwards, curved lines are allowed. These curves should be carefully traced and made uniform and accurate. When towns are located on sloping or hilly sites with portions lying at the foot of these slopes, nearly level, as often may occur on river banks, it is important to guard against the sewers of the flat districts being flooded by the discharge of those on the slopes. In such cases the higher levels can be provided for by an intercepting-sewer passing along a contour line decidedly above the flat districts, into which all the sewers from the slopes should discharge, and which can be led to its destination without risk of flooding the lower streets by its contents. In all cases where the sewage of the lower part of a town has to be raised by pumping, this principle of *interception* is very important, in order to avoid pumping such sewage as can be delivered at the desired point by gravity. It is often worth while, if the works be on a large scale, to spend a considerable sum in cutting through hills or bridging valleys with such "high-level" intercepting-sewers, rather than to encumber the lower districts with their contents.

If the town is so densely peopled, or likely to become so, that the surface-water of the streets cannot properly be discharged directly into the water-courses, so that any considerable part of it must be provided for in the sewers, there is a good deal of judgment to be exercised in determining upon the proper quantity to thus provide for. If the sewers are made larger than needed, not only is capital wasted, but their self-cleansing power is impaired thereby. On the other hand, if made too small they become gorged with heavy rains above their carrying capacity, the water rises in the inlets and is backed-up in house-drains to the great inconveniences of the house-holders. The lower parts of London have been much afflicted in this way during the unusual rain-falls of the past two years.

The great intercepting-sewers recently constructed along the banks of the Thames are proportioned so as to carry off, besides the expected flow of sewage, a rain-fall of one-quarter of an inch in 24 hours from their water-shed. Many of the tributary sewers receive and bring in a good deal more than this at times, but provision is supposed to be made for the overflow of this surplus into the river. Whether the evil is to be attributed to an inadequate provision for this overflow, or to inadequate capacity in the branch sewers, we are not fully informed ; but it is certain that much inconvenience has arisen in the lower part of London which has been newly built upon within a few years. I copy the following from the London *Engineering*, of January 16, 1880: "A comparatively new danger to health in the metropolis occurred during 1878 and 1879. In some districts, owing to the heavy rain-fall, houses were flooded from the sewers during almost every heavy storm. Consequent upon this the cellars, kitchens, and down-stairs sitting-rooms were as often coated with solid matter of the sewage in hundreds of houses, both north and south of the Thames. Although this was in part due to excess of rain, still the chief cause was that the existing sewers were much too small to carry off the refuse from the great number of new houses that are annually added to London. These may be reckoned by miles in length additional for each year. At last the evil became so great that the Metropolitan Board was compelled to take up the matter. New sewers are in course of construction which will for the present alleviate the evil. But these temporary measures, of course, will only act as a palliative, and it requires no great amount of foresight to perceive that ere long the whole sewerage system of the metropolis will have to be reconstructed."

This is an editorial in a journal which is not given to sensational articles, still I doubt if Mr. Bazalgette, the engineer of the Metropolitan Board, would agree to the idea expressed in the last paragraph.

The quantity of surface-water that will naturally run into the sewers during a given time, after a heavy rain, varies largely according to the circumstances. The following considerations all affect the rapidity with which rain-water will drain upon the surface: viz., the character of the surface as to improvement by building and pavement; *e. g.*, a city with few open spaces has most of its surface paved or roofed; under such conditions, some 80% or 90% of the actual rainfall will get into the sewers within twenty-four hours. But just in proportion as the surface is covered with gardens or grass-plots, the drainage will be delayed. So that in many suburban towns less than 50% will drain off in winter, and less than 20% in some short summer rains when the ground is warm and the evaporation rapid. The character of the slope affects this question also. The sides of hills drain much more rapidly than plains. So that the engineer must take all these questions into account in providing for the surface-water. Local acquaintance is often of great service in determining such questions, where the judgment and experience of a man goes farther than any possible computation in arriving at a proper conclusion. If the steep, sloping side of a hill is bounded at its base by a district nearly level, the water will drain from the slope with great rapidity, and will be likely to overtax the sewers on the plain in sudden bursts of rain, if special pains be not taken to prevent such a result. Where the hill district is not large enough to warrant the construction of an intercepting-sewer to keep its drainage out of the plain, it is sometimes feasible to relieve the sewers at the base of the slope by overflows into natural water-courses by special short conduits. But where the flow from the slope must be carried for any considerable distance by the sewers on the plain, the latter will need to be constructed quite large, to avoid being overtaxed on such occasions. We sometimes have a large quantity of rain in a few hours. Published records of rain-fall in New England show that we often have a fall of over an inch per hour for an hour or more. It is better, if possible, to guard against such emergencies by ample overflows, than to increase the size of the long sewers in a plain, provided the opportunity is found to discharge the water into streams. For the increase of size in such long sewers would be seldom needed, requiring a large outlay of capital for rare occasions, and a sewer less likely to keep itself clear by scour at all other times.

The rules practised in different cities in the same climate and inhabited by a people of similar habits are found to differ quite widely in regard to the quantity of rain-fall provided for within a given time. In Boston, where the population is quite dense, and very few open squares with grass-plots exist, and where in the older part of the town the surface is hilly, the drainage necessarily follows short lines of streets, radiating from the hill-tops and discharging under the old system, by a large number of outfalls, into the surrounding tide-water. In many of these lines of sewers the fall is quite rapid, and the surfaces which feed the sewers are steep and mostly covered with buildings and pavements. Here it has been the practice to provide for one inch of rain-fall per hour getting into the branch sewers, and even with this ample allowance some localities at the foot of the hills (such as Dock Square) have been flooded during violent rain-storms. The new intercepting-sewer, which is now being constructed to receive all these short branches, will be expected to carry only a rain-fall of one-quarter of an inch, or less, per hour, on the surface drained by it. The difference is in part because of the greater steepness of the area feeding the branch sewers causing a rapid drainage, and in part from the relief by overflows by which a large portion of the water may be gotten rid of before it enters the intercepting sewer during violent storms. Moreover, the farther the water flows from its gathering ground, the more is a short and sudden burst of rain diffused over the length of the system, making less show the farther it runs; just as freshets which occur near the source of a river appear at first in a large rise over a short distance, but, in passing down some hundreds of miles, the rise is much less in height, but perceptible over a longer district than at first..

In proportioning the sizes of sewers for a desired capacity of discharge, and an inclination fixed, as it generally will be, by the local topography, the tabulated results of various authors are found based upon formulæ where the co-efficients of friction have been deduced from their experiments. But as the smoothness of the surface and the uniformity and shape of the conduit affect the velocity of flow very considerably, regard must be had to these disturbing elements, either by eliminating their existence or by making due allowance for them in the computations. The fullest and most recent sets of tables that have been published on the discharge of sewers are to be found in the works of Baldwin Latham. But in all cases where sewers of any considerable size are to be provided for, experiments with the precise conditions of the problem, where possible, form a much better reliance than any printed tables. The formulæ published by different authorities differ only in the value of the co-efficients and the care with which the circumstances of the case are foreseen and met.

The following are some of the formulæ used by the best authorities :—

Chezy's formula :

$$\text{(General form, } V = \sqrt{2\,g\,h}\text{).}$$

$$V = B\ \sqrt{r\,s}$$

where B is to be determined by experiment.

$$r = \frac{a}{p} = h\,m\,D \text{ (or "hydraulic mean depth")} \begin{cases} a = \text{area.} \\ p = \text{wet perimeter.} \end{cases}$$

$$s = \frac{h}{l}\frac{\text{height}}{\text{length}} = \text{sine of slope.}$$

By Beardman, $B = 94.2$.

By D'Aubisson, $B = 95.6$ over $V = 2$.

By Eytelwein, $B = 93.4$.

Weisbach's formula :— $V = \dfrac{\sqrt{2gh}}{\sqrt{1 + e + c \times \frac{l}{d}}}$

c = co-efficient for friction, depending on material, and also varying with velocity.

e = co-efficient for entrance, depending on form of end of pipe, and therefore inconsiderable in long pipes or conduits.

d = diameter of pipe and l = length of pipe.

DISPOSAL OF EXCRETA, FLUID AND SOLID.

We have touched in a general way upon the importance of the immediate removal of the excreta of our bodies. We have also considered, more in detail, the methods of removal of the volatile excreta of the lungs and skin by ventilation. It remains to consider the removal of the solid and fluid excreta thrown off by the bowels and kidneys. The method in which this may best be done must vary somewhat in different climates, soils and habits of life. What we have to do with chiefly is our own climate and the habits now existing in our own community, wherever the population is gathered in towns or cities. This is one of the most vexatious problems with which the sanitarian has to deal, for the reasons that the same methods which may succeed in one locality are found to fail in another, and because there have been various rival schemes before the public, promoted by parties who sought to get a profit from the operation, and who naturally looked upon the question with more or less bias in favor of their own methods, to the exclusion of all others.

There has been a great effort made, particularly in England, to utilize human excreta by various chemical processes. These all endeavor to separate the solids from the fluids and to leave the water in a condition sufficiently pure to avoid its being a nuisance when discharged into running streams. Up to a certain point all parties agree, viz., that the organic refuse, when separated from the water of sewage, should be devoted to fertilizing the soil, and therefore all aim at the production of a commercial manure, which it may be for the profit of the farmer to buy and apply to his crops. They would thus be acting in unison with that endless cycle of physical change, before alluded to, where all decay in animal life forms the food of plants, these plants again forming the food of animals. The difference of opinion arose as to the method of treatment, but if the prospect of profit by the sale of the product to the farmer were given up, the only motive remaining, that of disposing of these matters for the best advantage of the whole community, would combine the various conflicting opinions, so far as they happen to be adapted to the circumstances of the case to be treated. So far as our present experience goes, this question of possible profit by sale of the product seems to be settled in the negative. It remains, then, for each community to employ such method as is found to be most consistent with its peculiar circumstances.

The various plans for removal are generally divided into two general classes, the "water-carriage" and the "dry" system.

Our own countrymen have seized upon the water-carriage system with great unanimity, and in many cases perhaps without proper consideration of the conditions which are essential to its success, viz., a copious water-supply, and a system of sewers adapted to the purpose, with an opportunity to discharge the contents of such sewers without becoming a nuisance to themselves or to others. In all towns which have the means to provide a water-supply and to construct sewers, and a proper place to discharge them, consistent with the welfare of others, there is no question but that the system of water-carriage has merits that will put all dry methods quite out of the field. It is with regard to such places as do not possess such means or opportunities that the merits of dry removal deserve attention.

It is universally agreed that any plan is bad which involves the *retention* of excreta in or about a house for more than twenty-four hours at most. Immediate and regular removal is of the first importance. On this account nothing can be much worse than the privy-vault, especially if connected with the house by continuous roofs. The gases evolved by the decomposition of the contents of such vaults or cess-pits pervade the whole house by diffusion, so that no quantity of disinfectant or deodorizer which can be applied to such cases can afford anything more than temporary relief. Unfortunately this system is still very largely in use not only in country villages and isolated houses, but in our old towns and cities as well, especially among the poorer class of dwellings, where the owners have not felt able to make the expenditures necessary for adopting the method of water-carriage.

The methods for emptying vaults, and removing their contents, have been very much improved of late. In place of the offensive wagons, with their furniture covered with filth, which formerly filed out from our city over all the leading thoroughfares every night, we have now compact tanks on wheels, kept perfectly clean outside, and filled by means of pumps and hose which accompany them.

Estimates at the office of the Board of Health rate the number of vaults still in use within this city [Boston, Mass.], at about thirty thousand, of which two-thirds, say twenty thousand, are closed vaults, having no connection with the sewer. There are from five thousand to seven thousand of these cleaned out annually, indicating that they average about three years without cleaning. Since some are cleaned every year and even oftener, it follows that some are allowed to remain much longer than three years without cleaning. It is now over thirty-one years since the city has had an abundant water-supply, with which the use of water-closets became practicable. This large use of the vaults up to the present day serves as an example of the slow rate of change in customs of this kind, and how much remains to be done to bring our own community up to the standard which we recognize to be the only proper one.

Those communities whose topography and surroundings do not favor the disposal of excreta by water-carriage and sewers must have recourse to some of the dry methods. These can be used to better advantage in small compact communities like prisons, schools, and other public institutions, where supervision can be safely depended upon. In such places these methods have given satisfactory results where carefully developed and administered, and they will doubtless continue to be so used. Several systems of removal without water are described in detail in the Seventh Annual Report of the Massachusetts Board of Health. But as their use in our country is likely to be very limited, I shall content myself with this reference without any further description. Among the best of these methods is that known as the dry-earth system, with the earth-closet in place of the old privy. Dry loam is used to mix with every alvine discharge at once. It has the effect to deodorize fecal matter, and absorb the gases of its decomposition. It is well adapted for private houses of the better-class in the country, where the owners cannot afford the cost of the water-closet system with its attendant conditions of water-supply and sewers. But the earth-closet, like all other methods of dry removal, is dependent for its success upon the vigilant care of those who have it in charge. Any remissness on their part is fatal, and the devices which appear so satisfactory when carefully managed, become terrible nuisances inside of a house, if the least neglect is allowed. The difficulty that would arise in furnishing the necessrry quantity of dry earth and in removing that which had been saturated, when applied to large communities, has prevented, hitherto, the application of the earth-closet system to any whole towns or cities. The removal of excreta from cities in any way except by water, involves a great deal of labor and cost. The quantity voided per thousand of mixed population is estimated at one and one-quarter tons per day. This would amount to upwards of three hundred tons daily for the city of Boston alone. If this were all to be removed by the earth-closet system, an equal amount of earth, say three hundred tons, must be brought in from the country in a dry state, every day, and the whole with the excreta, amounting to six hundred tons in all, removed daily from the city's limits. The cost of such a system, properly supervised and inspected, would thus be very onerous, while the difficulties arising in carrying out the detail of distribution and collection in a satisfactory manner would be practically insurmountable. In considering the collection of excreta by water-carriage the whole question of the drainage of towns must be considered in its broadest relations, taking into view all the varying conditions referred to in the previous lectures.

LECTURE VI.

THE VENTILATION OF SEWERS.

ALTHOUGH the sewage should not be allowed to remain long enough within the sewers to undergo much decomposition, yet much of the sewage is, when admitted, partly decomposed, and as more or less of its impurities continually adhere to the walls of the sewers from day to day, it is important that the gases evolved from such decomposition should be removed. In fact, without efficient ventilation the sewers very soon become public nuisances rather than benefits. They are in that case the active and efficient agents for the rapid diffusion of disease, from house to house, from street to street, and from quarter to quarter of a great city. In using the sewers for the removal of liquid refuse, we have had the help of the force of gravity, but in dealing with these gaseous products this force turns against us, and works the other way, impelling the noxious gas upwards towards the branches and inlets whence the sewage came, or up any lateral street sewer the course of which lies in a convenient direction. If ample means are not provided for replacing these gases by fresh air, the process goes on and accumulates them in large volume, and these gases, impelled by the well-known forces of diffusion and gravity, seek and actually obtain entrance to every house with which the sewer has connection. Very few of our houses have traps outside their walls in their main-drains, and even where they have, this gas has the power of passing slowly through the trap water by absorption, to be given off again on the other side whenever it accumulates to such an extent as to largely replace the common air in the sewer or drain. The insidious nature of such an enemy is one of its worst characteristics, for it acts by invisible agencies. The worst of these gases can hardly be detected by the sense of smell, the only sense with which we are endowed having any semblance of the function of the watch-dog in guarding us against such attacks. Individual action on the part of the householder is quite powerless against this evil. No system of traps, even if employing all the patents now on record, would suffice to stop it. Neither is the perfect ventilation of the house-drain itself, however important, able to cope with the lack of ventilation in the sewer. The office of house-drain ventilators is local only, and can never relieve to any appreciable extent, the want of ample change of air in the sewers themselves, even if it were safe to adopt such a course. Some cities have attempted to remedy the trouble by connecting the rain water spouts of the houses directly with the sewers, so these pipes could act as sewer vents, and I have myself at a former time vindicated such a practice under certain limitations. But this remedy is plainly inadequate to the duty assigned, besides endangering the houses themselves. Its inadequacy is seen when we consider that the gases from the sewer are most apt to invade houses during a heavy rain. The volume of rain water entering the sewer at such times is often very large in this climate, where two inches of rain have been known to fall in a single hour in a summer shower. The influx of this large volume of water must of course displace an equal bulk of gas, for it cannot absorb or dissolve it without a good deal of time, and then only to a limited extent. Other parts of the sewer, down below the hills, are often at such times running full, perhaps more than full, and running under a pressure, while the outfall is perhaps beneath the surface of the river or tide-water into which it discharges, thus sealing the outlet for gas. Of what use at such times are the rain water spouts? Every one of these is adding to the pressure, not only by bringing in new volumes of water, but of *air* too; for though the vertical leaders on the house fronts do not run full, the current through them is ro rapid that the air is pulled along with the water into the sewer by friction.

