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METHODS FOR THE DETERMINATION
OF
ORGANIC MATTER IN AIR.

BY

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METHODS FOR THE DETERMINATION OF ORGANIC MATTER IN AIR.

By David Hendricks Bergey, B.S., M.D.

A number of methods have been devised for the estimation of organic matter in air. The results that have been obtained by these different methods are, however, quite variable even under the same atmospheric conditions. The difficulties that were encountered in estimating the quantity of organic matter in expired air, while conducting the research on The Composition of Expired Air and its effects upon Animal Life,[1] demonstrated the fact that some of the methods in use were unsatisfactory. At the suggestion of Dr. Billings some of these methods have been tested and compared as to their reliability and adaptability for hygienic investigations.

The methods that are now in use fall into two groups. In the first group of methods the organic matter is converted into ammonia either by the Wanklyn, Chapman, and Smith[2] process and estimated with Nessler's reagent; or by direct nesslerization of the absorbent used to abstract the organic matter from the air; or, as in one of the methods, the distillate is carried into dilute sulphuric acid and the amount of free acid estimated by titration with deci-normal ammonia.

In the second group of methods the organic matter is oxidized by boiling with a dilute solution of permanganate of potash, and titrating with oxalic acid solution, as in the estimation of organic matter in water.

All these different methods are colorimetric in their nature. They are also only indirect methods inasmuch as they afford no clue as to the nature or quantity of organic matter—as such—that is present in the air; the end-products in all of the methods being of an entirely different nature from the organic matter itself.

The modifications of the methods of both groups by different experimenters consist principally in variations as to the form of absorbent used and the modes of absorption, or in the manner of applying the reducing agents. In most instances the modifications of the apparatus employed are of minor importance.

The methods of the first group have much in common. Chapman[3] took advantage of the process devised by Wanklyn, Chapman, and Smith[3] for the estimation of organic matter in water by its conversion into free and albuminoid ammonia, and adapted it to the estimation of organic matter in air. He aspirated the air through cotton-wool, or through gun-cotton, asbestos, or pumice-stone, and then subjected the absorbent to distillation, thereby converting the organic matter derived from the air into ammonia. He found that aspiration through asbestos gave the most reliable results.

Moss[4] passed a measured quantity of air through four wash bottles of 100 c.c. capacity, each containing 50 c.c. of pure distilled water, except the first, which contained also 50 c.c. of pure hydrochloric acid. The absorbent solutions are then subjected to distillation and the ammonia evolved from the organic matter estimated with Nessler's reagent.

R. Angus Smith[5] aspirated measured volumes of air through pure distilled water contained in an absorption tube. The water is then subjected to distillation and the ammonia estimated by means of Nessler's reagent.

The method employed at the Montsouris[6] Observatory, near Paris, consists in drawing a known volume of air through bent tubes or through a "rose," laid in a cooling mixture. The suspended particles in the air are condensed and retained, and are then taken up with pure distilled water; or in addition to the cooling mixture the air is conducted through pure distilled water. The distilled water containing the suspended matter from the air is then subjected to distillation and the ammonia estimated by means of Nessler's reagent.

In the laboratory of the Medical Officer of Health,[7] in Glasgow, the apparatus employed at the Montsouris Observatory is slightly modified. The air is drawn through a "rose" which is placed in a small vessel containing a quantity of small glass beads lying in dilute sulphuric acid. The sulphuric acid and beads are then transferred to a clean retort, the acid is neutralized with solution of sodium carbonate, when the estimation of ammonia is conducted in the usual manner.

Fodor[8] uses two U-shaped tubes containing pure distilled water acidulated with sulphuric acid. The air is filtered through glass-wool and the amount of organic matter in the dust is determined by distillation, as well as the amount contained in the acidulated water. The two absorbents are subjected to distillation separately, thus showing the amount of organic matter in each of them.

Lehmann[9] recommends Uffelmann's method in which the air is aspirated through two small flasks, the one containing a dilute solution of sulphuric acid and the other a dilute solution of caustic potash, each of about one per cent. strength. These solutions are then mixed and the oxidizable matter determined by distillation and testing with Nessler's reagent.

A modification of Chapman's method which has met with considerable favor consists in the aspiration of a known volume of air through freshly ignited finely granular pumice-stone contained in a narrow absorption tube. The subsequent treatment of the pumice-stone is similar to that first employed by Chapman. This method was devised by Professor Remsen[10] and has since been used by Miss Talbot[11] and by Dr. Abbott.[12]

Smee[13] employs a large glass funnel, sealed at the neck, and filled with cracked ice. The moisture and suspended particles in the air are condensed on the exterior surface of the funnel and are collected in a small beaker placed underneath the funnel. The condensations are then subjected to distillation and the ammonia estimated by means of Nessler's reagent.

Fox[14] prefers what he calls the "pulverization of water method." It consists in bringing consecutive portions of fresh air into intimate contact with a small quantity of very pure water which is being reduced to a minute state of subdivision by pulverization in a glass cylinder about eight inches in length and two inches in diameter, and which is furnished with a large india-rubber stopper. This stopper has two perforations, into one of which the air pipe of a Bergson's spray producer is fitted; the other is intended for the passage of a straight glass tube about twelve inches long and one-fourth inch in diameter. Thirty cubic centimetres of pure distilled water are placed in the cylinder, and this serves to wash the air of all its impurities as it passes through the fine spray formed in the cylinder by the spray-producer. The thirty cubic centimetres of water used are then diluted to 100 c. c. with distilled water, and the whole subjected to distillation in a small retort, the distillates being tested for ammonia with Nessler's reagent.

Miss Talbot[11] concluded, as the result of some determinations made with Remsen's method, that all of the organic matter fails to be converted into ammonia during the first distillation. She found that the second and third re-distillation of the distillates uniformly give higher results. She sought to overcome this difficulty by aspirating the air directly through the boiling permanganate in the retort.

Dr. Abbott[12] found, as the result of his investigations, that in "31 estimates made upon the outside air, the air of the laboratory, air from over decomposing meat infusions, and the air from over sewage, we have failed to obtain evidence of the existence of more than a trace of gaseous, nitrogenous, organic matters, other than ammonia; the amounts being constantly so small as to fall far below the permissible limits of experimental error."

For the direct estimation of ammonia in air Uffelmann[15] employs the following method: Twenty to thirty litres of air are aspirated through 10 c. c. of dilute sulphuric acid; this is then tested with Nessler's reagent and the color produced compared with that of a solution of ammonium chloride of known strength. He uses 0.3147 g. NH_4Cl in 1 litre of water, which is equal to 0.100 g. NH_3 to the litre. This solution is diluted with water (for the comparison) until its color is similar to that produced by the sample of air. A yellow color indicates 0.005 mg. NH_3 in 100 c. c. of water.

A method which I employed in an earlier series of experiments[1] consists in conducting measured volumes of air through a coil of glass tubing laid in ice so as to condense the atmospheric moisture and dust. The fluid collected in this manner is then subjected to distillation. The chief difficulty in this method is the slowness with which the condensation of moisture takes place. It is only on days when the atmosphere is nearly or completely saturated with moisture that an appreciable amount of fluid is collected. On clear days the evaporation of the moisture often exceeds the condensation, and in consequence the fluid already collected may be lost through evaporation.

A method employed by Gray,[16] of New Zealand, consists in collecting the rain water as it falls and subjecting it to distillation.

The methods of the second group also have a common object, the determination of the amount of oxygen required to oxidize the organic matter in a known volume of air. These methods differ, however, very greatly as to the forms of apparatus employed by the different experimenters.

R. Angus Smith[5] used a flask of about 100 cu. in. (1175 c. c.) capacity. The air is pumped out of the flask by means of a hand bellows, so that the air of the place may pass in to take its place. The flask is then closed with a rubber stopper perforated by two holes, the one containing a glass tube through which a weak solution of permanganate of potash is introduced from a small burette; the other opening allows the air that is displaced by the permanganate solution to escape. A small quantity of the permanganate solution is used at first and agitated with the sample of air. More of the permanganate solution is added as fast as it is being decolorized, a permanent color indicating that the "air contained no more material capable of decomposing permanganate." The solution of permanganate which Smith used was of such strength that 1 c. c. tested with proto salt of iron equalled 0.00225 g. of metallic iron, or, 0.00032 g. of oxygen. Alkaline salts seemed to him to be more sensitive than pure permanganate.

A second method devised by Smith is as follows: Thirty cubic centimetres of water containing a small amount of a weak solution of permanganate of potash of known strength, are shaken with the air in a flask of known capacity. The flask is refilled with air and again shaken—"air washing,"—and this process is continued until all the permanganate is decolorized. The volume of air required to decolorize the permanganate will indicate the quantity of organic matter contained in it.

Uffelmann[15] determines the quantity of organic matter in air by means of a solution of permanganate of potash, of which 1 c. c. equals 0.395 mg. of $KMnO_4$, or 0.1 mg. of oxygen, and requires 0.7875 mg. of oxalic acid to neutralize it. The permanganate solution is placed in a small flask, the stopper of which carries two glass tubes. One of these tubes is of sufficient size to serve as a dust-filter and contains freshly ignited asbestos or glass-wool; the other tube serves to connect the apparatus with a small aspirator, about one litre in capacity. The apparatus is cleansed with hot permanganate solution. One cubic centimetre of the permanganate solution is then placed in the flask with 9 c. c. of pure distilled water, and acidulated with several drops of dilute hydrochloric acid. Ten to twenty litres of air are aspirated through the apparatus. The asbestos or glass-wool absorbent is transferred to a clean casserole with 60 c. c. of distilled water; 2 c. c. of $KMnO_4$ solution and 1 c. c. of dilute sulphuric acid are added and boiled for five minutes. The unreduced permanganate remaining in solution is then titrated with oxalic acid solution. The permanganate solution in the flask is treated in the same manner. The two results will show the quantity of gaseous and of dust-form of organic matter in the air aspirated through the apparatus.

A second method devised by Uffelmann is as follows: Two flat-bottomed test-tubes, each closed with a double-bored rubber stopper, are attached to each other. A dust-filter of asbestos or of glass-wool is attached to the entrance-tube of the first test-tube. The first of these test-tubes contains a dilute solution of caustic potash and the second a dilute solution of sulphuric acid; each solution being of about 1 per cent. strength. By means of a rubber syringe of 50 c. c. capacity, 10 to 20 litres of air are pumped through the apparatus. The two solutions are then mixed and the amount of organic oxidizable matter determined in the usual manner.

Carnelley and Mackie[17] employ a solution of permanganate of potash of $\frac{n}{1000}$ strength, 1 c. c. of which equals 0.008 mg. of oxygen, or 0.0000056 litres of oxygen at 0° C. and 760 mm. The solution is usually kept of $\frac{n}{10}$ strength and diluted as required; about 50 c. c. of dilute sulphuric acid (1 : 6) being added to each litre of the weak solution. For the collection of samples of air large, well-stoppered jars, of about 3.5 litres capacity, are used. The jars are first rinsed with a little of the standard permanganate, and when not in use some of the solution is always kept in them so as to assure complete cleanliness from any reducing substance. Before using the jars are drained. The sample of air is collected by pumping out the air contained in the jars with a small hand bellows and allowing the air to be examined to flow in. Fifty cubic centimetres of the standard solution of permanganate are run into each jar, when it is tightly stopped and well shaken for at least five minutes. Twenty-five cubic centimetres of the permanganate solution are then withdrawn by means of a pipette and placed in a glass cylinder holding about 200 c. c. Twenty-five cubic centimetres of the fresh standard solution are placed into a similar glass cylinder for comparison. Both of these solutions are then diluted up to 150 c. c. with distilled water and allowed to stand for ten minutes, after which the tints of the two solutions are compared. Standard solution of permanganate is now run into the first cylinder from a burette, until the tints of both solutions are of the same intensity; usually from $\frac{1}{2}$ to 6 c. c. of the standard solution are required. The amount of standard solution added to the solution in the first cylinder is a measure of the bleaching effected by the organic matter in the known volume of air on one-half of the permanganate employed. The results may be expressed either in terms of the number of cubic centimetres of the $\frac{n}{1000}$ solution bleached by 1 litre of air, or, as they prefer, by the number of volumes of oxygen required to oxidize the organic matter in, say, 1,000,000 volumes of air, *i. e.*, the 25 c. c. of solution from a 3.5 litres flask, in which 50 c. c. of standard solution had been used, required 3 c. c. to bring its tint up to that of the cylinder containing the fresh standard, or the entire 50 c. c. would have required 6 c. c. This represents the number of cubic centimetres of standard permanganate bleached by 3,500 — 50 = 3,450 c. c. of air; consequently $\frac{6}{3.45}$ = 1.74 c. c. is the bleaching effected by 1 litre of air, or 0.0000097 litre of oxygen, or 9.7 volumes of oxygen are required to oxidize the organic matter in 1,000,000 volumes of air. Correction for temperature is considered unnecessary, as its effect falls within the limits of experimental error.

Nékám [18] repeated Uffelmann's experiments, giving particular attention to the question whether all of the organic matter is absorbed by the permanganate; and also whether the permanganate suffers reduction from other reducing agents in the air. He found the permanganate to undergo spontaneous reduction while it oxidizes the organic matter very slowly.

Archarow [19] also employed Uffelmann's method, but so modified the apparatus as to conduct the air through the permanganate in a fine stream. The permanganate was also kept at a somewhat higher temperature than the surrounding air, about 43° C., as this was found to facilitate the oxidation of the organic matter. The best results were obtained with acid permanganate solution. The accuracy of the method diminishes with the concentration of the permanganate solutions—a solution containing 0.026 mg.$KMnO^4$ to the litre being most satisfactory.

Some of the methods which have been here reviewed have been tested in this laboratory a number of times in order to determine their reliability. In most instances the same method of absorption was resorted to for the estimation of either the ammonia or the reducing power of the organic matter in the air. It was possible therefore to estimate the quantity of organic matter in the air in terms of both the end-products which have served thus far for the estimation of organic matter by the various experimenters.

In those methods in which the organic matter is converted into free and albuminoid ammonia the retort and condenser used for the distillation process are previously rendered free from ammonia by the prolonged distillation of distilled water that contains but very small proportions of ammonia. The absorbent material, whatever the form that has been used, is transferred to the clean retort and diluted with a sufficient quantity of twice distilled water to bring the whole amount up to 500 c. c. The preparation of sufficient quantities of twice distilled water having a low ammonia-content is not always an easy matter. This is especially the case with the laboratory water-supply. The sewage contamination of the water supply is so marked as to make it impossible to remove all the ammonia in the second distillation, owing to the presence of considerable quantities of urea in it. By using spring water this difficulty was largely obviated. In each determination it is necessary to deduct the ammonia-content of the distilled water that was used to dilute the absorbent material from the results obtained for the determination.

In those methods in which the reducing power of the organic matter upon permanganate was determined the process was carried out in a porcelain casserole which had previously been cleansed by boiling with some of the permanganate solution. The strength of the solution of permanganate of potash employed was 0.4 g. to the litre of water, and was titrated before each experiment against a solution of oxalic acid containing 0.7875 g. to the litre of water, and 10 c. c. of which equalled 1 mg. of oxygen. In these methods it is also necessary to make deductions from the results obtained for each determination for the amount of oxygen consumed by the organic matter in the twice distilled water that had been used to dilute the absorbent material to 100 c. c. In each determination 6 to 8 c. c. of permanganate solution are added to the diluted absorbent material, and also 5 c. c. of 25 per cent sulphuric acid, and the boiling continued for five minutes.

METHOD I.

A. Total oxidizable matter. In this method the total oxidizable matter in air is determined by aspirating a known volume of air through 100 c. c. of twice distilled water, contained in a Pettenkofer absorption tube, and then determining the amount of oxygen consumed by this absorbent as compared with the same amount of the water before the experiment, the difference between the two results representing the amount of reduction produced by the organic matter in the volume of air aspirated. The results obtained by this method are given in Table II; the form of apparatus employed is shown in Fig. 1.

B. Free and albuminoid ammonia. The free and albuminoid ammonia is determined in the 100 c. c. of twice distilled water, used as the absorbent material in this method, and through which a known volume of air has been aspirated, and the amount of ammonia found in the same quantity of the water before using is deducted from the results of each of the determinations. The results obtained by this method are shown in Table I; the form of the apparatus is the same as that shown in Fig. 1.

METHOD II.

A. Determination of the gaseous and dust-form of organic matter in air, according to the method of Uffelmann. A small Erlenmeyer flask, of 100 c. c. capacity, and closed with a rubber stopper having two openings, contained the absorbent material which in this method is 25 c. c. of $\frac{n}{2000}$ solution of permanganate of potash acidulated with sulphuric acid. The openings in the rubber stopper of the flask carry two short pieces of glass tubing; the one is connected at its upper extremity with a small globe-shaped glass tube containing freshly ignited asbestos or glass-wool, and the lower extremity of the tube extends nearly to the bottom of the flask. The other glass tube is bent at right angles just above the stopper, and terminates just below the inner edge of the stopper. The other end of this tube is connected with the aspirator.

The gaseous form of organic matter is retained in 25 c. c. of permanganate solution in the flask. Its amount is determined by diluting the permanganate solution with 75 c. c. of twice distilled water and boiling in the ordinary manner, deducting the amount of oxygen consumed by the 75 c. c. of water from the end-result.

The dust-form of organic matter is determined by transferring the asbestos or glass-wool absorbent to a clean casserole, adding 100 c. c. of twice distilled water, 6 to 8 c. c. of permanganate solution, and 5 c. c. of 25 per cent. sulphuric acid, and then boiling for five minutes and titrating with oxalic acid solution in the usual manner. In each determination it is necessary to deduct the amount of oxygen consumed by the 100 c. c. of water from the end-result. The results obtained for the gaseous and dust-form of organic matter in air by this method are given in Table III; the form of apparatus employed is shown in Fig. 2.

Method III.

A. Total oxidizable matter. This method is a modification of that employed by Remsen. The air is aspirated through freshly ignited and finely granular pumice-stone contained in a glass absorption tube, 18 c. m. in length and 1 c. m. in diameter. The pumice-stone is then washed into a clean casserole with 100 c. c. of twice distilled water, and the oxidizable matter determined in the usual manner. From the results so obtained it is necessary to deduct the amount of oxygen consumed by the 100 c. c. of water, and by a similar amount of the pumice-stone before it is exposed to the air. In some of the experiments a dust-filter of freshly ignited asbestos was prefixed to the absorption apparatus to exclude all dust. The results obtained by this method are given in Table VI; the apparatus employed in this method is shown in Fig. 3.

