SMITHSONIAN MISCELLANEOUS COLLECTIONS.

— 1073 —

HODGKINS FUND.

THE AIR OF TOWNS.

BY

DR. J. B. COHEN,
Of Yorkshire College, Leeds, England.

[WITH TWENTY-ONE PLATES.]

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[These Lectures were submitted by Dr. J. B. Cohen, of Yorkshire College, Leeds, England, in the Hodgkins Fund prize competition of the Smithsonian Institution.]

Lecture 1.—Close Rooms.

Perhaps I ought first to explain my reason for selecting for these four lectures the subject of "Town air," a subject which, if it can not be characterized by the word *dry*, certainly does not sound attractive. My reasons are threefold—its importance to health, a personal interest in the subject, and a desire to arouse the same interest in others.

I wish that I could paint for you my ideal city of Leeds—a smokeless atmosphere through which the sun, when he did shine, would shine with his full brilliancy, wide streets interrupted by open spaces with green turf, trees, and flower beds, and a little ornamental relief to the dead monotony of our brick walls.

I am sure you will all agree with me that under such conditions our moral and physical well-being as a community would be vastly improved. "There are two great wants," writes Miss Octavia Hill, "in the life of the poor of our large towns, which ought to be realized more than they are—the want of space and the want of beauty."

You may at once stamp these views as Utopian. Speaking for myself, I have every expectation of seeing them realized. I think that if people can only be convinced of a possibility it is not a long step to its becoming a reality. I think I shall have no difficulty in convincing you of the possibility. Although everyone is quite aware that town air is a different article from fresh country air, it excites very little notice unless, as sometimes happens, we are brought face to face with it during foggy weather when the dirt and impurities accumulate under a thick layer of mist. The reason, I think, is to be found in the fact that air is invisible.

"Seeing is believing" is a common saying, and I suppose the reverse is true.

How long has it taken civilized communities to recognize the evil effects of bad water? Clear, sparkling water may contain the germs of disease, yet we see nothing of them. The death roll of all our battlefields probably does not number so many victims as that of contaminated water. What is the result? An unlimited quantity of pure water is regarded as the first essential to health. We go far afield for it. Manchester, at a cost of £3,000,000, drinks the water from the rivulets of Cumberland. Liverpool pays a high price for the water of the Welsh hills.

As regards the air we breathe, we stand much in the same relation as Mohammed to the mountain. As we can not bring pure air to the town, we go and seek it in the country or by the sea; that is, those of us who can afford it.

But there are many Mohammeds who never see the mountain. How many there are may be judged from this fact, that according to the registrar-general's report, out of a population in England and Wales of 29,001,018 on April 5, 1891, 20,802,770 persons were urban and 8,198,248 were rural, i. e., nearly three-quarters live in towns as against about one-quarter resident in the country.

What is the effect of this town air upon the urban population?

Where changes are occurring which are imperceptibly affecting individuals, and to the cause of which we therefore can not definitely point, it is possible by coordinating a large number of observations to so multiply the effect that we can arrive at a very probable estimate of it and lay our finger on the cause.

By means of *statistics* from the health returns of medical officers we can compare the health of the town with that of the country. Dr. Tatham, medical officer for Manchester, in a life table compiled for Manchester, has shown that "if we take three periods, under 25 years of age to represent youth, the period between 25 and 65 to represent maturity, and ages above 65 to represent old age, it will be found that males in Manchester are young for 94 per cent, mature for 87 per cent, and old for 46 per cent as long as in England and Wales. We are almost forced to the conclusion that in Manchester men grow old sooner than in the country as a whole."

What may be said of Manchester may also be said of Leeds and other industrial towns. This, of course, might be put down to the strain and worry of business life; but if we compare the diseases from which people die in town and in the country, those who have examined the medical returns must have been struck by the number of deaths in towns from diseases of the respiratory organs, pneumonia, phthisis, etc. My friend and colleague, Mr. Wager, of the Yorkshire College, took some trouble to obtain statistics on these points in regard to Leeds, and found that the percentage of deaths from diseases of these organs was considerably greater in the town than in the surrounding districts. As I prepared this lecture, the quarterly return from the medical officer for Manchester arrived for the quarter ending September, 1893, and here I found that out of 400 deaths between the ages of

25 to 45 years by far the largest number (122) are due to phthisis, and the next largest number (38) to pneumonia. This high percentage of deaths from such diseases is characteristic of all large manufacturing centers.

But we need not have recourse to these statistics to assure ourselves of the beneficial effects of fresh air. We have all experienced them. Statistics, however, emphasize the cumulative effect of imperceptible changes—an effect which you will all admit is sufficiently serious.

There is such a thing known as cumulative poisoning. White lead, for example, taken internally in minute quantities will in time produce the effect of a poisonous dose. Bad air is also an example of a cumulative poison.

According to Professor Foster, the average individual inhales 2,600 gallons of air in twenty-four hours, or about 34 pounds by weight, as against 5½ pounds of food, liquid and solid, or six times the weight of food. If we had to buy our air at so much a pound or pay rates on it at so much a cubic foot or gallon, we should take good care that it was not adulterated; for we distinguish fresh air as we do fresh butter from the second-rate article. There is, however, an important distinction between food and air regarded in this way. If the food we take is not quite as nourishing or as good as it should be, the digestive process is sufficiently adaptable to select the good and reject the bad; but the lungs are infinitely more delicate in structure and function, and we can not with impunity inhale a vitiated air and expect our lungs to select the pure and reject the impure without permanent injury to our breathing apparatus as well as to our whole body.

Before passing to the subject of "Town air," I should like you to grasp and keep well before you the idea that we are living at the bottom of a great ocean of air, that we are surrounded on all sides by matter invisible because composed of minute particles (separated by spaces which are big in comparison with the particles) but none the less material.

That the air has weight was first demonstrated by Galileo about the middle of the seventeenth century. I will repeat his experiment:

A glass globe (fig. 1), furnished with a brass stopcock is evacuated by the air pump, the stopcock closed and the vessel then carefully counterpoised. On opening the stopcock air rushes in with a hissing sound, and the balance now sinks at the arm to which the globe is suspended, thus showing that the air has weight.

Now, this invisible matter or gas is not a single gas, but a mixture of gases—mainly two.

One of these gases is nitrogen, an inert gas, whose chief properties are negative. It constitutes about four-fifths of the total bulk of the air and serves to dilute the other constituent, oxygen, which is the active part. This gas helps things to burn and supports life by consuming waste tissue and keeping up the animal heat. In these processes the free oxygen is removed from the air by entering into combination with the substances which it burns or consumes.

A piece of charcoal is attached to an iron rod, which passes through a metal plate (fig. 2). The charcoal is first heated until it begins to glow, and is then brought into a glass jar containing oxygen. The charcoal immediately glows with dazzling whiteness by uniting with the oxygen to form carbonic acid.

I shall have very little more to say about these two gases, but shall now direct your attention to another gas, carbonic acid, which is always present in the air, usually in a minute quantity. Its presence may be most readily shown by exposing to the air some clear limewater in a glass basin, when the surface is soon coated with a white film of carbonate of lime. It is also a very heavy gas, as I can show you by the following experiments:

In fig. 3, *a* represents the vessel containing the clear lime-water, which on standing becomes covered with a white film of carbonate of lime; *b* represents the vessel containing the heavy gas, carbonic acid, upon which the soap bubble floats. The apparatus figured at *c* is for generating carbonic acid. It consists of two vessels, which are connected by glass tubing. The larger vessel contains marble. By pouring acid down the funnel a brisk effervescence occurs, carbonic acid being evolved, which bubbles through the second vessel containing water to remove impurities, and is then used for filling *B* with gas.

A large glass beaker (fig. 4) is suspended at one arm of a balance and carefully counterpoised. By slowly inverting another beaker containing carbonic acid above the open mouth of the suspended one, the latter becomes filled with the heavy gas and descends.

The following table gives the volumes of the different gases in pure air in 100 volumes and also the total weight of these gases:

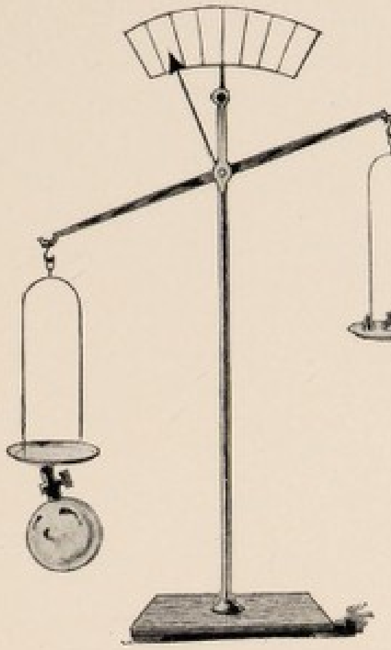
Composition of the atmosphere.

Oxygen	20.61
Nitrogen	77.95
Carbonic acid	0.03
Aqueous vapor	1.40
Nitric acid	Traces.
Ammonia	Traces.
Ozone	Traces.

Composition of the atmosphere in tons.

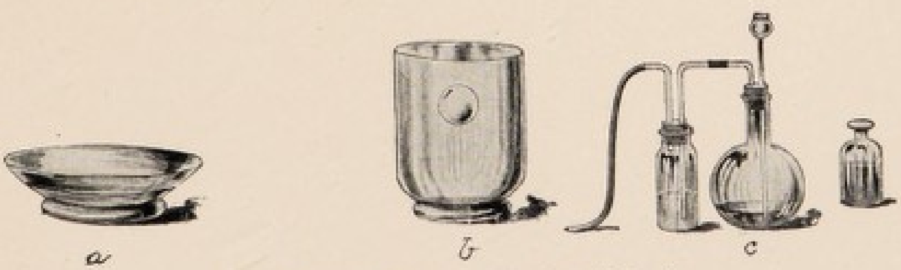
	Millions of tons.
Oxygen	1,233,010,000
Nitrogen	3,994,593,000
Carbonic acid	5,287,000
Aqueous vapor	54,460,000

Where does carbonic acid gas come from? From coal, charcoal, or other fuel when it burns. (The jar in which the charcoal was previously burnt in oxygen was shaken with limewater, and by becoming



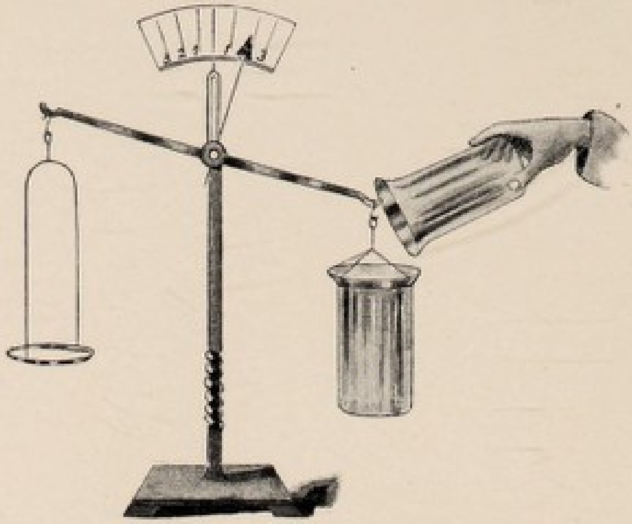
1.—Apparatus for weighing air.

2.—Charcoal in oxygen.



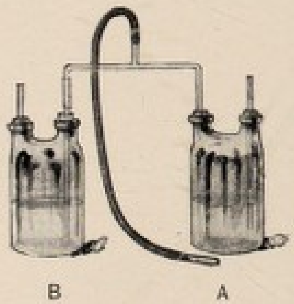
3.—Demonstration of carbonic acid in air.

THE AIR OF TOWNS.



4.—Weight of carbonic acid.

5.—Demonstration of carbonic acid in breath.



6.—Demonstration of carbonic acid in the lungs.

7.—Production of carbonic acid.

THE AIR OF TOWNS.

turbid indicated the presence of carbonic acid.) It is given off from the breath, as the following experiment will show:

By filling a bell jar (fig. 5) with water and breathing air into it from the lungs an atmosphere is obtained within the jar which readily extinguishes a taper, indicating the large percentage (about 5 per cent) of carbonic acid in the breath.

Two bottles (fig. 6), each provided with a double neck, are so connected that air may be drawn into the lungs through the liquid contained in *A* and expelled through the liquid in *B* without removing the tube from the mouth. If clear limewater is introduced into these two vessels, that contained in *B* will very shortly become turbid, indicating the presence of carbonic acid in the lungs, whilst *A* remains clear.

Carbonic acid is produced by fermentation and the decay, which is another form of fermentation, of animal and vegetable substances.

A solution of grape sugar is introduced into a flask (fig. 7), together with a quantity of brewers' yeast. The flask is provided with a cork through which a bent tube passes. The longer limb dips into a test glass containing limewater. If the flask is allowed to stand at the ordinary temperature, the liquid begins to froth and bubbles of carbonic acid rise through the limewater, turning it milky. After a few hours a sufficient quantity of alcohol will be formed to enable its presence to be demonstrated. On bringing some of the liquid into a flask fitted with a long glass tube and boiling it, the vapors passing out of the tube will take fire and burn with the blue flame of burning alcohol.

All these processes go on at the expense of the oxygen of the air, which in time would disappear. It has been estimated that it would require 900,000 years to consume all the oxygen in the air and convert it into carbonic acid. Long before this, however, life would have ceased on the earth, for a slight increase in the amount of carbonic acid or diminution of oxygen would render the atmosphere unfit for respiration.

We are fortunately not threatened by any such catastrophe. No accumulation of carbonic acid can occur in the open air under natural conditions, for although carbonic acid is a heavy gas, it rapidly diffuses.

Two flasks (fig. 8) are connected by a long piece of narrow tube. In the lower flask the heavy gas, carbonic acid, is introduced, and in the upper one, the light gas, hydrogen. Owing to the property of diffusion some of the heavier gas will be found after a time to have passed into the upper flask and the lighter gas to have passed downward.

Carbonic acid therefore becomes quickly disseminated through the atmosphere. Vegetation now steps in. The green coloring matter of plants, termed chlorophyll, has the property in presence of sunlight of splitting up the carbonic acid, absorbed from the air around, into carbon, which it retains for its own growth, and into oxygen, which is restored to the atmosphere. We need not, therefore, trouble ourselves with the accumulation of carbonic acid wherever vegetation is allowed to flourish, and where the quantity of carbonic acid does not accumulate too rapidly to be dealt with by nature in this manner.

It is therefore obvious that overcrowding, want of open spaces, and the absence of vegetation favor the accumulation of carbonic acid.

Overcrowding has, however, been dealt with by legislation, and where legislation steps in we may be sure that the evil is a real and a pressing one.

Governments and municipalities have recognized the importance of open spaces, of streets of a certain width, of open spaces at the backs of houses, of a certain number of cubic feet for each inmate in lodging houses, hospitals, workhouses, prisons, etc.