The danger to the house from using rain spouts as sewer vents is manifold. The workmanship of such pipes may be defective in the beginning, as it often is, for it is not considered important to make rain spouts *air-tight*. However tight in the beginning, defects would arise from corrosion, giving escape to the foul gas perhaps close to windows of sleeping-rooms, without notice. Moreover, if put together in the most perfect manner, and kept in good repair, such pipes have open tops at the eaves, generally close under the windows of attic chambers, where they may deliver the poisonous gas to the lungs of some person whom sleep has rendered peculiarly liable to the attack. Such a device for ventilating sewers is at best but a makeshift, and for the above reasons is likely to do quite as much harm as good to dwelling-houses. The character of the poisonous emanations from sewers is not definitely known. What is most to be dreaded in this way is contagion from diseased discharges. We have in city sewers a grand laboratory for such matters. They are here mixed up from all sources and diffused at random, being liable to contaminate with disease whole districts which had otherwise been unvisited by contagion, and polluting the homes of the most cleanly of the population with emanations of the vilest sort. Such enforced contact with our neighbors as comes necessarily with city life is quite bad enough at best. This would be adding to the necessary exposure of the street car, the school room and the theatre, the refined and ingenious device of inoculating disease by delivering the dangerous influences from a thousand privies and sinks, by metallic tubes opening under the chamber windows of such of our population as are unlucky enough to be obliged to sleep in an attic !

Before discussing the remedies for the collection of noxious gases in sewers, it may be best to consider the natural forces which are at work in the sewers with which we have to deal. First of all we must divest ourselves of the notion that air or gas of any kind can be readily pushed aside and got rid of inside of a sewer, as it can be above ground, where we are familiar with it. So long as air circulates freely in all directions, we are apt to forget its material and substantial character. We know, though we do not always keep the fact in mind, that the air is always exerting an expansive force of some 14 6 pounds per square inch, in all directions, as the reaction under the weight of the fifty miles or more of air above our heads. This is subject to small variations, but never exceeding about 10% of the whole in any one place. This variation is shown by the height of the barometer, and is subject to hidden causes which we know very little about. So long as the air in our sewers is allowed free communication with the outer air at frequent intervals of space, no difference can exist between the tension of the air within and without ; but the moment we obstruct such communication, various causes begin to act, either separately or combined, as the case may be, to produce a different tension. Among these causes the following are prominent :—

(*a*) Change of temperature within the sewer.

(*b*) Introduction of water by rain-fall, or by flow of tide, or locally in small sewers by the influx of sewage water in considerable volume from the neighborhood.

(*c*) Wind-pressure, exerted by winds blowing in at the outfall.

(*a*) Sewers are generally too deep below the surface to be much affected by the change of temperature of the outer air, except by direct circulation of air through openings. When not disturbed by other influences, their temperature, without ventilation, approaches the mean temperature of the climate, say about 48° or 50° in this latitude. Suppose, then, an influx of water to take place from some manufacturing establishment, as is often the fact, heated to 100° Fahrenheit. During the process of cooling, the water does not seem to fall in temperature as fast as the air rises. A cubic foot of water weighs about as much as 815 cubic feet of air, while the specific heat of air is less than one-quarter that of water (about 0.238). It follows that when water is cooled by air in contact with it, a cubic foot of water in losing one degree of temperature will heat $\frac{815}{0.238} = 3{,}420$ cubic feet of air one degree on the same scale, or 342 cubic feet will be raised ten degrees. It may be said that the water is cooled in part by contact with the walls of the sewer. Very true ; but water has more capacity for heat than any substance we have to deal with, so it is able to heat an equal volume of bricks, mortar, and earth about 2½° Fahrenheit for every degree it loses thereby. Hence, although the surplus heat of the entering water would eventually all be taken up and scattered in the surrounding soil, this process would occupy a considerable time, during which the air in the sewer would perhaps be temporarily heated some thirty or forty degrees. What would be the effect of this ? Air expands about $\frac{1}{490}$ of its own volume for every degree of additional heat we impart to it ; so that if heated 24½° we add 5% to its volume at equal pressure, or 5% to its pressure if confined within the sewer at a constant volume. The normal tension of the air is equivalent to about thirty-four feet of water pressure, as is well known by anyone who tries to lift water by pumping. Hence an accession of 5% to its normal tension by raising its temperature 24½° is equal to 5% of thirty-four feet, or 1.7 feet, say twenty inches of water pressure. None of our traps are sealed by over six inches of water at most, and rarely by more than two or three inches. We have, then, an expansive force more than three times as great as the power of resistance of even a six-inch trap, produced by heating the confined air 22½°. The force developed by heating it 7° would then render worthless any trap having less than six inches depth of water seal. It will readily be seen that many causes may produce such a change of temperature.

Of course the *lowering* of the temperature by an equal amount would produce an equivalent effect in the other direction, and tend to force the traps from the houses outward, which would often break their seal by taking out their water.

(*b*) The next disturbing force mentioned was by the introduction of water, from rain-storms or tides, or increase of flow of sewage. Of these, the first two are generally fitful and in large quantity. In our country the rain-fall is generally admitted to the sewers, and their sizes are therefore adjusted to receive it. But the maximum flow of sewage is so small in comparison with that of the rain water in our climate that the ordinary dry weather flow is but a driblet when compared with their contents when running full Such rains as may fill them often come suddenly, and the water enters the sewer at intervals of a few hundreds of feet, by trapped openings, which prevent the exit of air. Sewers that have a limited slope are often nearly or quite filled for considerable lengths. The entrance of water from the streets in such volumes must summarily expel the air that was before in the sewers, if it can find any way to get out. It may often happen that a long sewer is at such times filled with water at two separate parts of its course, while some intermediate portion, having a more rapid fall, may not fill so soon. If the influx of water continues to increase, the air in this portion may soon become subject to a pressure of several *feet* of water, and seek exit through every private drain that is in connection. Even if the junctions of such private drains were below the water line in the sewer, the pressure would still be transferred through the water, which will back up in these branch drains and force back their contents into the houses. The subsidence of the flow when the rain abates leaves voids which the outer air is sure to fill speedily. If direct access is not given, it will find its way through any private drains, emptying all their traps at once, and leaving them to remain empty till filled by drainage from the house they serve, which house in the meantime throughout all its interior becomes a ventilator for the sewer.

In cities which drain into tide water, the outfalls of the sewers are generally covered at high water, either every day or at spring tides. If the ends are not provided with gates, the tides enter and fill the sewer as far back as its level allows. If gates exist, they shut with the flow of the tides, and the sewage accumulates within, with a result almost exactly similar to that which would take place with no gates. In either case a large volume of air is displaced by the accumulating water or sewage with every flood tide, only to be drawn back again when the sewer is emptied on the ebb tide. If the interior does not communicate freely with the outer air, a pressure of several feet of water must necessarily result, alternating with a corresponding partial vacuum every twelve hours.

Large variations of pressure within the sewers may often occur from the variable quantity of *sewage* as well as of rain-water. Nearly all the sewage from houses is discharged during the hours of daylight ; hence there must be a periodic increase and decrease of the amount of air space within the sewers depending on the quantity of sewage flowing. This is particularly noticeable with manufacturing establishments, where much water is used during working hours. Of course the air must leave the sewer to make room for the sewage in the morning, and as the flow of sewage diminishes towards evening, the outer air crowds in to fill its place by whatever openings or ducts are found most available.

(*c*) Wind pressure is the last of the causes named as acting to disturb the equilibrium. This generally acts by blowing in at the outfall. The pressure created there is transferred almost instantaneously throughout the whole system of branch sewers which connect with the main trunk. The amount of pressure exerted by the wind is of course dependent on its velocity. A storm wind with a velocity of fifty miles an hour may not be of frequent occurrence, but a wind with a velocity of forty miles an hour is not uncommon. Such a wind exerts a pressure of eight pounds per square foot, or .055 pounds per square inch. We have nothing to prevent this from entering our houses through the drains except the traps in the latter. The efficiency of these depends entirely upon the depth of their water seal. Small traps have frequently but a single inch of depth of seal, while a very large number of those which are placed on the waste pipes of bowls and sinks have less than one inch and a quarter depth of seal. Now every inch of depth of water gives a pressure of only .054 pounds per square inch, which, as just shown, is not enough to resist a high wind blowing in at the mouth of a sewer, provided its upper ends have no free communication with the outer air to relieve this pressure. Moreover, during the months when our houses are artificially heated, there is always a pressure existing from the outside inward through all the cracks and openings near the basement levels, which will aid the sewer air in effecting an entrance, there being at such times a slightly reduced pressure or partial vacuum within the house, by reason of the heated air in it having less weight than the outer air.

The above considerations show conclusively that whatever remedy is applied should be repeated at very frequent intervals of space, for though the disturbing force of the wind does not act with much force except near the outfall of the sewer, all the other disturbing causes which have been referred to are likely to act at any part of the system, and are often acting at various separate places at the same time, while the intermediate parts of the sewer may be filled with water, that would effectually prevent the air from passing from one point to another. In fact, the passage of air within the sewer can never be relied on for any considerable distances, to relieve local pressure, for not only are the intermediate parts liable to be filled with water when such communication is most needed, but the resistance offered by friction within the walls of the sewer is very considerable. In short, we must provide local relief to meet and remedy local disturbances, and apply such remedial measures within short distances of one another.

LECTURE VII.

THE VENTILATION AND CLEANING OF SEWERS.

NO city in the world has spent so much as London upon this subject. The reports of the Metropolitan Board of Works give a complete history of their experience, from which the following abstract is gathered. The original method of ventilating their sewers was by the "gully gratings" or inlets at the sides of the street. These were efficient so far as ventilation of any kind could help the wretched condition of these old, half-choked receptacles of filth. But, as may readily be imagined, they became sources of great annoyance to foot-passengers, as well as to the adjacent residents, so that while the sewers themselves have recently been made "self-cleansing," these openings near the sidewalks have been trapped as fast as others were made in the centre of the street, by building shafts for that purpose, with perforated covers. During the period of transition, however, from the former filthy condition of their sewers to their present comparatively clean condition, through judicious reconstruction, various complaints arose from certain localities, on account of the bad odors arising from these new vent-holes. This subject has given rise to a prolonged investigation by experts, who experimented during a period of several years upon various devices for alleviating or entirely removing the source of complaint. But the system of frequent vents in the centre of the streets has never yet been abandoned, simply because no other device has yet been found adequate to take their place. We learn from the report of 1865 that the subject of the ventilation of the sewers was referred to a committee who were then experimenting upon the ventilation of the Southern Outfall Sewer by artificial draught, created by furnaces in Woolwich Dockyard. This committee employed Sir J. Bazalgette and other experts, and finally made a report in 1872, giving a review of all the various methods that had hitherto been adopted in the metropolis. They stated that the amount of success attending these various methods "was variable, depending on the local circumstances of each particular case." In short, no one method was shown to be generally applicable, and most of the expedients tried were found to have an effect that was only palliative, even for the locality where it seemed best adapted to the circumstances there existing.

Among the experiments tried, a large class were with the view of deodorizing and disinfecting the gases which escaped from the street vents. The device which attained the largest measure of success in this direction was that of suspending charcoal, spread upon gratings, one above the other, in the vertical shafts above the sewer, through which the air must pass while moving upward on its way to the open air in the street. So long as this charcoal remained dry and loose, it worked well, and afforded considerable relief in certain localities. Its use was adopted by Liverpool and various other towns, in a similar manner and with similar results. Various patented devices were applied for holding and exposing this charcoal in a manner which should least obstruct the passage of the air, while keeping it free from dirt and water falling from the street, and giving the largest facility for renewal when it became clogged. Such renewals were frequently found necessary in most places, in order to keep the apparatus in efficient condition. This involved considerable cost and trouble for attendance, besides the outlay for the apparatus itself. Moreover, the Board states, in summing up the whole subject, that although the results were sufficiently favorable to warrant the use of charcoal in some of the air-shafts which were sources of annoyance and complaint, it was found that their use was attended with no little inconvenience ; for the charcoal obstructed the exit of air through the shafts, thereby causing such an accumulation of bad gases in the sewer as to endanger the safety of the men whom they sent to work in them. "It therefore became necessary that such vents should be cautiously and not generally applied."

Experiments were also made by disinfecting or deodorizing the air from the vents by use of acids and of chlorine gas generated in the shafts by apparatus placed there for the purpose. Although a partial relief was had in some cases, the variable nature of the foul gases to be dealt with prevented this method from being adopted, except in certain limited cases where peculiar circumstances existed ; so that such a method could be but very partial in its application, and could never become general.

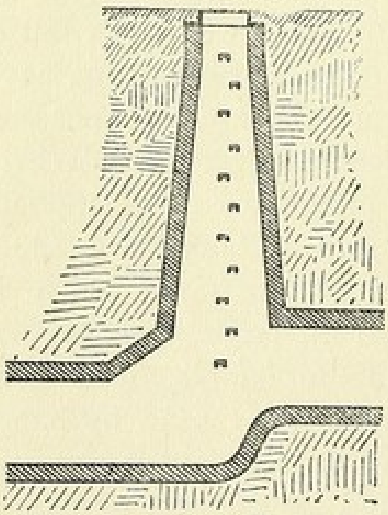
The plan of ventilating the sewers by air-flues connected with the furnaces and shafts of factories and other buildings was tried in some localities south of the Thames, and the effects was considered beneficial by the residents of the immediate neighborhood. But the good effects were confined to a small district in each case, and it was doubted whether any large portion of the noxious gases evolved was actually consumed by this method, for this reason, viz.—the vacuum produced by the artificial draught was inevitably supplied by the air entering the sewer through an immense number of openings in the close vicinity of the locality where the exhaust draught was applied, so that the air drawn out from any part of a long sewer near which a furnace was applied was to a large extent replaced, not, as was desired, by the offensive gases from distant parts of the sewer, but by pure air rushing down through the numerous small openings near the furnace, leaving the more remote places uninfluenced. For this reason, also, the method used in mines, where there are only two openings to be dealt with, is inapplicable to sewers. Moreover, where the chimneys used were not public property, the owners of the factories or furnaces objected to such connections being made with their chimney shafts, while in many parts of the city no such factories existed. In order to provide chimneys and furnaces specially for such localities, and maintain them in blast, a very large cost would be incurred for a remedy that would at best be confined in its action to a very small district in each case, for reasons given above.

The plan of ventilating sewers by pipes carried up the outsides of houses, which we have hitherto discussed and objected to, was also tried in London to some extent, but was condemned because of the reasonable objections of the owners of the buildings, and "in consequence of the liability of the gas to descend into the chimneys and windows of such houses." The Board tried an experiment in the east end of Southwark Street, by erecting an ornamental ventilating shaft, in the centre of the thoroughfare, with refuges and lamps, and the extension of this system to other localities was discussed. Its adoption was estimated to cost from £200 to £300 in each case, according to the position and depth of the sewer, exclusive of the cost of maintenance. If this system were to be largely extended, it was found that the details must be varied to suit the local peculiarities which must be considered and provided for in each case, which would involve a separate study for each locality, and prevent the possible diminution of cost by a repetition of the forms of the appliances to be used. In short, it was found that every new case must be tentative in its nature, and therefore not susceptible of having any accurate estimate made of its cost. The only principle settled upon as capable of a wide and successful application was that of flushing the sewers with such a copious supply of water that the decomposing subtances clinging to their sides or flowing through them should be largely diluted ard carried away before sufficient time should be given for the generation of noxious gases in any considerable volume. To accomplish this result, frequent flushing would be needed, during periods of drought ; but during periods of rainy weather the natural influx of water might sometimes take the place of flushing, especially in a climate like ours, where rain in the summer months frequently falls in large volumes during a few hours. The Committee of the Metropolitan Board were requested to continue their investigations, treating each case as the local circumstances might indicate. Four years more were spent in experimenting, but with no result, except that the various devices tried were found to give various degrees of success in various localities, as before. In 1876, the committee reported a sort of digest of their conclusions, as expressed above, giving them in a concise form.

CLEANSING OF SEWERS.