B. Free and albuminoid ammonia. Remsen's method. By this method the free and albuminoid ammonia are determined by transferring the finely granular pumice-stone, through which a known volume of air has been aspirated, to a clean retort with 500 c. c. of twice distilled water. Before beginning the aspiration of air the pumice-stone is moistened with some twice distilled water. From the results obtained in each determination it is necessary to deduct the amount of ammonia given off by the same amount of water, as well as by the same amount of the pumice-stone. The results obtained by this method are shown in Tables IV and V; the apparatus employed is shown in Fig. 3.

Method IV.

A. Carnelley and Mackie's method. In this method the air contained in a four- to six-litre flask is agitated with 50 c. c. of $\frac{n}{1000}$ solution of permanganate of potash for about five minutes. Then 25 c. c. of the permanganate solution are placed into a flat-bottomed glass cylinder of such size that it is filled to within about 5 c. m. of the top when the permanganate solution is diluted with 125 c. c. of twice distilled water. Another glass cylinder of similar size contains 25 c. c. of fresh permanganate solution diluted with 125 c. c. of water. The tints of the solutions in these cylinders are compared after about ten minutes, and the tint of the solution in the first cylinder is deepened so as to compare with that in the second cylinder by the addition of a few drops of the $\frac{n}{1000}$ solution of permanganate from a burette. The amount of permanganate solution required for this purpose indicates the bleaching effected on one-half of the permanganate solution in the flask by the organic matter in the air which it contained. Since 1 c. c. of the $\frac{n}{1000}$ permanganate solution is equal to 0.008 mg. of oxygen, it is easy to calculate the number of milligrammes of oxygen required for the entire sample of air used. The results obtained in this method are given in Table VII.

B. Carnelley and Mackie's method modified. This method differs from the foregoing in that the permanganate solution is run into the flask from a burette until no further bleaching effect is noted. The flask contains 50 c. c. of pure distilled water, and the bleaching effected is shown by the tint of the water after it has been agitated with the sample of air for several minutes. The permanganate solution is added until a very faint rose tint is perceptible in the water and remains permanent for five minutes. The permanganate solution used in this method is $\frac{n}{2000}$ strength; 1 c. c. equals 0.004 mg. of oxygen. The number of cubic centimetres of the permanganate solution required to produce the faint rose tint in the 50 c. c. of water will indicate the amount of organic matter in the sample of air used. The results obtained by this method are given in Table VIII.

METHOD V.

A. In this method the ammonia in the air is estimated directly, by aspirating the air through a $\frac{n}{10}$ solution of sulphuric acid (100 c. c.) which is contained in a Pettenkofer absorption tube and afterward titrating the acid with a $\frac{n}{10}$ solution of ammonium hydroxid, 1 c. c. of the ammonium hydroxid solution being equal to 1.7 mg. of NH_3. The results obtained with this method are given in Table IX; the apparatus employed is shown in Fig. 1.

B. By aspirating the air through 100 c. c. of pure distilled water contained in a Pettenkofer absorption tube and nesslerizing; the depth of the color produced being compared with standard ammonium chloride solution. The results obtained with this method are given in Table X.

C. Uffelmann's method, by aspirating the air through 10 c. c. of diluted sulphuric acid and titrating with Nessler's reagent.

METHOD VI.

By this method the sulphuretted hydrogen and the sulphurous acid gas in the air are determined directly by aspirating air through a Pettenkofer absorption tube containing 100 c. c. of a $\frac{n}{10}$ solution of iodine. The quantity of iodine remaining unchanged in the solution is determined by titrating with a $\frac{n}{10}$ solution of sodium hyposulphite, using starch paste as an indicator. One c. c. of the sodium hyposulphite solution is equal to 1.7 mgs. of H_2S, or 3.2 mgs. of SO_2. The results obtained by this method are given in Table XI.

The results obtained by these methods show quite variable amounts of organic matter in the air. This is what one would expect to find, but the great difficulty in such an investigation is that it is not possible to make satisfactory control experiments. There is no possibility of establishing a standard for comparison, yet by making simultaneous determinations with the different methods on the same air some idea as to their reliability may be obtained. The experimental error in each of the methods is necessarily very large, and in some of the methods is so great as to render them almost entirely useless. The more cumbersome the apparatus and the more complicated the method the greater will be the experimental error. Since there is no way known as yet of determining the organic matter directly, it becomes necessary to select the method, which gives the most closely concordant results in air of approximately the same degree of purity, or in several duplicate determinations on the same air. The method which constantly gives the lowest results in simultaneous determinations is also probably the one to be preferred as being the most reliable. This method will naturally be the one in which the danger of contamination can be reduced to a minimum, and requires the simplest form of apparatus, and yet affords reasonable certainty that all of the organic matter is absorbed.

Judging from the results obtained in the several series of simultaneous determinations (see Tables XII to XV), it is no easy matter to decide which of the different methods is to be preferred as being the most reliable. Taking all the points into consideration, however, it appears to me that the Remsen absorption tube and the absorbent material recommended by Remsen—freshly ignited granular pumice-stone—affords the most trustworthy results. The absorption tube is small and easily cleansed, and the pumice-stone can be freed from organic matter by prolonged incineration in a platinum crucible. The process of distillation employed in this and several of the other methods is, however, liable to lead to considerable error, especially in inexperienced hands. The amounts of ammonia to be derived from the organic matter in several hundred litres of air are extremely small, so that without the utmost caution in the entire manipulation the experimental error may exceed several times the amount of ammonia really present. Aside from these difficulties there is also the difficulty of securing absolute freedom of all ammonia in the retort, condenser, and in the receivers, as well as the great difficulty generally experienced in preparing distilled water sufficiently free from ammonia to make its use safe for the purposes required in these methods.

The pumice-stone also affords the most reliable results in the methods depending upon the oxidation of the organic matter in the air by means of permanganate solution. Since, however, the results obtained in this manner are influenced by the presence of other reducing bodies in the air, this cannot be looked upon as being an ideal method.

It is evident that the quantity of organic matter in the air varies from hour to hour and from day to day. As to the source of this organic matter, it may be stated that this will vary constantly with the locality and the nature of its surroundings. The dust of the air is undoubtedly a rich source of ammonia and is also an active reducing agent upon permanganate. The relative proportion of the organic matter in the air that is of a nitrogenous nature seems to be quite large, yet it is evident from the results of analyses that a portion of the organic matter is non-nitrogenous in character. It is probable that a large proportion of the nitrogenous organic matter in the air exists in the form of dust particles arising from vegetable and animal débris, and that the proportion of gaseous, nitrogenous organic matters is much smaller than is commonly supposed, at least in ordinary air; and such as do exist are presumably of the form of amines from putrefactive processes. Such gaseous bodies could occur in large amounts only in the vicinity of excessive quantities of putrefying materials, or of certain manufacturing establishments, as, for instance, soap factories or bone-boiling establishments.

In the opinion of Gray,[16] "the organized nitrogen exists in the air in the form of germs and minute organisms and possibly of minute particles of disintegrated organic matter. The combined nitrogen contained in rain is derived from three sources: the ammonia compounds derived from the decay of animal and vegetable substances and from the combustion of fuel; the organic matter existing in the air; and, lastly, the nitric acid resulting either from the oxidation of ammonia, and probably some of the organic matter, or, from the direct union of atmospheric oxygen and nitrogen under the influence of electrical discharges taking place in the atmosphere."

From the fact, therefore, that the greater portion of the organic matter in the air is in the form of dust particles, and that but a relatively small proportion of it is usually present in the gaseous form, the method of analysis which will be most likely to present results that possess any degree of accuracy will be the one which abstracts the dust particles most efficiently from the sample of air analyzed. In the second place, the most reliable method will be the one in which the organic matter is converted into ammonia with the least possibility of any considerable experimental error arising from the manipulation. The method which has seemed to me to meet all these indications most satisfactorily is that of Remsen. Here the absorbent material consists of finely granular pumice-stone that has been freshly ignited for twelve to twenty-four hours. This is filled into a small glass absorption tube, twenty centimetres in length, consisting of a narrow portion four centimetres long and three millimetres in internal diameter, and of a wider portion sixteen centimetres long and twelve millimetres in internal diameter. The mouth of this tube is closed by means of perforated rubber cork bearing a short piece of glass tubing through which the air enters. This tube is cleansed by placing it for some hours in a mixture of bichromate of potash, sulphuric acid, and water. It is thoroughly rinsed with twice distilled water, until free of all trace of the cleansing mixture, and wiped on the outside with a clean towel. It is now ready to be filled with the freshly ignited pumice-stone. This is transferred from the plantinum crucible with a clean, porcelain, spoon-shaped spatula. As soon as the pumice has cooled somewhat it is well moistened with twice distilled water, the rubber stopper is put in place, and the narrow portion attached to a gas-meter or aspirator by means of rubber tubing. The moistened granular pumice-stone thus affords an excellent absorbent for the dust particles in the air aspirated through it.

None of the absorbents used in the other methods seem to afford such favorable opportunities for the abstraction of the dust particles in the air. This is especially the case with liquid absorbent materials. The air passes through these in the form of fine bubbles, but under such circumstances the dust particles may also pass with these air bubbles, because they are moistened with considerable difficulty. Neither can the absorbent materials used in the other methods be subjected to such purifying processes as the pumice-stone, which can be heated to redness without injuring its absorbent powers.

Those methods in which the organic matter is determined by estimating the quantity of permanganate reduced by it seem to be less satisfactory in many respects than those in which the organic matter is converted into ammonia. In the first place, such results are always influenced by the reducing action of other bodies in the air besides those of organic nature. In the second place the rate at which many organic bodies become oxydized by the permanganate is sufficiently slow to escape detection by this process as ordinarily conducted. Finally, the process of determination by boiling with acidulated solution of permanganate of potash and titration with oxalic acid solution is a very delicate one, requiring considerable care and experience to obtain concordant results.

Those methods in which the determination is made with cold permanganate solution, and where the amount of organic matter is estimated colorimetrically, are open to several objections. The permanganate acts quite slowly in cold solution and without any degree of regularity. The estimation colorimetrically, as in the method of Carnelly and Mackie,[17] is a most uncertain process because of the difficulty of detecting slight variations in the tints of permanganate solutions of the strength employed by them, or even of solutions of but half that strength. It appeared to me that the operation was rendered somewhat easier by using a permanganate solution of only one-half the strength recommended by them. The same objections apply to those methods in which cold solutions of permanganate are shaken with successive portions of a sample of air until they are decolorized, as in R. Angus Smith's "air-washing"; and in methods already described in which the permanganate is added slowly to a sample of air in a flask as long as it is being decolorized. Under such conditions the permanganate acts slowly and unsatisfactorily; and there is great difficulty in recognizing the exact point of neutralization since the end-reaction is not sharply defined, and as yet there appears to be no way in which it can be made more definite.

THE RESULTS OBTAINED IN AIR ANALYSES BY THE DIFFERENT METHODS.

METHOD I.

Absorbent material: twice distilled water.

Absorption apparatus: a Pettenkofer absorption tube.

TABLE I.

No. of experiments.	Date, 1895.	Source of the air aspirated.	Time taken in aspirating.	Amount of air aspirated.	Window.	Mgs. of NH_3 in 1 cbm. of air.	
						Free NH_3.	Alb. NH_3.
1	20-VI	Room	7 hours	36.0 L.	Closed	69.444 mgs.	458.333 mgs.
2	20-VI	Sewer pipe	7 "	73.6 "	....	47.554 "	33.967 "
3	21-VI	Room	6½ "	33.0 "	Closed	75.757 "	181.818 "
4	21-VI	Sewer pipe	6½ "	109.0 "	....	27.522 "	22.935 "
5	22-VI	Room	6 "	26.0 "	Closed	0.000 "	250.000 "
6	22-VI	Sewer pipe	6 "	84.9 "	....	0.000 "	88.339 "
7	24-VI	Room	7½ "	122.0 "	Closed	0.000 "	0.000 "

This table shows analyses made of the air of one of the rooms of the laboratory, and of the air of one of the soil pipes at the same time on several successive days, the organic matter being converted into ammonia. The windows of the room were closed on each day. The results obtained from the room-air are uniformly higher than those obtained from the air of the soil pipe. With one exception, the proportion of albuminoid ammonia in the air of the soil pipe is smaller than that of the free ammonia, while in the room-air, with the exception of the last analysis where no ammonia was found, the albuminoid ammonia is far in excess of the free ammonia.

TABLE II.

No. of experiments.	Date, 1895.	Amount of air aspirated.	Time taken in aspirating.	Source of the air.	With or without dust-filter.	Mgs. of O. consumed for 1 cbm. of air.
1	8-IV	114.0 L.	23 hours	Room	Without	4.3859 mgs.
2	8-IV	38.9 "	49½ "	Sewer pipe	"	4.0785 "
3	9-IV	90.0 "	24¼ "	Room	"	5.2884 "
4	11-IV	128.0 "	31 "	"	"	4.7701 "
5	11-IV	246.7 "	31 "	Sewer pipe	"	0.5253 "
6	15-IV	243.0 "	46½ "	Room	"	0.7920 "
7	15-IV	191.8 "	46½ "	Sewer pipe	"	0.5874 "
8	18-IV	220.0 "	50½ "	Room	"	0.6114 "
9	18-IV	209.4 "	50½ "	Sewer pipe	"	0.3903 "
10	20-IV	285.0 "	50 "	Room	"	0.2193 "
11	20-IV	141.5 "	50¼ "	Sewer pipe	"	0.2718 "
12	22-IV	198.0 "	49¼ "	Room	With	0.4613 "
13	22-IV	117.4 "	49¼ "	Sewer pipe	Without	0.6876 "
14	25-IV	296.0 "	49 "	Room	"	0.2484 "
15	25-IV	191.8 "	49 "	Sewer pipe	"	0.4600 "
16	27-IV	314.0 "	48¾ "	Room	With	0.3434 "
17	27-IV	90.0 "	48¾ "	Sewer pipe	Without	0.6535 "

This table shows analyses made of air taken from the same sources as those recorded in Table I, but in this instance the quantity of organic matter is estimated by its reducing action on permanganate instead of being converted into ammonia. In two of the analyses of the room-air a dust-filter had been placed before the absorption apparatus, but since no analyses were made on the same day without the use of a dust-filter the results obtained afford no information as to the effects of such a dust-filter on the results obtained. The results obtained without the use of a dust-filter, on succeeding days, are in some instances even more variant than those with, and without, the use of the dust filter. No suggestion can be offered to explain the very high results obtained in the first four analyses. No uniform relation can be determined between the relative amounts of organic matter in the room-air and that of the soil pipe in the results obtained by this method, as seemed to be the case in the results recorded in Table I.

METHOD II.

Absorbent materials: (a) purified glass-wool, (b) acidulated permanganate solution.

Absorption apparatus: two small Erlenmeyer flasks, connected by rubber tubing; modification of Uffelmann's apparatus.

TABLE III.

No. of experiment.	Date, 1895.	Amount of air aspirated.	Time taken in aspirating.	Source of the air.	Window.	Mgs. of O consumed for 1 cbm. of air.	
						Gaseous form.	Dust-form.
1	7-VI	30.0 L.	1 hour	Room	Closed	0.31746 mgs	3.80952 mgs
2	7-VI	25.0 "	1 "	"	"	13.33333 "	2.09523 "
3	8-VI	30.0 "	1 "	"	"	0.63492 "	0.63492 "
4	10-VI	27.0 "	1 "	"	"	0.35273 "	0.17637 "
5	20-VI	7.3 "	2¼ hrs.	"	"	19.56947 "	19.56947 "
6	21-VI	8.8 "	5 "	"	"	54.11255 "	16.23376 "
7	22-VI	6.7 "	3¼ "	"	"	0.00000 "	21.32196 "
8	24-VI	7.5 "	5¼ "	"	Open	19.04761 "	6.39420 "
9	24-VI	8.3 "	5¾ "	"	"	5.73723 "	34.42340 "
10	26-VI	5.5 "	4¼ "	"	"	17.65224 "	
11	26-VI	8.0 "	3¾ "	"	"	8.82612 "	
12	26-VI	10.0 "	3¾ "	"	"	19.41747 "	72.81553 "
13	2-VII	8.4 "	6½ "	"	Closed	5.75109 "	11.50218 "
14	2-VII	8.25 "	5½ "	"	"	5.75109 "	
15	2-VII	12.1 "	5¼ "	"	"	5.75109 "	34.50654 "
16	3-VII	17.3 "	5¼ "	"	Open	19.64195 "	15.67989 "
17	3-VII	8.0 "	4½ "	"	"	33.90776 "	79.11812 "
18	3-VII	8.4 "	5½ "	"	"	43.05748 "	40.45307 "
19	8-VII	7.6 "	6¼ "	"	"	25.42588 "	44.49529 "
20	8-VII	8.05 "	6½ "	"	"	6.00114 "	48.00912 "
21	8-VII	10.2 "	6 "	"	"	4.73619 "	18.94476 "

This table shows analyses made on room-air, mostly in duplicate and triplicate, with separate estimations of the gaseous and of the dust-form of organic matter. The results obtained in simultaneous determinations on the same air show a marked variation. This variation in the results seems to be intimately connected with the quantity of air that was aspirated through each apparatus; the greater the quantity of air aspirated the smaller the relative proportion of organic matter found, both as to the gaseous and the dust-form of organic matter. There is no indication from the results obtained of any definite relation between the quantity of organic matter in gaseous form to that in the form of dust.

The objections to this method are that the amounts of the absorbent materials are quite small and consequently incapable of absorbing any material portion of the organic matter from the air passed through them. The small quantity of absorbent material also necessitates the aspiration of the air in very slow current. The results obtained are quite variant in simultaneous determinations on the same air, and are influenced to a marked degree by the quantity of air used. Another objection is the difficulty with which the glass-wool is boiled with the permanganate on account of the bumping and spirting that take place even though the heat applied is barely sufficient to keep the fluid at the boiling point. With the utmost care possible several of the determinations of the dust-form of organic matter were so vitiated from this cause as to necessitate their omission from the table.