This will help to check the accumulation of carbonic acid. But although people are content to live in crowded and smoke-laden towns, vegetation is not so easily persuaded to forego its natural atmosphere, and the smoke question must be dealt with before we can stop the deposition of soot and let in the sunlight to give the necessary vitality to plant life, which should flourish in the very center of our big towns. Let us see now what the evil is. Here is a table showing carbonic acid found in different places:

Carbonic acid in the air.[1]

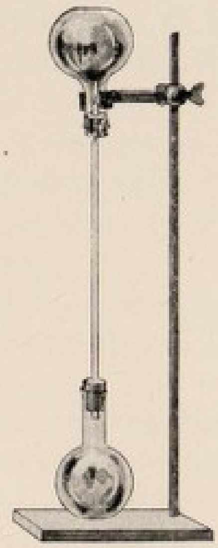
	Volume, per cent.
In mines, largest amount found in Cornwall	2.5000
Average of 339 analyses	0.7850
In theaters, worst parts as much as	0.3200
In workshops, down to	0.3000
About middens	0.0774
During fogs in Manchester	0.0679
Manchester streets, ordinary weather	0.0403
Where fields begin	0.0369
On the Thames at London	0.0343
In the London parks and open places	0.0301
In the streets	0.0380
On the hills in Scotland, from 1,000 to 4,406 feet high	0.0332
At the bottom of the same hills	0.0341
Hills below 1,000 feet	0.0337
Hills between 1,000 and 2,000 feet	0.0334
Hills between 2,000 and 3,000 feet	0.0332
Hills above 3,000 feet	0.0336

The amount seems very small. Perhaps the following diagram will represent the proportion more graphically:

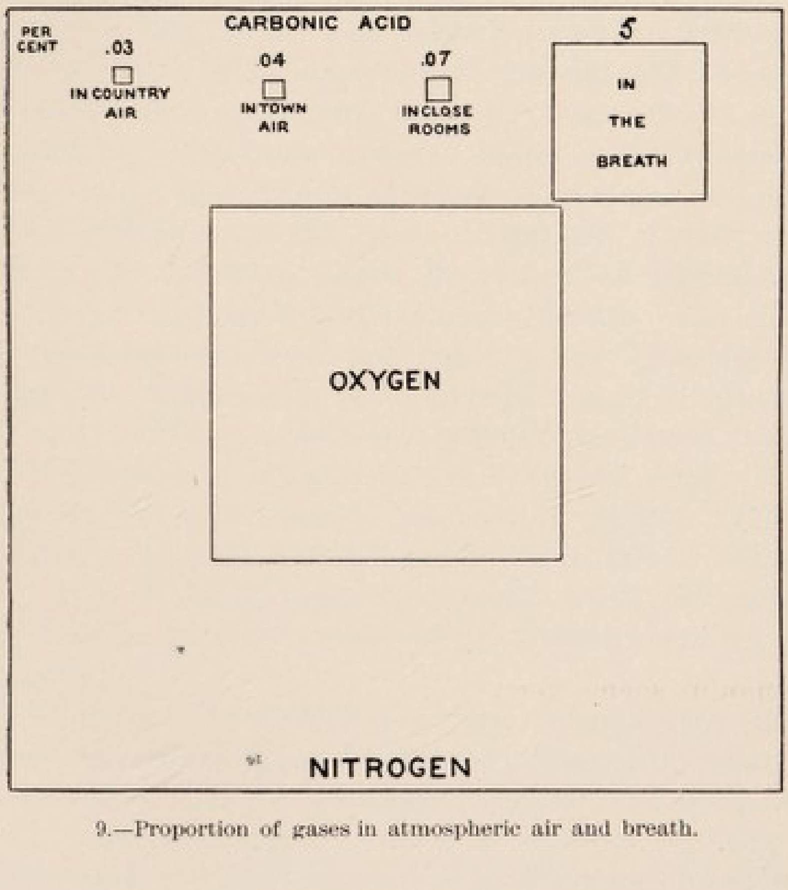
The diagram (fig. 9) is divided into squares showing the proportion of nitrogen, oxygen, and carbonic acid in the volume of air indicated by the large square.

Although the proportion of carbonic acid in good and bad air is so inconsiderable, we must not be led into supposing that the difference is negligible. There are many examples known to the chemist in which

[1] Angus Smith.



8.—Diffusion of carbonic acid.



9.—Proportion of gases in atmospheric air and breath.

THE AIR OF TOWNS.

a minute quantity of impurity may produce effects *apparently* quite disproportionate to the cause. We have it on the authority of Professor Roberts-Austen that a difference of one-tenth per cent of carbon in steel rails may be a very serious matter.

The steel cylinder, containing compressed oxygen, which recently burst at the station at Bradford with such fatal effect, contained only three-tenths per cent too much carbon—an amount, however, quite sufficient to account for the mischief.

The steel dies used in the mint should strike 40,000 coins on the average, yet if the die contained one-tenth too much carbon it would not strike 100 pieces without cracking.

Let us see what is the full effect of the difference in carbonic acid in town and country air. If we take country air to contain 0.03 and town air 0.04 per cent of carbonic acid, or a difference of 0.01 per cent, it will amount to about 1 additional quart of carbonic acid inhaled during the day, supposing we take into our lungs 2,600 gallons of air per diem.

This would weigh about 30 grains, an amount sufficient to kill ten people if the poison were as virulent as white arsenic. Moreover, we must remember that if we inhale 1 quart of carbonic acid more we take in 1 quart less of life-supporting oxygen. Is carbonic acid really so poisonous that a quart or gallon more carbonic acid and a corresponding amount of oxygen less would be hurtful to this extent? The answer is "No." Although from experiments made by Angus Smith in an air-tight leaden chamber, when pure carbonic acid was introduced to the extent of 3.84 per cent, two friends suffered after a few minutes from headache, and he himself soon felt great discomfort, it is known that workers in soda-water factories, where the amount of carbonic acid in the air reaches 0.1 per cent, are not injuriously affected. Yet our senses detect the difference between town and country air. We can perceive the difference between Manchester town air and that of the outskirts—a difference of only 0.0034 per cent—or between the air of the streets and the parks of London, which amounts to 0.004 per cent. Why can we detect these minute differences? Because, as Angus Smith says, carbonic acid always comes in bad company. It is its bad companions that affect us. It is the sulphurous acid, which accompanies burning coal and gas; it is the organic poison which accompanies the exhalations from the body.

The latter is the subject to which I now wish to direct your attention.

It is obviously very important to determine minute differences of carbonic acid in the air so that we may guard against the least increase in carbonic acid in the atmosphere. As little as 0.004 per cent can be detected by our senses, as we have seen, and a difference of 0.02 per cent is not pleasant when caused by want of ventilation. Angus Smith says: "We all avoid an atmosphere of 0.1 per cent in a crowded room, and the experience of civilized men is that it is not only odious, but unwholesome. When people speak of good ventilation in dwelling houses they mean, without knowing it, air with less than 0.07 per cent of carbonic acid. We must not conclude that because the quantity of carbonic acid is small, the effect is small. The conclusion is rather that minute changes in the amount of this acid are indications of occurrences of the highest importance."

What is the substance which accompanies the breath?

Dr. Ransome says that "the aqueous vapor arising from the breath and from the general surface of the body contains a minute proportion of animal refuse matter which has been proved by actual experiment to be a deadly poison. It is this substance which gives the peculiar close, unpleasant smell which is perceived on leaving the fresh air and entering a confined space occupied by human beings and other animals, and air thus charged has been fully proved to be the great cause of scrofulous or tubercular diseases, and it is the home and nourisher of these subtle microscopic forms of life that have lately become so well known under the title of germs of disease or microzymes. It is probably the source of a large part of that increase of mortality that seems inevitably to follow the crowding together of the inhabitants of towns." These views are shared by such eminent men as Dr. Foster, Prof. Du Bois-Raymond, Dr. Carpenter, Sir Douglas Galton, and others.

But in what manner has the above statement been put to the proof?

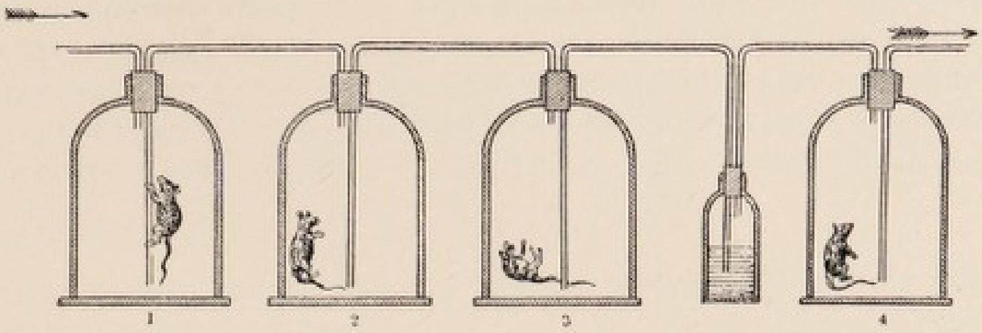
I desire to refer to a very ingenious experiment which has been carried out by the French physiologist Brown-Séquard.

Fig. 10 represents diagramatically an experiment similar to that of Brown-Séquard. Four bell jars are connected by glass tubes in such a way that by aspirating air through the open tube connected with the fourth bell jar a current of air is made to travel through the series in the direction indicated by the arrows. Between the third and fourth bell jars a vessel is inserted containing strong sulphuric acid, which removes the organic matter from the air passing into the last bell jar. By confining mice in these jars, the first mouse will get the fresh air, the second will breathe air vitiated by the first, and so on, the last mouse breathing the whole of the carbonic acid given off from the lungs of the first three. In this experiment the third mouse would die, but not the fourth, proving that it is the organic poison rather than the carbonic acid in bad air that produces the most serious effects.

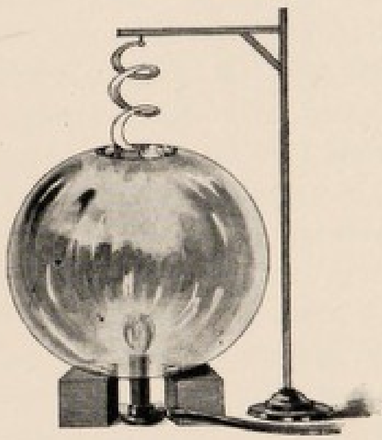
Whatever may be the exact nature of this poison, of which little more than its mere existence is known, there can be little doubt that the amount in town air, indicated by 0.001 per cent, produces a cumulative effect upon our vitality, which makes us long for fresh country air, and which no doubt enhances the depression induced by the gloom of our city surroundings.

Health like charity begins at home, and we should therefore start by studying the conditions under which we live in our own dwellings.

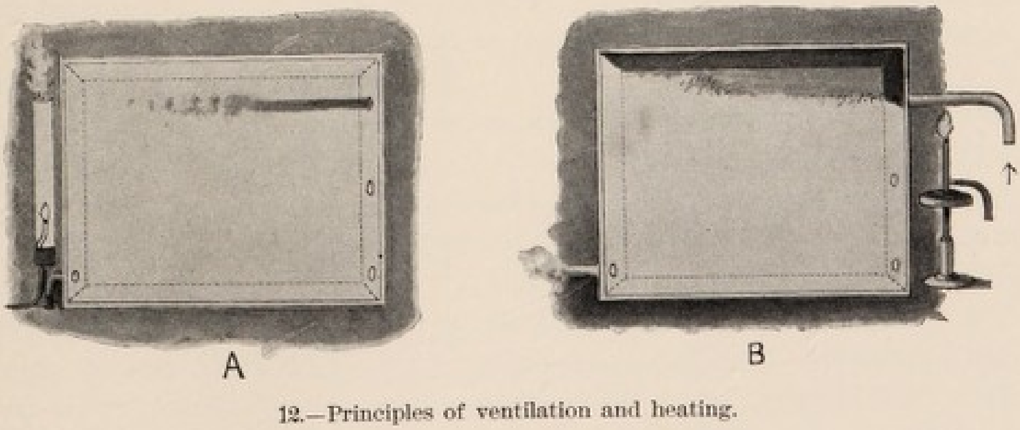
Let us consider the case of a person sitting in a room and consuming



10.—Brown-Séquard experiment with expired air.



11.—Ascent of warm air.



12.—Principles of ventilation and heating.

THE AIR OF TOWNS.

2,600 gallons of air in twenty-four hours, or breathing out 16 cubic feet an hour of air containing 5 per cent of carbonic acid. For the air to remain fairly fresh the amount of carbonic acid should not rise above 0.06 per cent; that is to say, the amount of carbonic acid should not increase more than 0.02 per cent, supposing the air to contain originally 0.04 per cent. How much fresh air will be needed per hour? This may be calculated as follows: $\frac{5}{0.02} \times 16 = 4{,}000$ cubic feet.

Air can not be renewed more than three or four times per hour without producing a perceptible current or, as we should say, causing a draft. It therefore follows that each individual should be allotted at least $\frac{4000}{4} = 1000$ cubic feet of air space. This renewal of air in closed places constitutes a branch of study termed *ventilation*. I have not time to discuss fully this important subject. A whole course of lectures might be delivered upon it. All that I can do in the short time at my disposal is to indicate the principles which underly it. The replacement of vitiated air by fresh air without creating draft is the basis of good ventilation.

This necessitates a flow of air. This flow of air may be produced by mechanical means—a fan or pump driving in air, exhausting the bad, or doing both simultaneously—or, more frequently in dwelling houses, by the natural currents produced by hot air.

When air becomes warm it expands. A certain bulk of this air compared with an equal bulk of the original air will be lighter. The warm air therefore ascends, colder air replaces it, and a flow of air is thereby produced. To show that warm air ascends, a large glass globe open at the top and bottom is supported upon blocks (fig. 11). On introducing a Bunsen burner at the lower opening a strong upward current of air is produced, which causes a spiral of paper pivoted to the horizontal rod to revolve rapidly. Strips of tissue paper gummed around the edge of the top opening form vertical streamers, also indicating the presence of an air current. Toy fire balloons of tissue paper illustrate this property of heated air exceedingly well.

It is for this reason that the warm air, which includes the expired air, finds its way toward the top of a room. It is for this reason also that an open fireplace with a good chimney produces a current of air, which rushes up the chimney to the extent of 150 to 300 cubic feet per minute. These two effects may be combined to draw off the vitiated air by introducing an opening into the chimney near the ceiling. But although by this means bad air is withdrawn and fresh air enters, the method of ventilation can not be considered wholly satisfactory. In my dining room with a good fire burning, I have found that the air passes up the chimney at the rate of 240 cubic feet a minute with the door open, and 200 cubic feet a minute with the door closed. In the first case the fresh air comes mainly through the open door; in the second, it finds its way through the chinks round the door or between the window sashes. It naturally follows that where cold air is entering through small inlets to supply 200 cubic feet a minute, drafts are frequently experienced by persons in the room, unless mechanical contrivances are arranged for directing the cold air to the top of the room.

It follows that ventilation produced by the currents set up by warm air is closely connected with the methods of warming a room. Regarded from this point of view, the open fireplace is the reverse of economical. The whole of the heating is here produced by radiation; that is, by heat passing from the fireplace to the walls, ceiling, and floor, which in turn transfer their warmth to the air in contact with them, and this represents a small fraction of the heat passing up the chimney.

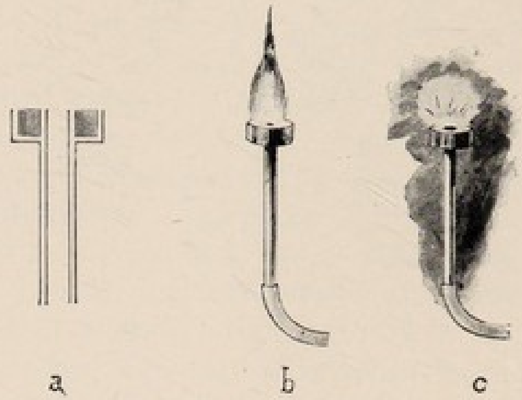
A more economical method is to warm the air of rooms by means of steam or hot-water pipes; but in this case there is no natural ventilation, no fresh air is introduced as with the open fireplace, and special means must be provided to supply the defect.

Another method is to supply a house with fresh air, which has been slightly warmed by passing it around a stove fixed in the basement or out of doors. In this case, if a suitable exit is provided to permit the vitiated air to escape, a constant current of fresh air is set up, which may effect the whole heating and ventilation of an ordinary dwelling house at a comparatively small cost for fuel. In large buildings, such as warehouses and factories, the same result is effected by pumping in at the basement fresh air, warmed by passing through a stove and mixed in any desired proportion with cold air and drawing off the vitiated air by means of an exhaust fan placed at the top of the building. These principles may be demonstrated by the following experiments:

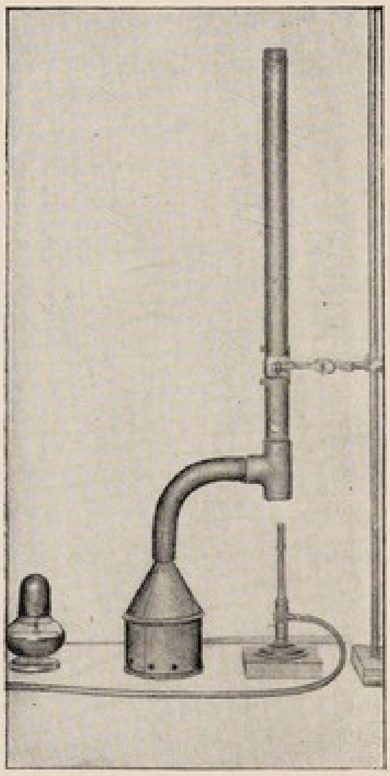
The illustration (fig. 12) represents a shallow, air-tight box with a glass front. Three small circular holes are bored along one side equidistant and one at the bottom of the opposite side. In *A* this hole is fitted with a glass ⊤ piece, the top vertical end of which passes through a cork of a lamp chimney. Through the same cork a gas burner is fitted. The box is filled with a dense fog by blowing in ammonium chloride fumes and is brightly illuminated by a lantern. When the gas jet in the chimney is burning, one of the circular holes is opened to the air, and the lower vertical end of the ⊤ piece closed, we have on a small scale the conditions of ventilation in a room with an open fireplace. The air enters through one or all of the circular holes, appearing in the fog like black smoke, and the white fumes are observed to issue from the top of the lamp chimney. The other experiment figured at *B* is to illustrate heating and ventilation by warm air. Air enters the box through the bent pipe, which is heated by a burner. The warm air, which appears at the top of the foggy chamber as a dark cloud, gradually displaces the fog, which is driven out at the lower left-hand aperture and the chamber is thus filled with warm fresh air.