The inclination of sewers is generally governed more or less by the topography of the surface ; but in flat districts, where the fall is limited by Nature, a sewer must, in order to be self-cleansing, have an inclination that will secure a velocity of at least three feet per second in small pipes, and of two and one-half feet in larger sizes. Where this cannot be otained without pumping, pumps are often applied, which by lifting the sewage to a sufficient height enable us to conduct it farther from the city, and to a point of discharge which is more eligible than could be found nearer. If the large sewers are not self-cleansing, arrangements must be made for ample flushing at frequent intervals, and perhaps also the removal of sand by hand, which must be taken out through the man-holes. The heavier part of the road detritus is generally intercepted by pockets or catch-basins at the inlets under the curb-stones; but in heavy rains the water does not remain long enough in these pockets to deposit the finer silt, which is therefore very likely to be deposited within the sewers themselves. The modern forms for sewers with small, narrow inverts are much less likely to collect deposits than the older forms or circular sewers ; yet the latter are sometimes adopted, as in Chicago, for lack of height below the street level, to develop the oval form. This is admissible for such sewers as are generally half filled, or more, with their ordinary flow, and in that way more likely to be kept clean by scour. In order to favor the velocity of flow, and guard against checking it by all possible means, great care should be taken that all inlets and junctions should be at an oblique angle. Rectangular junctions are always found to produce eddies and favor deposit, whether the inlet is applied on the side or top of the sewer. The ordinary house inlets are provided for by Y branches in pipe sewers, and by special branch blocks in brick sewers. Where sewers join at street-corners, those on either side the main should be curved around to approach parallelism before joining, and come together in a bell-mouth. The invert should be prolonged in a tongue beyond the point where the sides join, so as to guide the current as far as possible to a parallel course. Inverts of stone-ware are now made, and are superior to brick for two reasons. They not only resist the abrasion of sand for much longer time, but being made hollow, afford a channel for the ground-water, which is often a great convenience during construction in wet ground. This means of draining the soil-water, if adopted for permanent use, does not keep it so well separated from the sewage as may be desirable, for the sewage would almost inevitably leak into such ducts. Junctions are often made at man-holes, and many reasons favor their being so made, for convenience of inspection and cleaning out. In order to avoid the checking of currents which are inevitable when such junctions occur at a considerable angle in man-holes, Latham and other writers advise stepping down some six inches or more at the man-holes to accelerate the flow. (See Fig. 3.) Wherever there is sufficient fall to allow this and at the same time retain slope enough to keep up the proper velocity in the sewer, there may be no objection to such a course; but where there is no fall to spare, as may often be the case in flat districts, the loss of head by the ordinary man-hole junction ought to be avoided. This loss of head is partly due to the sudden change of direction of the current by bringing in the branch sewers at right angles with the main, and this can be avoided by a previous curvature of these branches near the man-hole. But a good deal of loss arises from the contraction of the vein of the current in entering the sewer as the water passes out of the man-hole. This can be remedied in a large degree by rounding off the corners, where leaving the man-hole, like a small

FIGURE 3.

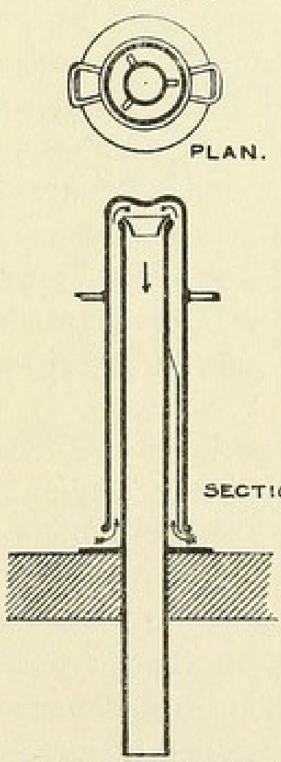


MAN-HOLE FOR SEWER.

bell-mouth, to conform with the vein of contraction. The method of stepping is advocated as an assistance to ventilation, it being alleged that the air in passing into the man-hole is by this step deflected upward, and finds a readier exit through the top of the man-hole into the street. But in practice I cannot attach much value to this consideration. This suggestion, whatever it may amount to, must depend on the supposed *momentum* of the air, which would tend to prevent it from rising and throw it across the man-hole, if built without a step ; but the velocity of the air, when at its greatest, can never be so great in a sewer provided with a number of man-holes, as to allow of any momentum being acquired by the air which would produce any practical result. Moreover, if the air is to be poured *out* at every man-hole, where is it supposed to come from ? If from the lower end of the system, near the outfall, the quantity of air so entering any sewer could, if all diverted upward, readily find exit at the first man-hole that it encountered, leaving no current to go beyond. The fact is, I imagine, that air is drawn *in* at all the man-holes of a district whenever a heavy rain-fall is running off, as the water subsides, and again every evening, as the amount of sewage flow due to the working hours subsides to the night flow ; and flows *outward* at all of them when the fluid contents are increasing from similar causes operating in the opposite direction. Whatever currents through the sewers are due to winds outside are influenced by the air entering at any point on the windward side of the town where the wind pressure accumulates by being confined between walls or otherwise, and goes out again on the leeward side of the town where it finds the least resistanue.

The flushing of sewers by intermittent flows or artificial methods is often found necessary to keep them clean in a district having a limited fall. Various methods are pursued for this purpose, suited to the local circumstances. Where streams of water are found at hand, they afford the best means of flushing, and provision can be made for using them by laying conduits and building tanks for that purpose. But where no such streams exist, the sewage itself is often dammed back by a gate till a considerable length of sewer is filled, or nearly filled, when, the gate being suddenly opened, the restrained water rushes along, and scours the sewer for a considerable distance. These gates are sometimes made to be operated by hand, requiring the presence of an attendant, and sometimes made to work automatically, by the height of the water. In conducting all flushing operations, care must be taken to guard against the flooding of houses by impounding sewage to too great an extent, and at the same time to use a current of sufficient volume and force to wash all the inside of the sewer. There is in all sewers a film of organic matter in a slimy condition, clinging to their sides, consisting chiefly of putrid, greasy refuse, emitting a very foul smell, and therefore not a desirable material to retain. Rain-water may assist in flushing sewers very materially, but as it is extremely intermittent in its action, some more reliable source is often needed, by which the process can be repeated at will and at certain intervals, found by experience to be required in any particular locality. It is usual to begin flushing at the lower end of a district and work back. Each successive discharge will generally be carried quite through the system in this case, unless large deposits have been allowed to accumulate through too long neglect, which may stop on the way and need following down the line by more water. Tanks are sometimes provided at the upper end of small pipe-sewers, to discharge automatically, when filled. If these are made to hold the sewage, a sufficient height is rarely obtained in flat districts to enable the tank to be filled without setting back the sewage to an inconvenient extent into the house-drains. It is better to use rain-water, brook-water, or water from the mains that supply the town, in such cases. It not only washes the sewer better than sewage, but avoids all chance of setting back the sewage in house-drains, for the tank can in that case be made entirely independent of the sewer, except while they discharge, which is done through a pipe at the base of the syphon at a similar level. The automatic syphon of Mr. Rogers Field of London is often used in England for this purpose, epecially for flushing house-drains. The best form of syphon for sewers is the annular one (see Fig. 4) composed of two concentric tubes, one inside the other; the inner tube forms the long or outlet end of the syphon, the outer tube being sealed at the top. The air is readily expelled from the syphon by a very small stream of water, if this can be made to fall *through the air* in the inner tube, instead of trickling down its sides, for which purpose a funnel-shaped mouth is provided at its top. The inner tube must dip in water at its lower end or outlet, before

FIGURE 4.



FIELD'S FLUSH TANK
ANNULAR SYPHON.

the air can be expelled; for which purpose a basin is constructed for it to dip in. If kept thus sealed all the time, however, the syphon would keep delivering the water as fast as it comes into the tank, which would defeat the object. It is is important, therefore, to allow the air to enter the syphon after discharging the tank. This is accomplished by applying a small syphon to empty the little basin in which the lower end of the large syphon dips. This small syphon is readily charged by the rush of water while the large one is in action, and as soon as the tank is emptied the small syphon draws the water off from the discharging end of the large one, and both are empty. As soon as the tank fills up, the first quart of water that overflows through the large syphon seals its lower mouth, and as this overflow continues, it is made to drop clear of the sides of the tube by the funnel-shaped appendage at its top, which turns the water into the centre of the tube. The small syphon is best when made of lead, which is a metal that suffers but very little change in such situations.

LECTURE VIII.

HOUSE DRAINAGE.

IT remains to consider the proper methods of constructing the private drains leading from each house, and the various fixtures and appliances for receiving the refuse from the house, in a manner which shall serve the convenience of the household and guarantee the speedy removal of all the sewage, without risk of leading into the house any of the gases of decomposing matter which may originate either in the sewers or the drains themselves.

Wherever the water-carriage system is used for removal of excreta, it is very desirable that sewers should also be provided. But as many suburban communities may not yet have provided sewers, and many good houses are frequently being built in isolated places where sewers cannot be expected to be constructed for a long time, it becomes important to consider the best substitute for sewers in such cases. The ordinary way is to dig a hole in the ground and line it with loose stone or honeycomb brickwork, into which the sewage may be led, and from which it is hoped it may soak away into the soil and be out of sight. Where the soil is very porous and the surface sloping away from the house, this method may succeed for some months and even years without much risk to the house, *provided* this cesspool is far enough from the house to prevent its odors from being carried back through the air, and provided pains be taken that the gases evolved by the decomposition always going on within the cesspool shall not be conducted back into the house through the drain pipe.

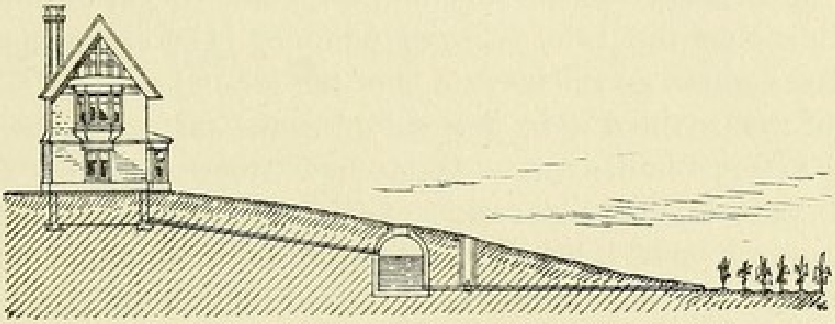
But this method can never be satisfactory. The great risk of all such contrivances is the contamination of the soil and the drinking-water, where this is drawn from wells or cisterns on the same premises. Dr. C. F. Folsom, Secretary of the Massachusetts Board of Health, relates, in the *Medical and Surgical Journal* for March, 1880, that a well which he tested was proved beyond a doubt to be contaminated by a privy vault one hundred feet distant, the well being sixteen feet deep. There was no unusual taste in the water, but suspicion had been directed to it from typhoid fever among those who drank its water. It follows, then, that all porous cesspools must be condemned. They store up the filth in the soil just deep enough below the surface to be out of sight, and out of the reach of the absorbent powers of grass roots, while even when ventilated they do not give access to a sufficient quantity of air in contact with the decaying mass of organic matter to insure its decomposition. The soil close about them soon becomes saturated with a vile compound, filling its pores by degrees, and finally refusing to carry off even the water, except during the dryest part of the year. Such contamination of the soil in the neighborhood of dwelling-houses is, under all circumstances, to be avoided. Cesspools should therefore be made tight by brick floors and walls, laid in hydraulic cement and plastered with as much care as if they were to act as rain-water cisterns. What, then, is to be done with their contents when filled? The best way in theory doubtless is to use it for fertilizing the soil. This may be done by pumping and carting where there is not enough land near the house suitable for its absorption. It can be distributed on the land by gravity where there happens to be land low enough, though small house lots seldom give this opportunity. In accomplishing this where there is land adapted to the purpose, an *intermittent* flow is desirable, both for the sake of flushing the pipes and avoiding deposits within them, and to allow the air an opportunity to follow the sewage as it soaks down into the pores of the soil. The air, thus admitted alternately with the fluids in the finely-divided pores, serves to oxidize a large portion of the organic matter—to burn it up, as it were, and form such new compounds as to favor its more ready appropriation by vegetable life. This intermittent flow has been attained with some degree of success by Field's flush tank. So far as its flushing power goes, it leaves little to be desired, but it is doubtful whether there is time enough left between its periodic discharges, ordinarily, to allow of much oxidation in the pores of the soil, for this process is a slow one, and must necessarily require a good deal of time where the quantity of sewage is considerable.

Mr. Rogers Field has introduced this process in England, and Col. Geo. E. Waring, Jr., has introduced it in this country and applied it for this purpose with some success. He distributes the sewage from the flush tank below the surface, in porous drain pipes with loose joints laid less than twelve inches under the surface. The end sought is to fill the whole system of these pipes with each discharge from the tank, and the sewage is to soak away from the joints of the pipes while the tank is being refilled. In some places this plan has worked well, while in others the joints of the pipe or the pores of the soil, or both, have apparently become choked with the solid particles held in suspension by the sewage, to such a degree that the absorbing power of the soil around the pipes has become impaired. The result is that the sewage bursts up to the surface and becomes a nuisance near the lower end of the system of distributing pipes. This fault can perhaps be remedied or avoided by a thorough underdraining of the soil and by taking proper pains in laying the drains and providing sufficient surface of land for absorbing a given amount of the sewage. Different localities and different soils give very different results, and it becomes very largely a question of judgment in matters of detail, to adjust the parts of this system so that it will work without further annoyance. It seems to be yet a matter of doubt, however, whether the distributing drains will remain *permanently* porous in any particular case where the quantity of sewage is considerable. The weak point in the system seems to be that certain portions of the pipes and the surrounding soil become so lined with the solid particles of the sewage that the pores are closed by degrees. This capacity for continued absorption will, however, depend very much on the physical character of the soil and the perfection of its under-drainage. The water must of course be given a free path to escape from below the pipes that distribute the sewage, either by selecting a locality with a subsoil that is always dry and loose, or by rendering it so by deep drainage. A perfect uniformity of condition in the porosity of the soil throughout the whole system of distributing pipes is hardly possible to be attained. It follows that when the less porous places begin to clog, a larger duty is imposed upon the remaining portion, till sometimes the greater part seems to become obstructed. The only remedy is to dig out the pipes and clean them, and the frequency of this operation can only be determined by actual trial. Since the pipes are not laid deep below the surface, the cost of such occasional cleaning out is not serious.

In all cases where a distribution of sewage is made on the surface or underground, a thorough underdrainage is absolutely necessary. Any locality where this cannot be attained within reasonable limits as to cost is therefore quite unfit for this method.

Distribution of the sewage on the surface, though requiring more attention at stated times than the method just described, is sometimes made use of with success, even on the small scale of one or more houses. I have myself a house occupied for three or four months of the hottest part of the year, where it is managed thus. (See Fig. 5.) A tight cesspool is made in the ground, about one hundred feet from the house, of a capacity sufficient to hold about one week's accumu-

FIGURE 5.



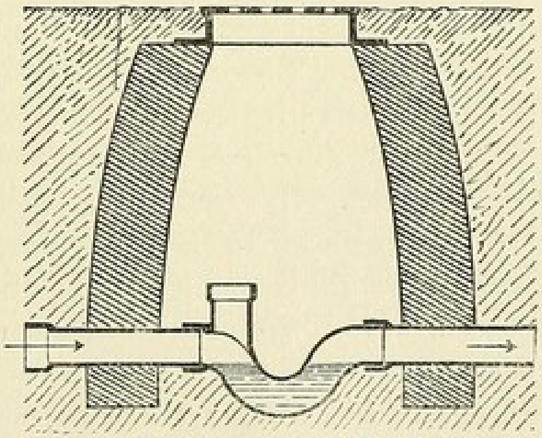
DISPOSAL OF HOUSE DRAINAGE BY SURFACE IRRIGATION.

lation of sewage. When filled, this fact is indicated by an overflow discharging on the surface behind the stable, which pipe also serves as an air-vent. (This pipe is not shown in the cut.) A trench was dug from the bottom of the cesspool, about one hundred and fifty feet long, with its bottom graded so as to drain the cesspool on to the surface of the ground in this distance. A four-inch stone-ware drain pipe was laid and buried in this trench. Just below the point where this pipe passes through the wall of the cesspool, a common four-inch brass-faced water stop-gate was set in the pipe with a four-inch pipe set upright from its top to the surface of the ground, through which a wrench or gate key can be inserted, to open and close the gate. By opening the gate, the whole contents of the cesspool are by this means discharged at will on the surface at the lower end of this pipe in five to ten minutes. At this point of discharge lies a plot of land used as a kitchen garden. While the sewage is flowing, a man with a hoe guides it here and there between the rows of peas and corn, so as to secure a tolerably uniform irrigation. The soil is light and sandy, and absorbs the whole in half an hour. By choosing for this process a time when the wind blows from the house to the garden, no inconvenience results, and the garden shows the benefits of this application of liquid manure. If this plan were to be used during the whole year, it would require more breadth of land and a greater distance from the house to avoid offense. But under the existing circumstances, where the character of soil and the slope of the surface, and direction of prevailing winds, all combine to favor this method, it has proved very satisfactory, and might be equally so if applied to a combination of houses. If the drain were allowed to discharge continually, directly from the house to the garden, it would flow as a driblet and accumulate a mass of filth at the point of discharge that would become a nuisance. The amount of attention required in this case is trifling, being only about ten minutes once a week, which is well repaid by the benefit to the crops.

The apparatus is all durable, and not likely to get out of repair. Its application without the labor of pumping is of course limited to those places where a sufficient slope of the ground exists to allow the bottom of the cesspool to be drained on to the surface of the ground within a reasonable distance. If no such slope exists, the labor of pumping by hand might be serious, and would, in case of a combination of several houses, justify the erection of a wind-mill or horse-power pump. If the houses were supplied by water under pressure, a larger quantity would probably be used than if it were all pumped, so that the size of the cesspool would either be increased, or the periods of emptying be made more frequent, all of which items must vary considerably with local circumstances and the wants of the families concerned.

Whether the house drains discharge into sewers or cesspools, there should always be a break or "disconnection," as the English call it, in the house drain near the point where the drain leaves the house. In mild climates the drain or drains are made to pour their contents from an open pipe or pipes into a gully or trap, exposed to the open air. In the climate of New England, and others, where frost would interfere with such an arrangement, the method described below is recommended.

FIGURE 6.



MAIN TRAP AND AIR HOLE FOR HOUSE DRAIN.