For these different reasons I consider this to be a totally unreliable and unsatisfactory method, and especially so with regard to the quantitative determination of the relative proportions of organic matter in air in its two forms, the gaseous and dust-form. In my hands it has failed utterly to differentiate between these two forms of organic matter.

METHOD III.

Absorbent material: freshly ignited, finely granular pumice-stone.

Absorption apparatus: a small glass tube, twenty centimetres in length, consisting of a narrow portion four centimetres long and three millimetres in its internal diameter, and an expanded portion sixteen centimetres long and twelve millimetres in its internal diameter, similar in size and form to the absorption tube used by Remsen and by Abbott in their experiments.

TABLE IV.

No. of experiment.	Date, 1895.	Amount of air aspirated.	Time taken in aspirating.	Source of the air.	Mgs. of NH_3 in 1 cbm. of air.	
					Free NH_3.	Alb. NH_3.
1	6-III	214.0 L	3 hrs	External	2.3360 mgs	9.3450 mgs
2	7-III	386.0 "	4 "	"	7.7430 "	1.2950 "
3	7-III	340.0 "	3½ "	"	1.4705 "	4.4110 "
4	8-III	343.0 "	3½ "	"	1.4570 "	2.9150 "
5	8-III	336.0 "	3½ "	Room	23.8095 "	29.7610 "
6	9-III	386.0 "	4 "	External	10.5260 "	13.1570 "
7	11-III	393.0 "	4 "	"	10.1770 "	12.7220 "
8	12-III	364.0 "	3¾ "	Room	19.2300 "	27.4720 "
9	12-III	295.0 "	3 "	External	13.5590 "	84.7450 "
10	13-III	293.0 "	3 "	"	0.0000 "	102.3880 "
11	13-III	310.0 "	3 "	Room	0.0000 "	32.2580 "
12	14-III	370.0 "	3¾ "	External	0.0000 "	10.8100 "
13	14-III	820.7 "	4 "	Sewer Pipe	10.9660 "	8.5290 "
14	15-III	741.5 "	3 "	"	25.6230 "	9.4400 "
15	15-III	300.0 "	3 "	External	0.0000 "	3.3333 "
16	16-III	1533.8 "	5 "	Sewer Pipe	4.5660 "	3.9111 "
17	16-III	330.0 "	3½ "	Room	12.1210 "	9.0909 "
18	16-III	340.0 "	3½ "	External	1.4705 "	1.4705 "
19	18-III	390.0 "	4 "	"	0.0000 "	5.1280 "
20	18-III	1075.4 "	3½ "	Sewer Pipe	21.8520 "	13.4830 "
21	19-III	1971.1 "	6¾ "	"	6.0870 "	4.5650 "
22	19-III	556.0 "	6¾ "	External	0.9000 "	3.5970 "
23	20-III	1282.5 "	4¼ "	Sewer Pipe	6.2380 "	0.7799 "

This table shows analyses of the room-air and of the soil pipe, and also of the external air, with the organic matter estimated as ammonia. In this table the greater proportion of free ammonia as compared with albuminoid ammonia in the air of the soil pipe is also shown, as in Table I; while in the majority of the analyses of room-air and of the external air the proportion of albuminoid ammonia is again greater than the free ammonia, as was shown by the results in Table I.

TABLE V.

No. of exp.	Date, 1895.	Hour of day.	Source of the air.	Atmospheric conditions.				Mgs. of NH_3 in 1 cbm. of air.	
				Clouds.	Tempt.	Bar.	Wind.	Free NH_3	Alb. NH_3.
						mm.		mgs.	mgs.
1	6-III	10.00 a.m.	External	Part Cloudy	5.5° C	775.3	S. E.	2.336	9.345
2	7-III	9.50 “	“	Cloudy	8.5 “	768.0	S. W.	7.743	1.295
3	7-III	2.00 p.m.	“	Raining	12.0 “	764.2	E.	1.470	4.411
4	8-III	10.00 a.m.	“	Cloudy	7.5 “	757.1	N. E.	1.457	2.915
5	8-III	2.00 p.m.	Room	“	8.5 “ 19.5 “	754.7	W.	23.8095	29.761
6	9-III	11.45 a.m.	External	Light Snow	−0.5 “	756.3	N. W.	10.526	13.157
7	11-III	12.10 p.m.	“	Snowing	0.0 “	769.1	N. E.	10.177	12.722
8	12-III	10.00 a.m.	Room	Cloudy Misty	2.0 “ 19.8 “	767.6	N. E.	19.230	27.472
9	12-III	1.45 p.m.	External	Foggy	3.0 “	767.3	E.	13.559	84.745
10	13-III	11.00 a.m.	“	Cloudy	8.0 “	766.5	S. E.	0.000	102.388
11	13-III	2.00 p.m.	Room	“	8.5 “ 20.5 “	764.1	S. E.	0.000	32.258
12	14-III	11.15 a.m.	External	Clear	3.5 “	764.8	N. W.	0.000	10.810
15	15-III	11.15 “	“	Raining	−3.0 “	766.0	N.E	0.000	3.333
17	16-III	9.30 “	Room	Clear	0.0 “ 18.0 “	755.8	N. W.	12.121	9.0909
18	16-III	1.00 p.m.	External	“	−0.8 “	756.5	N. W.	1.470	1.4705
19	18-III	11.45 a.m.	“	“	+5.5 “	759.8	N. W.	0.000	5.128
22	19-III	12.15 p.m.	“	Cloudy	4.0 “	763.2	N.E.	0.900	3.597

This table, containing the determinations of organic matter in room-air and in external air which form a part of Table IV, shows the atmospheric conditions prevailing at the time the analyses were made. The data as presented here show no marked variations in the quantity of organic matter in external air as the result of the atmospheric conditions. The most marked influence noticeable is the gradual decrease in the quantity of ammonia during several days of rain, snow, and fog; and also but a slight increase during the clear days immediately following that period. The season of the year at which these experiments were made is also most probably that in which the atmospheric influences on the quantity of organic matter in air are least effective. The amount of moisture in the soil at this season is sufficient to prevent the rise of large quantities of dust. The quantity of organic matter in the room-air was found to be constantly higher than that in the external air.

TABLE VI.

No. of experiment.	Date, 1895.	Amt. of air aspirated.	Time taken in aspirating.	Source of the air.	Mgs. of O consumed for 1 cbm. of air.
1	15-III	196.0 L.	2 hours	External	0.0000 mgs.
2	20-III	418.0 "	4¼ "	"	0.1955 "
3	21-III	698.0 "	7 "	"	0.0413 "
4	21-III	1429.0 "	4½ "	Sewer pipe	0.0000 "
5	22-III	598.0 "	6 "	External	0.0000 "
6	22-III	1174.5 "	4¼ "	Sewer pipe	0.1252 "
7	23-III	1938.5 "	6½ "	"	0.1240 "
8	23-III	660.0 "	6¾ "	Room	0.0000 "
9	25-III	1471.6 "	5 "	Sewer pipe	0.0000 "
10	25-III	623.0 "	5½ "	Room	0.0077 "
11	4-IV	576.0 "	6½ "	External	0.0000 "
12	4-IV	176.6 "	6¼ "	Sewer pipe	1.3600 "
13	5-IV	888.0 "	9 "	External	0.0054 "
14	5-IV	2547.0 "	9 "	Sewer pipe	0.0000 "

This table shows analyses made on room-air, external air, and the air of the soil pipe with the quantity of organic matter estimated from its action in reducing permanganate. The results obtained show no uniform relations in analyses of air from the same source on succeeding days. In a number of the determinations there was entire absence of any reducing action, and since it is improbable that there is at any time no organic matter in air drawn from such sources as these samples were taken, it is evident that this is not a reliable method for the determination of organic matter in air.

METHOD IV.

Absorbent material: a $\frac{n}{1000}$ solution of permanganate of potash, as employed by Carnelley and Mackie.

Absorption apparatus: flasks of about four litres capacity.

TABLE VII.

No. of experiment.	Date, 1895.	Amt. of air used.	Source of the air.	Windows.	Mgs. of O consumed for 1 cbm. of air.
1	9-V	3.885 L.	Room	Open	12.3552 mgs.
2	9-V	3.910 "	"	"	12.2762 "
3	10-V	3.885 "	"	"	12.3552 "
4	10-V	3.910 "	"	"	12.2762 "
5	11-V	3.885 "	"	"	10.3293 "
6	11-V	3.910 "	"	"	10.2301 "
7	11-V	3.885 "	"	"	12.3552 "
8	11-V	3.910 "	"	"	12.2762 "
9	13-V	3.885 "	"	Closed	28.8288 "
10	13-V	3.910 "	"	"	28.6444 "
11	15-V	3.885 "	"	"	8.2368 "
12	18-V	3.885 "	"	"	10.3293 "
13	18-V	3.910 "	"	"	6.9565 "
14	24-V	3.885 "	"	"	12.3552 "
15	24-V	3.910 "	"	"	12.2762 "
16	27-V	3.885 "	"	"	8.2368 "
17	27-V	3.910 "	"	"	8.1841 "
18	29-V	3.885 "	"	Open	8.2368 "
19	29-V	3.910 "	"	"	6.1381 "
20	31-V	3.885 "	"	"	8.2368 "
21	31-V	3.910 "	"	"	8.1841 "
22	1-VI	3.885 "	"	"	24.7104 "
23	1-VI	3.910 "	"	"	16.3682 "
24	3-VI	3.885 "	"	"	8.2368 "
25	3-VI	3.910 "	"	"	2.0460 "
26	4-VI	3.885 "	"	Closed	16.4736 "
27	4-VI	3.910 "	"	"	8.1841 "

This table shows analyses in which the organic matter is determined colorimetrically by comparing a portion of the permanganate that has been exposed to the air with the tint of an equal amount of fresh permanganate solution.

While the results show marked variations in the amount of organic matter in the air in a few of the determinations, the results cannot be taken as showing with any degree of accuracy the amount of organic matter that was really present. The objections to this method have already been considered elsewhere at sufficient length to require any further remarks. It is probably true, as claimed by Carnelley and Mackie, that for a rough estimate this method is not without some value. The principal points in its favor are the fact that it is portable and may thus serve to analyze air at a distance from the laboratory, and that it requires quite simple apparatus for its operation.

TABLE VIII.

No. of experiment.	Date, 1895.	Amt. of air used.	Source of the air.	Windows.	Atmospheric conditions.	Mgs. of O consumed for 1 cbm. of air.
1	2-VII	3.968 L.	Room.	Open	Clear	12.096 mgs.
2	10-VII	3.968 "	"	"	"	
3	26-VII	3.968 "	"	"	"	5.040 "
4	26-VII	3.910 "	"	"	"	5.112 "
5	16-VIII	3.968 "	"	"	"	6.048 "
6	16-VIII	3.910 "	"	"	"	6.112 "
7	20-VIII	3.968 "	"	Closed	"	4.032 "
8	20-VIII	3.910 "	"	"	"	4.092 "
9	26-VIII	3.968 "	"	Open	"	3.025 "
10	26-VIII	3.910 "	"	"	"	3.069 "
11	28-VIII	3.968 "	"	"	Partly Cloudy	2.016 "
12	28-VIII	3.910 "	"	"	" "	2.046 "
13	30-VIII	3.968 "	"	"	Cloudy	3.025 "
14	30-VIII	3.910 "	"	"	"	3.069 "
15	2-IX	3.968 "	"	"	Clear	4.032 "
16	2-IX	3.910 "	"	"	"	4.092 "

This table shows analyses made in which the organic matter is determined from the quantity of $\frac{n}{2000}$ permanganate solution that is decolorized when shaken with a sample of air in a flask. The results obtained with this method are only an approximate indication of the amount of organic matter in a sample of air. It is open to the same criticisms as the method of Carnelley and Mackie, and appears to give results that are equally as good as those obtained by their method. The points in its favor are the same as those claimed for their method, while it is probably easier to operate and requires less apparatus.

METHOD V.

Absorbent materials: (a) $\frac{n}{10}$ sulphuric acid; (b) twice distilled water.
Absorption apparatus: a Pettenkofer absorption tube.

TABLE IX.

No. of experiment.	Date, 1895.	Amt. of air aspirated.	Time taken in aspirating.	Source of the air.	Mgs. of NH_3 in 1 cbm. of air.
1	13-V	342.0 L.	26¼ hours.	Room	0.000 mgs.
2	13-V	55.0 "	26¼ "	Sewer pipe	37.090 "
3	15-V	191.0 "	26 "	Room	0.000 "
4	15-V	44.0 "	46¼ "	Sewer pipe	30.909 "
5	17-V	232.0 "	25 "	Room	0.000 "
6	17-V	67.9 "	25 "	Sewer pipe	25.029 "

This table shows analyses made of room-air and the air of a soil pipe in which the quantity of ammonia was determined directly. The air was aspirated through $\frac{n}{10}$ sulphuric acid and the amount of free acid remaining in solution then estimated by titration with $\frac{n}{10}$ ammonium hydroxid. The results obtained show the absence of ammonia in the room-air, while the quantity of ammonia in the air of the soil pipe appears to be of fairly constant proportions. This method appears to be sufficiently reliable for general use. The importance of the results obtained rests mainly upon the fact that they indicate to what extent the ammonia in the air, under certain conditions, may become a factor in the determination of organic matter in air with any of the methods in use.

TABLE X.

No. of experiment.	Date, 1895.	Amount of air aspirated.	Time taken in aspirating.	Source of the air.	With or without dust-filter.	Mgs. of NH_3 in 1 cbm. of air.
1	8-VII	110.5 L.	7 hrs.	Room	Without	0.0000 mgs.
2	8-VII	118.3 "	7 "	Sewer pipe	"	0.8450 "
3	23-X	8.25 "	5 "	Room	"	0.3030 "
4	24-X	8.0 "	2⅚ "	"	"	0.2500 "
5	25-X	8.0 "	4½ "	"	With	0.0000 "
6	25-X	8.0 "	4¼ "	"	Without	0.1875 "
7	7-XI	119.4 "	22⅓ "	"	With	0.0000 "
8	7-XI	73.0 "	22⅓ "	"	Without	0.0000 "
9	8-XI	68.2 "	24 "	"	With	0.0000 "
10	8-XI	57.5 "	24 "	"	Without	0.0000 "
11	9-XI	204.9 "	24 "	"	With	0.0360 "
12	9-XI	138.75 "	24 "	"	Without	0.0029 "
13	10-XI	131.5 "	23¾ "	"	With	0.0000 "
14	10-XI	88.25 "	23¾ "	"	Without	0.0056 "
15	11-XI	186.2 "	23½ "	"	With	0.0000 "
16	11-XI	212.0 "	23½ "	"	Without	0.00235 "
17	12-XI	82.0 "	23¼ "	"	With	0.0000 "
18	12-XI	192.5 "	23¼ "	"	Without	0.0000 "
19	13-XI	157.6 "	25¼ "	"	With	0.0000 "
20	13-XI	109.0 "	25¼ "	"	Without	0.0000 "

This table shows analyses made by aspirating the air through 100 c. c. of twice distilled water, and testing with Nessler's reagent; thus estimating directly the amount of ammonia in the air. Usually two simultaneous tests were made on the same air, the one with, and the other without, the attachment of a dust-filter. There appears to be some evidence of the direct influence of the dust of the air on the results obtained in this manner, though at times no ammonia was found even without the use of the dust-filter. At all times the quantities of ammonia found were quite small.

METHOD VI.

Absorbent material: a $\frac{n}{10}$ solution of iodine.
Absorption apparatus: a Pettenkofer absorption tube.

TABLE XI.

No. of experiment.	Date, 1895.	Amount of air aspirated.	Time taken in aspirating.	Source of the air.	Mgs. of H_2S in 1 cbm. of air.	Mgs. of SO_2 in 1 cbm. of air.
1	29-IV	82.0 L.	21½ hrs.	Sewer pipe	76.70 mgs.	144.39 mgs.
2	30-IV	191.8 “	48 “	“	24.81 “	46.71 “
3	1-V	212.25 “	22 “	“	30.43 “	57.29 “
4	2-V	238.0 “	21¾ “	Room	26.84 “	50.52 “
5	2-V	235.7 “	23¼ “	Sewer pipe	29.21 “	54.98 “
6	3-V	183.0 “	21¼ “	Room	30.65 “	57.70 “
7	3-V	123.0 “	21¼ “	Sewer pipe	33.88 “	63.79 “
8	4-V	128.765 “	69¾ “	“	64.69 “	121.78 “

This table shows analyses made to determine the quantities of other reducing bodies in the air besides those of organic nature. The results obtained are expressed as sulphuretted hydrogen in the one column, and as sulphurous acid in the other. Both of these react on the iodine in a similar manner, and it is impossible to separate them from each other in these analyses. The value of these results lies in the fact that they show the extent to which the results obtained as organic oxidizable matter with some of the methods are influenced by these reducing bodies when present in the air.

SIMULTANEOUS DETERMINATIONS.

In order to ascertain the relative value of the results obtained by the different methods, it was deemed advisable to make simultaneous determinations on the same air with several of the methods. Such a series of determinations should afford some indication as to which of the methods is probably the most reliable from the uniformity of the results which they give us.

TABLE XII.

No. of experiment.	Date, 1895.	Method.	Amount of air used.	Time taken in aspirating.	Source of the air.	Mgs. of O consumed from 1 cbm. of air.		
						Gaseous form.	Dust-form.	Total.
						mgs.	mgs.	mgs.
1	10-X	III-b	136.5 L.	$3\frac{2}{3}$ hrs.	Room			0.22916
2	10-X	II-a	8.0 “	$3\frac{2}{3}$ “	“	5.98728	14.66275	20.65403
3	10-X	I-b	8.0 “	$2\frac{1}{4}$ “	“			14.66275
4	11-X	III-b	172.75 “	5 “	“			0.63043
5	11-X	II-a	6.33 “	$5\frac{1}{6}$ “	“	3.12827	15.64137	18.76964
6	11-X	I-b	8.0 “	$4\frac{1}{6}$ “	“			15.71782
7	12-X	III-b	20.0 “	$3\frac{7}{12}$ “	“			10.09085
8	12-X	II-a	7.625 “	$3\frac{3}{4}$ “	“	11.58682	17.57121	29.15803
9	12-X	I-b	7.5 “	$3\frac{3}{4}$ “	“			8.67313
10	14-X	III-b	95.0 “	$4\frac{1}{3}$ “	“			0.87462
11	14-X	II-a	7.25 “	$5\frac{1}{12}$ “	“	7.01115	21.30313	28.31428
12	10-X	I-b	7.5 “	$4\frac{7}{12}$ “	“			14.72792

The marked variation in the total amounts of organic matter found in simultaneous determinations with these three methods shows that no reliance can be placed on the results obtained by at least two of these methods. The nearly uniformly low results obtained with method III-b indicate that this method is the preferable one of the three entering into this experiment.