The importance of placing within the reach of every person a method of determining quickly and accurately the amount of carbonic acid in the air has induced me to devise a process, a description of which will be found in the appendix.

13.—Luminosity by solid matter,



14.—Experiments with flame.



15.—Principles of smoke prevention.

THE AIR OF TOWNS.

Lecture 2.—Smoke.

Smoke is solid matter given off during burning. Gunpowder smoke is largely mineral salts and so is tobacco smoke. Coal smoke is soot—that is mainly what chemists call carbon. All the common inflammable substances, coal, wood, paraffin, petroleum, benzine, as well as coal gas, contain carbon and in luminous flames the carbon can readily be shown as soot. I have only to bring this white plate into the candle flame and we have as you see at once a deposit of soot. This soot in the flame is white hot and gives to the flame its luminosity. The luminosity imparted by solid matter to a nonluminous flame may be readily demonstrated.

Here is a blow pipe (fig. 13), fed with coal gas and oxygen, which gives as you see a nonluminous flame like burning spirits of wine, but it is nevertheless a very hot one, for as soon as I introduce a lump of infusible material, like quicklime, the latter becomes in a moment white hot and brilliantly luminous.

But an ordinary luminous flame is not necessarily a smoky one, because the soot burns when it reaches the outside of the flame and comes into contact with the air.

Why is it, then, that luminous flames are sometimes smoky and sometimes not? Coal and wood, benzine, paraffin, turpentine, and often tallow and wax candles burn and give off soot. It is because there is too little air where the flame is hottest. The soot as it passes up gets cool and when it reaches a new air supply it is too cold to take fire. It is this that makes a candle, with a wick that requires snuffing, give a smoky flame, because with the long wick it is supplying more combustible to the flame than the surrounding air can burn.

An ordinary oil lamp smokes until the chimney is put on. Then the draft up the chimney is increased, more air is supplied, the flame gets hotter and therefore brighter, and the soot is burned up.

Here is a smoky turpentine flame. By blowing oxygen through the center a brilliant nonsmoky flame is produced.

In *a*, fig. 14, we have a section of the apparatus. It consists of a metal tube, furnished at the top with a hollow metal rim, which is filled with cotton wool soaked in turpentine; *b* represents the smoky turpentine flame and *c* the flame after admission of oxygen.

Soot or coal smoke is then an inflammable part of the fuel and where soot is allowed to escape, the fuel is lost. If, then, we not only feed the flame with more air, but at the same time make the soot hot the smoke is consumed. These are the two simple principles of smoke prevention. Let me show you this by an experiment with a model furnace, flue, and chimney (fig. 15). This consists of a straight metal pipe open at both ends and perforated with air holes near the lower end. A bent metal arm is fixed on by a T piece and represents the flue. The furnace is represented by a turpentine lamp, which burns inside the sheet-iron case. Volumes of smoke issue from the top of the chimney until a Bunsen flame is introduced within the lower end of the chimney, when the smoke suddenly ceases.

Various forms of grates and furnaces have been proposed for preventing smoke; some utilize more of the heat, and so reduce the consumption of coal; others, by various devices of air inlets at certain times of firing and at special points of the grate, burn up the smoke before it passes to the flue.

I do not intend, for I do not feel competent, to explain the advantages or disadvantages of the large variety of smoke-preventing appliances now before the public. A great deal has been written on the subject by competent persons, and anyone who wishes for information may very easily procure it.[1]

What are the effects of smoke? Before attacking this question, we ought to consider the extent of the evil.

I am making determinations, which are now in progress, and though still very incomplete I am able to give an approximate estimate of the amount of solid matter in the air of Leeds which is mainly due to smoke. There is daily sent into the air of Leeds 20 tons of soot, of which one-half ton falls, and of that one-half ton, 20 to 25 pounds stick; that is, are not removable by rain. How have these figures been arrived at? I have found that in the town 100 cubic feet of air contain on the average over 1 milligram of solid matter which is mainly due to smoke. If, now, we take the most thickly populated area of the city as covering 4 square miles, and supposing the sooty atmosphere to penetrate to a height of 300 feet, the amount of solid matter will be about 800 pounds, constantly floating over these 4 square miles. If, further, we assume that the air of the town is renewed from ten to fifty times in twelve hours, according to the strength of the wind (and it is nearer the latter than the former number, as I will show in a moment), this will mean, taking the higher number, rather under 20 tons of smoke delivered to the atmosphere during the working day. Why do I take fifty as the frequency of atmospheric renewal? The difference in the amount of carbonic acid between country air and town air such as is found on the average in industrial centers like Glasgow and Manchester, and we may also include Leeds, is 0.01 per cent. There are at least 4,000 tons of coal burnt in Leeds every twenty-four hours, yielding 12,000 tons of carbonic acid, and in addition there are 300 tons given off from the lungs of the inhabitants, i. e., in all, 12,300 tons. If we keep to the same area of 4 square miles and the same height of 300

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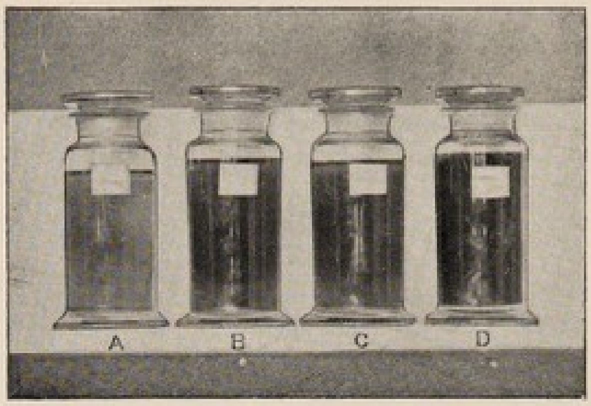
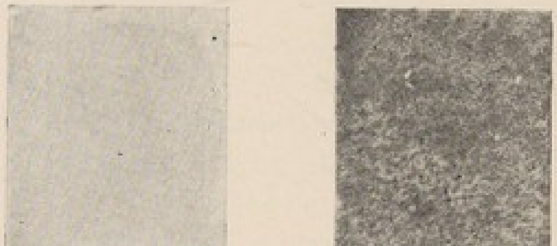
[1] I should recommend the following pamphlets: The report of "The National Association for Testing Smoke-Preventing Appliances," the address of whose secretary is Mr. Fred Scott, 44 John Dalton street, Manchester. "On the abolition of smoke from steam boilers," by T. Patterson, M. D. Publishers, Chronicle Office, Oldham. "The Smoke Nuisance," by Herbert Fletcher, published by John Heywood, Deansgate, Manchester. "Report of the Sheffield Smoke Abatement Association," published by Leader & Sons, 21 Fargate, Sheffield.



16.—Coal dust in the air.



A. Country Plate. B. Town Plate.

17.—Coal dust in the air.

The Air of Towns.

feet, which we took as the smoke-infected area, the amount of carbonic acid would be about 1 per cent higher in twenty-four hours, or would have to be renewed fifty times in twelve hours to keep down the average amount of carbonic acid to 0.04 per cent.

Let us attack the problem in another way. In Professor Roberts-Austen's report on the London smoke-abatement exhibition a large number of analyses are given, from which it is easy to calculate the weight of smoke from coal burnt in house fires. These analyses refer to different kinds of smoke-preventing domestic fire grates burning different kinds of coal. According to these results about 5 per cent of the coal burnt gets into the air. Mr. Russell, of the Yorkshire College, and myself experimented in the same direction and arrived independently at the same conclusion, without having referred to the results of Roberts-Austen's analyses.

If we take 100,000 tons as the house consumption of coal in the year for Leeds, this is equivalent to about 11 tons in twenty-four hours throughout the year. If we allow an equal amount for factory chimneys, this brings it to 22 tons in twenty-four hours. Or if we follow Scheurer-Kestner and take one-half to three-fourths per cent as the amount of coal given off as smoke from boiler furnaces, then if Leeds consumes 1,500,000 tons of coal a year, or 4,000 tons a day, one-half per cent upon this is equivalent to 20 tons a day. So you see that whichever way we work our calculation we can not get below 20 tons of smoke a day, and I consider that this figure represents a minimum quantity rather than the true average.

And now as to the amount that falls. The winter before last snow fell on January 7. A sample covering 1 square yard was carefully removed from a gravestone in the parish churchyard a short time after the fall ceased. The snow was melted and analyzed. Fresh samples were taken and analyzed on the following three days. They contained a variety of things in solution—ammonium sulphate, sulphate of lime, and free sulphuric acid, all mainly derived from coal. We need not trouble ourselves about these at present, although we can not mask the injury which this corrosive acid produces upon vegetation and the stone and brick work of our buildings.

It is the solid matter which now concerns us.

Here are some of the samples (fig. 16): *A* was collected on the first day, *B* on the second, *C* on the third, and *D* on the fourth. The accumulation of soot is evident from the depth of color.

The weight of solid matter carried down, as determined from the first sample, was equivalent to 16 hundredweight on the square mile. The additional weight of soot which accumulated each day was equivalent to 4 hundredweight on the square mile; or, if we take a smaller quantity as an average over the 4 square miles of the city, we arrive at the daily smoke fall of about one-half ton.

It is impossible to say what proportion of the soot in the air, during the snowfall, the 16 hundredweight represents, but it all points in one direction, that the waste of fuel in the form of unburnt coal passing into the air is prodigious. Estimated for the whole country, it would mean not an insignificant item of loss to the nation.

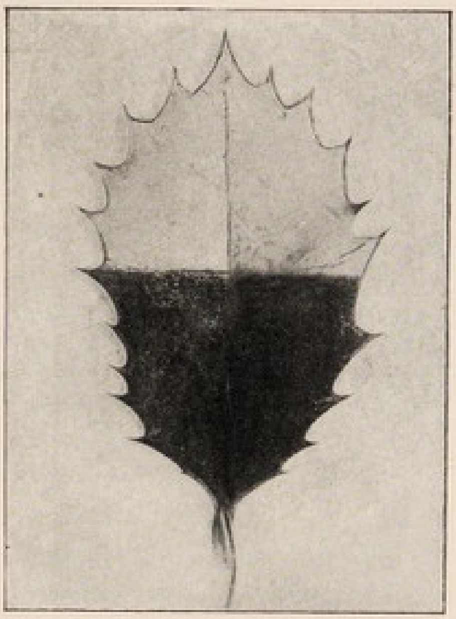
Before we can understand the effects of smoke we must learn its composition. I have analyzed two samples, one of which was deposited on the orchid houses at Chelsea during fog, and the other was obtained from my chimney sweep. They contained respectively 14 and 15 per cent of a nasty, sticky oil. Were the soot pure carbon it would be comparatively harmless. It would possess no smell, it would not adhere to anything, and the first fall of rain would wash it away. Unfortunately, this is not the case. Wherever the soot alights a great part of it sticks, and no amount of rain water will remove it. That is why our buildings become permanently black and foliage is discolored.

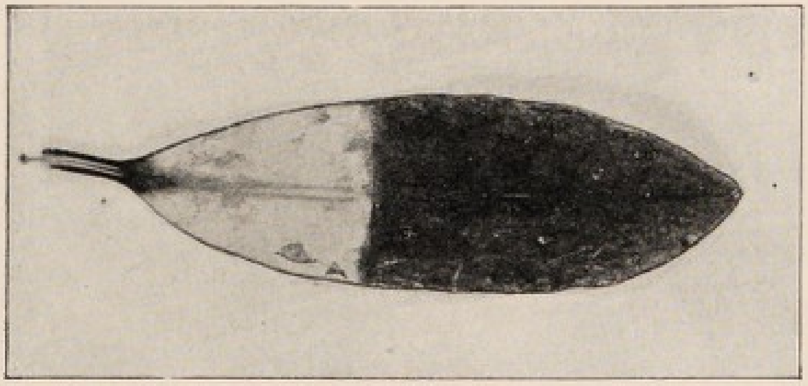
In order to demonstrate to you the effects of this sticky material in the soot, I analyzed the deposit on three glass plates, 1 foot square, which have been stationed in different spots—one at Pool (about 9 miles from the center of Leeds), one on the roof of the Yorkshire College (about 1 mile from Leeds), and one on the roof of the Philosophical Hall (in the town)—all being removed from the immediate neighborhood of chimneys. This is the appearance (fig. 17) which two plates present after a years' exposure, one in the country and the other in town. *A* remained clean and transparent, whereas *B* was quite opaque.

A series of experiments of this nature extending over many months, in which the deposit after washing was weighed, showed that the deposit on the Philosophical Hall plate was twenty-four times and on the Yorkshire College plate ten times that on the Pool plate, the latter being insignificant in quantity.

The effect of breathing such a filthy atmosphere can only be indirectly gauged. That it plays no insignificant part, by clogging the air passages, in bringing about the high mortality from respiratory diseases, so conspicuous in all industrial towns, can not for a moment be doubted. Its fatal effects upon vegetation are obvious. The green leaf of the plant is its perspiring organ, and the leaf is provided with little pores—the stomata. When these get clogged with soot the plant dies, just as a human being would if the pores of his skin were closed by a layer of varnish. But the soot in the air does more than this. The plant derives the principal material for its growth from the carbonic acid in the air. By the aid of the green coloring matter, the chlorophyll, which is found in the leaf or stem, the carbonic acid of the air is decomposed, the oxygen being restored to the atmosphere and the carbon retained by the plant. This process only occurs vigorously in sunlight. What, then, must be the effect of the black deposit upon the leaf in shutting out that light, and what must be the effect of the smoke-laden air in preventing the passage of the sun's rays?

Here are photographs of two leaves gathered near the town (fig. 18). From half of each the deposit of soot has been wiped off and the





18.—Photographs of leaves, showing deposit of soot; half removed.

THE AIR OF TOWNS.

green color then bleached, without disturbing the sooty deposit on the other half.

The diminished amount of sunlight received in the town of Leeds may be gathered from the simultaneous records taken at the Philosophical Hall and at Adel (4 miles from the city). In the year 1892, there was 43 per cent, and in 1893, 30 per cent more sunshine at Adel than in Leeds. This is the record of hours of sunshine, but not of its intensity. The latter, had it been recorded, would probably have shown a still greater difference.[1] I said that the snow in the parish churchyard contained acid—sulphuric acid. This acid is, like soot, derived from coal, for it is never found in the country. The sulphur in the coal, which is present to the extent of from 1 to 3 per cent, burns, and a portion passes up the chimney as sulphurous acid, and then into the open air. It is this sulphurous acid which imparts to town fog its choky and irritating effects. In the open air it is rapidly converted into the much more corrosive substance—sulphuric acid, which nearly always accompanies soot, and it is found with soot on leaves, and probably promotes their early withering near towns. Moreover, it corrodes the mortar and stone work of our buildings.

The following table, prepared by the Manchester air analysis committee, gives the analyses of deposits upon leaves gathered in and near the city. The places are arranged in the order as we pass from the outskirts to the center of the town:

Deposits on holly or aucuba leaves collected December 14–16, 1891.

[Milligrams per square meter of leaf surface.]

Locality.	Solid matter.	Sulphuric acid.
Alexandra Park	131	7.2
Owens College	315	10.4
Hulme	420	26.0
Harpurhey	443	19.0
Infirmary	728	27.5
Albert Square	833	24.2

It has been said that however much you may do away with smoke, you will never remove this acid; it will still pass into the air. Quite true; but to anyone who advances that as an excuse for the smoke maker, I would say this: Soot is an oily substance not wetted by water. The acid, therefore, attached to it is not washed away by rain so rapidly as it certainly would be, if it were not in contact with this film of oily matter. Although sulphurous and sulphuric acids are injurious to plants, I do not believe the quantity given off from our chimneys would prove nearly so hurtful as it is now in company with soot.