Whenever cesspools of any kind are used, especial care must be taken to thus break the continuity of the drain between them and the house, for the reason that cesspools, however well ventilated, are but retorts for the production of the gases evolved by the decomposition of their contents, and also serve to retain, and perhaps to multiply, the germs or seeds of contagion that pass away from our bodies with the alvine discharges. The most efficient way to accomplish this disconnection in a climate where the the winters are severe, is to have a running trap in the drain, of similar connection with the drain itself, round and smooth, and to open the drain to the air on the side of the trap towards the house. (See Fig. 6.) As it is desirable to have this trap accessible, it is usually walled around up to the surface, with a cover like that of a coal-scuttle at the top. In order to admit the air freely this cover should be perforated with holes. If the snow is likely to cover it for any length of time, a four-inch pipe should be laid into the man-hole under the cover, extending a few feet above ground to admit the air. When sewers are provided, some writers on the subject favor the omission of this trap on the main drain, on the ground that it obstructs the continuous flow of the sewage, and that the air of sewers, when properly constructed and ventilated, is not likely to be so bad as that of the house drains. But I prefer the outside air to either, and do not regard the slight delay of drainage in passing through this one trap, as of much consequence. If it is so constructed as to have no square corners for the accumulation of deposits, and if all the drainage of the house flows through it, nothing can stay there long. But this trap should never be applied without the air-hole as described above, on the house side of the trap. In order to avoid the accumulation of deposits of solid matter in the trap, a small amount of rain-water should be admitted to the drain, either here, or at some point where convenient inside the house. Much inconvenience often results when this is omitted.

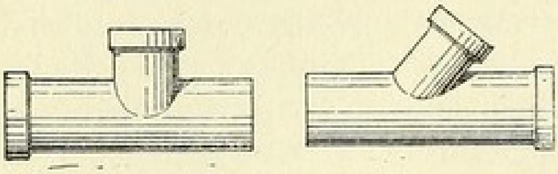
The material generally used for drains outside the house-walls is glazed stone-ware. It is a good material for the purpose when well made. It is furnished in lengths of two and three feet, with special forms for branches and bends. The defects to be avoided in using it are chiefly distorted forms, easily detected by the eye. It should be put together with hydraulic cement, care being taken to keep the joints concentric. Some people recommend hemp gaskets, to be used to hold the adjacent pieces concentric; but unless more length of socket is provided than in the forms now made, there is not much to be gained by using the gasket.* Care should be taken to provide a continuous support for the the pipe between the sockets by bedding it in cement for the whole length, unless good packing gravel is at hand, which can be rammed in on either side. If this is not done, the weight of the filling is likely to break the pipe, particularly the smaller sizes. Care should also be taken to wipe out the surplus

* An obstruction in a drain dug up a few weeks ago was found to be caused by the man who laid it having driven in too much gasket, which projected into the interior and made a dam.

cement that is likely to project on the inside. If this is not done, solid rings of cement will be thus formed, that will dam up the sewage and entirely stop the pipe.

In laying pipes that are too small to allow a man's arm to work inside, say nine inches and smaller, this wiping the inside joint must be done with a swab held by a rattan, about a foot longer than the joint of pipe, kept in the last piece laid down and drawn through every joint after the cement is applied. In making connections between all drains rectangular junctions called T-branches should be avoided, except on vertical lines. The joints known as Y-branches are the only ones fit to be used on horizontal lines. (See Fig. 7.) The use of rectangular connections is sure to be followed by deposits, through the eddy caused by the conflict of currents, as explained in the case of sewers.

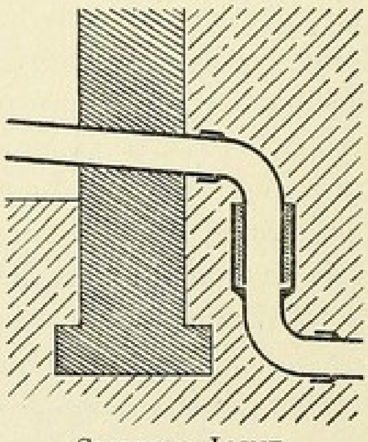
FIGURE 7.



T-BRANCH. Y-BRANCH.

A most important matter in laying drains is the character of the foundation on which they are laid. If upon filled land, it is liable to settlement, and since the stone-ware pipe, jointed with cement, is perfectly rigid, the least settlement breaks it somewhere, and leakage occurs. The building generally rests upon piles in such places, and the drain being therefore on a rigid foundation when it leaves the house-wall, is sheared off near this point by the settling of the material outside the wall in which it rests. The substitution of iron pipe for the stone-ware between the house and sewer does not remedy the trouble, for even iron would be broken under such circumstances. Where there is a foot or two of fall to be spared, the trouble may be remedied by making a step downward in the drain just outside the house-wall (See Fig. 8), making a verticle joint with a long lap, and packing it with elastic cement; but this extra fall can hardly be provided in Boston upon the filled lands, without getting below tide-water, at least, not until the new system of drainage shall come into use, through the intercepting-sewer now in progress. The weak point being just outside of the house-walls, can generally be made accessible in the same man-hole which

FIGURE 8.



SLIPPING JOINT.

serves for access to the main trap and air-hole ; so that breakage can be detected and repaired without great cost, and, if inspected frequently, without incurring the risk of saturating the soil with filth in contact with the cellar walls, as is often done by such leakage. I have seen it in some cases penetrating through stone foundation walls and up through concreted floors from the saturated soil outside. It is next to impossible to shut such filth out of cellars after the soil once becomes thus polluted, for it is both fluid and gaseous, and penetrates the minutest pores. Even where the soil is firm, drains are often found to be broken just outside the cellar walls if they are laid above the bottom of the cellar excavation, as is sometimes done, owing to the loose condition of the soil that is filled under them at this point, where recently excavated. This can be corrected by puddling the filled material under the drain by water, and waiting a week or two after such puddling before laying the drain. It should be remembered that drains when once laid and buried are out of sight and out of mind. A slight defect through poor workmanship can only be detected after some months, perhaps years, during which time the soil may have got polluted to an incurable degree. It therefore becomes of the first importance to see that the drains are laid in a permanent and workmanlike manner at first, otherwise the pollution may go on till the house is rendered untenable which would otherwise have been healthful.

SIZE AND INCLINATION OF DRAINS.

The size and inclination of house-drains are important matters, to be settled by proper principles. Where but little rain-water is to be provided for, a four-inch pipe is large enough for any ordinary house-drain whether outside or inside the walls. But it is generally desirable to take into the drain the rain-water from at least one-half the house roof, for the sake of flushing the outside trap. Moreover, the stone-ware pipe when as small as four inches in diameter is too imperfect in shape to make a continuous smooth conduit, without slight offsets at the joints that interfere with the flow. So it is generally conceded that private houses should have at least six-inch drains when made of stone-ware and receiving some rain-water from the roof. This size is large enough for the sewage of five hundred persons or more, unless the rain-fall from more extended roof-surfaces is to be provided for. In this case the size of the drain is to be governed, first by its inclination, which is generally limited by local topography, and second, by the size of the roof to be drained. In our climate, a rain-fall two inches per hour upon the roof-surface should be provided for, adjusting the size of the drain to carry this rain-fall. In such cases the sewage can be practically ignored, for its volume is insignificant in comparison with the rain-water. The problem becomes then a question in hydraulics, and reference must be had to the governing elements and well-known physical laws, from which we compute the required size. In order to make drains self-cleansing, their contents should have a velocity of at least two and a half or three feet per second. To attain this in a six-inch pipe a slope of one and one-half per cent. is required, when the drain is running half full, and it seldom is filled above that point. If this rate of slope cannot be attained, some provision must be made for frequent flushing to avoid deposits, for it must not be forgotten that the cardinal rule in drainage is to *keep everything moving*, and allow no sediment to remain in the pipes. Drains are often made of unnecessary size. This is a more serious defect than would at first appear, for increase of size beyond what is required for carrying capacity is an actual injury, by diminishing the scouring power of the current. It cannot be expected that the interior of our drains and sewers will be so clean as to be entirely free of the gases of decomposing matter, but it is very desirable to reduce their volume to a minimum, and then to apply all possible precautions to prevent their mixing with the air we breathe.

The large increase of the quantity of water used in our houses at the present day, compared with that used by former generations, is justly regarded as a most valuable agent for raising the standard of cleanliness among the poor and for contributing to the comfort and luxury of the wealthier classes. But it must not be forgotten that the use of water in this way brings with it an increase of risk if not properly got rid of. The more water we use to dilute our sewage, the further it will penetrate through the pores of the soil, unless securely led off in proper channels, to proper places.

LECTURE IX.

HOUSE DRAINAGE.

DRAINS *within the house walls* are next to be considered. These demand still more care and skill than the drains outside. In the latter case the soil has certain absorbent powers, combining chemically with the products of decomposing filth, or holding air in its pores for the oxidation of the noxious compounds, which are thus rendered innocuous. Moreover, the poisonous influences within the walls are more likely to be absorbed by and act upon our systems through the lungs than if out of doors, where they are diluted more or less by the outer air. A New England climate does not admit of much fresh air being admitted into the houses of those who cannot afford to heat it during six months of the year. The suffering from frost is immediate, leading the poor man to calk up every crack, while the injury from bad air is a slow poison, warning us only by the sense of smell, a sense which soon becomes benumbed, and rarely becomes sufficiently imperative to lead to action. In fact, its importance is not appreciated by a large part of our population. They might perish with the cold if they let in the air, so they choose the chance of living without it. We must therefore expect bad ventilation among the poorer classes in cold weather. The volatile exhalations of the skin and lungs are not always so easy to get rid of as the fluid and solid excreta. But in getting rid of the latter, if we do not take great care, they too become gaseous, and return to plague us in the air already heavy with the exhalation of the lungs and skin.

The introduction of water-closets in tenement-houses should therefore be guarded with special attention, or the benefits to be derived from their use will be more than cancelled by the evils which may arise from their defective construction.

It must be remembered that houses situated on high places, though enjoying the advantage of good opportunity for drainage, may be more exposed than lower sites to the invasion of bad gases from drains and sewers, for the very reason that they are higher, for these gases are light, and are always tending upward. It is well known that the pressure in our gas-mains increases very perceptibly as we rise a hill, being about double the ordinary working pressure at an elevation of two hundred and twenty feet above the works, and although the gases in our sewers may not be so light as illuminating-gas,* they are somewhat lighter than ordinary air, and are therefore always tending upward by their buoyancy. This tendency is aggravated during the winter by the rarefied condition of the air within our houses, the ordinary heating of which always creates a slight inward pressure from the outside in all the lower stories.

As a general rule, it is of course advisable to limit the length of the drains within the house walls to a minimum, for the reason that a large number of joints increases the risk of leakage. In planning the lines and course of drains, therefore, this should be kept in view.

In planning the general arrangement of plumbing fixtures, care should always be taken to have them arranged as *compactly* as consistent with convenience, and to avoid scattering them about in remote parts of the house, from which the drain pipes can rarely be collected and combined with a proper fall to guard against deposits being formed in them. It is also a matter of no small importance to place the drain and waste pipes so they can be readily accessible for inspection and repairs, without tearing up floors. Where located under basement floors, loose trap-doors should be left for access, and if the drain is necessarily below the surface of the ground it should not be buried, but walled in on each side by brick, and covered by planks or flags that can be easily removed.

The material for drains within the houses should be of metal, in all cases. Stone-ware pipe cannot be trusted on account of their fragile nature and porous joints, through which gas can penetrate, though they may be impervious to water. For all main-drains and soil pipes, cast iron is the best material. It is made in lengths

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* Ordinary illuminating gas has a specific gravity of 0.42, that of air being 1.00. The increase of pressure in gas-pipes as they extend up to a higher level, is due to the difference in weight between the air and gas for the height traversed: gas when distributed from the works is under a pressure of about two inches of water.

The weight of a cubic foot of water is	62.4	lbs.
" " " " of air is -	0.08	"
" " " " of gas is -	0.0336	"
Difference between air and gas equals -	0.0464	" per cubic foot.

We have then the following proportion:—

.0464 : 62.4 :: 1 : 1335 inches, or 111 feet elevation for one additional inch of water pressure in the gas-mains, which is an increase of about 50 per cent. over the ordinary pressure near the works.

of six feet, with all the necessary special forms for joints, bends, etc. Its joints should be filled with melted lead, and well calked. Right-angled connections must be avoided, except in vertical pipes, for the same reason as has been given for outside drains. Oblique connections can always be provided for by arranging the lines of pipe for the purpose, if care be taken. Vertical lines of drain from water-closets, generally called soil-pipes, were formerly made of lead, and this material is still used in England. But iron has taken its place in this country for several years, with success. It has these advantages : Its rigid nature renders it less likely to get out of place than lead, which often sags and changes form. Lead is also more subject to corrosion from the gases existing in drains than cast iron. Wrought-iron would rust away rapidly, but cast iron rusts only on the surface, and seems capable of enduring for twenty years or more, while lead is often found badly corroded in ten years. The corrosion in lead takes place along the joints where in contact with the solder, probably from galvanic action, excited by the contact of the two metals. Lead is often exposed to damage, as is shown by these samples before us, taken from houses in this city, also from rats, which gnaw holes in it, and nails carelessly driven in securing the wood-work have often made holes that were not discovered for several years. The joints of iron pipe are sometimes put together with putty by poor workmen, but it can never be relied upon for any length of time. It soon crumbles away and becomes worthless. The lead should be applied nearly or quite at a red heat, so as to penetrate the thinnest parts of a joint without becoming chilled. When cooling, it contracts so much that it must be upset with calking tools, applied around the whole circumference.

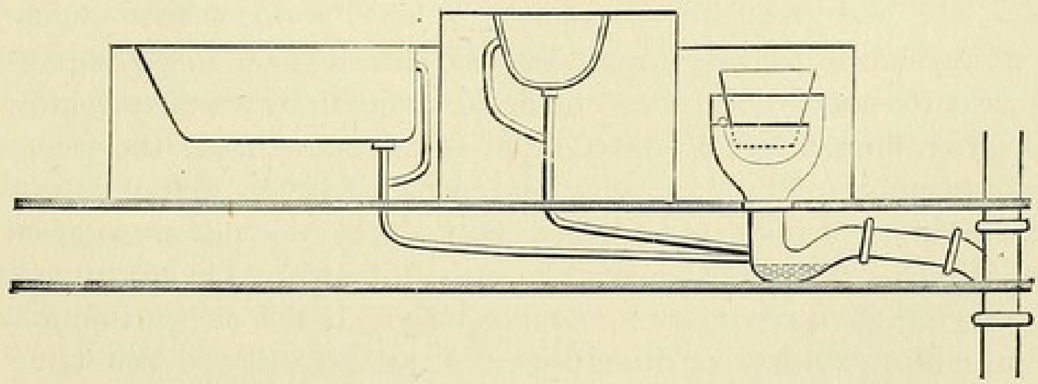
The small waste-pipes from bath-tubs, bowls, sinks, etc., are generally made of lead, which is a very suitable material. Where entering the iron pipes, the joint is often made by applying hydraulic cement, putty or red lead. But the proper way is to solder a brass ferrule to the lead pipe, which is inserted into the bell of the iron pipe. This gives a stiff material, against which a lead joint can be calked, in the same way as between two pieces of iron pipe. When lead traps are used under water-closets, the joint between these and the iron soil-pipes should be secured in the same way.

Every vertical line or "stack" of soil-pipe should extend through the roof of the house at least four inches in diameter, and far enough above the roof to ensure its end from being filled with snow. The end should be left wide open. If a smaller pipe than one four inches in diameter be used, the part projecting above the house roof will be liable to be filled with hoar frost on cold nights in our climate. With this arrangement a constant draught is maintained through the house-drains; entering at the vent-hole close to the outer trap, and passing up through the roof of the house. The temperature of the house in winter is always enough above that of the outer air to sustain this draught. In summer, the sunshine on the upper end of the pipe will encourage it, for the hole at the lower end is below the surface, where the ground cools the air and thus renders it slightly more dense. This upward draught is reversed for a moment whenever a considerable charge of water is emptied into the drains from the upper stories of the house, for the water pushes the air down as it falls, and other air takes its place from the upper end of the pipe. If both of these holes are not kept open, trouble will be sure to follow the use of the drains, for the water rushes down the vertical pipes with considerable velocity, and if it nearly fills the pipe, it acts like a piston, to drive all the air in advance. If the free escape of this air were not provided for by the vent-hole at the bottom, the air within the pipe would be forced out at any or all the branch drain-pipes in the lower story, forcing their traps and blowing their contents up through the waste-holes in a very disagreeable manner. The puff of air that is thus driven out of the house-drain at its lower vent-hole by a descending charge of water from the upper stories, has sometimes been objected to on the ground of a possible offense arising from it at the mouth of the man-hole over the trap previously described, but this is not found to exist in practice. The air from a well-ventilated drain is not so foul as to pollute the air outside the house to any great extent, though when allowed to escape and taint the air *within* the walls, where the dilution is very much less, and the process is a cumulative one, the result is much more serious. Moreover, as before explained, the escape of air at this lower vent is only by occasional puffs forced out by descending charges of water, while at all other times the draught is inward at the lower vent-hole. So that this very air which may have been forced out for a moment into the man-hole chamber, is again drawn up through the pipe and delivered at the top of the house above the roof, before it has an opportunity to escape from the top of the man-hole itself. Practically, no reason appears to exist why these vents should not be placed near the house, outside, in either the front yards, on the sidewalk, or in the back yard, as the case may be. If the man-hole cover is liable to be covered with snow for any depth, an air pipe of four or five inches diameter should be lead up from beneath the cover, to terminate a few feet above the ground, at the top of a back-yard fence, or similar position, as before described.