TABLE XIII.

No. of experiment.	Date, 1896.	Source of the air.	Amount of air aspirated.	Time taken in aspirating.	With or without dust-filter.	Method.	Mgs. of O consumed for 1 cbm. of air.
1	4-III	Room	52.0 L.	$6\frac{2}{3}$ hrs.	With	III-b	3.8658 mgs.
2	4-III	"	72.7 "	$6\frac{2}{3}$ "	Without	III-b	7.2145 "
3	4-III	"	13.1 "	$6\frac{2}{3}$ "	With	I-b	8.2900 "
4	4-III	"	15.4 "	$6\frac{2}{8}$ "	Without	I-b	6.3661 "
5	5-III	"	158.0 "	7 "	With	III-b	1.7684 "
6	5-III	"	113.2 "	7 "	Without	III-b	3.6374 "
7	5-III	"	13.75 "	7 "	With	I-b	35.6506 "
8	5-III	"	13.3 "	7 "	Without	I-b	20.6398 "

The results obtained with method III-b show a constant influence from the dust-filter attached, but those obtained with method I-b fail to show such an influence; in fact, the results are invariably higher, from some unexplained cause, in the determinations with the dust-filter than in those in which it was not used. It seems, therefore, that method I-b is not reliable, even with the utmost care possible.

TABLE XIV.

No. of experiment.	Date, 1896.	Amount of air aspirated.	Time taken in aspirating.	Source of the air.	With or without dust-filter.	Method.	Mgs. of NH_3 in 1 cbm. of air.	
							Free NH_3	Alb. NH_3
1	6-I	434.5 L.	$23\frac{1}{4}$ h.	Room	With	III-a	0.0092 mgs.	0.0103 mgs.
2	6-I	1051.9 "	$23\frac{1}{4}$ "	"	Without	"	0.0294 "	0.0175 "
3	7-I	437.0 "	25 "	"	With	"	0.0137 "	0.0034 "
4	7-I	1033.5 "	25 "	"	Without	"	0.0387 "	0.0062 "
5	9-I	838.0 "	25 "	"	With	"	0.0095 "	0.0053 "
6	29-I	1158.6 "	25 "	"	Without	"	0.0232 "	0.0081 "
7	25-II	698.5 "	$24\frac{1}{2}$ "	"	With	"	0.0114 "	0.0078 "
8	25-II	766.9 "	$24\frac{1}{2}$ "	"	Without	"	0.0182 "	0.0071 "
9	26-II	686.5 "	$24\frac{1}{3}$ "	"	With	"	0.0182 "	0.0043 "
10	26-II	758.7 "	$24\frac{1}{3}$ "	"	Without	"	0.0237 "	0.0158 "
11	27-II	727.5 "	24 "	"	With	"	0.0343 "	0.0013 "
12	27-II	819.8 "	24 "	"	Without	"	0.0536 "	0.0030 "
13	28-II	480.0 "	$25\frac{3}{4}$ "	"	With	"	0.0156 "	0.0041 "
14	28-II	873.9 "	$25\frac{3}{4}$ "	"	Without	"	0.0583 "	0.0005 "

This table shows the results obtained in a series of simultaneous determinations with Method III-a, with and without the use of a dust-filter. It will be noted that in each instance the free ammonia is lower with than without the dust-filter, and only in two instances is the albuminoid ammonia lower without than with the use of the dust-filter. The total ammonia is, however, constantly lower with than without the use of the dust-filter, so that there is strong evidence that the dust in the air is the source of a large part, if not all, of the organic matter. It is probable that the dust-filter of asbestos failed to filter out the finer dust particles, and it is from these we still get the reaction of ammonia in these determinations with the use of the dust-filter.

TABLE XV.

No. of experiment.	Date, 1895.	Amount of air used.	Time taken in aspirating.	Source of the air.	With or without dust-filter.	Method.	Mgs. of NH_3 in 1 cbm. of air.		Mgs. of O consumed for 1 cbm.
							Free NH_3	Alb. NH_3	
							mgs.	mgs.	mgs.
1	15-X	7.25 L.	4¾ h.	Room	Without	I-a	0.0052	0.0317	
2	15-X	192.0 "	4¾ "	"	"	III-a	0.3448	0.6896	
3	16-X	8.0 "	4⅔ "	"	"	I-a	0.1250	0.7625	
4	16-X	8.0 "	4⅚ "	"	"	III-a	0.0625	0.5000	
5	21-X	7.5 "	6 "	"	"	I-a	0.0666	0.0133	
6	21-X	7.25 "	6 "	"	"	III-a	0.0000	0.0000	
	1896.								
7	12-III	41.0 "	6¾ "	"	With	III-a	0.0000	0.0268	
8	12-III	38.7 "	6¾ "	"	Without	III-a	0.0129	0.0516	
9	12-III	15.75 "	6¾ "	"	With	I-a	0.0000	0.0666	
10	12-III	14.1 "	6¾ "	"	Without	I-a	0.0000	0.0422	
11	12-III	3.775 "	....	"	"	IV-a			3.1788
12	12-III	3.83 "	...	"	"	IV-a			3.1331
13	12-III	3.754 "	...	"	"	IV-b			2.6638
14	13-III	3.775 "	....	"	"	IV-a			8.4765
15	13-III	3.83 "	....	"	"	IV-a			8.3550
16	13-III	3.754 "	....	"	"	IV-b			4.2621
17	13-III	38.0 "	6 "	"	With	III-a	0.0000	0.1184	
18	13-III	82.9 "	6 "	"	Without	III-a	0.0240	0.0904	
19	13-III	7.85 "	6 "	"	With	I-a	0.0000	1.0191	
20	13-III	7.75 "	6 "	"	Without	I-a	0.0000	1.2903	

The results in this table seem to indicate that the amount of organic matter, as shown by Methods IV-a and b, bears some relation to the amount of ammonia as shown by Methods I and III. The results obtained with Method III are lower as a rule than those obtained with Method I. The influence of the dust-filter on the quantity of organic matter recovered from the absorbent material is most marked with Method III.

CONCLUSIONS.

1. The quantity of organic matter bears an intimate relation to the amount of dust floating in the air. It is probable that the gaseous

organic matter forms but an exceedingly small proportion of the total organic matter.

2. The attachment of a dust-filter of asbestos to the absorption apparatus produces results that are constantly lower than those obtained without the dust-filter.

3. The most reliable method for the estimation of organic matter in air is that known as Remsen's method, and is called Method III-a in this research. The pumice-stone seems to be the best form of absorbent material because it can be thoroughly cleansed by heat without changing its condition or usefulness.

4. Those methods which determine the organic matter from its reducing action on permanganate do not seem to afford as satisfactory results as those in which the organic matter is estimated as ammonia.

This work was performed while holding the Thomas A. Scott Fellowship in Hygiene in the Laboratory of Hygiene, University of Pennsylvania. I desire to express my thanks to Dr. John S. Billings, Director of the Laboratory, and to Dr. A. C. Abbott, First Assistant, for the valuable suggestions and assistance with which they favored me during the progress of the work.

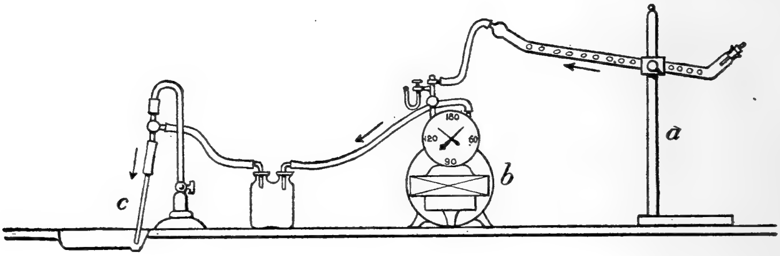

Fig. 1.—Apparatus used with Methods I, V, and VI. This apparatus consists of: *a*—a stative which supports the Pettenkofer absorption tube containing the absorbent material; *b*—the gas-meter which measures the volume of air aspirated through the apparatus; and *c*—a Chapman water pump, by means of which a slow, steady current of air is maintained through the apparatus.

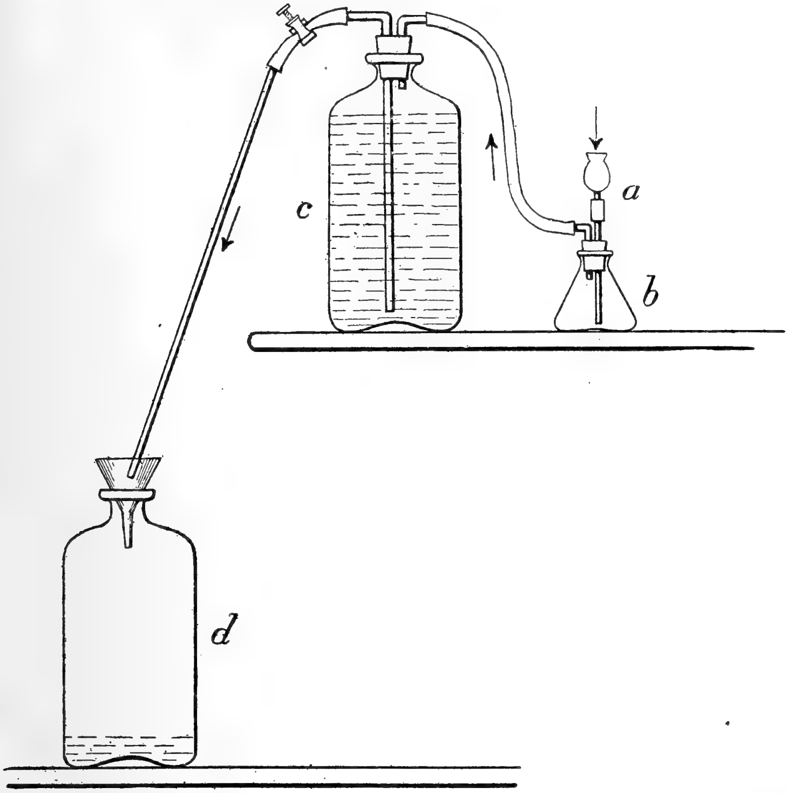

Fig. 2.—Apparatus used in Method II. It consists of: *a*—a small globe-shaped glass tube containing the glass-wool absorbent for the dust in the air; *b*—a small Erlenmeyer flask containing the acidulated permanganate solution to absorb the gaseous organic matter; *c*—a graduated flask of eight litres capacity, which serves as an aspirator; and *d*—another eight-litre flask into which the water drains from the aspirator.

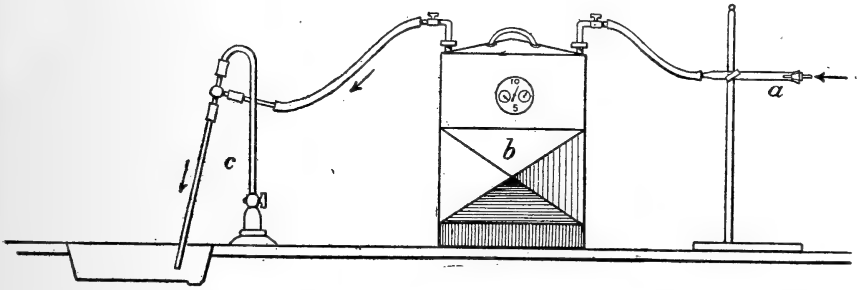

Fig. 3.—Apparatus used with Method III. It consists of: *a*—a small glass tube, twenty centimetres in length, consisting of a narrow portion four centimetres long and three millimetres in its internal diameter, and a dilated portion sixteen centimetres long and twelve millimetres in its internal diameter. This tube contains the granular pumice-stone which serves as the absorbent material in this method; *b*—is the gas-meter; and *c*—a Chapman water pump.

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HODGKINS FUND.

AIR AND LIFE.

BY

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Member of the Société de Biologie, Demonstrator in the Institute of Comparative Pathology in the Paris Museum of Natural History.

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II.—AIR FROM THE CHEMICAL POINT OF VIEW.

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INTRODUCTION.

A great chemist, J. B. Dumas, once said that living organisms are nothing but "condensed air." He thus expressed, in terse terms, the result of the investigations pursued by himself and others into the relations of the atmosphere to living beings.

My purpose, in the following pages, is to show how closely Dumas's statement agrees with ascertained facts, even more closely than he himself supposed. It is also desirable to briefly instance and illustrate the varied ways in which air influences the general life of the globe. If the ordinary definition of the word were not an impediment to its use in the present case, I would say that I purpose making a general sketch of the "biology" of the atmosphere. More exactly and appropriately I may use a quite similar term, and say that the subject-matter of this essay is the "natural history" of the air—taking the term in the sense given to it by Geoffroy St. Hilaire—an essay upon the properties of air considered in its relations to living beings, upon its composition, its contents, its origin, its varied modes of action.

While I shall especially and particularly consider air in its relations to life, I shall also refer briefly to its relations to other subjects, pointing out those which it would be useful to investigate further in order to increase the scope of our knowledge.

The study of the atmosphere is truly one of great magnitude; its relations to the remainder of the universe are so varied and important, the subjects which it suggests are so numerous and take us through so many fields of inquiry, that a comparison suggests itself forcibly—just as the atmosphere surrounds our whole planet and forces itself into the clefts and fissures between its elements and rocks to the depths of the soil, in the same manner does the study of air pertain to all departments of science, to geology as well as astronomy, to physics no less than to chemistry, and to biology in the largest sense of the term.

While it would be a hazardous enterprise to undertake a complete review of so important a subject, it may prove useful to give a rapid sketch of some features, and that I shall endeavor to do, by showing what air is, physically and chemically considered, what is its origin, what it contains, and of what use it is to life. Doubtless this is but a small part of the subject, but this sketch may contribute to show how vast and varied is that chapter of science that goes under the name of the "study of the atmosphere."

I.—Air Considered from the Physical Point of View.

Vast as are the proportions of the atmosphere it is none the less invisible. It surrounds us on every side; we are bathed in it, and we do not see it; when it is not in motion we do not feel it. Although having material existence and creating material effects, for evil or for good, it is immaterial to our senses. This fluid, this gas, may, however, be weighed. Jean Rey[1] and Otto von Guericke[2] were the first who gave positive proof of this, and showed that a glass receiver in which a vacuum had been made—even imperfectly—weighed less than the same receiver in normal and free connection with the surrounding atmosphere—that is, full of air—and, on the other hand, a receiver into which air is forced and maintained under pressure weighs more than the same receiver full of air at the normal pressure *pro loco et tempore.* One liter of air, pure and dry, under the pressure of 760 millimeters, at 0° temperature, and at the latitude of Paris, weighs 1.293 grams (Regnault). It weighs more if the pressure is higher, less if it is lower; and hence a liter of air has more weight at the bottom of a shaft in a mine than at sea level, and less on top of a hill or mountain. The higher the altitude at which air is weighed the less it weighs, because it expands, the same weight of air occupying a larger space or volume. Air is more dense at low stations, less dense in the higher strata of the atmosphere, so that when the weight of air is mentioned it is always given with reference to a certain altitude, to a certain pressure, and also to a certain temperature and hygrometric state, because these different conditions exert a considerable influence upon the matter.

As in the case of other gases, air is made up of molecules, and these are considered as being in a state of perpetual motion. It has been reckoned that the number of impacts or collisions to which each molecule is subjected during each second, in the tremendous turmoil which takes place in the air, amounts to something like 4,700,000,000! These molecules are exceedingly small, and Sir William Thomson (Lord Kelvin), Clerk Maxwell, and Van de Waals give their dimensions as being less than a fraction of one-millionth of a millimeter, 1 cubic centimeter of air, at 0° and 760 millimeters pressure, containing, in round numbers, some 21,000,000,000,000,000,000 of these molecules.

I have referred to the fact that the weight of the air is not the same in all localities. It also varies in the same locality. The sum total of

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[1] Jean Rey, French physician and physicist, said, in 1630, that if tin is burnt in contact with air, it increases in weight, and this increase is due to air which has been absorbed by the metal during the combustion.

[2] Otto von Guericke, born 1602, died 1686. He also demonstrated atmospheric pressure by means of the instrument called the Magdeburg hemispheres—two hollow hemispherical cups which it is very difficult to separate when a vacuum has been created in the interior.

the weight of the atmosphere, wherever considered, varies every day more or less, often appreciably within the limits of a few hours and even minutes. This could not happen, of course, if the weight of the strata of air did not vary also. The weight of the whole atmosphere increases or decreases because the weight of the air, considered at any region vertically above the point where the observation is made, increases or decreases. These variations of weight, or pressure, are indicated by the barometer—devised in 1643 by Torricelli, pupil and friend of Galileo—and the oscillations of that instrument are only indications of the differences of the weight or pressure of the air.

Now, as the pressure is increased at low stations, and diminished at high ones, and, as there is a very definite and regular connection between differences of altitude and barometrical indications, it is conceivable that the barometer may, to some extent, and with certain limitations, yield information as to the altitude at which an observer finds himself. It is sufficient to mention the fact; the methods by which it is established would require too long an exposition.