There are real or imaginary difficulties in the way of stopping smoke from house fires, yet I firmly believe that before another generation has

[1] Since this lecture was delivered experiments on the intensity of the light have been made and will be found in Appendix II.

passed away people will look back upon the hideous heap of black stones stowed away in an ornamental box in every dwelling room as we now contemplate the tinder box or the tallow candle. But if domestic chimneys are responsible for half, or even more than half the smoke, it is no reason why we should suffer from the other half if it can be removed. Let me now direct your attention to the legal aspect of the question. It may be said that this lies beyond the province of the scientific man, but my conscience would not be satisfied if I did not link to a subject, which I regard as of serious importance, the knowledge of how the evil may be compassed. Legislation in regard to smoke abatement is to my mind as simple as it is just.

The Public Health Act, 1875, part 1, subsection 7, states:

"For the purposes of this act, any fireplace or furnace which does not, as far as practicable, consume the smoke arising from the combustible used therein, and which is used for working engines by steam, or in any mill, factory, dyehouse, brewery, bakehouse, or gas work, or in any manufacturing or trade process whatever, shall be deemed to be a nuisance, and liable to be dealt with summarily in the manner provided by this act."

This is in regard to furnaces. In respect of chimneys, the second part of subsection 7 of section 91 says:

"For the purposes of this act any chimney, not being the chimney of a private dwelling house, which emits black smoke in such quantities as to be a nuisance, shall be deemed a nuisance, and liable," etc.

Put briefly, the law is this: Every factory-chimney owner who is not using the best practicable means for preventing smoke, whether the quantity is large or small, is acting contrary to the law.

Before the alkali act existed, wherever alkali makers erected their plant they were like plague spots; vegetation died for miles around, making the neighborhood of the works a bare wilderness like the district of St. Helens is to this day. The alkali act did not stop these works. It simply prescribed that the best practicable means should be adopted to prevent the escape of acid, and inspectors were appointed to see how far this could be carried out. What happened? Before long a most efficient method was found to condense the acid fumes. The acid turned out to be a profitable commercial article, and now the amount of acid escaping into the air is invariably under the minimum quantity—a very minute amount—prescribed by the present act of Parliament.

Government has acted with equal wisdom in regard to factory chimneys. No particular form of furnace is prescribed, but only the best practicable means for preventing smoke.

If, then, a manufacturer is sending out not black smoke, but one particle of soot—

"Be it so much
As makes it light or heavy in the substance
As the division of the twentieth part
Of one poor scruple; nay, if the scale do turn
But in the estimation of a hair,"

which might by other and better means be prevented, he violates the law.

The second part of the act relating to chimneys should be unnecessary if the first were properly carried out. That it is necessary, arises from the fact that convictions are almost impossible, because the smoke maker may always urge in his defense that his furnace is the best he can procure for the purpose, which statement the magistrate is usually willing to accept.

Could it be shown that the complete consumption of smoke would be to the advantage of the smoke maker, as it was in the case of the alkali maker, factory chimneys would soon cease to smoke. Before I go further, I wish to establish a claim to understand the smoke maker and to sympathize to some extent with him. I was for a few years assistant manager in a large chemical works. If there is an industry where excuse may be found for smoke it is in a chemical works. Of the five boilers on the works some were used for machinery, others for distilling purposes. Sometimes during the day the boilers were working at low pressure, at other times they had to deliver the maximum amount of steam. Then there were a large number of small furnaces for special products, and here, again, the firing was irregular from the necessity of the case. In addition to this, noxious vapor had to be treated before the gases escaped into the chimney. One could scarcely expect that with all this intermittent firing, the chimney should make no smoke. Much more might be urged on the part of smelting works, which have even greater difficulties to encounter in the way of fume and the nonobstruction of draft. Yet no works are exempt from the act, and the best practicable means should be enforced everywhere.

Now, although I think I am able to take a fair view of the manufacturer's case, my sympathies, I confess, are with the workingman. No doubt some of these men, the firemen, are directly responsible for much unnecessary smoke. This has often been advanced as an excuse for the manufacturer. I do not think it is a legitimate one. A manufacturer ought to know and appreciate better than his workmen the evils of smoke, and should exercise the authority he possesses to enforce his more enlightened ideas. It is certainly the workman who bears the brunt of the polluted atmosphere. I lived for a time near the works I have described, right in the heart of a manufacturing district. Of the character of the district you may form some idea from the fact that within almost a stone's throw of my door were three tar works, two other chemical works, an iron foundry, a fire-brick works, a colliery, and an alkali works. Opposite my lodging was a row of cottages similar to the row in which I lived and behind it, like a great scaffold, rose the winding gear of the colliery. At the back of the house was the yard of a tar works with its desolate, black beds of pitch, and beyond a mountain of alkali waste, sending forth day and night its fetid odor of sulphuretted hydrogen. This smell, combined with the vapors of pitch, which was run out in the early morning, was sometimes wafted into my bedroom and would awaken me with an indescribable feeling of nausea. Fill up the scene with a forest of smoky chimneys, begrimed walls, screeching steam whistles, and the steady rumble of strings of coal carts, and you have a picture which represents the not unusual surroundings of the workingman in a manufacturing district. There he lives, buried in one great, blank mass of ugliness, neither vestige of green around his dwelling nor even an untainted sky above his head.

I do not think that in passing through such a spot it is possible to imagine the life that belongs to these surroundings. It certainly made an impression upon me, which I never previously realized and which I shall not readily forget. Perhaps not the least melancholy side to this picture is the reference, which Mr. Acland made to it in a recent speech: "All those who are making a careful study of the condition of our towns were perfectly aware of this fact, that a great deal of the work in the towns, which necessitated strong and healthy men, especially in London, was done by those who had been brought up in country homes, and not in those of the towns." However, I have no wish to appeal to any sentimental feeling. Political economy has nothing in common with it, we are told, and "business is business," which I suppose means the same thing. I have pointed out that some few works have to fire their furnaces intermittently and some smoke or fume may be unavoidable. This does not apply to the large majority of steam users, who require a fairly steady steam pressure throughout the day. Let us see what is the opinion of persons who have carefully studied the question.

The Sheffield Smoke Abatement Association subcommittee, after a careful experimental inquiry, state that "it is certain that smoke may be almost entirely and completely prevented from steam-boiler chimneys." Deputations from the corporation of Bolton, Rochdale, Blackburn, Bury, Oldham, Middleton, and many local boards, made a round of visits to smokeless works, and the corporation of Rochdale passed a resolution that there was to be found in the market apparatus, by which coal could be burnt for trade purposes economically and smokelessly. A special subcommittee of the Blackburn corporation passed a resolution, stating that "they are convinced that the smoke nuisance in Blackburn can be for all practical purposes done away with by the application of these coking machines, and that it is of advantage to the steam users to use them; and they are further of opinion that no hardship will be inflicted upon steam users if the law respecting nuisance from smoke is strictly enforced." The larger boroughs named are now all prosecuting.

From the following list of works using smokeless appliances, compiled by Mr. Herbert Fletcher in 1888, it is interesting to note the great variety of industries represented. To this list must be added, further, 28 firms representing 174 boilers since adapted with smokeless appliances.

19.—Leeds, England; overlooking Kirkstall Road. (From photograph.)

THE AIR OF TOWNS.

INSTANCES OF FIRMS USING SMOKELESS FURNACES.

The following is a list of firms who are known to be burning bituminous coal smokelessly, and whose works should be visited by manufacturers before stating on oath that they have done everything possible in order to comply with the Public Health Act. The furnaces are by Vicars, Sinclair, Cass, and Jukes:

Royal Mint	London.
Hydraulic Power Co	Do.
Lion Brewery Co., Lambeth	Do.
Southwark and Vauxhall Water Co	Do.
De la Rue & Co., printers	Do.
Waterlow & Son, printers	Do.
Sir Jos. Causton & Sons, printers	Do.
Wm. Clowes & Son, printers	Do.
Wyman & Sons, printers	Do.
Jos. Barber & Co., wharfingers	Do.
J. S. Bradford, paper makers' materials	Do.
Leadenhall Market Cold Storage Co., ice makers	Do.
J. W. French & Co., flour mills	Do.
Vogan & Co., millers	Do.
W. B. Dick & Co., oil mills	Do.
Jas. Gibbs & Co., oil mills	Do.
Peak, Frean & Co., biscuit makers	Do.
Henry Tate & Sons, sugar refiners	Do.
David Martineau & Son, sugar refiners	Do.
Abram Lyle & Son, sugar refiners	Do.
D. & W. Gibbs, soap works	Do.
Rich'd Wheen & Son, soap works	Do.
Jno. Knight & Son, soap works	Do.
Hy. Ashwell	Nottingham.
Tetley & Son, brewers	Leeds.
Tait & Sons, sugar refiners	Liverpool.
Gossage & Sons, soap works	Widnes.
Musgrave & Sons, cotton spinners	Bolton.
Walter Cannon, cotton spinner	Do.
P. Crook, Limited, cotton spinner	Do.
Wardle & Brown, cotton weaving	Do.
John Fletcher, colliery	Do.
Astley & Tyldesley Coal Co., colliery	Manchester.
Colman, mustard	Norwich.
Electric Supply Co., electricity	Liverpool.
Brandley Mining Co., Limited, lead mines	Keswick.
Wilson, "Evening News"	Edinburgh.
North British Rubber Co., india rubber	Do.
R. & R. Clark	Do.
Alex. Cowan & Son, paper	Do.
Jas. Milne & Son	Do.
W. & R. Chambers, printers	Do.
Gall & Inglis, printers	Do.
Gunn & Cameron, "Daily Mail"	Glasgow.
Brown, Stewart & Co., paper mills	Do.
J. & P. Coats, thread mills	Paisley.
F. S. Sandeman, jute mills	Dundee.
Pirie & Sons, paper	Do.
Robertson & Orchar, iron foundry	Do.
Chas. Lyell	Do.

There is only one conclusion to be drawn from this, that the majority of smoke makers are acting in violation of the law. The smoke banners which they fly from their chimney tops are the black flags of piracy. They are pirating the pure air, which is the property of everyone.

Here is a scene (fig. 19) which may be observed any hour of the day in Leeds.

What remedy, then, should I propose? I would have a government, not a municipal, smoke inspector, a scientific man of wide practical experience, like our alkali inspectors—the offices in fact might be combined. In the matter of smoke abatement, the local authority and inspector are useless. I am not speaking specially of Leeds, for in nearly every town where a strong desire has been shown to abate smoke, the local authority, which had the power, has usually done nothing. The ratepayers' representatives are either smoke makers or have smokemaking friends, and the municipal smoke inspector is, as a rule, not equal to the task.

The relation of a municipal to a government smoke inspector might be compared to that of a sympathetic friend and the family doctor. You have a bad headache and feel ill and your good-hearted friend calls in. After making inquiries, he suggests various remedies as certain cures for your ailment. You say you have tried everything under the sun, but you are no better. Then comes the family doctor. "Hello!" says he; "I see what is wrong; we'll soon put you all right."

I will read you the deliberate utterance on this subject of Her Majesty's ex-chief alkali inspector, Mr. A. E. Fletcher, which ought to carry weight:

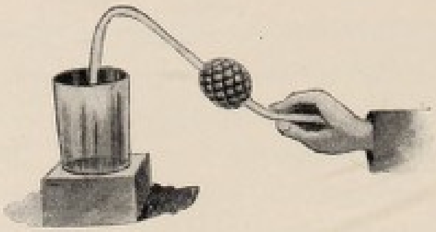
"There are difficulties in making any change. Masters will not take the trouble to alter their furnaces, nor will the men alter their method of stoking the fires unless they are compelled. The numberless alterations made in the construction and conduct of chemical works during the last twenty years would never have been carried out but for the pressure brought on the manufacturers by means of the alkali act. So it will be with the smoke nuisance. Men are too idle or too much occupied to move in such a matter until pressure from outside is applied. The moral pressure must come from the public; and it should be made some one's business to see that the law regarding it is put in force."

This question is a workingman's question. He is or should be most interested in it. His health, his home, and his surroundings are infected by the smoke plague far more than those of his wealthier neighbors.

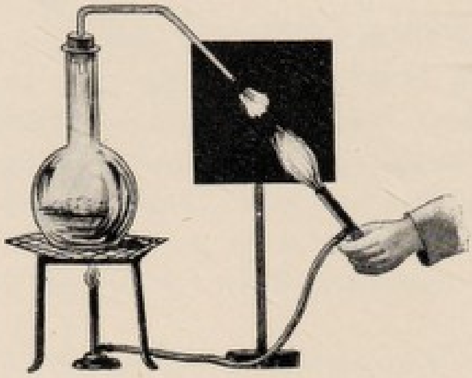
I believe that if the employer were obliged to put in an efficient smoke-preventing appliance, of which there are several in the market, he would reap advantages in two ways. He would probably economize in fuel and the health of his workmen would be improved. But, as the alkali inspector says, the manufacturer will not change his method until he is obliged, and the moral pressure must come from the public.

May it before long be said of Leeds not only of the morning, but of all and every day,

"This city now doth like a garment wear
The beauty of the morning; silent, bare
Ships, towers, domes, theaters, and temples lie
Open unto the fields and to the sky
All bright and glittering in the smokeless air."



20.—Moisture drawn from the air.



21.—Moisture taken up by the air.

22.—Dust particles in the air (highly magnified).

THE AIR OF TOWNS.

Lecture 3.—Town Fog.

Before discussing the nature and effects of town fog, we will begin, as in the first lecture in the case of carbonic acid, by seeking for its origin.

Town fog is mist made white by Nature and painted any tint from yellow to black by her children; born of the air of particles of pure and transparent water, it is contaminated by man with every imaginable abomination. That is town fog. How does this mist arise? It is water vapor or steam always present in the air in varying quantities, which by a fall of temperature suddenly appears either as mist or rain, snow, hail, or dew, according to the extent and rapidity of cooling and the amount of water vapor present in the air at the time. The following experiments will make this evident:

A little ether is placed in this bright silvered cup (fig. 20); on rapidly evaporating the ether by blowing air through it by means of a hand bellows the temperature is lowered, and the bright surface soon becomes dimmed with a deposit of moisture from the air.

If, on the other hand, I bring a flame under the jet of steam (fig. 21), which is now visible through partial condensation in the form of mist, i. e., fine water drops, the mist suddenly vanishes, for the warmer air can now take up the water in its invisible form as vapor. When I remove the flame the mist again appears.

There is one interesting and curious fact about the formation of fine particles of mist or the larger particles we call rain drops or dew—that the starting point, the nucleus, of each of these particles of water is a speck of dust, a speck so minute that it is generally invisible to the naked eye. Without dust there is no mist or rain or dew. It is solid matter which is the starting point for the deposition of moisture. What would happen if air free from dust were saturated with moisture and the temperature fell? Water would be deposited, but only on solid objects. It would deposit on the ground and on our buildings. It would stream down the walls of our houses and soak the surface of the earth. Every solid thing out of doors would be wet, but no mist would appear and no rain would fall.

Mist is the offspring of vapor and dust. What is the character and quantity of this dust? We know that it exists. We know that it is very plentiful in our houses. As far as we know, it exists everywhere; but of course the quantity varies and varies enormously, as we shall presently see.

Here is a slide (fig. 22) which shows some of the things composing the dust of a dwelling room highly magnified.