The arrangement described above is essential to every house. By this means every part of the main drain is not only kept in accord with the normal atmospheric pressure, but is also swept by a constant current of air. If there be more than one stack or vertical line of soil-pipes, each one should extend through the roof separately.

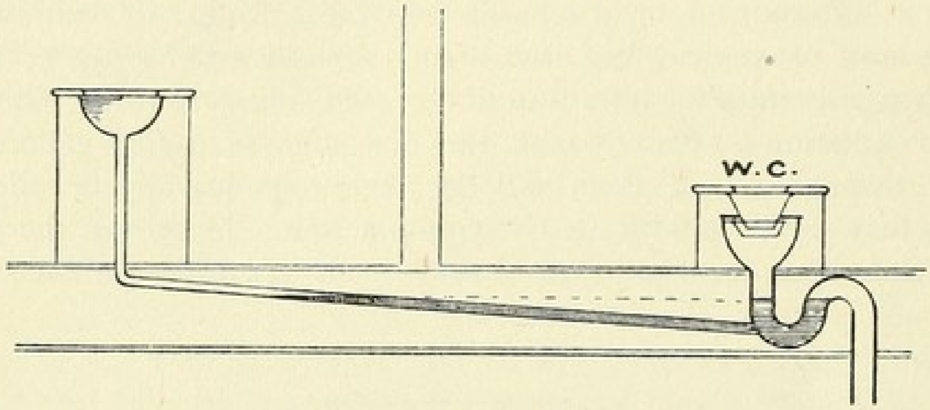
Smaller branch waste-pipes leading from bowls, bath-tubs, sinks, etc., can all connect or discharge into the soil-pipe or main-drain where most convenient, but each branch should also have a vent to the open air, and a separate trap under each sink, or bowl. Without such ventilation for each branch, the discharge of a few gallons of water through any of them will be likely to empty any or all the traps that connect with it, by syphon action. Moreover, the discharge of water down the vertical stack itself will often produce this

FIGURE 9.



effect, by the friction between the descending water and the air in the branch pipe at the junction. It is always best to lead the waste from each bowl, or tub *separately* to the soil-pipe or drain. If these branches connect with one another before joining the soil-pipe, the drainage through one is very likely to disturb the air in the other, and thereby destroy the seal in their traps. It has been a common practice among plumbers in this country to lead the waste water from bath-tubs, bowls, etc., into the trap of the nearest water-closet, below the water line ; but such a practice is never advisable, for several reasons. The discharge of warm water into this large trap heats up its contents, which are generally composed in part of fecal matter, and the steam and odors arising therefrom are very likely, by their expansion when so heated, to find some crack by which they can penetrate into the rooms. Moreover, a slight sagging of one of the pipes or a tipping of the trap itself, which sometimes occurs in time, will throw the connection above the water line and destroy the seal. (See Fig. 9). Another defect in this method of connecting wastes of bowls to water-closet traps arises from the length of waste under the floor which has so little fall that the trap water holds the water back in it for several feet, where it has ample time to make noxious deposits. (See Fig. 10.)

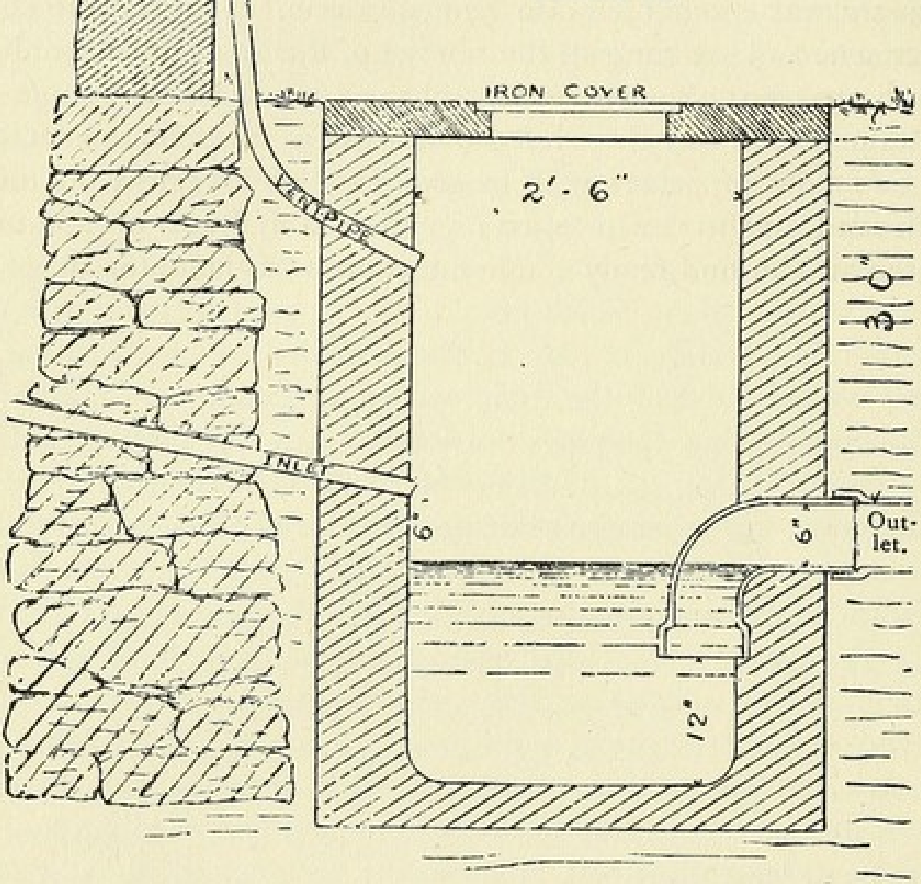
FIGURE 10.



It is usual to provide a small tank or cistern in the upper part of a house, from which water can be drawn, when wanted, more rapidly than from the small pipe which supplies the house from the street. Such a tank is fed by a faucet governed by a float, so that it is kept nearly full. As any defect in the action of the float might cause the tank to overflow, it must always be provided with an overflow-pipe, to carry off the water in such an emergency. If this overflow-pipe is connected to a waste or drain-pipe, the foul air will rise through it and escape through its open mouth at the top, where it may taint the water by being absorbed by it, or taint the air about it. No trap placed upon such an overflow can be relied upon, for the flow occurs so seldom that such a trap would lose its water by evaporation and soon become worthless. The safer way is to discharge such overflow pipes in the open air, either outside the house, in a rain-spout, or on the roof. If this cannot be conveniently arranged, they should be allowed to discharge over an open sink or bath-tub, or similar receptacle, without direct connection with the drains. Where no public water supply exists, large tanks for storage of rain-water are sometimes constructed as a source for domestic supply, located under the ground, with overflows discharging into the main-drain. Such a course should never be allowed. No intervening trap can serve for stopping the back flow of gas, because the overflow does not occur often enough in dry weather to ensure the presence of water in such traps. Such overflows ought to be discharged on to the surface of the ground, or in a pit filled with loose stones in a porous soil, where the water will readily soak away at all times. An instance occurred within my own observation a few years ago, where the overflow of a rain-water tank discharged into the main drain. This became choked with grease, and set back all the sewage of the house into the cistern, through the overflow. The water was used for all domestic purposes, and its pollution was discovered only through the nauseous taste it had acquired after some weeks' accumulation of sewage in the cistern.

This leads us to the question of grease in drains, a prolific source of annoyance in our climate. The grease comes from the washing of dishes in kitchen sinks, which goes down the wastes mixed with warm water in a fluid state. It soon becomes chilled in cool weather, and adheres to the sides of the drain, where it accumulates continually, till sometimes filling the pipes for long distances. If the drain has a very rapid descent, the flow of water may sometimes prevent this accumulation, but otherwise some provision is needed for intercepting the grease in a small tank. The nearer this tank is to the sink the better, to guard against the choking of the pipe above the tank. Where the sinks are located against the outer wall of the house, the tank is best placed outside the walls, where the grease can be removed without creating a nuisance in the house. Such a tank is shown in this section (Fig. 11), built of brick and hydraulic cement, plastered smoothly inside. For small and medium houses it should be at least three feet long on the inside, and about two feet wide, with rounded corners. The outlet should be made of a bent joint pipe dipping under the water, so that the grease, while floating on the surface, will not be drawn into it. The inlet should be at least six inches higher than the outlet, so as not to be obstructed by the accumulation of grease, which takes place in the form of a thick scum on the water. It is also best to allow about a foot below the mouth of the outlet in the clear, for accumulation of sand and other solid matter which is heavier than the water. A man-hole cover is placed on the top, through which the grease may be removed as occasion may require. The soil-pipes from water-closets should never discharge into this receptacle. It should be arranged upon the branch leading from the kitchen and pantry sinks only, having its outlet connected with the main drain where convenient. If the sink is not situated near enough to the outside of the house to allow this grease tank to be constructed outside the walls, it can be made in the cellar or basement, of wood, and lined with heavy lead. In such cases, the grease does not cool so readily as on the outside, and if the tank is not of a liberal size, the grease is liable to pass through

FIGURE II.



before being separated from the water. Whenever drains become choked with grease, if the pipe is accessible, it can be cleared by pouring hot water over the outside in a small stream, for half an hour or less. This heats up the whole contents, and the softened grease then passes along with the water that is applied inside. But the better way is to catch the grease before it gets into the pipes. If once allowed to coat the inner walls of the drains, much trouble will ensue.

I have before alluded to the need of having the plumbing fixtures inside the house arranged as far as possible in compact groups. It is a very common fault among architects to so arrange them that their drain-pipes are led across considerable lengths of floor spaces, with little or no fall, terminating, as before described, in a water-closet trap, just below the floor, which sometimes holds the water for several feet back in this horizontal reach of pipe. (See Fig. 10, p. 104). Whenever a bowl-full of water is discharged into such a flat waste, the lower end of which is filled with water, the air that happens to be in the pipe above such water is displaced and is driven out. Where can it escape? Sometimes it finds a branch waste coming in from another apartment, and is blown up through that, and through the trap and waste-hole of a wash-bowl in a sleeping-room or dressing-room attached. Sometimes it bubbles up in one's face in the bowl that is discharged. Sometimes it is pushed forward and bubbles up in the water-closet. The result in either case is far from satisfactory, and shows how important it is to give each line of waste an independent and unobstructed course to the main drain or soil-pipe, where the air can find ready communication with the outer air.

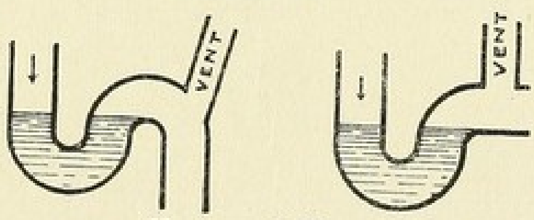
LECTURE X.

APPARATUS USED FOR HOUSE DRAINAGE.

I WILL now endeavor to explain some of the leading characteristics of the several styles of apparatus in most common use in this market, grouping them as far as possible in classes, according to the principles governing their action. I propose first to discuss various kinds of traps. These devices all depend upon the same principle, viz.: that a small depression or chamber is made in the drain or pipe, in which the sewage is retained, as a seal, to prevent the passage of air and gases.

Since it is desired to retain as little of the sewage as possible within the drains, for reasons before given, the smaller we make the depression or water-chamber of the traps the better, provided they are efficient and can be relied upon to retain their water at all times. The simplest form of trap is the ordinary S-bend, formed now-a-days by casting the lead in a mould, so it may be seamless. (See Fig. 12.) This form is not likely to become a place of deposit for the grease or other solid matter in the sewage, and if it could be relied on to retain its water it would always be the best form, because of its cleanliness. It is, however, extremely likely to lose its water-seal by syphon action, whenever the waste-pipe runs full below it, or whenever any slight vacuum is produced in a connecting pipe into which it may discharge. The remedy for this is to admit the atmospheric pressure just below the water-seal by a vent-pipe, and if this is as large as the trap and waste-pipe, and not too long, it will be efficient. Such pipes cannot of course be opened directly into the house, but must communicate with the air by means of extensions leading up through the roof, or into the soil-pipe above all branches that bring drainage into it, supposing this pipe to extend itself through the roof with an open end in all cases.

FIGURE 12.

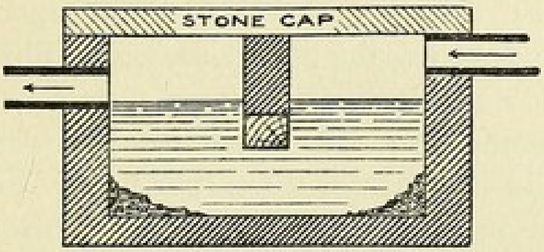


VANTED S-TRAPS.

The cost of such a vent-pipe and the lack of a proper place to lead it, where it may have a continuous slope to avoid the accumulation of water from condensation, especially in old houses, is often a serious objection, and has given rise to various other styles of traps. The opposite extreme is the cesspool trap, which we often find in the basements of houses built thirty years ago, and sometimes in buildings designed and erected within ten years by architects who ought to have known better.

The cesspool trap (See Fig. 13) is a small tank, sometimes of only one or two cubic feet capacity, into which the drainage enters at one end and goes out at the other at a slightly lower level. The sewage is of course retained in it up to the level of the outlet. In order to stop the flow of gas upward, a partition is made, extending across the tank, but not entirely closing across the bottom, often starting on a bar of iron or wood some inches below the water-line, and extending to the top or cover. This is an effectual bar to the passage of gas, but the corners of the tank favor an accumulation of foul matter from the sewage which putrefies and gives off to the house drain more bad gas than would be found in miles of a well-constructed sewer. The remedy therefore may be worse than the disease, and such cesspools are never to be tolerated, except on the wastes of the kitchen and butler's sinks, for the interception of grease, as before described, and then they should be made with rounded corners, and frequently cleaned out.

FIGURE 13.

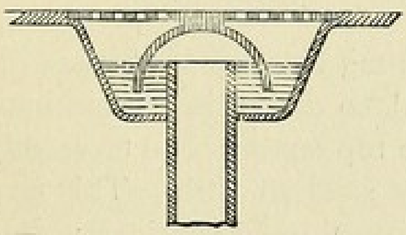


OLD STYLE OF CESSPOOL TRAP.

The various forms of traps between these two extremes are too numerous to admit of illustration except by classing them.

A very common form is that of the bell-trap (See Fig. 14); it is generally found under sinks, as a part of the outlet strainer, and is generally a mere subterfuge, and worse than nothing, inasmuch as it tends to give a false sense of security where none exists. An inverted cup or bell is attached to the under side of the strainer, made to dip into an annular depression around the upper end of the waste-pipe. Since the flow of water around the edge of the cup can never be much accelerated by pressure from above, the

FIGURE 14.

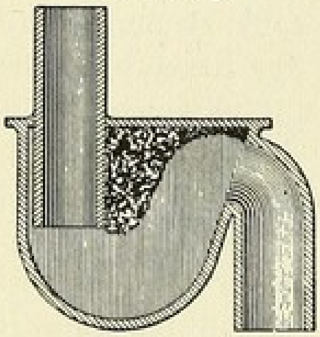


BELL TRAP.

chamber being close up to the bottom of the sink where the flow is obstructed by the strainer, and since the water-way is so shaped as to favor the accumulation of crumbs and sand, it frequently gets choked, while the seal is so slight, rarely over ¼ or ½ an inch, that a very slight vacuum below will cause the water to be forced out of it and render it inoperative.

Another faulty form of trap is the D-trap (See Fig. 15), generally made of lead, and largely used by some of our best plumbers, at least till within a short time. Its faults are forcibly illustrated by this specimen before you, which was recently taken from a house in this city, which is cut open on the side, showing the accumulation of filth which has been deposited, so as to leave a narrow channel for the water through the centre, while more than three-fourths of the cavity is occupied by solid matter, even after it has shrunk somewhat by its drying since it was opened some weeks ago. In fact, the water-way is here reduced to an S-shaped channel through the putrid slime, the original shape of the cavity being entirely masked by its lining.

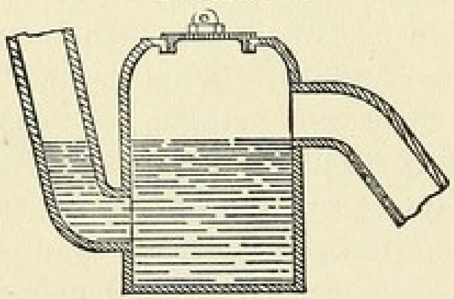
FIGURE 15.



D-TRAPS.