Since air is material and has a weight of its own, however variable, it must press upon all organisms. It is not difficult to estimate with some precision the weight of the superincumbent air. For each square centimeter of our skin, the pressure exerted is exactly that of a vertical column of mercury 1 square centimeter in section, and of the same height as the barometrical column at that moment. If the barometer stands at 760 millimeters, the pressure is exactly that of 76 cubic centimeters of mercury, and as each cubic centimeter weighs 13.6 grams, the sum total, per square centimeter, is 1 kilogram 33 grams, or about 15 pounds per square inch. Taking the skin surface of the average adult to be something like 1½ square meters (15,000 square centimeters), the weight with which the atmosphere presses on each of us amounts to 15,450 kilograms; but under ordinary circumstances we do not feel this enormous load, because the pressure is exerted in all directions; from within outward as well as from without inward, from below upward as well as from above downward. To perceive this pressure, it must be removed from one side, as when the hand is placed over the open end of a cylinder in which a vacuum is being formed; then one feels the strong pressure pushing the hand toward the opposite end of the cylinder. Of course the pressure exerted upon the body and all objects, is lessened as the altitude increases, or the barometer falls; and, reciprocally, if the barometer rises, or if the body be at a low station—in a mine for instance—the pressure is higher. The total weight of the atmosphere, at sea level, under normal circumstances, averages some 5,000,000,000,000,000,000 kilograms—that is, the millionth of the weight of our planet itself; or, to use other terms, the weight of a continuous stratum of mercury 76 centimeters high, and covering the entire surface of the globe, both sea and land. This is a fairly high figure for a substance so nearly immaterial that it escapes our vision. However, air is not always invisible; it may be seen very clearly; it may also be touched and handled, although no one would undertake to do so, or to recommend the feat. Whilst it is gaseous under normal pressure and circumstances, it may be made to assume the liquid form when subjected simultaneously to the influence of considerable cold and very high pressure. High pressure alone is not sufficient. Under a pressure of 3,000 atmospheres, 3,000 times that of ordinary sea-level pressure, oxygen and nitrogen remain gases (Natterer); but if at the same time the temperature is lowered, they immediately assume the liquid condition. MM. Cailletet and Pictet have obtained liquid air by means of pressures of 300, 500, or 1,000 atmospheres cooperating with intense cold, with the cold corresponding to 100° or 200° below zero (Celsius or centigrade). Under such circumstances air may even assume the solid form; the liquid air freezes into a solid block.[1]

No one could venture to touch this liquid or solid with the bare skin, for two reasons; one being that, of course, air can be kept liquid or solid only under the circumstances of its production, and instantly becomes a gas under normal pressure or temperature; the other, that, even if the transformation were not instantaneous, the intense absorption of heat (production of cold) which accompanies the passage from the liquid or solid to the gaseous state would be more than sufficient to kill instantly all living tissues in the vicinity.

It is enough for our present purpose to simply mention the importance of air as an elastic fluid, and the part played by this gas in luminous, thermic, acoustic, and electric phenomena, where it is an all-important medium. It is also sufficient to remind the reader of the temperature of the atmosphere and its varied movements, from the light breeze that cools the hot summer days to the cyclones and tornadoes which destroy buildings and tear up the strongest giants of the forests. Lastly, the atmosphere is very far from being unlimited. It ceases at some distance from our planet, becoming very thin and rare even at altitudes that are not exceedingly great, such as 5,000 meters (Mont Blanc, 4,813 meters; Gaurisankar 8,840 meters), and while we are not prepared to state the exact distance from the earth at which all traces of air disappear, it is generally admitted that above 320 or 350 kilometers (1 kilometer=1,000 meters) height, vertically, there is no atmosphere worth mentioning. Of course, at such altitudes, the air must be exceedingly thin and rarefied, as it is in the exhausted receiver of the air pump.

It is commonly said that air is tasteless and odorless. Pure air

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[1] The gas is first cooled down to 30° below zero, and then compressed under 200 or 300 atmospheres. It remains fluid; but if a small amount of it is then allowed to escape, the sudden expansion—which is accompanied by a production of cold, while compression causes heat to be evolved—cools down the remainder of the air, the temperature falls to 200° below zero, and the air immediately assumes the liquid condition. Lower down it freezes and becomes a solid block.

may be unable to affect the olfactory membrane; but this is not the case with the atmosphere generally. The air that surrounds us is full of scents and odors, but we are so accustomed to them that we take no notice thereof. But after we have spent some time in an atmosphere where most ordinary odors can not conveniently gain access, and then return to our ordinary surroundings, the case is altered, and we perceive a very powerful odor. This has been noticed by different observers after a considerable sojourn in deep caves, such as the Mammoth Cave in Kentucky. The air in these caves is nearly odorless, and when, after a few hours spent in this scentless environment, the visitor emerges again into the open, the atmosphere seems powerfully, even violently, scented or odoriferous, and some persons may even be temporarily affected by the intensity of the sensation. During the sojourn in the unscented air the olfactory cells have rested, but the renewal of their activity, generally unconscious, is accompanied by a very strong sensation which however soon fades.

The atmosphere does not stop at the surface of the seas, nor does it cease at the surface of the soil. It penetrates both, the former especially. In the latter the access of air is very soon arrested by the compactness of the rocks or strata, and, generally speaking, the proportion of air in the soil is very small in all cases where there are no clefts, fissures, or deep underground galleries. In the superficial layer, however, the case is different; air is always present in appreciable proportions in the less compact parts where plants push their roots and seek their nutriment; and in the deepest shafts, caverns, caves, and other natural or artificial excavations of the soil, air exists. It should not be expected to find there as pure a gas as that which surrounds the exterior of the planet. In the soil many slow but continuous chemical reactions are going on between the air and the solid constituents, and the result is an alteration of both sets of elements; some chemicals of the earth and rocks are transformed, and while the air loses some part of its constituents new elements are added to it, and thus its normal composition is soon altered. This is the reason why great care should always be exercised to ascertain the condition of air in all deep cavities, and even in normal excavations if they are rather secluded. The air may have been so much altered in its composition as to have become unfit for the maintenance of life, and cases are on record where it consisted almost entirely of carbonic acid. Among the investigators who have specially concerned themselves with the chemical composition of "ground" air, Boussingault has obtained interesting results, showing that while 1 cubic meter of normal atmosphere contains about 4 deciliters (or 0.216 gram) of carbon, 1 cubic meter of ground air contains 9 liters (or nearly 5 grams), which is twenty-two or twenty-three times more. In recently manured soil the proportion is much more considerable, and the amount of carbonic acid may be twenty-four times as great as in atmospheric air. This considerable amount of carbonic acid in ground air fully explains a number of accidents, inasmuch as while the proportion of this gas is considerably increased that of oxygen is greatly diminished.

Air penetrates to a great depth in water, whether fresh or salt. This is shown by the number of living forms found, not only at the surface or in its neighborhood, but at the greatest depths to which man has yet been able to lower his nets, dredges, and sounding apparatus. Since living organisms exist in the depths of the ocean, and since they are physiologically, in their most important features, constructed on the same principles as those which live near the surface, it is obvious that in the waters of the deep, air must be dissolved of which they take advantage for their respiratory functions. Direct and precise observation fully confirms this inductive reasoning. Many instruments have been devised for the purpose of obtaining water from different depths. One of the first was the bottle, which was used by the Kiel committee. This bottle, firmly stopped and empty, was lowered to the required depth, and a sudden pull was enough to cause it to open, the surrounding water filling it in a few seconds. Many similar implements have been since invented by Bunsen, Meyer, Mill, Buchanan (*Challenger*), Ellman, Sigsbee (*Blake*), Richard, Villegente, and Paul Regnard. The description of these instruments is given at length in many works—for instance, in T. Thoulet's Océanographie (Vol. I), Paris, 1890, and P. Regnard's La vie dans les eaux, Paris, 1891—where the reader who desires full information on the matter may find it, and it will suffice for our purpose to give a general summary of the results obtained, without detailing the methods by which water is brought to the surface from different depths, or those, familiar to all, by which the gases contained in water are extracted and submitted to chemical analysis. In short, the results of these experiments fully and completely confirm the opinion above expressed, that even at the greatest depths water does contain air; that the atmosphere extends down to the nearly unfathomable abysses of the ocean.

As to rivers and lakes, or other shallow waters, the demonstration is most easy. Their water contains oxygen, nitrogen, and carbonic acid. But it is a noteworthy fact that these gases are not to be found in the proportions in which they exist in the atmosphere. Strictly speaking, one can not say that there is any air in water. What we find are the elements of air, the latter being all present, but their proportions being different from those in the normal atmosphere. For instance, 1 liter of river water contains from 4 to 8 cubic centimeters of oxygen; from 12 to 18 cubic centimeters of nitrogen, and from 2 to 20 or 25 cubic centimeters of carbonic acid. These proportions differ greatly from those which these three constituents have in normal air, and it must be noted that the variations are different in different rivers or even in the same river when examined in different places. Take the Seine River, for instance. Each liter of water contains 32.1 cubic centimeters of gas, of which 3.9 are oxygen, 12 nitrogen, and 16.2 are carbonic acid. Take the Rhone River, on the other hand, and you find 34.8 cubic centimeters of gas, of which 8.4 are oxygen, 18.4 nitrogen, and 8 carbonic acid. These differences are less surprising after reflection. Each river may and does differ in chemical constitution from other rivers, and even from itself, at different times and places, because of the difference in the nature and quantity of the chemical operations going on in the water. The chemical composition of the banks varies, and the activity of living organisms within the waters also varies. Such differences must exert their influence upon the chemical composition of the latter, and we have abundant proof that they do so. If the water of the same river, taken at different places at the same moment, is tested chemically, differences are observed which are sometimes considerable. For instance, the Thames, above London, contains 7.4 oxygen, at Hammersmith 4.7, at Somerset House 1.5, at Woolwich 0.25. Whence arise these considerable variations? They are easily explained by the fact that the river receives a large quantity of organic débris, vegetables, dead animals, and a large number of dead or dying substances or organisms; the débris combines with oxygen, and thus the amount of this gas is greatly diminished. The consequence is that the fish often perish through asphyxia, the amount of oxygen being inadequate. The same occurs in Paris. After its passage through the city, the Seine is generally quite unfit to support the life of most aquatic animals. Many species are not to be seen in the river at Paris, nor below it for some distance, although found above, where the water is sufficiently pure and aerated, and some 10 or 20 miles below, where aeration has been sufficient to make up for the loss, the water having absorbed enough fresh oxygen from the atmosphere.

So much for one series of differences in aeration. But another series exists which is even of greater interest. The aeration of waters, or the absorption of gases by water, varies according to general external conditions, among which temperature and pressure rank highest—not only general pressure, but, so to speak, individual pressure, or, to put it in other terms, the proportion of any given gas in a mixture. Under identical conditions, each gas, moreover, has its own special coefficient of solubility. While nitrogen is feebly soluble, ammonia is highly so. This fact helps us to understand why it is that the gases which spontaneously dissolve in water in contact with the atmosphere do not, when extracted from the water, yield a mixture even distantly comparable to air: how it is that the elements of air are not found in water under the proportions they bear to each other in the atmosphere. While water contains the constituents of air, it contains such proportions of these constituents as are peculiar to it. However, the latter are provided in sufficient quantity, and normal river water is quite adequate to maintain the life of aquatic animals. This applies to fresh waters generally, for ponds and lakes have the same conditions as rivers.

Some special points are to be noted concerning salt water. Of course the constituents of atmospheric air are met with in sea water. But, generally speaking, the variations in the proportions of these constituents are less numerous and of less importance. The seas, generally considered, make up a more homogeneous whole than any river of large dimensions. Between the south Atlantic and the north Atlantic less differences are to be expected, and less found, than in the Thames or the Seine, below and above London or Paris. A priori it is obvious that there are less causes of difference in aeration in the two parts of the Atlantic than there are in any of the two rivers in two points not 10 miles apart. It is quite obvious also that local differences, such as exist at the mouth of a great river that has just passed through a large town, as is the case with the Hudson, the Thames, or the Gironde, must be very soon dissipated in the enormous mass of the ocean through the agency of tides, currents, and winds. Upon the whole, generally speaking, none of those local differences are of any real importance. There are, however, differences which should be noticed, but their causes are quite different from those which obtain in the preceding case. The most important are observed when we compare specimens of water obtained from different depths. Carpenter noticed the fact and comparing specimens of water obtained in the same vertical line, at depths of 750, 800, and 862 fathoms, he observed the following composition of the air extracted:

	750 fathoms.	800 fathoms.	862 fathoms.
Oxygen	18.8	17.8	17.2
Nitrogen	49.3	48.5	34.5
Carbonic acid	31.9	33.7	48.3

While the proportion of oxygen decreases with increasing depth, that of carbonic acid increases in a marked manner. No very satifactory explanation of this fact has been yet provided.

We have now sufficiently dwelt upon this topic, and none will doubt that air—that is, the constituents of air, to put it in exact terms—intimately mingles with the waters that cover three-fourths of our planet. While waters do not contain atmospheric air as such, and while the gases dissolved in them do not make up normal air, they contain the elements of the latter, and the proportions are sufficient to maintain aquatic life. We may consider that these elements are found in water, even at the most considerable depths, although we have no positive proof of it.

Now, it is quite clear that since the mass of the waters contains organisms that breathe and live, and since life goes on notwithstanding the unceasing production of carbonic acid and the destruction of oxygen, both necessary consequences of their life and respiration, there must exist some unceasing agency by means of which new oxygen is added and carbonic acid carried away. Otherwise aquatic life would soon cease. In other terms, there must exist a perpetual exchange between the gases dissolved in the waters and those which make up the atmosphere, just as there goes on a perpetual exchange between the air of any place where the atmosphere is vitiated—a town, a manufactory, a room—and the air of the streets or surrounding country. And the exchanges which go on between air and water, and between the general atmosphere and those multitudinous centers, great or small, where the normal proportions of the gases of air are being constantly altered, must indeed be most nicely adjusted, since by no method have we yet been able to detect any alteration in the composition of the atmosphere. The equilibrium must be unceasingly maintained. That equilibrium is a very interesting matter. Interesting in two senses—practically, since life depends upon it, and from the scientific point of view, as it is the consequence of a general established law.

How, then, is that exchange effected between air and water, without which life would soon extinguish all life, without which the living organisms of water would soon render life impossible to themselves and to their congeners? By means of what may be termed "the breathing of the waters." The waters breathe—that is, expire obnoxious gases and inspire those that are useful; they expel carbonic acid and collect oxygen. Diffusion is the main agency of this grand function of waters, and it is enough that both air and water be in presence and contact to insure the operation. But diffusion is not alone at work; another agency cooperates. It does not at first seem that dust would have any influence, and few would suppose that it plays any part here. It does, however, and the enormous quantity of it which, imperceptibly in most cases, is carried from the land over the seas, where it falls and slowly sinks to settle at the bottom as a soft red or gray mud—the first stage of new strata of rocks—is a great help toward the respiration of the seas. As J. Thoulet has shown, every particle, however small and minute, carries some air which adheres to it and does not escape when submerged; this air slowly dissolves in the surrounding water. The experimental proof is easy. Bring some water to the boiling point, in order to expel the gases dissolved in it, and then add some potash and pyrogallic acid. This mixture turns black when in presence of oxygen by reason of the action of the latter on the acid. Under ordinary conditions, the experiment being thus prepared, what one witnesses is this: The surface of the water blackens and the black color extends slowly toward the bottom, according to the ratio of diffusion of atmospheric oxygen in the mixture. The rapidity, or rather slowness, of the change of color is the measure of the slowness of diffusion. Now, throw some fine dust into the vessel containing the water so prepared. What happens then is that each grain or particle, while falling through the liquid, leaves behind it a black line which marks its path exactly, and there are as many vertical streaks in the colorless solution as there were particles of dust thrown into it. Each particle's atmosphere of air acts upon the pyrogallic acid, and instantly causes the change of color. The experiment is a very elegant one, and provides a very convincing demonstration, and when one thinks of the number of dust particles (either of terrestrial origin or coming from the interplanetary spaces under the form of microscopical meteorites) which uninterruptedly pour down on the oceans like some paradoxical dry rain, it is conceivable that the importance of these infinitesimal particles to all aquatic organisms is great. From this point of view, a catastrophe like that of Krakatoa becomes a blessing, and each volcanic outbreak with its concomitant cloud of dust and cinders, which often spreads over hundreds of square miles, and gives forth a soft slow rain of solid particles which fall through the air to the water and thence to the underlying abysses, is doubtless a benefit to aquatic organisms. It may seem absurd to speak of the beneficial influence of volcanic catastrophes upon the denizens of the ocean; the fact is nevertheless incontestable. Nature abounds in such curious and unexpected interactions. Most of these, as yet, escape us, but some now and then become apparent, and go to show how difficult and complex is the study of life or biology, in its real sense, and how essential is the knowledge of circumstances and surroundings.

The experiment which has just been referred to suggested to Paul Regnard the means of measuring, so to speak, the rapidity of the ocean's respiration, the rapidity of diffusion of the aerial gases in water, and especially that of oxygen, which is the most important for organisms. The method is very simple. All that is required is a large glass tube, some 3 yards long, closed at the lower end, placed vertically, and filled with water holding Coupier blue in solution, saturated with hydrosulphide of soda. This solution, a pale yellow in color, turns blue under the influence of oxygen. The tube thus filled is left to itself and each day an observation is made of the point to which the blue layer has extended. The first day the mere surface only is blue, but by degrees the underlying strata also turn blue, according to the rapidity with which atmospheric oxygen diffuses and is absorbed. Under such circumstances, P. Regnard noted that in the course of three months oxygen diffused no farther than about a yard from the surface, and the rate of propagation is hardly a centimeter per day. If such is the normal ratio, air penetrates water at the rate of 4 meters per year, and if, "at the beginning"—of which so much is said, and so little known or knowable—the sea was entirely devoid of oxygen, no less than a thousand years were required to allow atmospheric oxygen to penetrate to the depth of 4,000 meters, a depth which we all know is not uncommon in the ocean.

It is thus seen that the respiration of waters is very slow—at least it is very slow so far as diffusion alone is concerned. But, as already noticed, diffusion is not the sole agency, and it is quite clear that the white crested waves, all foam and sparkling with air bubbles, that the winds, the currents, the tides, and lastly the dust particles have done and are doing much to hasten the process, and accelerate the execution of the great respiratory function of the deep. No method, unfortunately, has yet been devised for measuring the rapidity of this process; and before it can be done, some manner by which the approximate number of dust particles falling into the seas can be ascertained should of course be discovered. The problem is a difficult one, truly.

II.—Air from the Chemical Point of View.