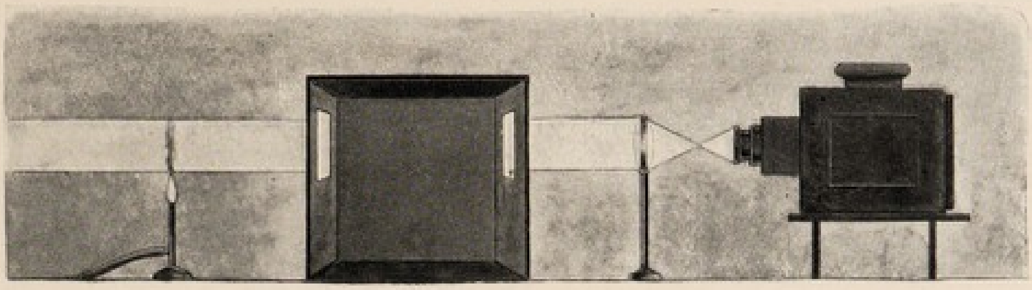
We find in it particles of soot, crystals, fibers, vegetable cells, spores and pollen grains, starch grains and meteoric iron, the remains of insect life, and living germs. Of the character of this dust, I shall have more to say in my next lecture. Much of it is so fine that it is invisible under ordinary circumstances. It is only when a beam of light in a darkened place, a ray of sunlight in a room, a street lamp on a dark night, illuminate these little particles so that they stand out against a darker background that we see them—the so-called motes dancing in the beam. It is, in fact, these little particles which make the beam of light. Without the particles the path of the beam would be invisible. The path of light from a luminous body without solid matter to obstruct and reflect it is absolute and unqualified darkness. Here, if I pass a strong beam of light from an electric arc lamp (fig. 23) through the side windows in this wooden box free from dust the beam is cut out where it enters the box and reappears on the other side, where the light emerges.

We can learn something more from this experiment. The dust is mainly organic; that is, the product, living or dead, of animal and plant life, living germs or dead spores or animal and vegetable refuse matter; for if I now bring a red-hot poker or a Bunsen flame beneath the beam, black smoke appears to rise. The black smoke merely indicates the absence of dust particles where they are burnt up by contact with the source of heat. I will now perform a third instructive experiment to show how little of the dust breathed into our lungs finds its way back into the air; for the air passing out of the lungs cuts a hole in the beam, showing the absence of dust in the breath. These interesting experiments were first devised by the late Professor Tyndall.

I take an ordinary lamp chimney (fig. 24), at the bottom of which a bent tube passes through a cork. By breathing out air from the lungs at the constricted part of the beam, the beam is interrupted from the absence of dust.

And now let us see how far our theory of fog is capable of illustration.

I have in this large glass vessel (fig. 25) air standing over water. The air is of course saturated with moisture. There is within the vessel a little electric lamp, which will render more evident any change taking place within. If I cool the air, moisture will be deposited, but according to our theory it should only appear as mist, if dust particles are present. As the air in the vessel has been standing out of contact with the outside atmosphere for two days, we may assume that the dust now has all subsided and dropped into the water. On cooling the air, we should see no mist. We can cool the air conveniently and rapidly by making use of the property which air possesses of becoming colder on sudden expansion. I have only then to exhaust the air partially by an air pump by attaching it to this bent tube which passes into the interior to produce the necessary conditions for the formation of mist. Now I have done so, and you observe that no mist appears. I can now, through this second bent tube, draw in a little air laden with dust from the room. I will now cool the air again, and you see at once that a fog appears within the vessel. If I pass in more dust particles, which I am now doing, and pump out the air again, we have



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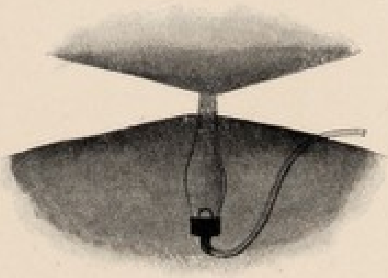

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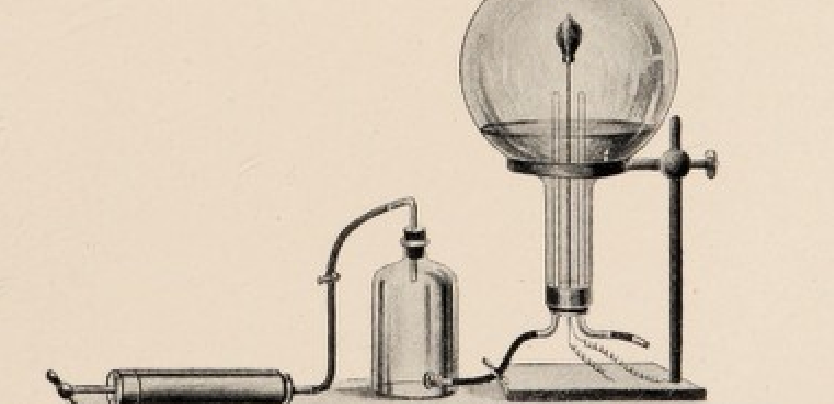
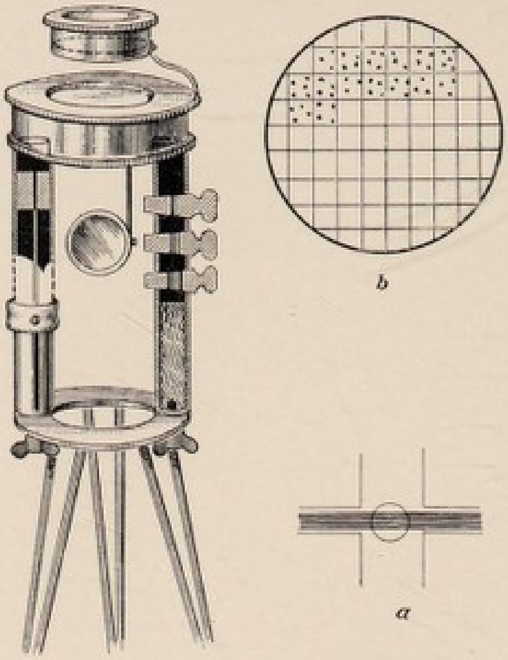
23, 24.—Beams of light through dustless air.



25.—Nature of fog.

THE AIR OF TOWNS.



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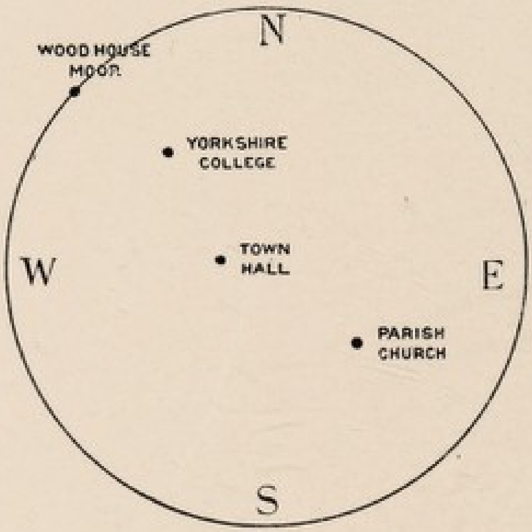

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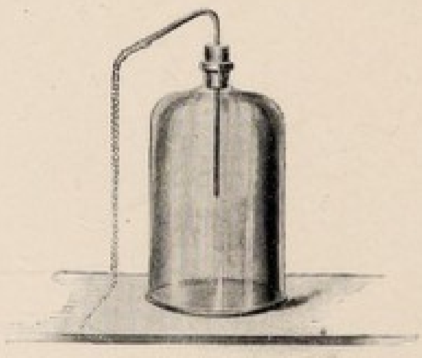


28

The Air of Towns.—Determination of Dust Particles in the Air.

a very typical and dense Leeds fog. The more dust particles there are, the thicker the fog.

Before passing to the subject of town fog, I should like to say a word or two about the weight and number of those dust particles which we see play such an important part in the production of fog. The experiments we have just seen have been turned to account by the distinguished physicist John Aitken, to determine the number of dust particles in the air. By using a small vessel and dusty air largely diluted with air free from dust, he has succeeded in producing an apparatus, in which the dew drops or mist drops are sufficiently small in number to be counted. As the apparatus is exceedingly simple in construction, I propose to explain it. Fig. 26 represents the instrument, which for the sake of explanation, is drawn partly in section. It consists of a shallow circular metal box of known capacity, furnished top and bottom with glass plates. It stands upon two cylinders opening into it. One cylinder forms a small air pump and contains a piston. The other is provided with three taps, the bores of which hold a measured volume. The top tap holds the smallest and the bottom one the largest volume. Below these there is a plug of cotton wool, and at the bottom of cylinder, which is closed at the end, is a small hole through which air can enter. Above the metal box is a magnifying lens and below a reflector. The lower glass plate of the box is divided into measured squares, etched on the glass. The atmosphere within the box is kept saturated with moisture by means of strips of damp blotting paper. By drawing down the piston with the taps in the position shown in the diagram, air enters the metal box through the cotton plug, which frees it from dust. To test a sample of air, one of the taps (determined by the amount of dust present) is turned through a right angle so that the bore is horizontal. It now communicates directly with the outside air as represented at *a*, which shows it in section. By turning it back, the bore again communicates with the metal box. The piston, which is at the top, is now drawn down and the sample of dusty air is drawn up along with filtered air into the metal box. By again raising the piston and drawing it down rapidly, a deposition of moisture occurs, which falls in drops on the glass squares, such as is represented on the top squares in the diagram at *b*. These drops are counted and from this the number of dust particles may be ascertained.

The following are the average number of dust particles in town and country air taken from Aitken's observations: Country, 8,000 to 100,000 per cubic inch; town, 1,000,000 to 50,000,000 per cubic inch. I was not satisfied with simply exhibiting Mr. Aitken's results, and so I borrowed the instrument, which he kindly placed at my service, in order to find out the character of the air in Leeds. The following results were obtained on a fine day with the wind blowing from the northwest. The relative position of the places of observation are noted on the diagram (fig. 27).

Number of dust particles in Leeds air

	Per cubic inch.
Woodhouse Moor, northwest wind	530, 000
Tennis Court, Yorkshire College	852, 000
Town Hall Square, Leeds	1, 228, 000
Paris Churchyard, Leeds	3, 638, 000
Glasgow Town, northwest wind (Aitken)	3, 736, 000
Flour mill, Leeds	3, 113, 000

There is one curious fact about these results, to which I would call your attention. There are, you will observe, fewer dust particles in a flour mill, where the air is thick with dust, than in the comparatively clear air of the churchyard. This was a puzzle to me at first, but I think it may be explained by the fact that the particles in the flour mill are larger and therefore more visible. As to the size of the particles, they may be accounted for possibly by coalescence produced by electrification. This curious effect of coalescence of dust particles by electrification may be easily demonstrated. We have only to connect one conductor of an electric machine with a wire passing through the top of a bell jar containing fumes from burning magnesium, when, on turning the machine, a little whirlwind of particles is set up and in a moment, as you see, all the solid matter has deposited in coarse grains round the sides of the vessel (fig. 28).

Let us now return from this digression to the fog once more and follow its life history.

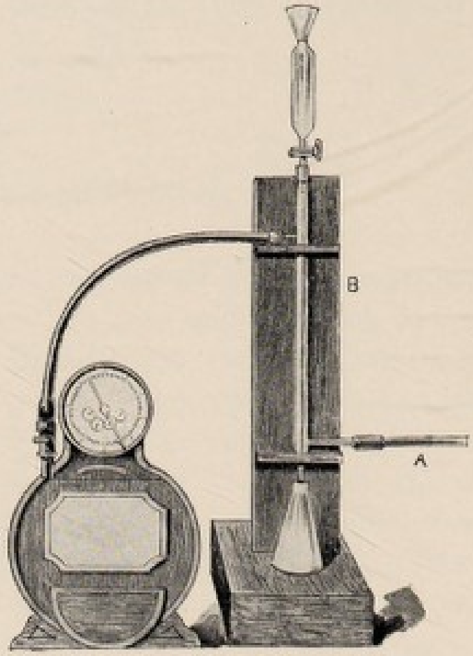
With a calm atmosphere, a high barometer and a fall of temperature, a film of water coats every little floating particle of dust, as it were, with an overcoat to keep out the cold. A white fog slowly enshrouds the town. Each particle of dust now heavily weighted with its unwonted cloak of moisture has its progress impeded, hangs or falls, but does not rise, and in its turn impedes the movement of the air. Stagnation of the atmosphere is produced, especially as wind is light with fog. What happens? An accumulation of products of combustion occurs, viz, of carbonic acid, sulphurous acid, and soot, which under ordinary conditions are rapidly dispersed. Our senses give us abundant evidence of this in the case of soot and sulphurous acid. Our faces and clothes are soon begrimed and our eyes and throats suffer from the irritating effects of the acid. Carbonic acid shows a like increase, again illustrating the well-known axiom that carbonic acid always comes in bad company.

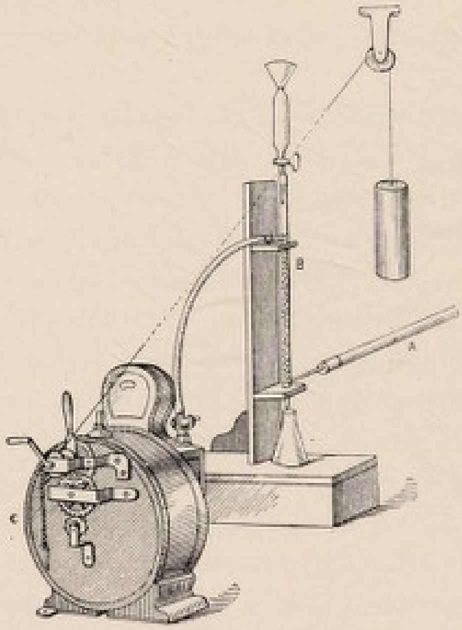
The table which I now project on the screen shows the increase of carbonic acid during fog:

Carbonic acid in London air.[1]

January 19, 1882. Slight white fog	0. 048
January 25, 1882. Dense black fog	. 105
February 1, 1882. Very fine	. 047
February 3, 1882. Slight fog	. 062
February 4. 1882. Dense black fog	. 107

[1] Dr. Russell.





29

THE AIR OF TOWNS.—DETERMINATION OF SULPHUROUS ACID IN THE AIR.

February 14, 1882. Very fine	0.041
December 8, 1882. Fine	.040
December 10, 1882. Thick, white fog	.094
December 11, 1882. Thick, white, darker	.110
December 11, 1882. Later very dark	.141
March 31, 1883. Fine	.037
April 3, 1883. Very foggy	.133

You will notice that where the fog is long continued the amount of this gas increases threefold.

The next slide gives the average amount of sulphurous acid in Manchester air during four months of 1892, as determined by the Manchester Air Analysis Committee:

Sulphurous acid in Manchester air.

[Milligrams of SO_2 per 100 cubic feet.]

Month.	Minimum.	Maximum.	Average.
September	0.7	3.5	1–2
October	0.7	6.0	2–4
November	2.0	12.0	6–8
December	3.0	30.0	6–10

And the following table gives a number of determinations from the same source in the outskirts and the center of the town, showing plainly the increase of acid during fog and the larger proportion in the center of the town:

[Milligrams of SO_2 in 100 cubic feet.]

Date.	Outskirts.	Center of town.
September 5	0.7	1.8
October 14	0.8	3.53
November 5	1.7	4.9
November 10	2.5	4.1
November 13	3.3	7.6
November 17	2.0	5.9
November 19	2.96	8.4
November 22	4.2	*a* 9.7
November 27	9.3	*a* 15.7
December 17	2.3	9.2
December 21	16.5	*a* 32.2
December 22	12.7	*a* 22.6
December 23	12.7	*a* 25.8

a Fog.

I should now like to explain to you briefly the apparatus which I devised for the Manchester Air Analysis Committee for making these determinations of sulphurous acid.

The apparatus used for the determination of sulphurous acid in the air consists of three parts (fig. 29). A, a long glass tube, about half an inch in diameter, open at both ends, which is fixed horizontally so as to project into the open air; B, a glass tower, about 30 inches high and 1¼ inches in diameter, open at the top, and drawn out into a fine jet at the bottom. Two side tubes are fixed to the tower, one near the bottom and the other on the opposite side near the top. The tower is filled to within 1 inch of the upper sidepiece with glass beads, and into the open top a tap funnel is inserted through a tightly fitting cork. The lower side tube is attached to the horizontal tube; the upper one, by means of wide india-rubber tubing, to a combined meter and aspirator, C. This is an ordinary wet meter converted into an aspirator by attaching toothed wheels to the revolving drum and driving the wheels by means of a wire cord passing over a pulley and carrying a weight. A series of dials register the volume to the one-hundredth of a cubic foot. The method of conducting the experiment is as follows: About 250 cubic centimeters of a solution of hydrogen peroxide in water, containing about 1 milligram of active oxygen in each cubic centimeter, is poured into the tap funnel, from which it is allowed to drop onto the glass beads at the rate of about one drop a second. The liquid passes down and out at the lower end of the tube through the jet, and falls into a flask placed below. A drop of liquid which permanently fills the jet seals it effectually from the entrance of air from the interior of the room. After running through, the liquid is poured back into the funnel. The weight being wound up, the volume indicated on the dial is read off, and the drum set in motion. With a column of beads of about 20 inches and a weight of 20 pounds, 20 cubic feet can be aspirated in an hour. Once started, the apparatus needs no further supervision until either the weight has reached the ground or the solution of hydrogen peroxide has run out of the funnel. The period required for this is readily determined, so that no time is lost in looking after the apparatus.