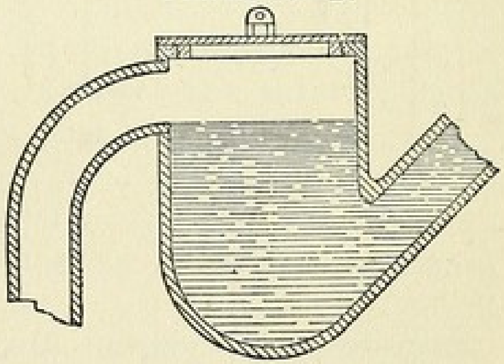
A form now in general use, particularly among Boston plumbers, is the round or "bottle" trap, made thus, and often serving as a trap for several wastes from different bowls or tubs in different apartments (See Fig. 16).

FIGURE 16.



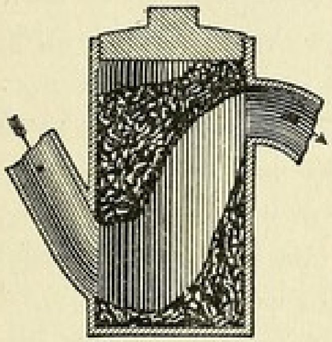
ROUND TRAP.

FIGURE 16—B.



Its merits are that it requires a very strong blast of air through it to drive the water out and destroy the seal, so that this seldom happens. Moreover, the cleaning screw at the top enables one to readily get access to the interior for removing the sand or filth. This trap is often placed directly under floors, with the screw just visible through a hole in the floor for inspection and cleaning. Its faults are that it is a cesspool, though perhaps a small one, and soon becomes a place of deposit of a vile and putrid filth, which is not desirable to harbor anywhere in our houses—even in our drains.

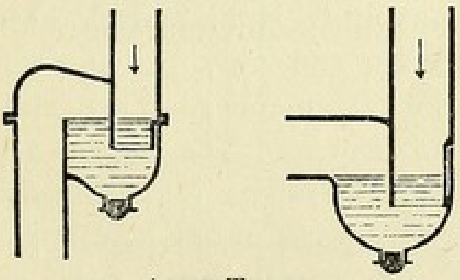
FIGURE 17.



Housekeepers rarely, if ever, open these traps for cleansing. They are in out-of-the-way places, and are rarely thought of. The form with rounded bottom (Fig. 16—B) is more likely to keep clean than the flat bottom, which often accumulates filth, as shown in Figure 17.

It will be readily seen that the security against the loss of the water-seal by syphon action is greatest in those traps which, like the D-trap and bottle-trap, have a marked expansion of the water chamber, which admits of air being blown freely through them without displacing and losing much of their fluid contents. It is also easy to see that any such expansion of the water-chamber is likely to encourage a deposit of filth in a short time, and this deposit is not only an evil in itself, but serves to fill up all such parts of the chamber as are free from the force of the current, and finally to reduce it to a mere crooked channel, like this in the D-trap, very similar to the simple S-trap in its form. The ingenuity of the inventors of the various styles of traps, some of which, as shown in Fig. 18, has therefore been spent in trying to make a practical compromise between the tendency to lose the seal by syphonage and the tendency to accumulate deposits. This effort has also given rise to various forms of mechanical devices for closing the opening by a solid valve, which it was hoped might effectually stop the passage of gas in the direction opposite to the flow of water. A variety of such valves have been produced, and are now for sale in the market, most of which are hinged flaps like ordinary pump-valves, except that they are made with turned and fitted metallic seats. If the fluids passing through were always clean and free from solid matter, these might work satisfactorily. But of course this cannot be the case. The result is that the valve seat often becomes the place of deposit of hairs, and particles of lint, grease, etc., which adhere to it and prevent the valve from shutting tightly. All the valves that are hung on hinges are subject to this defect. A better form of valve for such a purpose is the ball-valve, which rarely applies the same face

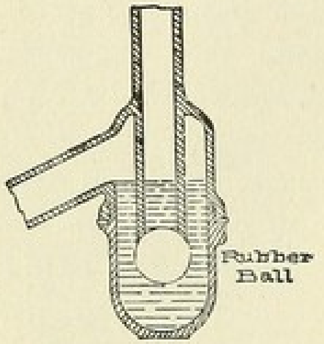
FIGURE 18.



ADEE TRAPS.

to the seat for any length of time, and by its continual shifting and rolling tends to keep the seat partially wiped. The hinged valves, for the above reason, have never come into general use, and are mostly limited in their application to the narrow circle of the practice of their inventors. The best form of ball-valve is the inverted or floating ball. This principle is incorporated in Bower's trap. (See Fig. 19). The more ordinary form of ball-valve used in pumps has an upturned seat with ball resting on it. By inverting the valve seat and turning it downward, it is rendered less likely to become the place of deposit of hairs and lint, but of course the valve becomes inoperative the moment the trap loses its water, on which it depends to float the valve against its seat. The ball is made of hollow vulcanized caoutchouc, which is quite pliable, and readily adapts itself to form a comparatively tight joint against the seat so long as water enough remains to float it. Moreover, its compressible quality is an advantage in case of frost, which might otherwise burst the receptacle. If these traps were always made of the best quality of material and the parts well fitted, they would be more reliable than at present, the lead being sometimes too hard, and the screw joint has too little width for a reliable washer. The manufacture is limited to those controlling the patent, so that the market can only be supplied through them: the responsibility of workmanship and good materials is therefore concentrated and subject to control. The makers are already aware of these faults, and have undertaken their remedy. The device, if well executed, would be a very useful one, and might be recommended without qualification for general use if supplied with an air-vent to prevent loss of water by syphonage.

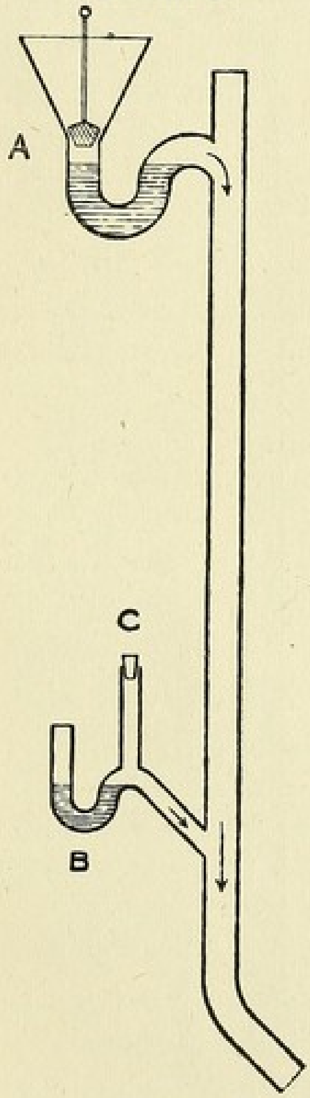
FIGURE 19.



BOWER'S PATENT TRAP.

The loss of water in an ordinary trap by syphon action is a phenomenon too familiar to require illustration ; but the loss of the water in any trap by a rush of water through *another pipe*, with which it may connect, is apparently seldom thought of by many of the plumbers who have fitted up our modern dwellings. I have accordingly set up this apparatus to show how this is done. (See Fig. 20). A hopper at the top of this vertical soil-pipe is provided with a plug, by which it can be discharged at will. The descending column of water passes by the Y-branch with a small trap on it at B, with such force as to drag along with it from this branch the air that it contained, and the small trap loses its water in an instant, unless it is provided with an air-vent at C. This vent has a cork in it. I will remove the cork and discharge the hopper again. You see by means of the glass test-tube, outside of the trap, that the water-seal is not disturbed this time. But if the vent-tube, instead of opening here at C, had been only one inch diameter or less, and some thirty feet long, with crooks in it, the air might have been so detained in it by friction that it would not have supplied the vacuum quickly enough to avoid disturbing the water-seal in this small trap.

FIGURE 20.

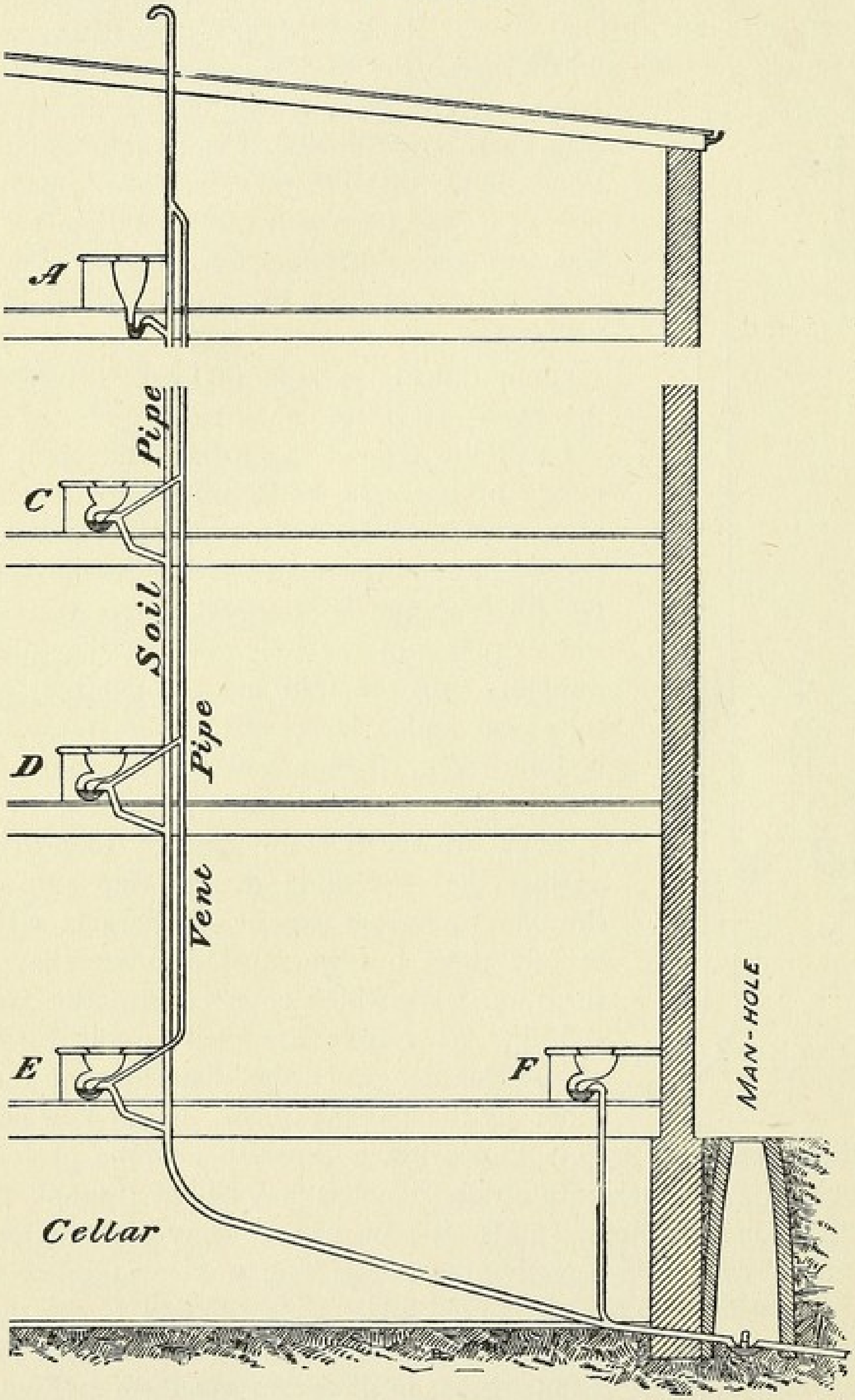


I will now remove this S-trap and apply by means of putty, a bottle-trap, with a glass tube outside to show the amount of water it contains at any moment. It has no air-vent. On discharging the hopper above you see the air rushes in not only through the inlets, bubbling into the trap, but through the test-tube also, and a large part of the trap-water is blown out, though not quite enough to destroy the seal, which was a deep one.

Thus we see it is not enough to provide against the syphoning of the trap into or through which we may be discharging water at any time, but we must also see that all the other traps which connect with the same soil-pipe or system are well supplied with air, to guard against the disturbing of their water by the passing rush. In all new constructions, the better way is to provide a separate air-pipe, at least two inches in diameter, into which branches may be led from all the small traps on each floor. This air-pipe, can, if convenient, extend up through the roof independently; but as it may in our climate be often filled with hoar frost in a cold night when exposed to the outside temperature, a safer way may be to branch it into the upper end of the soil-pipe, which is four inches in diameter, as shown in Figure 21, above all branches by which drainage may enter, to create disturbance.

A good deal has lately been said about the inefficiency of traps to stop the circulation of gases in our drains, especially by the patentees

FIGURE 21.



or their agents, who wish to introduce mechanical valves for the same purpose. These people allege that every trap is capable of passing bad gas, by the solution or absorption of such gas in the trap-water to be given off on the other side into the air having access to our rooms. The experiments of Dr. Fergus tend to show that this transfer is actually made, to a limited extent, when the gas accumulates on one side of the trap in a very *concentrated form;* but more recent experiments, conducted with a good deal of care, by Dr. Carmichael, of Glasgow, show conclusively that in practice this transfer is not likely to occur, unless the concentration of bad gas becomes much more marked than is ever likely to be found in sewers with even a moderate supply of ventilating or breathing holes. Moreover, the transfer of germs or organic spores, however minute, was not found to take place in such a manner, *i. e.*, by absorption and subsequent exhalation from the trap-water. The old-fashioned trap, then, with a simple water-seal, may be accepted as a perfectly safe device to check the circulation of gases in drain-pipes, so long as the normal atmospheric pressure is freely admitted in the manner and at the points above described, to preserve the water-seal from disturbance through pressure or vacuum. Dr. Carmichael states that the amount of gas actually transferred through the water of an ordinary trap to be so minute as to be "perfectly harmless."

Another frequent cause of the loss of water-seal in traps is by *evaporation*, which in our dry climate is likely to occur in many traps that are not in daily or very frequent use. Bowls or sinks in spare chambers or other apartments which may be unoccupied for several consecutive weeks or even months, should either be supplied with a dash of water occasionally, or if disused for longer periods, disconnected from the drain system entirely. A neglect of this precaution in an unoccupied apartment may lead to a serious contamination of the air, which may not only circulate into other rooms that are occupied, but which sometimes is absorbed by the bedding, upholstery, carpets and wall-paper, so that it becomes next to impossible to rid the room of the noxious odor by ventilation, even after its source is cut off.

Traps are often relied upon in overflows of tanks and in cellar drains. These drains are generally used at such rare intervals that their traps may lose their seal by evaporation, and as the memory can hardly be relied upon to replenish their water when exhausted, it is better to avoid depending on it.

Overflows, as I have said before, should *never* be discharged into drain-pipes, but over open sinks or bath-tubs, or out of doors. Cellar ground-drains are often discharged into the sewer or house-drain by necessity. In all such cases a separate trap should never be depended upon, because of its liability to dry up. The better way is to lead such drains into the main trap, *i. e.*, the trap on the main house-drain just outside the walls, connecting below its water line or discharging in the open air just above the vent-hole, as found most convenient.

If connected with the drain system without such precaution, we should thereby ventilate our drains or sewers into the air spaces of our foundation walls, which is not advisable.

LECTURE XI.

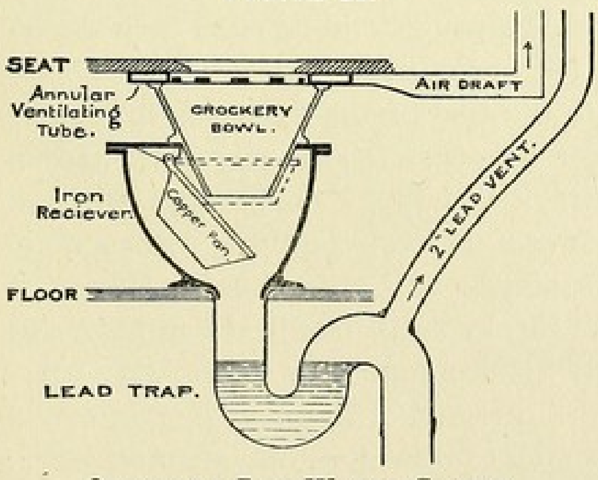
APPARATUS USED FOR HOUSE DRAINAGE.

NEXT to traps, there is no fixture used in connection with modern house drainage of so much importance as the water-closet. A great deal of inventive talent has been expended upon these contrivances, and though they have been a good deal improved of late, there is still room for further improvement. Several quite distinct classes are now in use and sold by the dealers, having each certain merits and faults of their own, which may render each class more suitable to certain places than others. Let us then examine these several types in detail.

The forms in most common use, and therefore best known in our community are the "pan-closets" and the "hopper."

The pan-closet is shown in section by Figure 22. It consists, beginning at the bottom, of a trap just below the floor, generally four inches in diameter, and constructed of iron or preferably of lead, unless the iron be enamelled on the interior, to avoid the rough surface of cast-iron. Above the floor is the cast-iron receiver, to which, on its top, the crockery bowl is attached by putty. A copper pan of one or two quarts' capacity is hung under the bowl, upon a pivot, so that when level and full of water, this water stands two or three inches deep in the bowl, and forms there a second trap so long as the closet is at rest and supplied with water. When the closet is used, the handle is raised and the pan is tilted on its pivot, emptying its contents into the iron receiver and thence into the trap below.

FIGURE 22.