Considered by the ancients, and even by modern philosophers till a very recent period, as one of the four initial elements (earth, air, water, and fire), air was unable to keep this position after the birth of modern chemistry. Like most other substances it has had to reduce considerably its pretensions. They were of no avail in presence of the methods of chemistry. Instead of being, as formerly supposed, an element, a homogeneous matter out of which no known method of reduction can obtain two or more differing substances, air has shown itself to be nothing more than a mixture of different elements. A mixture, a mechanical mixture; not a compound. Air is not like water, in which two gases, oxygen and hydrogen, are combined and make up a third body exceedingly different in properties from those out of which it is made, nor like the enormous number of compounds known to chemistry in which two or more elementary substances are combined in definite proportions and form new substances more or less peculiar, but invariable, and possessing properties which neither of the elements possesses; it is a mixture only. This may be demonstrated in various ways. When nitrogen and oxygen, the fundamental elements of the air, are mixed together, no heat is evolved, no heat is absorbed, as is the case in the preparation of most compounds. Again, the refringency of air is equal to the mean of the refringency of oxygen and nitrogen when experimentally mixed in the proportions in which they occur in the atmosphere; and the ratio of oxygen to nitrogen is not a simple one; lastly, when in presence of air, water dissolves different proportions of the different constituents of the former; it dissolves each gas according to its own proper coefficient of solubility.

These four proofs are considered as more than sufficient to show that air is a mixture, not a compound. It may be added, moreover, that while the composition of the atmosphere is fairly uniform as a whole, it is not absolutely so; the one or the other constituent is more or less abundant according to circumstances. No chemical compound offers such variability in composition; its constituents are constant, always the same, and in the same ratios, while in a mixture every variation is possible, and may be expected.

And now, what are the constituents of this mixture? Our knowledge of these elements, as well as that of air itself, considered as a whole, is of recent date. While it would require more space than we can spare to give a full historical account of the chemistry of air, the principal facts may be briefly summarized.

As has been previously stated, a French physician, Jean Rey, was the first who proved the materiality of air, and his experiment was repeated and confirmed by Galileo in 1640, and by Otto von Guericke in 1650. Jean Mayow, in 1669, was the first to prove that air is not an element, a homogeneous substance. He suspected the fact that air contains two different gases, of which the one, which he called "nitro-aerial," maintains combustion or fire and respiration, while the other does nothing of the sort. In short, he suspected the presence of the two different gases which are now named oxygen and nitrogen. Had he lived longer, Mayow might have discovered the facts which are the basis of Lavoisier's fame.

In 1774 Priestly[1] made a great step in the right direction when he succeeded in obtaining the separation of the two principal gases which make up air, and on the same date Scheele[2] did the same, going somewhat further, as he discovered the ratio of what he called "dephlogisticated air" (or oxygen) to "phlogisticated air" (or nitrogen). Both, however, fell into the same error. Both considered the two gases as identical, but possessing different properties. No doubt the properties are different, but the differences are inherent to the gases themselves; the one is not a form of the other and can not be transformed into the other, and the differences are much more numerous than these two pioneers of chemistry perceived.

To Lavoisier was reserved the honor of providing precise and unassailable knowledge concerning the nature and composition of air. To prove that air, as already demonstrated, is made up of two elements, the one adequate the other inadequate to maintain combustion and respiration, was no difficult task. But he went farther on his road by means of the following experiment, one that is fundamental in the history of chemistry: He placed a known amount of mercury, carefully weighed, in a retort whose long curved neck opened into an inverted glass tube placed on a mercury trough. By means of a curved pipette he sucked out part of the air in the tube, and consequently the mercury rose within it to some height. The point to which the mercury rose was carefully marked, and then the retort was submitted to the influence of heat. The temperature was 360° C., and on the second day he perceived that small red pellicles were forming at the surface of the mercury. During a week, the heating being continued, the pellicles kept forming, and then no more appeared. He kept up his fire during four days more and then put it out. When the apparatus was cooled

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[1] Born in England in 1733; died in Pennsylvania, 1804.

[2] Born in Sweden in 1742; died 1786.

down, he saw that in the glass tube the mercury rose higher than before the experiment, and he observed that the remaining gas was unable to maintain respiration and combustion. In it small animals died and a light went out. He then collected the red pellicles, weighed them, put them in a retort whose neck opened under a glass tube filled with mercury, and heated the retort to 400° C. The pellicles melted away; they yielded a certain amount of mercury which was deposited in the neck of the retort, while in the glass tube some cubic inches of a peculiar gas had accumulated at the top. The volume of this gas corresponded exactly with the volume of air which had disappeared in the preceding experiment, and this gas was fully able to maintain combustion.

Thus was performed the first analysis of air, and Lavoisier came to the conclusion that that fluid contains two gases—one which forms one sixth of the whole volume and is favorable to combustion and respiration, while the other, amounting to five-sixths of the whole volume, is favorable to neither. The first was oxygen; the last azote, or nitrogen.[1]

It is now more than a century since these facts were discovered, and became the corner stones of modern chemistry. Up to that time it was mere empirical alchemy, and a fabric of erroneous notions. A number of methods, much superior as far as precision is concerned, have been devised for the purpose of air analysis, and of gas analysis generally.

The eudiometric method, propounded by Gay-Lussac and Humboldt, is one of the best known. It is based upon the fact that if hydrogen is added to air, and the electric spark passed through the mixture, the oxygen of the air and the hydrogen added to the mixture combine in definite and constant ratio and form water. A very simple calculation gives the amount of oxygen contained in the mixture. The weighing method of J. B. Dumas and Boussingault, invented in 1841, is quite different. It is based upon the fact that when air, deprived of aqueous vapor and carbon dioxide, is made to pass through a tube containing metallic copper reduced by means of hydrogen, and heated to redness, it yields its oxygen to the copper, and if the copper is weighed before and after, the amount or weight of oxygen contained in the volume of air experimented upon is at once known. If the remainder of the gas, that portion which has not combined with the copper, be collected in an empty receiver weighed before and after the experiment, the increase in weight of the receiver shows the quantity of nitrogen contained in the original volume of air. Twenty other methods, more or less similar to the preceding one, have been devised by Brunner, Regnault and Reiset, Doyère, Bunsen, Williamson, Russell,

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[1] These names were given by Lavoisier. Oxygen is derived from ὀξύς, acid, and γεννάω, to produce, because one of the properties of oxygen is to form acids when combined with many other substances. Azote is derived from privative α and ζωή, life, because azote is not suitable for living animals, and can not maintain life.

etc., but this is not the place to describe them, and all text-books of chemistry give a full account of them.

It is enough for our purpose to know that it is fully established that atmospheric air is a mixture; that this mixture is principally made up of oxygen and nitrogen, and that we are provided with methods and implements by means of which air may be analyzed, and the least traces of its constituent elements detected.[1]

These elements are numerous, but they differ greatly in importance.

Fundamentally, air comprises 20.81 volumes of oxygen, 79.19 volumes of nitrogen, and some ten-thousandths of carbon dioxide. In some localities or under certain circumstances a few other[2] gases may also be found in air, in very small quantities.

We must now consider in turn each of these elements.

Oxygen comes first. Not that it is present in the greatest abundance, but from many points of view it is a most important part of the atmosphere.

This gas is heavier than air as a whole (while nitrogen is lighter), and in 1,000 liters of air there are 208 liters of oxygen against 792 of nitrogen. This ratio seems to be constant, although Dalton and Babinet, arguing theoretically, supposed that oxygen is less abundant in the air at high altitudes, and that the proportion of this gas decreases as the distance from the sea level is increased—oxygen being rather more abundant in low regions, and near the surface. Of course, if such were the case, the reverse would obtain for nitrogen. This gas should be more abundant at high levels, and less near the sea level. According to the views of Dalton and Babinet, at 10,000 meters above the sea level, 1,000 liters of air should contain only 184 liters of oxygen against 816 of nitrogen. These speculations may be interesting, but as they

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[1] In view of recent facts this is too positive a sentence. Great was the surprise of the chemists when they heard that Lord Rayleigh and Professor Ramsay had discovered a new element in atmospheric air. This should inspire them with some caution, and induce them not to put so much faith in the infallibility of their methods. More of this hereafter. [Note added to proofs in 1896].

[2] To the normal constituents of atmosphere one remains to be added, and that is argon, discovered in the year 1894 by Lord Rayleigh and Professor Ramsay, to whom, on this account, the $10,000 Thomas Hodgkins prize has been most deservedly awarded.

Argon, thus called because it seemed to be an inert and inactive gas, slow to combine with other substances, was certainly contained in Cavendish's test tubes, but Cavendish considered it as nitrogen, and thus failed to add this substance to the list of chemical elements. Argon is present in the atmosphere in the proportion of somewhat less than 1 per cent; M. Th. Schloesing obtains 0.935 argon for 100 air, in volumes. MM. MacDonald and Kellar have in vain endeavored to detect argon in the chemical constitution of animals and plants (mice and pease), but Mr. Ramsay has found it in meteoric iron. Argon liquefies at —128° under 38 atmospheres pressure, and freezes at —189°. It is not as inactive as at first supposed, as Berthelot has been able to combine it with benzine under the influence of the electric discharge. This gas does not seem to play any active part in respiration; it is inert and useless, like nitrogen. [Note added to proofs, 1896.]

are in direct contradiction with positive facts and observations we may dismiss them as "children of fancy." The chemist Thénard analyzed air collected at 7,000 meters height by Gay-Lussac, and found no trace of such difference. Similar observations, due to Dumas and Boussingault, prove that these theories are not sustained by stern reality, and, in brief, chemists are agreed that, as far as oxygen and nitrogen are concerned, the composition of atmospheric air is uniform and constant, with very slight exceptions. This is the result of numerous observations made in different and distant places, at different heights, at distant epochs, and Dumas and Boussingault, who have devoted much work and time to the matter, have always obtained similar ratios, or at least ratios so nearly identical that the differences are not more considerable than may occur in the best-conducted experiments—they keep within the limits of unavoidable errors. So we may consider air as being as perfectly uniform in composition, as it might be expected to be in view of the circumstances.

Now, where did this oxygen originate? Whence does it come? From what source is it supplied? A complete answer to this question can only be given by those who know how things stood in the beginning, and who understand the origin of matter, force, life, and some other of those troublesome and perplexing problems. Oxygen must be a very anciently established inhabitant of our planet, and its origin, like that of the "old" families, is lost in obscure mystery. At all events there it is, and wherever it comes from, howsoever it has been evolved, one thing seems positive, and that is the fact that there are at present, as far as we know, no important sources whence a considerable amount of this gas may be derived and added to the current stock. In view of this, the stability of its normal ratio in the air, notwithstanding the enormous quantity of it consumed by living beings and in combustion, becomes a riddle well worthy of some attention.

We know that the entire atmosphere contains over one million billions of kilograms of oxygen; that nearly one-half of the weight of the minerals of our globe is oxygen; that eight-ninths of the weight of water consists of this same gas, which is, moreover, abundantly present in the tissues of all living organisms. On the other hand, we know at present of but one source of oxygen, discovered by Priestley, and further investigated by Perceval and Senebier. I refer to plants. It is a fact familiar to all that plants are endowed with the faculty—ascribed to the chlorophyll contained in their tissues[1]—of breaking up carbon dioxide into its elements; that is to say, into carbon which goes to the repair or increase of the tissues, and oxygen, which, on being freed, diffuses itself throughout the surrounding atmosphere. There certainly is one source of oxygen. Are there any others? Their existence is doubtful. Of course we know that a number of chemical

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[1] The fact is probable but not certain, for chlorophyll has not yet been satisfactorily separated from the tissues in order to investigate its chemical powers.

reactions effect the liberation of oxygen, water electrolysis, the decomposition of chlorate of potassium, or of sulphuric acid under the influence of heat, for instance; but do any of these chemical processes, or any others similar in result if not in method, occur in nature on any important scale? We do not know, but it seems doubtful. At all events, since the composition of the atmosphere remains fairly constant, there must be some agency by means of which the enormous mass of oxygen which is daily, hourly, at every moment, absorbed in consequence of the organic and inorganic combustions occurring over the whole globe, is, sooner or later, returned to the atmosphere. Plants are the only agency at present known by which this process is effected. At all events they effect part of it. But are they equal to the task of effecting the whole? The question has not been yet answered in quite satisfactory terms. Mr. T. L. Phipson has recently endeavored to fill this gap, and to show that plants are even a more important source of oxygen than is commonly admitted. He cultivated a convolvulus plant in an artificial atmosphere, entirely devoid of oxygen, but containing some proportion of carbon dioxide, with the result that a part of the latter gas disappeared, its place being taken by oxygen, which can only have been evolved by the plant. Mr. G. Meyer had previously expressed the opinion that oxygen is thus generated, but Mr. Phipson's experiment is of great interest. The whole matter is very important, for, if the oxygen contained in the atmosphere has been evolved by plants, one may ask whether there has not been some time when the atmosphere was very poor in oxygen and very rich in carbon dioxide, and whether some time may not arrive when, conversely, the atmosphere will be well provided with oxygen and very deficient in carbon dioxide. If such were to be the case, the equilibrium and homogeneity of air, as far as its composition is concerned, would be very unstable and temporary matters. But no answer of a satisfactory character can yet be given to such questions.

It may be added that, according to less recent data, 1 hectare (a little over 2 acres) of forest exhausts each year the atmosphere of some 11,000 kilograms, or 5,596 cubic meters, of carbon dioxide, while in return it yields nearly as much (5,594 cubic meters) oxygen. A field of oats, similarly, returns about as much oxygen as it absorbs carbon dioxide. Perhaps other agencies are at work and make up for the enormous consumption of oxygen effected by human, animal, and plant respiration, and by inorganic combustions generally, and it does not seem to us that adequate proof has yet been furnished that plants alone are able to return to the atmosphere the oxygen which they, with all other living beings, take from it. Leaving out of the question the subject of the origin of oxygen, it is very difficult to ascertain the methods by which, notwithstanding an enormous consumption, the ratio of this gas remains fairly constant at the present time.

While the proportion of oxygen in air is constant, or tolerably uniform, it must not be forgotten that certain local conditions may tend to increase or decrease its normal ratio. Nor could it be otherwise. However rapid the diffusion of gases, it is reasonable to suppose that when one of the constituents of the atmosphere is being rapidly subtracted or added in great quantities, the normal ratio in that vicinity must be more or less altered. In a crowded room where ventilation is inadequate the ratio of oxygen decreases, and the same happens in places where intense combustion is going on—in mine shafts, where slow oxidization of materials is a nearly constant phenomenon. In brief, where the destruction of oxygen is not compensated by rapid ventilation, the proportion of this gas to the remainder of the air must decrease. Under the same conditions, of course, the ratio of carbon dioxide must and does increase, as repeated observations have shown. But such local accidents, such limited alterations of the composition of the air, have no influence on the general atmosphere; they are temporary, very slight, and therefore rapidly obliterated. Even the respiration of some two, three, or four million inhabitants, as in a large city, does not affect the composition of the air of the streets; and London, Chicago, or Paris exert no more influence on the surrounding atmosphere, into which they pour torrents of carbon dioxide, than any forest, for instance, where the case is reversed, and where oxygen is produced in abundance. Diffusion takes place immediately, and no appreciable alteration can be detected, save in very limited spaces and for a short period. And while the one gas is being removed in one place it is being added in another, and thus a compensation is rapidly effected.

Little need be said concerning nitrogen. This gas, as already stated, was discovered by Priestley, and Lavoisier showed that it is one of the elements of air. Its weight is lighter than that of air as a whole, and in 100 liters of air there are 79 of nitrogen. It neither burns nor maintains combustion; it plays no part in respiration; it can not help to maintain life. Not that it has any toxic properties, assuredly; but it is inert, indifferent, inactive. Little is known concerning its origin. We know that some mineral springs, sulphurous springs particularly, yield a certain amount of nitrogen, and the air ejected from the lungs of animals contains about as much as the same air when inspired. As is the case with oxygen, nitrogen seems to occur in the atmosphere in the same ratio everywhere.

The two gases, oxygen and nitrogen, are the main constituents of air, and compose the greater part thereof. They are the essentials, the other components, which must now be noticed, occurring only in very limited quantities, some in variable and small proportions. We might almost say that they are accessory components, judging from their quantity, had not experience shown that one of them at least plays a very important part in biology, one no less essential, in fact, than that of oxygen, for instance. This latter component is carbonic acid or carbon dioxide. It occurs only in very small quantity, 4 or 5 liters in 10,000 liters of air. This gas is comparatively heavy, and Priestley was cognizant of the fact that it is unable to support combustion or respiration. The proportions in air are not uniform and constant; they vary according to circumstances and places much more than is the case with the other gases. As early as 1827 De Saussure discovered very marked differences, obtaining as extreme figures 3.15 and 5.74 per 10,000. More recently, Boussingault and Lévy, comparing the proportion of carbonic acid in the air of Paris with that in the air of Andilly (a small village some 12 miles from Paris, near Montmorency), found also a notable difference between the two, there being 3.19 (per 10,000) in Paris and 2.99 in Andilly. Again, a somewhat smaller difference has been noticed by Roscoe and McDougall between the air in Manchester and that of the surrounding country; but at Clermont-Ferrand, in central France, Truchot found 3.15 per 10,000 and but 2.03 at the top of the Puy-de-Dôme, a neighboring mountain, and 1.72 at Pic de Sancy, another peak of the same group.

These instances are enough, we presume, to show that the ratio of carbonic acid to the total volume of the air varies considerably, much more than that of the two previously mentioned gases, and that this component is more abundant in cities than in the country.[1] This should not occasion wonder, as the amount of carbonic acid varies according to various circumstances of time and place. For instance, De Saussure noted that it increased during the night and during cloudy weather; its ratio changes with the season, from one year, and even from one month, to another, irregularly, and, in fact, from day to day. Above the ocean the variations are less, and in mid ocean the air is purer than over the continents. The same obtains on high mountains.