Thus we see that carbonic acid and sulphurous acid, as we should have anticipated, rapidly increase during fog, and, although I have no determinations of soot to record, the fact that it increases also is sufficiently evident.

If we assume that dust particles are the cause of fog, then it follows that the thickness of fog depends upon the number of these particles and the fog must be denser in the town than in the country. Moreover, each particle of water floating as fog becomes coated with a film of sooty oil—of that oil which forms so large a constituent of soot. What is the effect? Evaporation is retarded and the fog persists longer than it would were these particles composed of pure water only. To illustrate this, I wish now to refer to an experiment, which has been proceeding since the beginning of the lecture. I then called your attention to the fact that in each pan of this balance I had placed a large watch glass containing water. Onto the surface of one watch glass of water I had poured a drop of oil, which spread itself out into a film. You now observe that this pan has descended, showing that evaporation has proceeded at a greater rate in the other pan.

We have not yet touched upon the evils attending fog. Apart from the cost due to the extra daily consumption of gas, which is estimated in London at 25,000,000 cubic feet, or £3,125 per annum, there is a serious increase in mortality. The figures in the following table must be taken with some caution, as it is recognized that a fall of temperature increases the death rate; but there can be little doubt that the high mortality due to respiratory diseases which occur with the advent of fog must be in a large measure directly traceable to this cause:

Sickness and mortality in Manchester during the months of December (1890), January, and February (1891).

[Estimated population, 506,325.]

Week ending—	Weather (Town Hall).	Thermometer.		Sickness (weekly numbers).		Deaths (weekly n'mb'rs).	
		Maximum.	Minimum.	General, treated at public expense.	Infectious, reported to medical officer.	All causes.	Respiratory diseases and phthisis.
Dec. 6	Dry and cold, thawing	48.6	29.8	780	70	244	85
Dec. 13	Dry east winds, hard frost, some fog.	40.1	25.8	719	83	238	87
Dec. 20	.....do	40.1	18.6	672	70	294	121
Dec. 27	Dry east winds, hard frost (dense fog three days)	40.8	15.8	448	56	393	204
Jan. 3	Overcast, severe frost	41.8	26	691	59	328	165
Jan. 10	Overcast (foggy two days)	40.8	21.7	801	52	341	153
Jan. 17	.....do	43.8	27.8	853	66	336	156
Jan. 24	Overcast	48.7	17	708	51	278	109
Jan. 31	Overcast (clear two days)	51.6	36	818	61	263	95
Feb. 7	.....do	51.4	34.7	802	52	211	78
Feb. 14	Overcast	50.1	37.2	866	62	232	91
Feb. 21	Dull (dense fog two days)	52.7	27.6	787	54	291	104
Feb. 28	Clear (dense fog one day)	56.7	29	929	62	257	113

I have little more to add. We have learned one important lesson, viz, that dust is the mother of mist and rain.

Looking at the statistics of the annual rainfall since the beginning of the century, there appears to be a slight increase; but it may not be due to an increase of solid matter in the air. Whatever the facts may be, it is interesting to remember that dust is its own destroyer. Rain, snow, and mist drag it to the earth, and so wash and purify the air. Were it not so, though the ground would still receive its necessary moisture, the greater part of the 20 tons of smoke daily sent into the atmosphere of Leeds would continue to float forever in the ocean of air around us. That atmospheric dust is gradually delivered back to the earth is, however, poor consolation to us who suffer from town fog. Just as well might we promise to the drowning man a future abundant supply of air, for the lack of which he will in a few moments have ceased to live. A lecture is neither a fable nor a fairy tale and need point no moral; but before bringing it to a close I have one suggestion to make. Those who have followed my lectures thus far will, I am confident, agree with me as to the serious importance of this subject of town air from the nature and extent of air pollution here in the town of Leeds, its marked effect upon the life of its citizens, especially of its working population, and its effect on vegetation, and indirectly, therefore, on the possibility of purifying the atmosphere.

Our medical officers in their weekly or quarterly returns usually include a certain amount of interesting and useful information about the weather, the temperature, and the barometer readings. These weather statistics have their value in relation to epidemic and endemic disease. I do not wish to underrate them. But how vastly more important is it for us to know the extent of our air pollution. And the matter carries still further weight from the fact that the weather is beyond our control, but the purity of our town atmosphere lies in our own hands. We want our experimental stations, our watchtowers, within and outside the town, where the condition of the atmosphere may be constantly tested, where with every new progressive step in air purification we may mark the effect on the atmosphere as well as on the health of the citizens. This need be no costly undertaking. Three or four intelligent lads of 15 or 16 with a good board-school training under the control of the city analyst or other competent chemist could manipulate all the necessary apparatus, which in itself, as you have seen, is simple and inexpensive.

One word more. Ruskin, as Collingwood in his biography relates, kept for fifty years careful account of the weather and effects of cloud. He noticed that since 1871 there had been a prevalence of chilly wind, but different in its phenomena from anything of his earlier days. "The plague wind," so he named it, "blew from no fixed point of the compass, but always brought the same dirty sky in place of the healthy rain cloud of normal summers."

This "eclipse of heaven" Ruskin regarded, if not as a judgment, at all events as a symbol of the moral darkness of a nation. In whatever light we are inclined to regard Ruskin's opinions, he has ever been admittedly a most careful and trustworthy student of nature. May not this "eclipse of heaven" be the effect of our town smoke, which we know is perceived at a radius of 10 miles, and probably extends many times that distance from some of our large towns. I can not doubt that the total effect of the millions of tons of smoke sent yearly into the atmosphere of the United Kingdom must modify in some degree the character of our climate.

We ought, however, to take courage from the fact that, if we can not get pure country air in town, a vastly purer atmosphere is within easy reach if we would only grasp it. Then we may begin to think seriously of beautifying our buildings and streets and squares, and of realizing the ideal town described in my first lecture.

Lecture 4.—The Germs of the Air.

Until the beginning of the present century, physical science directed the minds of philosophers mainly toward the study of the infinitely great—the discovery of new worlds in space, the study of universal gravitation, and the measurement of the velocity of light. The present century has illumined a new path in the Dark Unknown. The science of to-day is essentially the science of the infinitely small. Dalton's atomic theory, a theory of the invisible atomic structure of matter, is the foundation of modern chemistry and physics. The germ theory of disease, a theory which involves the existence of the microscopic living matter dwelling within and around us, is the basis of modern pathology and surgery. It is to these minute organisms that I have now to direct your attention.

The discovery of these living particles, particles so small that it is probable that many of them defy the scrutiny of the most perfect microscope, originated in the study of a very ancient process, the process of fermentation.

Boyle, in the seventeenth century, in his "Essay on the pathological part of physik," with that almost prophetic clearness of vision which marked his conclusions, wrote as follows: "And let me add that he that thoroughly understands the nature of ferments and fermentations shall probably be much better able than he that ignores them to give a fair account of divers phenomena of several diseases (as well fevers as others) which will, perhaps, be never properly understood without an insight into the doctrine of fermentations."

The making of wine and the brewing of beer have been practiced in historic and prehistoric times. Theophrastes, who lived in Egypt B. C. 400, described beer as the "wine of barley." Noah, we read, "planted a vineyard and drank of the wine which maketh glad the heart of man," and one or both of these processes is practiced by nearly every nation, civilized and uncivilized, at the present day.

If the grape is crushed and left to itself at a moderate temperature it begins to froth. After a few days its sweetness, which was due to sugar, has gone and the juice has acquired a slightly burning taste. It now contains no sugar, but alcohol. If barley is moistened and allowed to germinate and the germination suddenly stopped by roasting the grain, the barley has a sweetish taste. It is now called malt. The constituents of the barley have been changed; a new substance has been formed, viz, diastase, a substance which has the peculiar property of converting the starch of the grain into sugar as soon as the grain is steeped in water. A little of this sugar has already appeared in the malt, and to this its sweetness is due. The malt is now steeped in water for a short time, the water is boiled and rapidly cooled, and this extract is called "wort." If a little yeast or brewer's barm is added to the wort it begins shortly to bubble up, and at the same time a white scum forms. This scum is yeast, which by the end of the process is four or five fold the quantity of the original yeast. The sweetness of the wort has gone, and in the place of sugar it now contains alcohol. The making of wine and the brewing of beer are very similar processes. In brewing, the brewer adds his ferment; in wine making, the ferment is with the grape. "What has been done consciously by the brewer has been done unconsciously by the wine grower."[1] The nature of this ferment—the yeast—was first examined in 1680 by Leuwenhoek in the early days of the microscope, and he found that it consisted of minute globules. More than a century and a half elapsed before our knowledge of these globules was materially increased, and then in 1835 Cagniard de la Tour, in France, and Schwann, independently, in Germany, on carefully observing these globules noticed that they threw out buds, that they were in fact a low form of plant life.

Here you see (fig. 30) the yeast plant in its various stages of growth, the single spherical cell, then the bud growing and developing, and finally separating from the mother cell and so forming a new yeast plant. If the liquid is undisturbed these cells remain together and appear to ramify like the lobes of a cactus leaf.

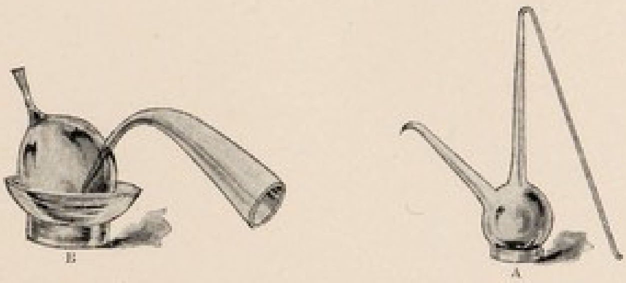
It was at this point that Pasteur took up the subject. I could easily devote a lecture—nay, a series of lectures—to the researches of this distinguished chemist, which are models of scientific acumen and experimental skill.

It may suffice to say that he incontestably established the fact, in spite of much opposition on the part of scientific men, that the conversion of sugar into alcohol is brought about, although we do not yet know how, by the living yeast cell during its life in the liquid. As long as yeast is excluded no fermentation takes place. How comes it, then, that wine ferments spontaneously, whereas beer does not? This question was also answered by Pasteur. The germs of the yeast plant are contained in the dust of the air which settles upon the grape. I will now show you on the screen the apparatus and explain the method by which Pasteur solved the problem.

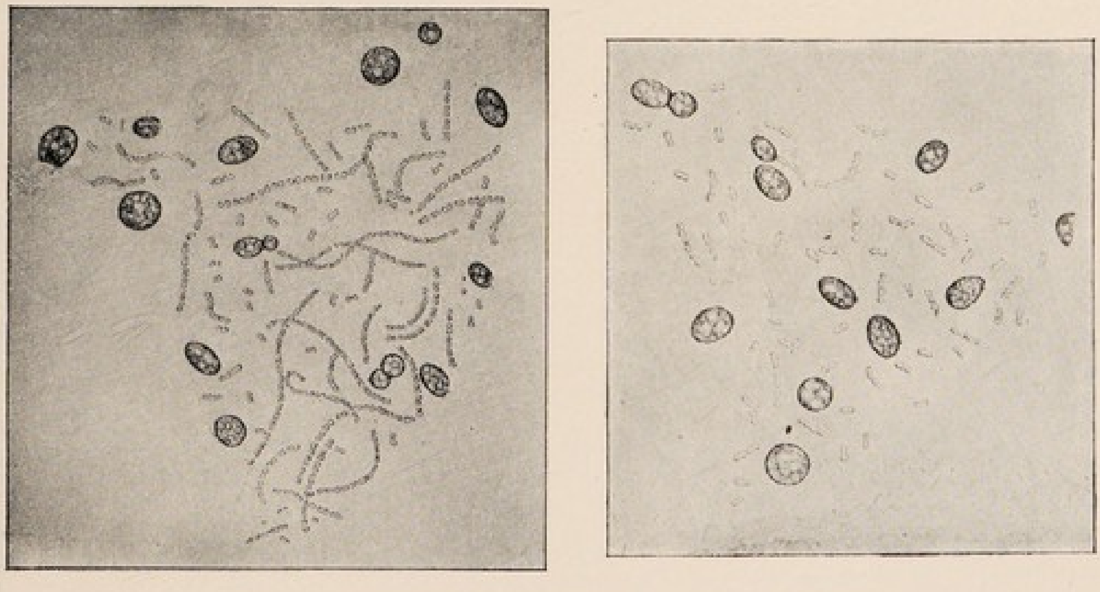
The flask *A* (fig. 31) has two necks, the one is drawn out to a point, and sealed, the other is also drawn out to a fine tube and bent, as shown in the figure. Although the end is turned up and open, no dust can enter. The point is inserted through the skin of the grape, as shown in *B* in the enlarged drawing of the same. After insertion the point is broken and the juice sucked into the flask by aspirating at the open bent limb. The point was then fused; in this way the dust from the outside of the grape was excluded and no fermentation took place.

[1] Professor Tyndall.

30.—Yeast plant.

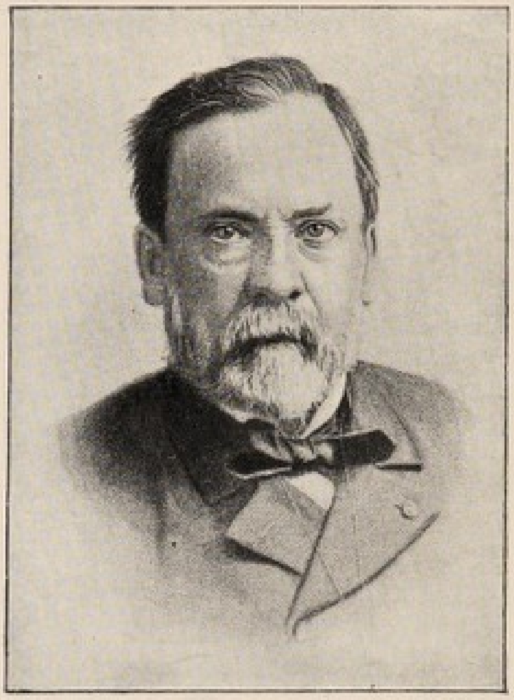


31.—Cause of vinous fermentation.



32.—Acetic and lactic ferments in sour beer. (Pasteur.)

THE AIR OF TOWNS.



LOUIS PASTEUR.
(1822–1895)

Yeast would also find its way into the brewer's wort; but this liquid is neutral and not acid like grape juice and is capable of nourishing other germs, which can not convert sugar into alcohol, but yield acid substances, as the brewer not unfrequently finds to his cost, when occasionally such germs find their way into the fermenting vat.

By adding pure yeast, the yeast being first in the field establishes itself generally to the exclusion of other forms of life just as soil sown with wheat will produce wheat and not weeds, as it would otherwise do. The souring of beer and wine next claimed Pasteur's attention and he found that certain much more minute forms of low vegetable life called bacteria or microbes had the property of converting sugar into acids.

Here are some of these much more minute germs which are found in bad beer growing in bead-like filaments side by side with the yeast cells (fig. 32). The study of the microbes led Pasteur to the discovery of a process for preventing wine from turning sour. He found that a temperature below the boiling point of water destroyed these germs. After the wine is bottled a short immersion in hot water will kill the germs without materially affecting the flavor of the wine, and the wine will undergo no change on keeping. This process is known as "pasteurization." The production of vinegar from beer and wine was found to be due to the microscopic ferment, which converts alcohol into acetic acid, known as mycoderma aceti or acetic ferment, and which, as just stated, is found in sour beer.

The germs of all these forms of vegetable life are found in the dust of the air. This dust when not stirred up gradually settles, and when the germs chance to sow themselves in good ground, with the temperature neither too hot nor too cold, they will immediately begin to grow and multiply, generally at a prodigious rate, living on the material and bringing about its conversion into new and usually simpler forms of matter.