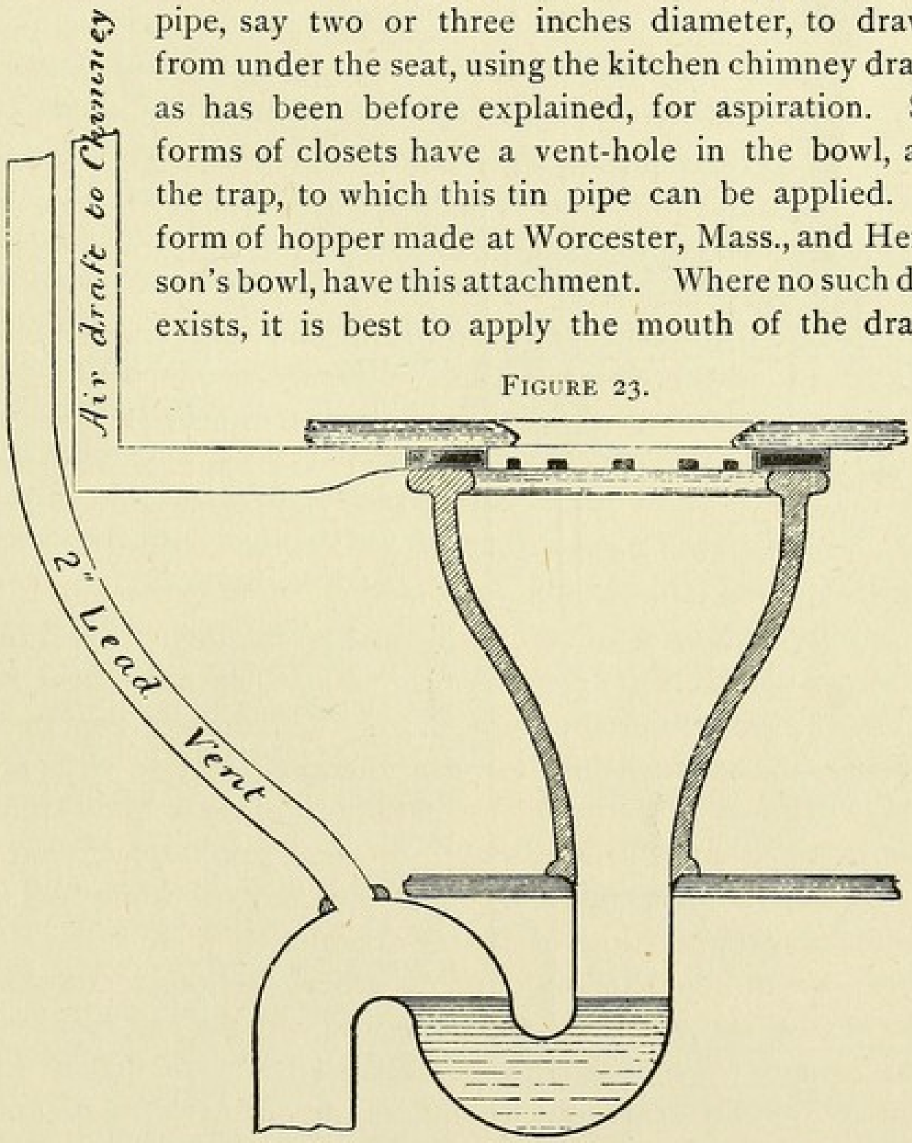


ORDINARY PAN WATER-CLOSET.

To the superficial observer, this seems to be a a perfectly safe device. The circulation between the soil-pipe and the room is ordinarily guarded by two traps, and as the pan is supposed to be kept full of water, the fecal matter is dropped directly into this water and becomes thereby somewhat deodorized. But though so popular and almost universally used in our country, this closet is a very defective one, and often becomes a great nuisance in a house from the following causes. The cast-iron receiver is soon smeared and spattered with filth all over its interior, which goes on accumulating by successive spatterings, till the decomposition of this lining, kept moist and warm, keeps the interior filled with foul odors. In fact, it violates the cardinal principles of house drainage, by affording a harbor for the continual and certain accumulation of filth within the house. We are told that the water in the pan above prevents its free access to the room ; but the pivot hole, by which the pan is tilted, is subject to constant wear, and is seldom air-tight. Moreover, the putty in which the bowl is bedded on the top of the receiver, is often found cracked, or gnawed away by rats, and however perfect these joints may be, there is a quart or two of the foul gas of the receiver always displaced by the tilting and emptying of the pan. The trap below the floor prevents it from escaping below, and it necessarily comes upward into the room. Attempts have been made to avoid this by providing vent-pipes to keep the air sweet in the receiver, but this is so foul that such attempts can at best be only palliative, while these separate vent-pipes extending from each water-closet receiver, all the way to the open air, if large enough to be of any use, would add so much to the cost of the device as to remove the chief argument for its use—cheapness. The only good reason for using the pan-closet anywhere, is this, that it can, if kept tight and in good repair, be made to answer a tolerable purpose with a more moderate supply of water than almost any other kind. Hence, it may often be used, if well cared for, by small families who have but a limited water supply, raised by hand pumping, or where no sewers exist, and where the filling of the cesspool at frequent intervals by a more copious discharge of water might prove a serious inconvenience. In such cases, and wherever used, the inside of the cast-iron receiver should always be coated with porcelain enamel, so that its surface may not so readily accummulate filth as the ordinary rough castings. But wherever water can be obtained in sufficient quantities and afterwards properly disposed of, we should remember that an adequate supply is absolutely essential to the success of the water-carriage system, and that we can never economize the use of water in such apparatus below a certain point without incurring serious risks. We must see to it that water enough is applied to quickly remove all the filth, or we are not justified in using the apparatus in our houses.

It is desirable to have water-closets located on the exterior walls of houses, so that outer air can be readily obtained by opening a window. But as this is often found difficult to accomplish on account of exposure to frost in the country, or the supposed greater value of light and air for other apartments in city houses, some substitute for the open window is desirable wherever water-closets are located in the interior of houses. The best arrangement is to apply a small tin pipe, say two or three inches diameter, to draw air from under the seat, using the kitchen chimney draught, as has been before explained, for aspiration. Some forms of closets have a vent-hole in the bowl, above the trap, to which this tin pipe can be applied. The form of hopper made at Worcester, Mass., and Henderson's bowl, have this attachment. Where no such device exists, it is best to apply the mouth of the draught-

FIGURE 23.

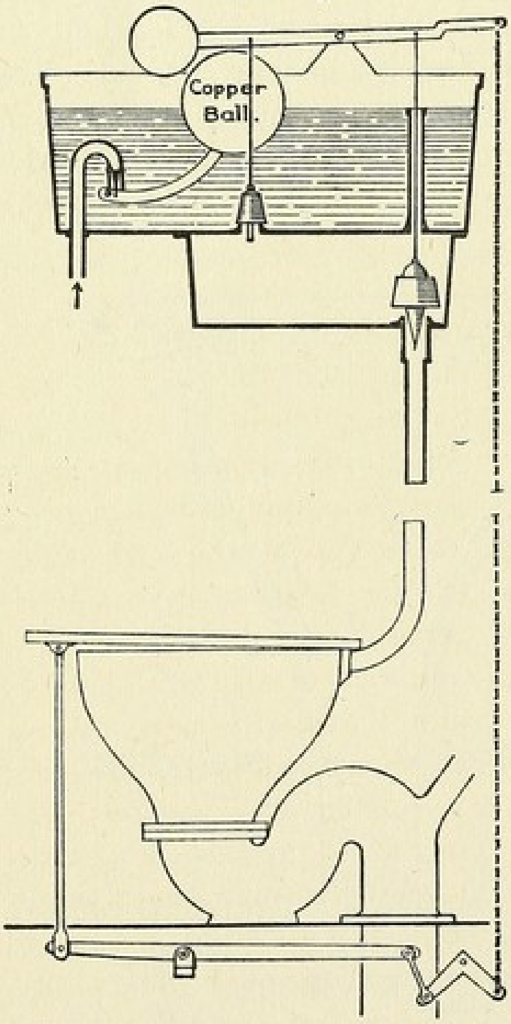


pipe directly under the seat. An annular flat tube is made for this purpose at Charlestown, Mass., of galvanized-iron, with slots around the inner edge, to be placed directly over the bowl and under the seat, as shown in Figure 23. This leads to the consideration of this form of closet, known as the "hopper," many forms of which have been in the market for years, but which has been generally considered an inferior article, owing to defects in its details and the inadequate supply of water generally given to it. These defects can easily be remedied, and are as follows:

Rough interior, leading to accumulation of filth, remedied by using crockery ware, or enamelled iron.

Improper application of the flushing water, which is often applied in the direction of a tangent to the circle, causing the water to spin about the inside of the bowl and fall by degrees, instead of dropping at once into the trap to expel its contents.

FIGURE 24.



TANK WITH AUTOMATIC SUPPLY.

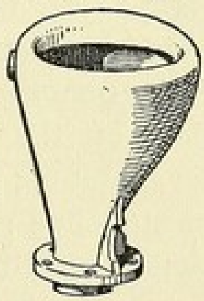
Lastly, insufficient supply of water, or the admission of water by driblets through an open faucet, depending on the uncertain memory or attention of the person using it, and using large quantities when left running, without giving that sudden dash required to clean the trap. The best form of water-supply to all closets is that from a special tank immediately over them, actuated by large valves and conducted thence to the closets by large pipes, never of less than one and a quarter inches calibre. With these precautions, the hopper closet can be made one of the most desirable forms for general use, its simplicity being a strong point in its favor. In order to ensure proper flushing, the quantity of water should be metered by a waste-preventing cistern, such as have been used for many years in England, and now manufactured here. (See Figure 24.) The automatic apparatus illustrated in this figure where the water-supply is operated by the weight on the seat, when properly adjusted, with strong and well-fitted apparatus, has many advantages, rendering the flushing independent of the uncertain memory of the person using it, and definite in its quantity.

All forms of hopper-closets should have the water-supply so adjusted as to be delivered with a *dash*, and not by driblets, the object being to completely expel the contents of the trap, which would soon become offensive if allowed to remain there.

The short hopper with the trap above the floor, shown in Figure 24, has the advantage, when properly proportioned, of holding the water higher than the long hopper (shown in Figure 23), and thereby exposing less surface above the water from contamination. If the trap, when located above the floor, would be exposed to frost, it is better to use the long hopper and put it below the floor.

The wood-casing around water-closets is liable to become soaked with spatterings of urine, and even if washed carefully every day, as it always should be, is often offensive, especially if much used by children or careless persons. This has led to the invention shown in Figure 25. This form dispenses with all wood-work, a most desirable feature for hospitals and other public institutions, if the floor is made of tiles, which are smooth and non-absorbent. This is a very cleanly piece of apparatus, and well adapted to warm climates or heated apartments.

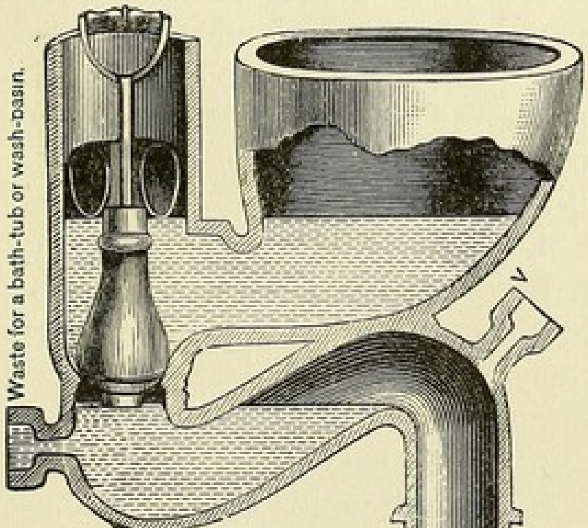
FIGURE 25.



RHOAD'S W. C.

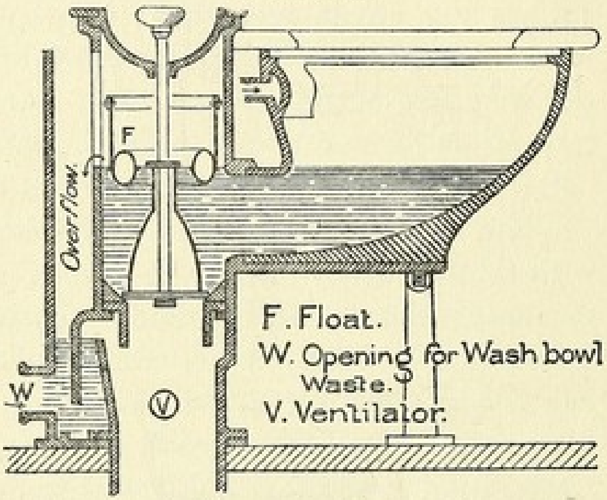
Another form of water-closet has been used to some extent within a few years, being first introduced here by Mr. Jenning's patent, viz.: the plunger-closet, several styles of which are now in the market, viz.: Jennings's, Zane's, Demorest's and Pearson's. They are used either with or without traps, as shown in Figures 26 and 27. The water is retained in bowls up to a certain level by a plunger or large plug, to be lifted by hand when discharged. The plunger is in an upright cylinder alongside the bowl, with which it communicates on the side. In this cylinder, or attached to it, is a float, which governs the water

FIGURE 26.



supply, maintaining it at a definite level by opening or closing a valve on the supply pipe. The advantages of this sort of closet are in its definite and adequate supply of water, maintained at such a height as to be sure of receiving all the fecal matter, and to thus avoid the soiling of the bowl by having it drop upon this dry surface, as sometimes happens in hopper-closets. The disadvantages are in the liability of the float-chamber to become foul by degrees, by filth adhering to its sides. Those patterns which have the smallest float-chambers are therefore the better ones. Since the float apparatus is not always certain in its action, such closets must always have an overflow, and in order to prevent the circulation of air from below, this must be trapped, which involves another risk, viz.: the loss of the trap-water by evaporation, if the overflow occurs but seldom. To guard against this, a driblet of water is sometimes thrown into the overflow trap every time the closet is used, by a small pipe branching from the supply-pipe. These closets deliver suddenly such a large body of water when discharged, that they flush the drain below very well; but they also, for this reason, occasion the risk of syphoning their own traps and others in connection with the same soil-pipe, if not guarded by good air-vents to supply the vacuum. These are applied directly under the plunger, to admit air to follow the water as it descends.

FIGURE 27.

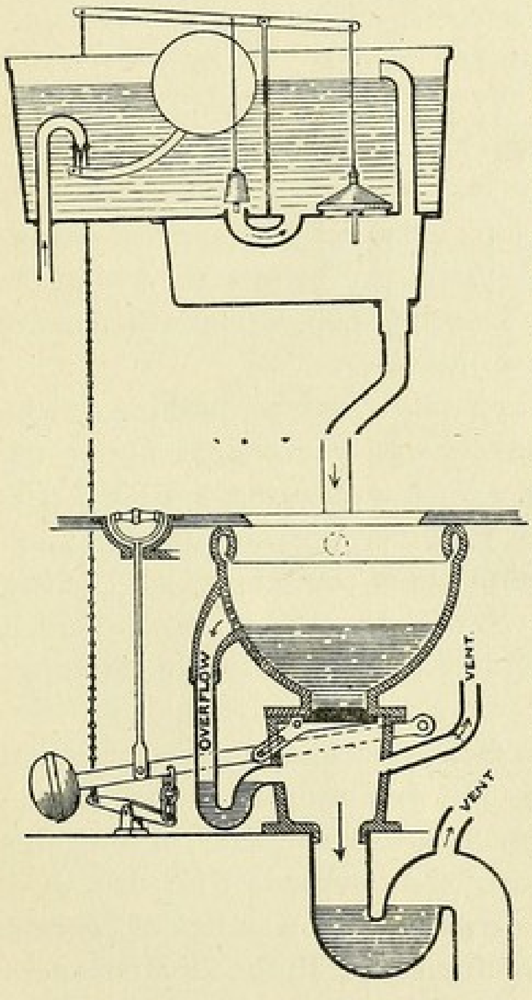


JENNING'S TRAPLESS WATER CLOSET.

It will be seen that all these plunger-closets take their water-supply through a valve attached to the apparatus, governed by the float, and governing in turn the supply of flushing water. The construction of these valves is various, and their action is not always reliable, which has at times caused considerable annoyance. If these valves can be made more certain in their action, and the float-chamber made more accessible for frequent cleaning, the apparatus can be made a very satisfactory one; but it needs careful treatment and good care.

Still another variety of water-closets remains to be described, viz.: those in which the base of the bowl is closed by a valve or flap, retaining the water and hinged on a pivot, which is rotated by lifting a handle, thereby discharging the contents of the bowl into a small chamber directly above the trap. (See Fig. 28). As the flap needs less room than the old-fashioned pan, this chamber for its accommodation is made quite small, so that but little surface is left for the deposit of filth, and an air-pipe connected directly below the valve and above the trap is depended on for the ventilation of this chamber. But if this air-pipe connects with the one by which the soil-pipe is ventilated, an air-passage is thus provided quite *around* the trap-water, and the trap becomes superfluous. Therefore, in order to avail ourselves of the security afforded by the trap, this vent-pipe must have a separate course to the open air. The trap, however, in this style of closet, as well as in the plunger-closets, is of doubtful utility, and useful only in those emergencies when the flap or the plunger gets out of order and fails to keep the water in the bowl. Whenever the bowl is filled, no air can pass up from below; neither can it while the plunger or flap is held up and the water rushing down, for the quantity of water held by all these closets is so great, and the discharge so sudden, that a downward current of air must always accompany and follow their discharge. When these valve-closets are well constructed, so that they are not likely to break down or get leaky at the flap, they form a very good piece of apparatus. The one here illustrated is the best of its kind in the market, and appears to be thoroughly well made. This kind of closet should never be used without a special tank and waste-preventing service-box, by which an adequate and sudden supply of water can be depended upon for flushing.