If, instead of considering the composition of air collected in the streets, in the country, or on mountains, we compare rather that which we breathe in dwellings and in all confined spaces where ventilation is more or less deficient, and where organic and inorganic combustions take place, with that which obtains in the open, the differences are still greater. Of course, it should be so. We must not forget that the air which each one of us expels through mouth or nose, at this very moment, contains nearly a hundred times more carbonic acid than was contained in the same air when we inhaled it a few seconds ago. This being the case, it is sufficient to imagine a confined room where one or many persons are sitting; there most certainly, provided the experiment lasts long enough, we shall find many different and increasing proportions of carbonic acid. That is, we might were the experiment not self-limited. For though, as Pettenkofer has observed, the 0.40 or 0.50

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[1] In Austria, the amount of carbonic acid is about 34.3 liters per 100 cubic meters of air; in Germany it varies between 32 and 34; in the desert of Lybia, Von Pettenkofer found from 44 to 49. These are rather high figures. During the expedition for the observation of the transit of Venus, analyses made in different countries gave the following results: Florida, 29.2; Mexico, 27.3; Martinique, 28; Haiti, 27.8; Santa Cruz, 26.6. At Cape Horn, Hyades observed 23.1 and 28.5 as extreme figures.

per 1,000, which is the normal proportion of carbonic acid, may rise in a tolerably well-ventilated room to 0.54 and 0.70, or to 2.4 in an ill-ventilated sick room, and reach to 3.2 in a lecture room, 7.2 in a schoolroom, and even 21 in a stable in the Alps where men and beasts are huddled together in winter, the chinks being stopped against the cold, there occurs a limit which can not be passed; if the ratio increases, men and animals must soon die, and the experiment is over, the production of carbonic acid having come to an end. When the composition of the surrounding atmosphere is the same as that of the air which each of us expires (over 4 per cent carbonic acid, and less than 16 per cent oxygen), death must soon result, because there is too much carbonic acid in the air to allow that in the system to escape, and not enough oxygen for the needs of the body. More will be said on this point later on. It is enough here to show how considerable the ratio of carbonic acid may become in confined space, and how much greater are the variations in carbonic acid than in oxygen or nitrogen.

The cause of these variations is obvious. They are in close relation to the variations in the production of the gas under consideration, and upon this matter information is abundant.

Carbonic acid is produced in many ways; it has many sources. One of them has been referred to—animals and mankind. Bipeds and quadrupeds, in fact all animals, indeed, all living organisms, are sources of carbonic acid. All beings, from mere yeast cells to the lords of creation, breathe; all or nearly all take oxygen from the air and return carbonic acid to it. It is a familiar fact that fermentation in most cases—in the case of sweet substances particularly—is accompanied by a considerable production of carbonic acid. In wine-producing countries cases of asphyxia often occur in the cellars where fermentation is going on, owing to the amount of carbonic acid produced. All higher organisms, plants, and animals have the respiratory function, and one of the acts of respiration is the elimination of carbonic acid through the lungs. This unceasing production of carbonic acid by living organisms, whether plants or animals, is very variable in its activity, even within the limits of the same species and of the same individual. It is well known that the male produces more than the female, the adult more than the very young or the very old individual, the strong more than the weak, etc. It is well known, also, that this production of carbonic acid is increased by exercise, movement, light, and food, while it is decreased by rest, darkness, inanition. On the average each man exhales 20 liters of this gas per hour, and nearly 1 kilogram per diem (of twenty-four hours). The production is more considerable in sheep, and a bull exhales between 7 and 8 kilograms during the same lapse of time. However, in order to well appreciate the ratio of carbon dioxide exhalation, instead of considering the whole amount produced by any individual, it is better to refer this amount to the weight of the individual animal or person, to ascertain the quantity evolved per kilogram of weight. Viewing the matter in this light, we perceive that birds are the animals that give out the greatest quantity of carbonic acid. While 1 kilogram of ox excretes from 3 to 7 grams of carbon per twenty-four hours, 1 kilogram of fowl or turkey excretes 20 grams on an average, 1 kilogram of young chickens 56 grams, and 1 kilogram of sparrow nearly 60 grams. These facts quite agree with the exceedingly active respiratory function of birds, especially small birds.

Boussingault many years ago established the fact that the town of Paris alone, taking into consideration men and horses only, exhales nearly half a million cubic meters of carbonic acid per twenty-four hours (at present three-quarters of a million would be nearer the mark, but still even below it), and estimating the whole population of the globe as being one billion and a half, we find that mankind alone pours into the atmosphere one billion and a half kilograms of carbonic acid per diem (1,500,000,000 kilograms); that is to say, 720,000,000 cubic meters. Per annum the grand total is, in round numbers, 547,500,000,000 kilograms, or 262,800,000,000 cubic meters. So much for mankind only. If we wish to take into account the production of carbonic acid by animals, the difficulties are certainly great, and we can only proceed inferentially, and with less certainty. Girardin puts the production of carbonic acid by animals at something like double that of mankind, if not treble—let us say double, which means 1,095,000,000,000 kilograms per annum. But there remain other sources of carbonic acid: all plants which, although decomposing carbon dioxide as part of their method of nutrition, breathe in the same manner as animals, and exhale carbonic acid; all the combustions going on in our houses—fires, lights—in our factories and works, etc. (in Europe alone 550,000,000 tons of coal are burned each year, which means 80,000,000,000 cubic meters of carbon dioxide); the slow but uninterrupted production of the gas which is going on over the whole globe through the gradual combustion of decaying vegetable matter; the mineral springs—those of Auvergne only in France, giving off, according to Lecoq, some 7,000,000,000 cubic meters of gas; volcanoes and their surroundings—Cotopaxi alone being considered by Boussingault as giving off more carbonic acid than a whole city like Paris; the natural sources of gas, such as the Grotta del Cane[1] near Naples, etc. Under such circumstances, it is very difficult to form any idea of the total amount of carbonic acid discharged into the atmosphere. Armand Gautier, however, comes to the very probable conclusion that this amount can not be very far from 2,500,000,000,000

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[1] The air in this grotto contains more than half its volume in carbonic acid. It derives its name from the fact that, in order to illustrate the noxious effects of the inferior stratum of air (where carbon dioxide, heavier, accumulates), it is the custom to introduce a dog into it, which soon falls, affected by asphyxia, while the visitors, owing to their higher stature, breathe the normal air, and feel nothing unusual. The dog, it must be added, is at once taken out into pure air, and soon revives, going through the experiment several times a day. Its health is very good, but its temper becomes unpleasant when a visitor appears. The animal knows what is coming.

cubic meters per annum, which means over 5,000,000,000,000 kilograms, the weight of the total atmosphere being 5,000,000,000,000,000,000—that is, one hundred thousand times greater. At all events, this is certainly below the mark.

Such being the enormous rate of production of carbonic acid, one may well wonder that the ratio of this gas in the total atmosphere remains as small as it is, it being easy enough to reckon what the ratio would become in the course of ten, twenty, or a hundred years, if there were not some agency at work by means of which it is destroyed or combined, and without which life would soon become extinct. That such agencies do exist and are in operation is a positive fact, and though we may not be acquainted with all of them, there are three at least which deserve notice. These agencies are plants, animals, and oceans.

Plants occupy the first place; for, while producing carbonic acid which they breathe, they absorb it in the course of the process of nutrition, taking its carbon into their tissues and yielding its oxygen to the atmosphere.[1]

Animals should be considered next; not all, to be sure, but all those which have a calcareous skeleton, internal or external. Such are corals, such are shellfish generally, and all aquatic and terrestrial animals, which, having a calcareous skeleton, must necessarily contain some amount of carbonic acid combined with lime. This compound seems to hold good for a long time, and if there are cases where the skeleton after death slowly decomposes, so that the carbonic acid has some chances of getting free again, there are a great many more in which it is preserved, and we know of considerable geological strata which are nothing else than enormous accumulations of the remains of animals that died centuries and hundreds of centuries ago. This process, by means of which a considerable amount of carbonic acid becomes fixed and imprisoned, so to say, was exceedingly active in earlier times; it is also very active at the present period, and the great space taken up by coral reefs in the mid Pacific and other oceans is but a gigantic laboratory of nature where carbonic acid is being, if not destroyed, at least hoarded and put by under a compact form, and, for a time at least, withdrawn from the general circulation of matter. To appreciate the importance of the storing process, it is only necessary to measure the thickness

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[1] A writer in the Belgique Horticole, Vol. XXXV, 1885, p. 227, gives the following evaluation: One hectare of forest (1 hectare equals 2.471 acres) produces yearly 3,000 kilograms of carbon—1,600 kilograms under the form of wood and 1,400 under the form of leaves (weighed dry and exclusive of other substances). During one hundred and fifty days (on the average) of active vegetation, the trees must draw from the atmosphere 5,596 cubic meters (11,000 kilograms) of carbon dioxide. In exchange they give nearly as much oxygen (5,594 cubic meters). With a field of oats the same proportion obtains—as much oxygen is given off as carbonic acid is taken in. Thirty-two persons give off as much carbonic acid as is taken in by 1 hectare of oats or of forest, and they burn as much oxygen as the said surface of field or forest produces.

and extent of such masses of organic remains. All know that in every geological formation calcareous strata of great thickness are found, which are merely agglomerations of skeletons, and Van Dechen has endeavored to form some idea of the quantity of carbonic acid which may be contained in such strata. The result is very striking. He comes to the conclusion that in the lime strata of the Carboniferous epoch alone there is an amount of carbonic acid imprisoned which is six times more considerable than that at present contained in the whole atmosphere. The problem has been carried further by Sterry Hunt. Taking this result into consideration, and forming an estimate of the whole quantity of carbonic acid combined with lime in the whole geological series, he finds that the amount of carbonic acid thus imprisoned in the calcareous rocks would, if entirely liberated, form an atmosphere two hundred times more considerable than that which at present surrounds the planet. In such a case the pressure would be so much increased that the gas would necessarily become liquid. The inference which he draws (Brit. Association for the Adv. of Science, 1878) is that the enormous amount of carbonic acid at present stored in the depths of geological strata has never been simultaneously, even for a short time, present in the atmosphere, but that it must have reached the latter in small quantities and gradually. Mr. Sterry Hunt is of opinion that all this carbonic acid has come to our planet from celestial regions in the course of hundreds of centuries. Whatever may be thought of this interpretation as to the origin of the gas, one fact remains unassailable, and that is the enormous quantity of the latter stored up in the earth's crust; and if in the course of time organisms have been able to accumulate such a provision and are still operating as they undoubtedly are under our very eyes, we certainly can not help coming to the conclusion that we have here one of the most important agencies by means of which the atmosphere is being unceasingly kept sufficiently pure for maintaining life.

Lastly, come the oceans. Few are aware that the salt waters play a most interesting and important part in the general regulation of the atmosphere, and are one of the agencies which by absorbing carbonic acid prevent it from overaccumulating in the air. Mr. Schloesing's remarkable investigations have shown that the seas contain a large amount of dissolved carbonic acid, a much larger amount, in fact, than is to be found in the whole atmosphere. The equilibrium is preserved as follows: When carbon dioxide becomes more abundant than usual in air, in consequence of an increased production of this gas, and no compensatory destruction or withdrawal is effected by plants or animals, part of it dissolves in the salt waters, and combines with the insoluble and neutral carbonate of lime, always present there, producing a soluble bicarbonate of lime which dissolves immediately, and, inversely, if the amount of carbonic acid in the atmosphere decreases, the soluble bicarbonate is decomposed into carbonic acid, which is set free and diffuses throughout the atmosphere, and neutral carbonate, which remains in the water. Briefly, so long as the tension of carbonic acid in the waters and that of carbonic acid in the atmosphere is the same, nothing is produced, but as soon as this equilibrium of tension is destroyed the sea restores it by the very simple process just described. This chemical adjustment works automatically at the moment it is needed, and to the extent and in the direction required. It must be added that this equilibrating function is possible mainly through the circumstance that the ocean contains a much larger amount of carbon dioxide than the atmosphere; according to Mr. Schloesing, about ten times as much. However great, then, the production of carbonic acid may be on the surface of the globe by all the agents we have enumerated, it would seem that the proportions of this gas in the atmosphere as a whole can vary but slightly, owing to the power of the sea to absorb it and maintain the equilibrium.

We have now exhausted the list of the agencies through which the amount of carbon dioxide in the air may be and is reduced when necessary, and they are important and powerful enough, as we have seen, to be equal to probable emergencies. Without them the globe would soon become uninhabitable. Poggendorf, in fact, has found that if all carbon dioxide produced could accumulate in the air the proportion would be doubled in eighty-six years. A few centuries would see the last of life as far as superior organisms are concerned.

Oxygen, nitrogen, carbonic acid, such are the main constituents of air. Those which follow are of less importance, but deserve a passing notice.

We may begin with ozone. This gas, discovered in 1840 by Schoenbein, has been made the subject-matter of many investigations by De Marignac, De la Rive, Becquerel, Frémy, Andrews, Tait, etc. Ozone is oxygen under a peculiar form—condensed oxygen, so to say, oxygen of high potency. It possesses strong oxidizing properties, and the amount which is found in the atmosphere varies considerably according to circumstances and places. This amount is on the average of 1 milligram per 100 cubic meters of air; 3½ milligrams are a maximum. This gas is generally wholly absent from the atmosphere of cities, and in the air which has passed through large centers of population. Paris offers good opportunities for illustrating this fact. When the wind is northerly, no ozone is found in the air at the Montsouris Observatory, situated in the south of Paris, while, when the wind is southerly and comes over the country without having yet crossed the town, ozone is found in the air. Generally speaking, then, the healthiest part of all towns is that which lies in the direction from which the prevailing wind comes; the air is purer and fresher and contains more ozone. In western Europe, where the prevailing winds are westerly and northerly, the northwestern and western parts are the most eligible.

The cause of the difference in the amount of atmospheric ozone is to be sought in the fact that cities contain a much larger quantity of oxidizable organic material than is the case with the country and small villages, and the result is that more ozone is absorbed from the atmosphere over and around cities than from the atmosphere over the country, over the fields, and especially over the oceans. Generally speaking, ozone is more abundant near forests and the sea; the atmosphere in mid ocean is particularly rich in it. May we not attribute the cause of the beneficial effects of life in the open air, of a residence in the country, near the sea or in the mountains, and of long sea voyages to the larger proportions of this gas found in those regions? Schoenbein thought so, and after him many have adopted the same view—among them an English physician, Cook, according to whom a definite relationship prevails in India between cholera and other zymotic diseases and the proportion of ozone in the air, the diseases increasing when ozone decreases, and decreasing when the latter becomes more abundant. In consequence of the greater abundance of ozone in the atmosphere over the country and in proximity to living plants, it might seem advisable to advocate the presence of plants in apartments, instead of excluding them as some feel inclined to do, arguing that plants are living beings, that they breathe, and that, accordingly, they increase the ratio of carbonic acid. The view in favor of plants has been strongly advocated by T. M. Anders (House Plants as Sanitary Agents, 1887, Lippincott); but the most important point which should be established in relation to this matter, the fact that plants do really produce ozone, does not seem placed on a satisfactory basis. Proof is still wanting. And this brings us to face the fact that very little is known concerning the origin of ozone. We do not know whether any agencies are at work now in nature evolving ozone to any important extent. In the laboratory ozone may be produced by the electric spark, and when so evolved causes the particular smell perceived in the vicinity of electrical machinery; ozone is also evolved during the electrolysis of water. Are we then to assume that in nature ozone is produced by thunderstorms, those gigantic counterparts of our electrical discharge, and under the influence of the electric currents so frequently in operation in the atmosphere? Many chemists think so, and if this is the case it should be easily shown that the ratio of ozone to air is in fairly exact relationship to the proportion of thunderstorms, or to their recent occurrence. Ozone should be most abundant under the Tropics, should decrease in high latitudes, where thunderstorms are least frequent, and should be more abundant just after a thunderstorm than before. But none of these points have been satisfactorily established.

Without attempting to solve the riddle and to ascertain the origin of ozone, a French chemist, M. Hautefeuille, who ascribes the blue color of the heavens, or of the atmosphere, to ozone, asserts that this gas is more abundant in the higher than in the lower strata of our atmosphere. It may be so; at all events we are not much the wiser for the assertion. While we know that ozone is nothing more than oxygen in an altered and allotropic condition, we are quite in the dark as to the methods by which this alteration is effected. We know that the ratio of ozone is very variable; that it is more abundant in May than in any other month; more abundant in the morning, from October to June, and in the evening, in July, August, and September, so that, upon the whole, it seems to follow fair weather and heat; but this hardly helps to solve the question, and much remains to be discovered.

Concerning ammonia, our information extends somewhat further than in the case of ozone. Ammonia is constantly present in the atmosphere. In 1857 Boussingault and, later, Schloesing, did good work in reference to this subject. They have shown that ammonia generally exists in combination with carbonic or nitric acid; only a small proportion is free. Its origin is easily ascertained, for ammonia is one of the by-products of organic putrefaction. Considering the amount of putrefaction which must take place on our planet, it is clear that this source is a fruitful one; and it must be added also that ammonia could not exist in an atmosphere where life was absent, nor in one where putrefaction was impossible, nor in an entirely aseptic atmosphere, the organisms themselves being aseptic. Although ammonia is a constant component, it is a very small one; air does not contain more than a few millionths of it; but water of atmospheric origin, rain, vapor, fog, etc., holds a larger proportion. M. Schloesing has devised ingenious apparatus and methods for ascertaining the proportions of ammonia in air and in rain water, as the matter is one of importance, particularly to agriculture, in view of the interchange of ammonia that occurs between air, rain, and ground water. One of the results has been to show that each hectare in France (something over 2 acres) receives yearly through rainfall, or from the atmosphere, 9.801 kilograms of nitrogen under the form of ammonia. This will be again referred to further on, when we come to consider the uses of this compound and its rôle in nature.

Other nitrogen compounds are also present in air—nitrous and nitric acids, for instance, both in very small quantities. It may be that they are formed under the influence of atmospheric electricity, as some experiments by Cavendish seem to show, and as indicated by some observations of Liebig, who detected nitrate of ammonia in the rain that falls during thunderstorms. It may be also, as Schoenbein suggests, that nitrous acid is formed by the action of nitrogen on water during the different oxidizations or combustions which go on rapidly in our works, factories, and so forth, and slowly in the field of nature. Nitric nitrogen is more abundant in and during winter, and it is more especially in rain water that its proportions have been ascertained. Generally some 0.73 milligram are present in each liter of rain water, and in France each hectare receives about 3.986 kilograms of this nitrogen through the rainfall. Added to the nitrogen received under form of ammonia, this gives us a total of 13.787 kilograms of nitrogen received by the soil.