The inference that putrefaction has a similar origin naturally suggests itself. We know that meat during warm weather rapidly becomes putrid. Such a piece of meat examined under a powerful microscope will be found to be swarming with bacteria. Now, it is found that exposure to the temperature of boiling water if sufficiently prolonged—for some bacteria die harder than others—will kill them, and the freezing temperature will render them inactive, though without always destroying them; that certain so-called antiseptics, carbolic acid, corrosive sublimate, boric acid, etc., act as poisons and kill them. We can recall for ourselves a number of instances where one or another of these methods is employed to prevent putrefaction and decay. Meat and milk are preserved by heating them in air-tight tins. In summer time milk may be kept from turning sour by boiling it, and game preserved untainted by parboiling it. In a similar manner cool larders and refrigerating chambers retard or prevent putrefaction.

Perhaps one of the happiest and most fruitful results of the study of this engrossing subject has been the antiseptic treatment of disease, first introduced by Sir Joseph Lister. In speaking upon this subject, the late Professor Tyndall said:

Consider the woes which these wafted particles during historic and prehistoric ages have inflicted upon mankind; consider the loss of life in hospitals from putrefying wounds; consider the loss in places where there are plenty of wounds, but no hospitals, and in the ages before hospitals were anywhere founded; consider the slaughter which has hitherto followed that of the battlefield, when these bacterial destroyers are let loose, often producing a mortality far greater than that of the battle itself; add to this the other conception that in times of epidemic disease the selfsame floating matter has mingled with it the special germs with produce the epidemic, being thus enabled to sow pestilence and death over nations and continents—consider all this and you will come to the conclusion that all the havoc of war ten times multiplied would be evanescent if compared with the ravages due to atmospheric dust.

If after disinfecting by killing the germs we can exclude the air, or the dust of the air, the most putrescent substances may be kept indefinitely without the slightest indication of putrefaction. Both Pasteur and Tyndall have established this fact in the most convincing manner, the former by allowing calcined air (that is, air passed through a red-hot tube) to come in contact with a highly putrescible substance like beef extract, the latter by giving the substance access to dust-free air in a chamber similar to one shown in my last lecture, the purity of the air being tested by a beam of light. I have referred to the relations of dust to epidemic diseases in the paragraph quoted from Professor Tyndall. This relationship is perhaps not quite so obvious as that which has been found to exist between the germs of the air and festering wounds.

To discover this relation, we must again seek it in a research of Pasteur—one of the noblest services that any man has rendered to his country. The outline of the story is briefly told.[1]

For fifteen years, a plague raged among the silkworms in the silk-growing district which lies to the southeast of France. From 130,000,000 francs, which was the value of the silk produced in 1853, it had dropped to 30,000,000 francs in 1862, and there was no sign of abatement of the disease.

In 1863 the French minister of agriculture offered a reward of £20,000 to anyone who should find a remedy. The district which suffered most was Alais, the country of Pasteur's friend, the chemist Dumas, who wrote to Pasteur, "I put a great price upon seeing you fix your attention on the question which interests my poor country. The misery there surpasses all imagination." In June, 1865, Pasteur gave up his post at Paris and with his wife left for Alais. The disease of the

[1]A fuller account may be found in Tyndall's "Dust and Disease."

silkworm was characterized by the appearance of black spots. It showed itself, moreover, in the stunted and unequal growth of the caterpillars, in the languor of their movements, fastidiousness in regard to food, and premature death. The black spots which appeared through the transparent skin of the silkworm had been examined and proved to be living corpuscles. These gradually took possession of the intestinal canal and spread, finally filling the silk cavities so that the worm when its appointed time came went automatically through the process of spinning, but without producing any silk. This was already known when Pasteur came upon the scene. By careful and constant use of the microscope he followed the life of these fatal corpuscles.

The life of the silkworm is like that of any ordinary caterpillar. When hatched from the egg the worm, which is not much larger than a pin's head, begins to feed and grow, casting his skin from time to time when his coat gets too tight until, having attained a length of almost 2 inches, he suddenly stops feeding and, having found a suitable spot, he begins to spin his silk web around him.

Within the cocoon he remains dormant for a time in the chrysalis state, and then in the form of the moth makes his way out of his silk prison. The puzzle which had baffled previous investigations was this: The eggs and the worm might appear sound and healthy and yet produce in the one case diseased worms and in the other, although spinning their silk cocoons, produce diseased moths or eggs. Pasteur proved that "the corpuscles may be incipient in the egg and escape detection, germinal in the worm and baffle the microscope." As the worm grows the corpuscles grow; in the chrysalis they are more distinct, and in the moth they invariably appear. A diseased moth then lays infected eggs which, owing to the minuteness of the corpuscles, appear healthy. Moreover, a diseased worm may infect a healthy one. Feeding together, corpuscles are transferred from the diseased to the healthy worm, and the infected worm, without immediately showing signs of disease, may spin its cocoon and eventually lay its eggs; but the eggs are all tainted. Instead, then, as silk growers were in the habit of doing, of selecting the eggs for the next year's growth from the moths which had survived the most successful cocoons, the microscope was brought to bear on the moths when the presence of these diseased corpuscles was invariably made evident. This is the practice now adopted by all silk growers, and numbers of women skilled with the microscope examine each moth as it emerges from the cocoon.

Here we have, then, the first distinct connection between living germs and the cause of disease, of infection, and of hereditary taint. The constant strain of microscope work, which restored to France her silk industry, produced partial paralysis from which Pasteur never quite recovered.

It would be easy to multiply examples to which this great discovery has given rise. Tuberculosis, diphtheria, wool-sorter's disease, leprosy, cholera, typhus, and tetanus have been traced to the existence of microscopic living matter (figs. 33, 34).

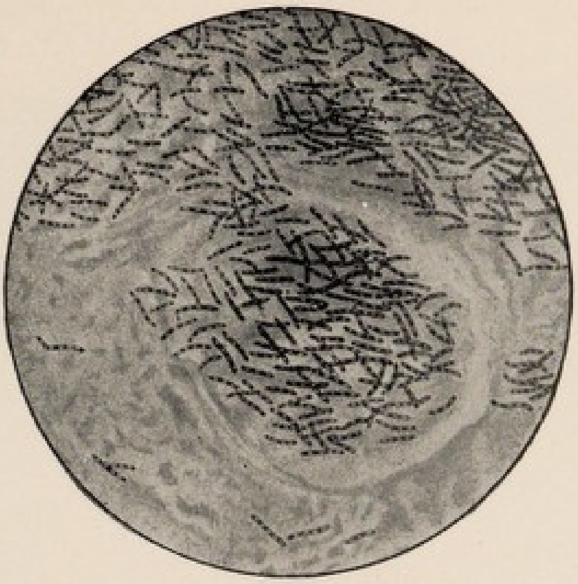
I have taken you over this little bit of history in order to indicate the importance of knowing the number and character of the almost invisible living germs of the air, and this must be my apology for introducing a subject which may seem to lie a little outside the special topic of town air.

If we examine dust under a powerful microscope, we find that it consists of a variety of things, which I enumerated in my last lecture Now, the greater part of this dust, although heavier than air and settling rapidly where the air is still, is so very fine as to be almost invisible except when illuminated by a bright beam of light. Can we gain any idea of the weight of these little particles? In my second lecture, I told you that the weight of dust in 100 cubic feet of air in town is over 1 milligram. In my last, that in the parish churchyard 3,638,000 dust particles were contained in 1 cubic inch. From this it may be calculated that about 40 million million dust particles weigh 1 grain and would occupy a space of 240 cubic yards, or a space measuring rather over 6 yards each way.

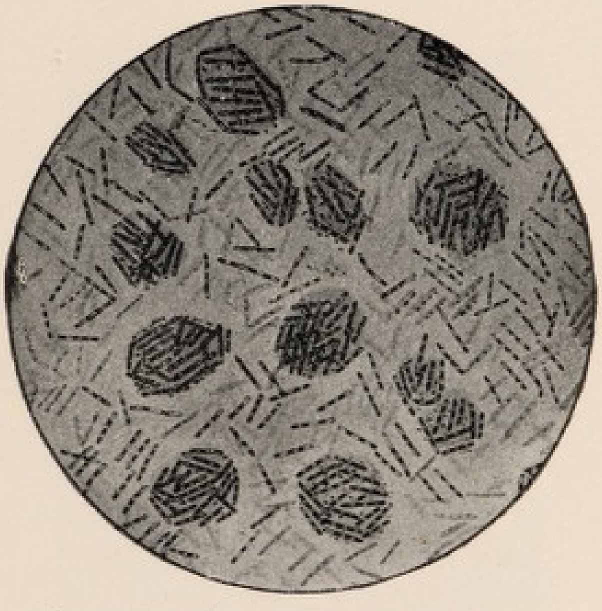
What proportion of the dust consists of spores, pollen, and fungi, and what proportion do the bacteria form? The amount of living matter in the air has been carefully investigated for a long period of years by M. Miquel, of the Observatory of Montsouris, situated on the outskirts of Paris. This careful experimenter has directed his attention mainly to determining the number of vegetable spores, fungi, and microbes in the air in various places and at various seasons of the year. He has determined the amount of vegetable matter and microbes in the streets, bedrooms, and living rooms of Paris and in the environs. He has drawn samples of air from the sewers of Paris, and from the top of the Pantheon, high above the town. He has examined the street dust, the dust of rooms, of the soil in the country, and in graveyards—in short, the dust of all possible places where disease germs might lie. Anyone who has leisure to take up the book "Les Organismes Vivants" can not fail to be interested in the results of so much laborious work and of so many carefully recorded facts. It would take too long and carry me beyond my subject, if I gave even a brief outline of these results; I must limit myself to town air and the minute organisms which inhabit it. The vegetable spores and fungi we may pass over briefly. This slide (fig. 35) represents the most common forms met with at the Montsouris Observatory; and the following table shows the average number throughout the year for the years 1878 to 1882 in 1 cubic foot.[1]

January	200	July	786
February	200	August	677
March	155	September	450
April	212	October	406
May	346	November	252
June	992	December	200

[1] Miquel.



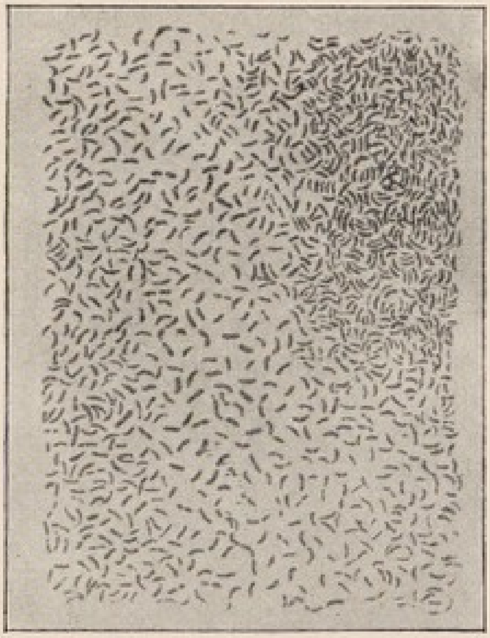
33*a*.—Bacillus of tuberculosis. ×1500. (Crookshank.)



33*b*.—Bacillus of leprosy. ×1500. (Crookshank).

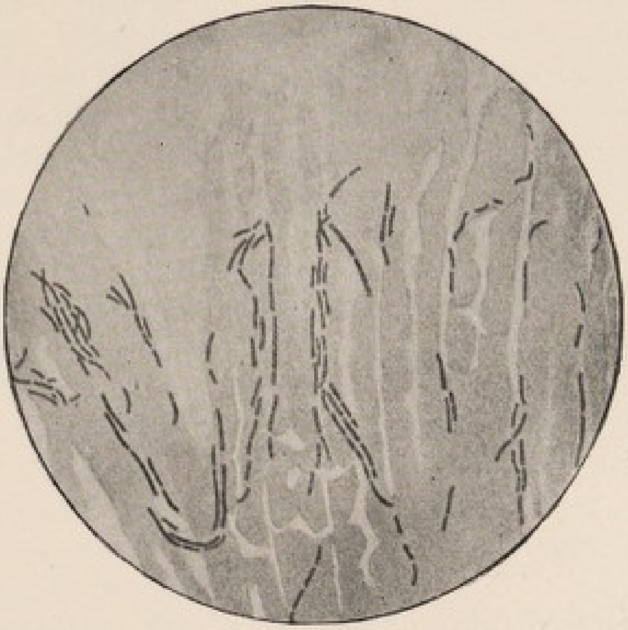
THE AIR OF TOWNS.

33c.--Typhus bacillus. (Schenk.)

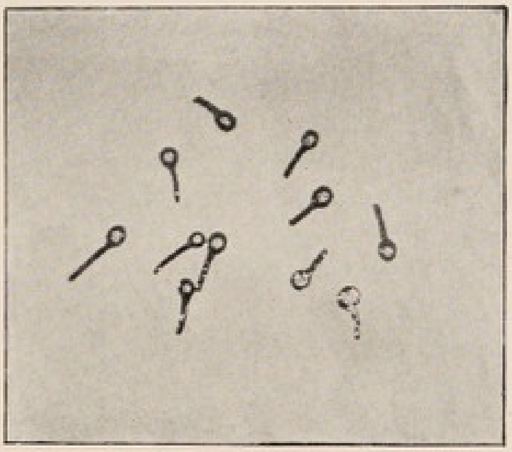


3 *d.*—Cholera bacillus. (Schenk.)

THE AIR OF TOWNS.



34*a*.—Bacillus Anthracis (the microbe of wool-sorter's disease). ×500. (Crookshank.)



34*b*.—Bacillus of Tetanus. (Crookshank.)

THE AIR OF TOWNS.

The average for the country is 200 and for the town 1,000. This refers to Paris, where there are plenty of beautiful parks and where trees line the larger streets. Where vegetation is nearly obliterated, as in the city of Leeds, the number will probably fall much below that of the country.

We now come to the much more minute inhabitants of the dust—the microbes or bacteria. Here are some of the commoner forms as seen under a powerful microscope (fig. 36).

There are globular and elongated forms, twisted filaments, spherical dots, and short, straight rods. Yeast cells, too, are often met with. They rapidly reproduce; the parent cell in the case of bacteria dividing into two or more new cells, and these again undergoing subdivision.

It may interest you to know how these almost invisible germs can be counted. Although the germ itself is only visible under high magnification, if the germ falls upon nutrient material it will soon produce a family circle readily visible as a spot of mold. One of the methods, which has been introduced by a German bacteriologist named Hess, is represented in the following diagram (fig. 37).

It consists of a glass tube coated with a nutrient jelly. The tube is first rendered sterile by heat, and then a measured volume of air is slowly aspirated through it by the aid of two bottles containing water, which can be alternately lowered and raised. The tube is then placed under the best conditions for the growth of the germs and excluded from the dust. Where a germ has fallen a spot of mold will soon appear, and such spots mark the residence of the original single germ.

The following slide (fig. 38) represents the appearance produced in the tube in three experiments made in a schoolroom: No. 1 experiment was made before the school assembled, the second in the middle of the day, and the last when the school closed.

One is struck by the great variety of these minute beings, and the difficulty of distinguishing them is increased by the fact that they appear to vary in shape with the nutrient material upon which they grow. If they are fed on beef tea they may take a different shape to that produced by a diet of agar jelly. There seems very little doubt that the number of species is very large, and very little is known, moreover, of their functions. It is certain that at least a few produce disease. It is equally certain that a large number, when inoculated into animals, are harmless. That these harmless ones serve a useful purpose in carrying on putrefactive change, acting as scavengers for the world's refuse, seems not unlikely; but the subject is still in its infancy, and one upon which, no doubt, fresh light will fall as bacteriological research progresses. The following table gives the proportion of dust particles, spores, etc., and bacteria in a cubic foot of town and country air:[1]

	Average total dust particles.	Spores, etc.	Bacteria in 1 cubic foot.
Country	864,000,000	200	2
Town	6,000,000,000	1,000	20

[1] Miquel.

The numbers represent averages throughout the year, but this includes considerable variations, which occur at different seasons of the year.

The shaded portion in the diagram (fig. 39) represents the number of bacteria, and the dotted line the temperature during the various months of the years 1879–1882.