FIGURE 28.



HELLYER'S WATER CLOSET AND SUPPLY TANK.

LECTURE XII.

PUBLIC PRIVIES AND URINALS.

THE need of some device has long existed by which the advantages of the water-carriage system can be brought within the reach of the large number of the laboring population who cannot afford the cost of the apparatus described above.

However well devised such an apparatus may be, nothing of the kind has ever met with any success, unless where kept under the supervision of the local authorities. Such apparatus has been perfected and used for some years past in Liverpool and Bristol, England, and something similar has been used in the schools at Dantzig for some years, and more lately in New York and Boston, where it is now in use in several tenement houses and public-school buildings with various success.

Annexed to the report of the medical officer of the Privy Council for 1874, is an interesting report by Mr. J. Netton Radcliffe on the means used in various towns for removal of excrement. Among his conclusions is the following (p. 154): "As regards the parts of a town or village inhabited by the poorer classes, a water-closet system may be managed so as to be entirely applicable to the circumstances of the most ignorant and the most careless population. Essential conditions of such applicability, however, are that the structural arrangements should be adapted to their purpose, and that the management should be wholly undertaken and efficiently done by the servants of the sanitary authority. Where these conditions are observed as thoroughly as they are observed in parts of Liverpool and Bristol, water-closets are the best means of removing excremental matters from the poor neighborhoods of a town.

"Since Dr. French has been medical officer, and mostly since 1866, he has ordered and obtained the conversion of 14,393 privies into water-closets; and there were in 1869, in Liverpool, 20,000 privies attached to ash-pits, and 31,150 water-closets, 2,150 of which are tank or trough-closets.

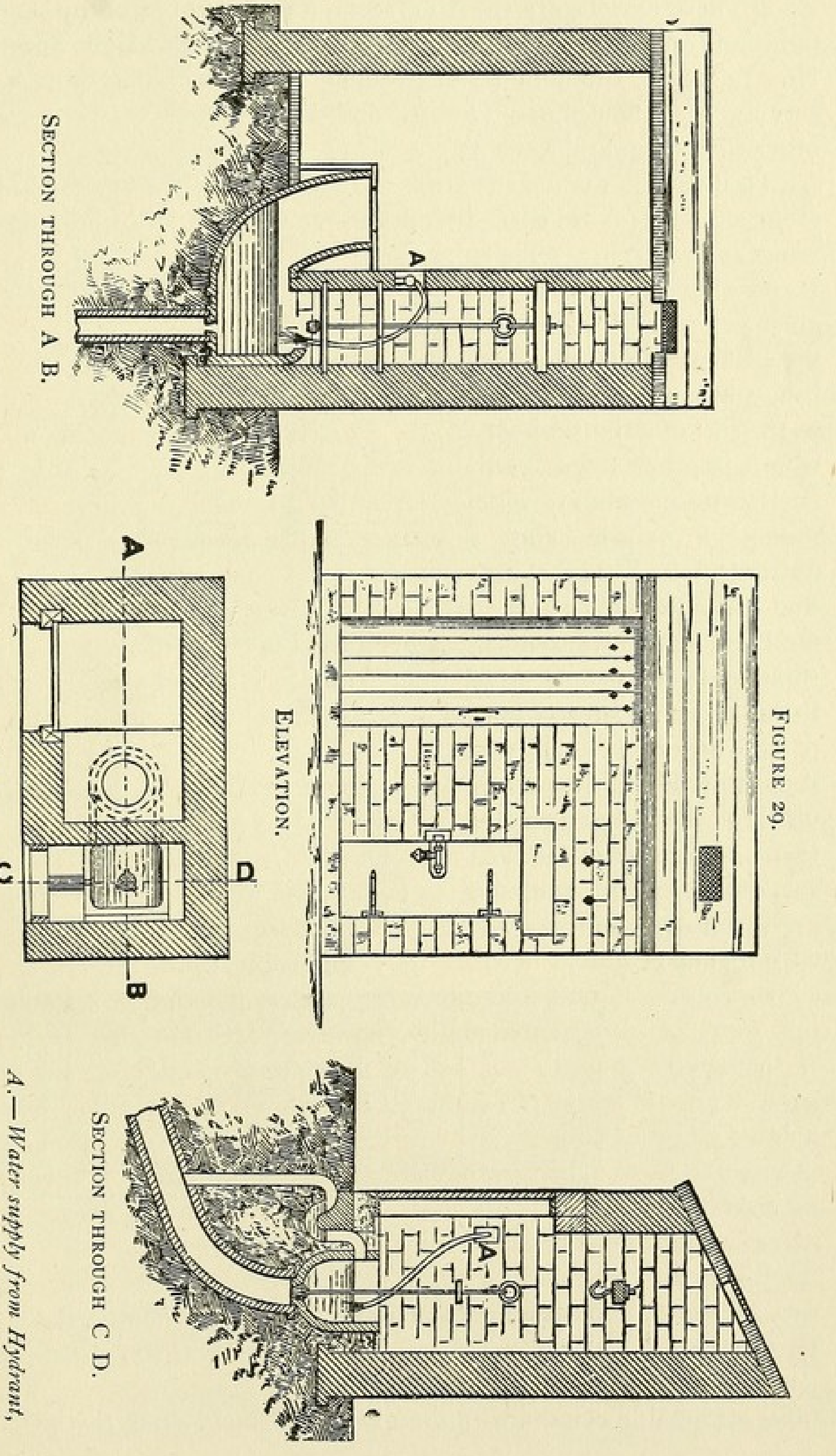


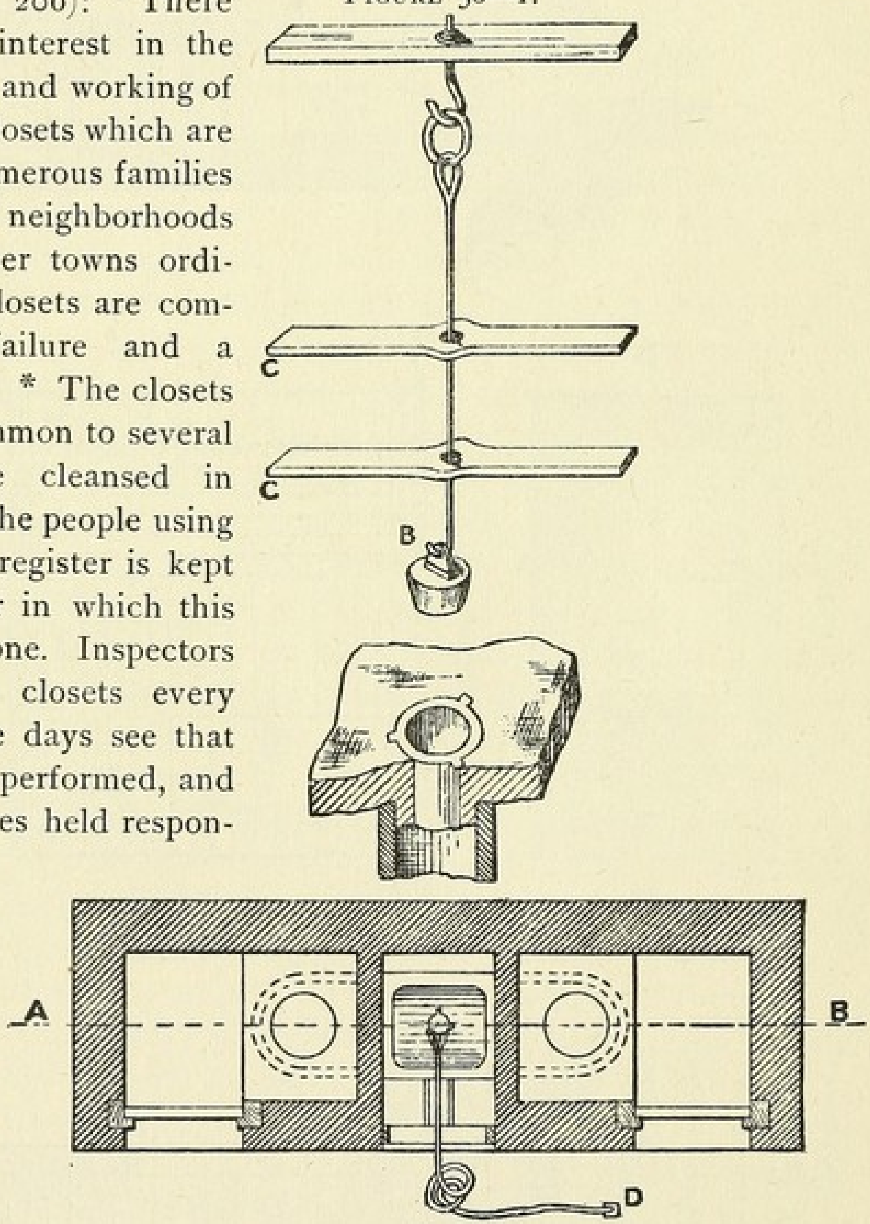
FIGURE 29.

A.—Water supply from Hydrant, with Hose inside Chamber.

"These closets are constructed on a pattern ordered by the Corporation, and approved as to details by the Borough Surveyor. Now in 1874, the number of troughs for trough-closets is 3,304, serving for about 6,000 closets, and the number of water-closets other than trough-closets, 43,395."

To illustrate the construction of these troughs the annexed plates (Figs. 29 and 30) are copied from the same report, with the following remarks (p. 206): "There is peculiar interest in the arrangement and working of the trough-closets which are in use by numerous families in the sort of neighborhoods where in other towns ordinary water-closets are commonly a failure and a nuisance. * * The closets that are common to several families are cleansed in rotation by the people using them, and a register is kept of the order in which this should be done. Inspectors visiting the closets every two or three days see that this duty is performed, and are themselves held responsible for any short-coming. By a little patience and firmness the inspector succeeds in obtaining the necessary cleansing, even among the most intractable classes, with very little assistance from the law. He

FIGURE 30—I.



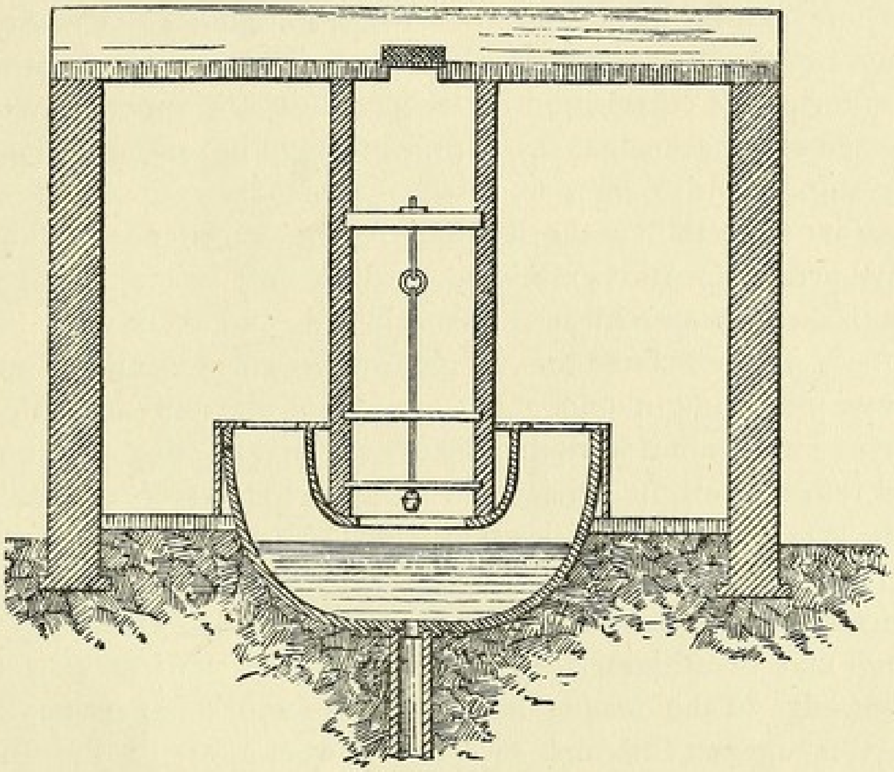
PLAN.

B.—Enlarged Drawing of Valve, Guide Rod (C), &c.

D.—Water Supply, with Hose from Hydrant fixed in Court.

will, if necessary, wait and see the closet cleansed out by the proper person. Last year only a dozen or so of people were summoned for

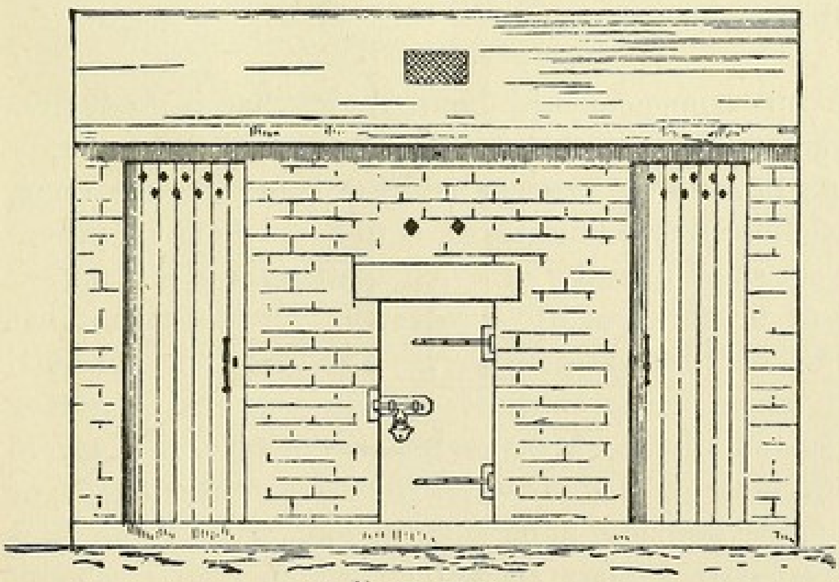
FIGURE 30—2.



SECTION THROUGH A B.

neglect in this respect, and three of the offenders had to be sent to prison. It will be seen from the drawing that in connection with these closets there is an opening of access to the trough and water-supply. This opening is for the scavenger, and the people using the closets have no concern with it. The scavengers are employed by the Corporation, and every day they visit each of the trough-closets, unlock the iron door of access, discharge the contents

FIGURE 30—3.



ELEVATION

of the trough, flush it out with hose and water, sweep it thoroughly clean, and leave it charged with fresh water for the next twenty-four hours' use."

"There can be no question of the admirable efficiency of the working of the arrangement above-described in the semi-public privies, nor of the recognition by the people of the superiority of the new to the old arrangements. Nor can there be any question that these results are due even more to the management of the whole business by the public authority than to the excellence of the constructive arrangements themselves. And not only is complete freedom from nuisance obtained where formerly filth and stink were universal, but Dr. French states that in 1868, when an epidemic of enteric fever was prevailing in and about Liverpool, the only localities that seemed exempt from it were the places occupied by the poor, in which we had removed all the privies and made trough water-closets."

One great difficulty in keeping such places free from vile odors arises from the extent of wood-work exposed to saturation by urine, the decomposition of which is quite rapid and extremely offensive. This evil may be mitigated by constructing the vertical slab under the front edge of the seat of hard slate or similar impervious material. It is against this slab or "riser" that most of the urine is voided, and when it is made of soft wood, as is generally done, it soon becomes a mere sponge for its accumulation and decomposition. The floors of such places should also be flagged with slate, and it would be far better if the seats could be made of a material less absorbent than wood.

URINALS.

There is no fixture connected with house drains that is productive of more annoyance than these, owing to the rapidity with which urine becomes putrid, and the careless habits of those who use them, or the neglect of those whose business it is to keep them in proper condition. A very small quantity of urine spattered on the surface of the fixtures or on the floor will render the whole surroundings offensive in a few hours in warm weather. The best form for such fixtures is that where water is always standing or rather *moving* through a trough, and all the surface on which the urine is likely to fall should be constantly wetted by water from a perforated pipe or sprinkler. Of course the more impervious the material of the floor the better. Glazed tiles or slate are good. Wooden floors should never be used for such places that are frequented by numbers of men and boys. In all places, whether in private houses or elsewhere, the frequent washing with warm suds is essential for the fixtures themselves and all their surroundings. This should be repeated several times a day for public places in warm weather, and never omitted more than twenty-four hours in any weather or any place. The disgusting condition of the surroundings of most urinals of public resort is too well known to need comment. The perfection of the fixture may help, but soap and water are essential, and cannot be dispensed with, whether the floor be pine, marble or tiles.