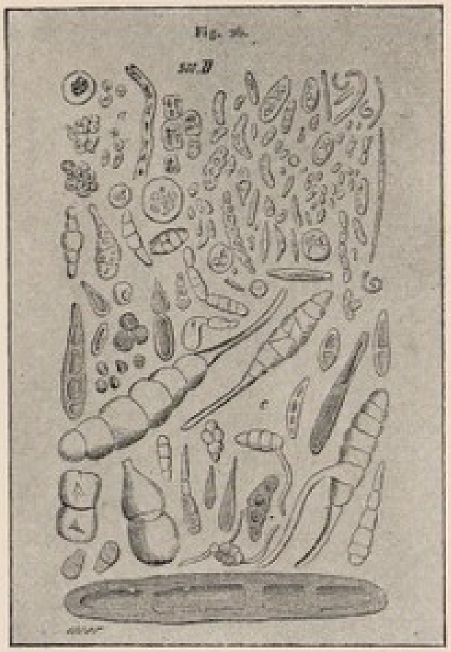
The number does not appear to vary proportionately with change of temperature; but if we compare the rainfall with the number of microbes we see at once a rapid diminution. The rain evidently carries them down to the earth. But they are far from being destroyed. The moisture seems to assist reproduction, for we find a rapid increase directly after rain. If drought is long continued the number falls off again. They die. Here, again (fig. 40), the shaded portion represents the number of bacteria, and the line the rainfall during the year 1879–80.

The number of microbes in the streets of Paris is on the average about 21 to 22 in the cubic foot, and this agrees with that found by Professor Carnelley in the streets of Dundee, viz, 20 in the cubic foot. Outside of Paris the number falls off to 2 whereas, in dirty, one-roomed houses Carnelley found 3,430 and Miquel in a neglected hospital ward 3,170 in the cubic foot. The effect of population in increasing the number of microbes may be represented by the following rough map of Paris (fig. 41), in which the number of microbes in a cubic meter of air observed at Montsouris is marked against the arrow denoting the direction of the wind. From this it will be seen that the largest number occurs when the wind blows across the town and the smallest number when it comes direct from the country—that is, from the south.

The number, 21 to 22, for the streets of Paris is a rough average. In dry, dusty weather, following rain, the number may rise to 150. Directly after wind and rain it may fall to an average of 6 per cubic foot.

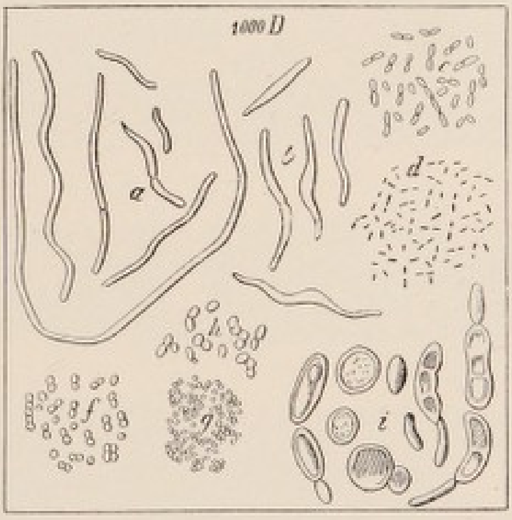
We can not be surprised that the washings of the air by rain, accumulating in the mud of thoroughfares, should be the gathering ground for microbes. The mud of streets is more than this. It provides food for their growth. It is the great source of bacterial propagation. When we open our windows to let in fresh air on a dry, windy day, we are welcoming these small visitors. The number of microbes in a grain of dust from the streets of Paris was found to be 84,240, nearly double that contained in similar dust obtained on the outskirts of the town.

Can we be astonished at finding domestic dust nearly as pregnant with living matter as that from the street, which, according to Miquel, is 64,000 in the grain? It might appear judicious to keep our windows closed under such a siege, but a moment's reflection will, I think, solve the difficulty. We do not know to what degree these microbes are mischievous. We do know to what extent fresh air is necessary to health. Let us admit air, but keep our dwellings, as far as possible, free from dust. Microbes settle rapidly in still air, and we have only



35.—Atmospheric microbes.

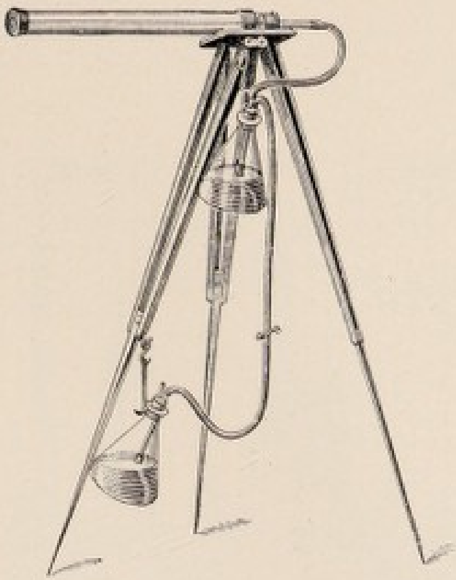
a, algae; *b*, cells of cryptogams; *c*, spores of cryptogams. ×500. (Miquel.)



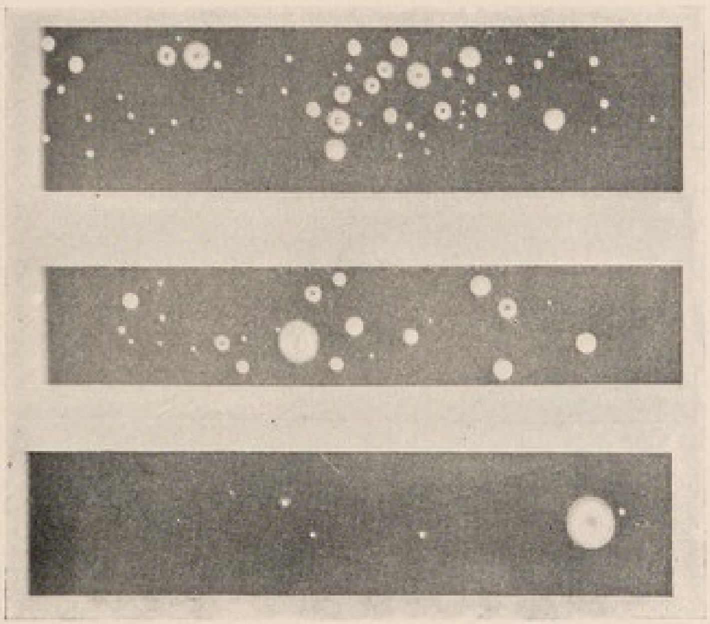
36.—Atmospheric microbes.

a b, vibrios; *c d*, bacteria; *f g h*, micrococci; *i*, torulae. ×1000. (Miquel.)

THE AIR OF TOWNS.

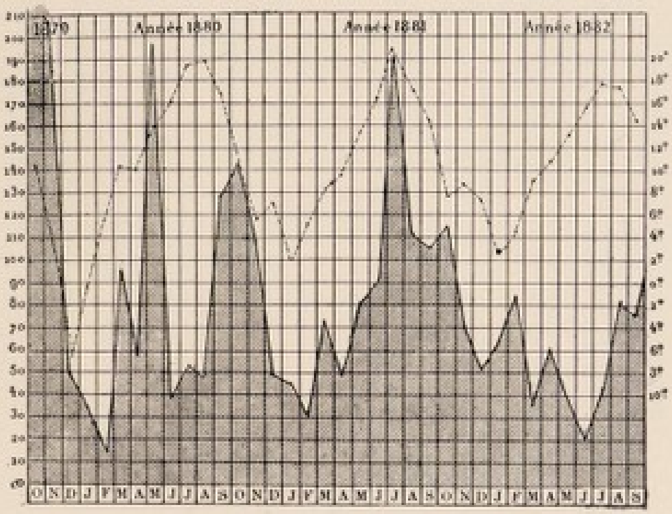


37.—Apparatus for counting microbes in the air. ,

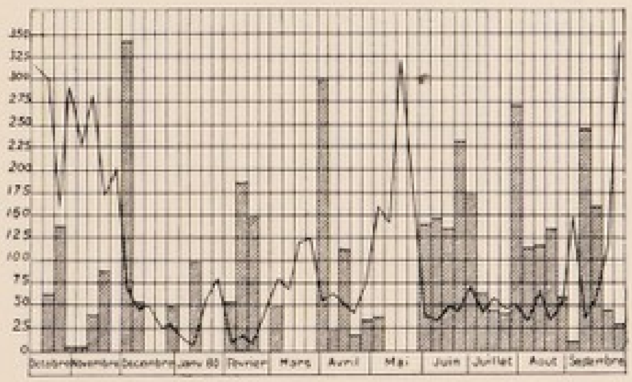


38.—Microbes in air of schoolroom.

THE AIR OF TOWNS.

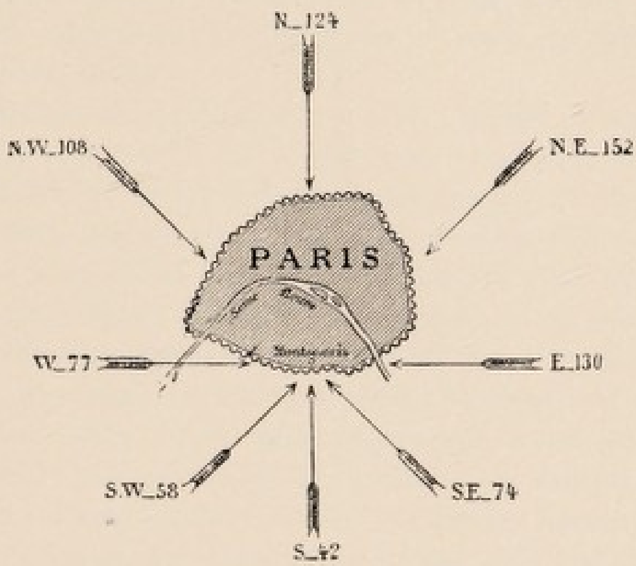


39.—The variation of the number of bacteria with the temperature. 1880-1882. (Miquel.)



40.—The variation of the number of bacteria with the rainfall. 1879-1880. (Miquel.)

THE AIR OF TOWNS.



41.—Influence of the direction of the wind on the number of microbes collected at Montsouris. (Miquel.)

THE AIR OF TOWNS.

to rise a few hundred feet above the ground level to prove it. On the same day Miquel found on the top of the Pantheon less than 1 on the average in the cubic foot; at Montsouris 1½, and in Paris streets about 12. At a height of almost 1,000 feet the number is about one-sixteenth of that on the ground level. On the high Alps, as Pasteur and Tyndall have shown, they disappear completely. If we want fresh air we know where to go. We must climb the hilltops. An idea of the great army of microbes which are constantly on the march out of a big town may be gathered from the number computed for Paris, viz, 40,000 million daily, a number which may be graphically expressed by supposing all the microbes in 11 gallons of soup, in full putrefaction, to arise and march away.

Ladies and gentlemen, my task is at an end. There is much that I have left unsaid in the course of these lectures. I should like to have alluded to the possibility of reducing domestic smoke, of the smoke of our warehouse and office buildings, of the better utilization of coal, and of the use of gas for household purposes. I should like to have said much more on the important subject of ventilation of our dwelling rooms and offices. These matters must be left for a possible future occasion. I should, however, be content with the result of these four lectures if you carried away, immovably impressed upon your minds, the fact that pure air is indispensable to health. Do not let us resemble people sitting in a close room who, by gradually becoming accustomed to their surroundings, grow oblivious to the polluted atmosphere they are breathing and the poison which they are slowly absorbing.

A chairman at a lecture which I once delivered on a similar topic to this said at the close: "I think the lecturer makes too much of these invisible things in the air. We seem to keep alive in spite of them." But we don't want merely to keep alive. We want to live without the burden of trying to keep alive. What future is there for a country two-thirds of the population of which inhabit towns, and of whom Mr. Acland said "a great deal of this work of the towns, which necessitated strong and healthy men, was done by those who had been brought up in country homes and not in those of towns."

As I have already said, impure air, no matter whether it arises from bad gases, soot, or disease germs, is injurious to health. If we are attacked by a wild beast we do not remain passive. We prepare to kill it or to run away. And if the health of a town population is slowly undermined, as it assuredly is, by causes which we can compass and prevent, as we can not run away to pure air, we must face those causes and stamp them out. There is much that the local authority can and ought to do, and which we should collectively see is done. But there is much that we as individuals can do ourselves. It is a duty to ourselves that these things should be done. It is equally a duty to the young and growing generation.

APPENDIX I.

A RAPID METHOD FOR THE ESTIMATION OF CARBONIC ACID IN THE AIR.

(1) *A standard solution of limewater.*—Pure water is left in contact with slacked lime until saturated. The clear decanted liquid is diluted with ninety-nine times its volume of distilled water. Make 1 quart or 1 liter.

(2) *Phenolphthalein solution* is made by dissolving one part of phenolphthalein in five hundred times its weight of dilute alcohol [equal volumes of pure alcohol and water]. Make 3 ounces or 100 cubic centimeters.

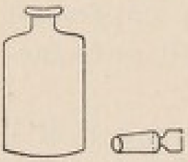


FIG. 1.

(3) *A 20-ounce stoppered bottle* with (preferably) a hollow stopper marked to hold 3 drams or 10 cubic centimeters.

A sample of air is taken by blowing air into the clean stoppered bottle (fig. 1) with bellows. Six minims or one-third of a cubic centimeter of the phenolphthalein solution is then added, and the measured volume of limewater is run into the hollow stopper. The limewater is poured into the bottle, the stopper inserted, the time noted, and the contents vigorously shaken. If the red color of the liquid disappears in three minutes or less the atmosphere is unfit for respiration.

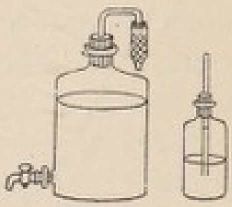


FIG. 2.

The stock of limewater should be kept in a bottle (fig. 2) furnished with a tap and coated within with a film of paraffin, and in the neck an open tube should be inserted containing pieces of caustic soda or quicklime. The phenolphthalein solution is best measured by means of a narrow glass tube passing through the cork of the bottle upon which the measured volume is marked. If the cork fits easily the liquid may be forced up exactly to the mark by pushing in the cork.

The following are estimations made in this manner compared with the results obtained by Pettenkofer's method:

Time.	Per cent volume of carbonic acid.
Minutes.	
1¼	0.1618
1⅜	.1379
1½	.1279
3½	.07716
4½	.05142
5	.0464
7½	.0351

APPENDIX II.

I have registered by a well-known method * the total daylight on a spot on Woodhouse Moor (a high open moor lying to the northwest of the town) nearly every day during the months November, 1895, to February, 1896. The same has been done at the Philosophical Hall (near the center of the town) and at Kirkstall Road † (a busy manufacturing center). In the latter place the smoke absorbs about one-quarter of the total daylight. The following are the results obtained. To economize space the results for each week are added together:

Light tests.

A comparison of the total daylight in different parts of Leeds.

Year 1895-96.	Woodhouse Moor.	Philosophical Hall.	Kirkstall Road.
July 1-7	Not recorded.	78.30	....
July 8-14	Not recorded.	88.30	83.60
July 15-21	Not recorded.	61.70	60.60
July 22-28	Not recorded.	65.30	58.50
Nov. 10-16	22.94	Not recorded.	20.61
Nov. 17-23	15.92	Not recorded.	12.25
Nov. 24-30	10.20	Not recorded.	6.10
Dec. 1-7	10.90	Not recorded.	10.34
Dec. 8-14	18.30	Not recorded.	7.17
Dec. 15-21	4.50	*a* 4.80	3.53
Dec. 29-Jan. 4	2.60	1.99	1.53
Jan. 5-11	4.65	2.32	2.51
Jan. 12-18	7.88	5.60	5.51
Jan. 19-25	8.17	5.90	5.47
Jan. 26-Feb. 1	13.66	9.02	8.04
Feb. 2-8	6.56	*a* 7.20	*a* 7.58
Feb. 9-15	8.28	*a* 9.05	*a* 10.57
Feb. 16-22	3.82	*a* 4.40	3.26

a The six numbers marked with an asterisk are exceptions to the general rule. For some unexplained reason, the amount of light registered on these dates is greater in the smokier parts of the town than on the open moor.

* The method used was to estimate the amount of iodine liberated on exposure from a mixture of potassium oxide and sulphuric acid. The numbers represent cubic centimeters of thiosulphate solution used.

† The position would be a little to the left of the center of the view shown in the photograph of Leeds.

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WASHINGTON CITY, *December, 1896.*

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