Much of it is borrowed by plants. It has been observed in England and in France that rain water collected in cities or in their immediate vicinity contains more nitrogen (especially under the form of ammonia) than that collected in the country some distance away. Towns where industrial pursuits are thriving and active, where factories and furnaces keep their chimneys constantly at work, produce a large quantity of ammonia. London, Glasgow, and Manchester are specially noted for this. Some amount of carbureted hydrogen exists in the atmosphere (one ten-thousandth), and its name, marsh gas, gives a clue to its origin. Sulphureted hydrogen, also present in very small quantities, has its origin in some volcanoes and in the disintegrative processes going on in dead bodies or other lifeless organic materials. It is therefore often found in the vicinity of graveyards and of fecal matter. It is enough to merely mention the presence of a very slight proportion of boric acid, which is ejected into the atmosphere by volcanoes—by some at least.

Iodine has been detected in small quantities by Chatin, who is of the opinion that its presence or absence in the air and waters bears some relation to the occurrence of goiter in the human species. Very little can be said in support of this view. The atmosphere undoubtedly contains saline particles, and all observers who use the spectroscope have been more or less annoyed by the fact. But these particles are present under the solid form. They are positively in suspension in the air, and not under the form of vapor nor of gas. No very considerable mental effort is required to ascertain the origin of such particles. Dust pervades the whole atmosphere—that is, the lower strata at least—dust which has been torn from the soil in all countries of the world, in the deserts of Sahara, Kalahari, Gobi, or Atacama, in the lowlands, from the flanks of the mountain ranges, dust that has been poured out from the bowels of the earth by Cotopaxi and Kilauea, Vesuvius and Colima, Erebus, and Terror, and all this dust contains a large number of saline particles. The seas also contribute their share. The wind sweeps off the crest of the waves, blows the foam and brine inshore, often to considerable distances, with the result that the atmosphere contains a proportion of the salts of the sea, which often cover with a perceptible coating plants fairly distant from the shore. Farther inland the proportion of sea salts is decreased, but while not themselves apparent they exert apparent effects upon plants.[1] Another curious influence is exerted by these particles in quite a different direction. It is well known that aqueous solutions of salts may, under peculiar circumstances, be supersaturated; that is, may contain a larger proportion of dissolved salt than is consistent with theory. If air is allowed to come in contact with the surface, such a solution often suddenly crystallizes. M. Gernez, who has thoroughly investigated these phenomena, comes to the conclusion that the sudden crystallization is due to the presence

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[1] Cf. P. Lesage: Influence du bord de la mer sur la structure des plantes.

in the atmosphere of a few particles of the corresponding salt, for it is a familiar fact that if the very smallest amount of a salt is dropped into a supersaturated solution of the same salt, the latter instantly crystallizes, just as a loaded gun goes off when the trigger is pulled. If this interpretation be correct, certainly air contains a large amount of sulphate of sodium, for supersaturated solutions of the latter crystallize very easily when not protected from contact with the general atmosphere. A fact that favors this explanation is that when the air in contact with a supersaturated solution is carefully filtered through a plug of asbestos or cotton it has no longer the power of inducing crystallization. It has been deprived by the plug of those particles which, by their conformity to the composition of the solution are able to induce the phenomenon referred to. If this explanation of M. Gernez is correct, the constant refusal of a supersaturated solution to crystallize when in contact with the general atmosphere would prove that the salt which it contains is not to be found free in the air. At all events, the interpretation is quite plausible and the fact is of interest.

Before dismissing this brief review of the main chemical constituents of the atmosphere, a word must be said concerning the volatile organic matters which Brown-Séquard and d'Arsonval thought they had found in expired air a few years ago. These two physiologists, collecting air expired by men or animals, and condensing, by means of cold, the aqueous vapor always present in such air, obtained a liquid to which they ascribed toxic properties. If such liquid is injected under the skin of an animal, it kills more or less rapidly, the results varying according to dose, the species experimented upon, and other circumstances. The inference was that expired air contains certain volatile substances excreted or exhaled by the lung surface and dissolved in the water derived from the condensation of pulmonary aqueous vapor, and from which they may be isolated by analysis. A very tempting inference, to be sure, for it seems clear that confined air vitiated by respiration, even after it is deprived of carbon dioxide, remains heavy, unpleasant, unhealthy, and even injurious, and if it has an unpleasant smell, the reason is probably because it contains peculiar organic matters. Do these matters—whose existence is suspected, not proven—accumulate in the liquid condensed by Brown-Séquard and d'Arsonval, and impart to it its toxic properties? The one great difficulty in answering this question is the fact that the different physiologists who have endeavored to repeat and confirm the above experiments in France, Germany, and Italy, have been unable to obtain the same results. They have not succeeded in obtaining from the breath any condensed liquid which had a toxic influence, and the most probable explanation is that some mistake was made by the original observers. When care is taken to exclude all elements except those derived from the breath no ill effects are observed on animals. It may very well have happened that Brown-Séquard and d'Arsonval did not take pains enough to prevent the contamination of the liquid, either by solid, and probably living, particles of nasal or buccal origin, or by impurities belonging to the apparatus and receiver in which condensation was effected. We can not, therefore, accept their original statement although there is a probability in favor of its truth. Further experiments are required to settle the matter.

III.—BIOLOGICAL RÔLE OF THE CHEMICAL CONSTITUENTS OF THE ATMOSPHERE.

Having now considered the constituents of the atmosphere, their relative proportions in the aerial mixture, their mode of production and distribution—that is, their mode of equilibration—and taking it as an established fact that the composition of air varies but slightly, remaining constant within the limits previously mentioned; having also briefly reviewed the part played by animate life in maintaining the composition of the atmosphere, we may now proceed to consider the chemical and physical influence of the atmosphere on the life of organisms.

For the sake of convenience and clearness, we shall begin with the chemical influence, and review in turn the influence of each separate constituent.

The life-maintaining gas of atmosphere, *par excellence*, is, to all appearances, oxygen—and we shall deal first with this element.

That its presence in air is indispensable for the proper execution of the respiratory functions is a fact familiar to all. Physiology has most clearly demonstrated, for a century past, the great importance and usefulness of this gas. It is essential to respiration. Man consumes large quantities of it.[1]

Inspired air, containing on the average 20 or 21 per cent of oxygen by volume—expired air containing only 16 per cent—4 per cent have, in consequence, been absorbed by the organism, and in twenty-four hours

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[1] It should be noticed that neither men nor animals ever breathe pure air, nor can they do so under normal and natural circumstances. The reason is obvious. The lungs are never totally emptied. Even after the deepest expiration, there remains in the lungs and air passages a residue of air that can not be expelled (owing to the anatomical impossibility of total pulmonary contraction), and such air is vitiated and unfit for respiratory purposes. The next inspiration brings a certain amount of pure air, but, as a matter of course, it mixes with the impure residual air, and therefore becomes vitiated to some extent. The only parts which receive strictly pure air are the superior air passages. At the end of expiration they are full of impure air; but the very first result of inspiration is to return all this impure air to the lungs, and to fill the air passages with pure air. A part of this goes to the lungs, and all that remains in the nose, trachea, etc., is pure. All mucous membranes have some respiratory functions, so that a proportion of this pure air is used; but the most important of the respiratory organs is bathed in a vitiated atmosphere, and one may truly say that neither men nor animals ever breathe really pure atmospheric air. A very simple and ingenious experiment has

an average adult retains over 740 grams, or 516,500 cubic centimeters, a total amount of 500,000,000 cubic meters per day for the whole of mankind. The amount of oxygen required varies somewhat according to sex and age within the limits of the same species. During childhood and old age less is needed than during the prime of life. An adult may require 910 grams in twenty-four hours; an 8-year old child is content with 375. Various circumstances, such as vigor, health, temperature, rest, exercise, and so on, increase or diminish oxygen consumption. This oxygen is absorbed in our tissues, which it reaches chiefly through the agency of the lungs and blood; a small proportion, however (one-eightieth of the amount absorbed by the lungs), is absorbed by our skin, which has, therefore, some respiratory importance.[1] All our tissues need oxygen; all breathe. For it must not be forgotten that the lung is nothing more than an instrument in the respiratory process; the chemical operation which is the essential part of this function takes place elsewhere, in the tissues themselves. The lung is only the door by which oxygen enters the system. Physiologists held quite different views a century ago, and Lavoisier himself supposed that the main act of respiration takes place in the lung. What really happens is that oxygen, introduced into the lung, filters through the very thin walls of the pulmonary capillaries, where it finds in the red blood corpuscles a substance called hemoglobin, with which it unites to form a compound which bears the name of oxyhemoglobin. A very unstable compound it is, for throughout the tissues, in the capillary vessels of the whole body, oxygen is allowed to escape and effect its work among the cells. Numerous and complex reactions take place, and one set of them results in the formation of carbonic acid. The blood, therefore, is nothing more than a vehicle; it carries oxygen to the tissues and brings back to the lungs carbonic acid, which, if not allowed to escape, would soon cause death. The "organic combustions" do not occur in the lungs, as was thought a century ago; their seat is in the tissues, throughout the whole body.

While respiration is common to all animals, it is not equally active

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been devised by Prof. Charles Richet in order to give an experimental proof of the soundness of this inference. All that is required is an india-rubber tube, some 2 or 3 yards in length, of rather wide bore. This tube is so adapted to the respiratory apparatus of a dog or rabbit, that by some means or other he is made to breathe through it. Under such conditions death from asphyxia soon results. This experiment merely exaggerates the normal conditions; adding the tube amounts to nothing more than lengthening the air passages, and putting a greater distance between the lung and the atmosphere. The result is not a matter of surprise—external air can not reach the lungs. Inspiration is not sufficient to draw to the lung the whole of the air contained in the tube, plus a sufficient amount of pure air. Each inspiration introduces some fresh air in the end of the tube, each expiration expels it, and none reaches the animal, which is unceasingly breathing the same air over again and perishes from asphyxia, although in appearance breathing as freely as possible.

[1] Cutaneous respiration is quite sufficient, in winter, to maintain life in some animals; the frog, for instance.

in all; it is more intense in birds than in mammals; more intense in mammals than in reptiles and mollusks. An active animal will consume more oxygen than one that is slothful, sleeping, lethargic, or hibernating. Yet all animals breathe; none can dispense with oxygen, and if that gas fails them they die.

It is the same with plants. While for their nutrition they exhale oxygen (chlorophyllian function) during the day, under the influence of light, they breathe at all times, absorbing oxygen and exhaling carbonic acid, as Priestley has shown. Here, also, the intensity of the function may vary. Plants need a great amount of oxygen during germination, and this explains why many seeds can not germinate under water, where the access of oxygen is retarded and inadequate, or in compact soil, where air—oxygen—is also deficient. One sort of seed requires the hundredth of its weight in oxygen, another is quite satisfied with ten or twenty times less; but all need oxygen, as De Saussure proved nearly a century ago.

Plants also need oxygen for their growth, and at the flowering period they use a large amount of it, chemical operations being then so very rapid and intense that a quite perceptible heat is given out. During all moments of their life, from birth to death, plants breathe. Separate parts, such as leaves, twigs, flowers, fruits, need and use oxygen also—they are not dead; and a nosegay in a room plays its part in the withdrawal of oxygen as well as the person sitting at the table, the cat sleeping near the hearth, the lamps, the fire. A fruit or a leaf, in any closed receiver full of air, alters the composition of the latter, withdrawing oxygen and giving carbonic acid in its place.

In brief, without oxygen there would be no life, no animals, no plants; the whole planet would be one desolate landscape of rocks and sand, from which the solar heat would in vain strive to elicit the merest blade of grass, the smallest insect.

Such being the case, some might incline toward the opinion that life is abundant and intense in proportion to the amount of oxygen, while, where air is deficient, life also is wanting. Logical extremes are, however, almost invariably absurd, and the researches conducted during the last twenty years, by Paul Bert and Pasteur especially, go to show conclusively that both opinions are equally erroneous.

Living beings, as they are at present, are adapted to life in an atmosphere containing one-fourth oxygen and three-fourths nitrogen. Experience shows us that if the ratio of oxygen is decreased even by one-fourth, life can no longer be maintained. The adaptation of organisms to the atmosphere is thus very close, and this suggests the idea that perhaps a change in reverse direction might also be injurious; that an increase in the ratio of oxygen might prove harmful. Paul Bert has thrown much light on this question, and his experiments have amply proven a fact which at first sight seems most improbable, but is less surprising to those who always keep in mind the fact that living beings are adapted to their environment, and that the adaptation is often very strict. He has shown that oxygen—the vivifying gas *par excellence*, that which is essential to life—is also a violent poison; a poison for plants as well as for animals, for the cells and the whole organism. All that is required is for oxygen to acquire a certain tension in the atmosphere or—what amounts to the same—be present in a certain ratio above the normal, and it becomes an agent of death. This can be demonstrated in two ways. Animals or plants may be made to live in a normal atmosphere, but under higher pressure than the average; or, again, they may be placed in artificial air where the ratio of oxygen has been increased. In both cases the phenomena are similar; in both, death is the result. While a satisfactory explanation has not yet been proposed in the case of plants, Paul Bert has been able to show that animals die in a superoxygenated atmosphere as soon as their blood contains one-third more than the normal ratio of oxygen, because, in such an atmosphere, the hemoglobin of the red blood corpuscles is saturated with oxygen—a fact which never occurs under normal conditions—and a proportion of this gas then dissolves in the serum of the blood itself. The oxygen dissolved in the serum does all the harm. The tissues can not withstand the presence of free uncombined oxygen; they are killed. This is the *quo modo* of the phenomenon. The *quare* is yet wanting: Why do the tissues require combined oxygen, and why does free oxygen kill them? Here is a riddle for physiologists; it is one worth their pains and trouble.

Now, it must be said that while a certain increase in the ratio of oxygen results in death, lesser increases of a temporary character may be beneficial. Every poison kills, doubtless, but there are doses which not only do not kill, but even confer benefit and improve health. This toxicity of superabundant oxygen is undoubtedly one of the most curious facts that recent years have brought to light, and it is a very positive and demonstrable one.

On the other hand, to say that without free oxygen there can be no life would be incorrect. Pasteur's investigations have shown that if some micro-organisms can live only where air and oxygen are present, others, which have been termed anaerobic, much prefer an environment where air is wanting. Such is the case with those which cause fermentation. They induce fermentation only when in a medium devoid of oxygen, and, as Pasteur put it, fermentation is a consequence of life without air. What then occurs in a fermenting medium? A particular kind of microbe—each fermentation is due to a particular sort or species of microbe—is conveyed, by air, by water, or is purposely introduced, into that medium. During a time it lives there upon the oxygen which it finds. At last oxygen fails; all the provision has been expended, and diffusion has not taken place rapidly enough to meet the needs of the micro-organism. The latter has then to shift for itself in some manner. Free oxygen is wanting, to be sure, but nevertheless there is oxygen to be had—oxygen in combination with one or the other of the substances dissolved in the liquid under consideration. This the micro-organism uses for its wants. It withdraws this oxygen and releases it from its fetters—not for the benefit of oxygen certainly, but for its own advantage. As this release can not be effected without releasing also at least one and often many other constituents which were combined with the oxygen, they also are freed, and their escape is one of the characteristic phenomena of fermentation. Let us take an instance, that of alcoholic fermentation. This requires water in which cane or grape sugar is dissolved (cane juice or grape juice). The microbe removes from the sugar a portion of its component oxygen, thus decomposing it into free carbonic acid and alcohol. This is one instance among a hundred. In all the process is fundamentally the same. In all processes of fermentation a microbe is present which, unable to otherwise obtain its requisite supply of oxygen, takes it by decomposing the surrounding substances, changing them into new compounds, containing in part the same elements as the original but differently united. So we see that, upon the whole, anaerobic micro-organisms, which seem more or less to shun free oxygen and air, do really breathe oxygen, as other organisms are wont to do. Thus, so far as some organisms are concerned, life is not impossible where free oxygen is wanting; and, on the other hand, wherever life is present, some method exists by which oxygen may be secured. While anaerobic micro-organisms seem to be exceptions, they fall under the general law that living organisms must have oxygen.

Between such anaerobic organisms and those which need free oxygen many transition forms exist. It will be sufficient to recall the fact that vegetable cells are aerobic and anaerobic simultaneously, since they can produce alcoholic fermentation. "Let us place a beet root in carbonic acid," says Duclaux, "we shall see it produce alcohol. Cherries, plums, apples, all fruits containing sugar, entire sacchariferous plants, under the same circumstances do the same. Their sugar is in part broken up into alcohol and carbon dioxide. The only difference between these cells and those of yeast is that the former are less suited for anaerobic life, and the fermentation which they effect is less complete than that effected by yeast, and they stop or die before all the sugar has been transformed. But such differences are only differences in degree." If we now turn to animal cells, we find that they are also, in fact, anaerobic. Have we not seen that free oxygen dissolved in the serum of the blood is toxic, and that it kills? That the tissues do not breathe pure or free oxygen, but require to have it offered to them combined with hemoglobin? And what is this, if not true anaerobiosis?[1] Hence we must draw the inference that while all

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[1] The notion that animal cells are anaerobic was propounded by Pasteur. A. Gautier, in 1893, took it up with some valuable arguments and experiments. These experiments have shown that quite a number of well-known disassimilation products

living organisms require oxygen, and must have it, a large number at all events require to have it offered to them in a combined form. All animals seem to prefer combined oxygen. As to plants, we are in the dark. Certainly free oxygen enters the stomata; but is the oxygen used as such by cells, or does it previously form some compound with some liquid in the plant? We do not know. What we do know, however, is that on our planet and under the present laws of organization and life where oxygen is wanting life is also wanting, and that where oxygen is in excess of the normal ratio life is impaired and after a time destroyed. Such is the main conclusion to be kept in mind.

We will now consider nitrogen, or azote. The name is significant. It means that this gas is not adequate to maintain life, for we all know that if an animal or plant be placed in an atmosphere containing nitrogen only, death ensues in a very short time. It should not be inferred that nitrogen is toxic. We inhale a large proportion of it without the slightest inconvenience; but it is inert, and neither burns nor maintains combustion. Its only function in respiration seems to be that of a diluent or moderator. Pure oxygen would be certain death, while, diluted with some amount of nitrogen, it is absorbed only in the requisite proportion. Nitrogen here plays the part of water added to wine—a useful part, most certainly, since we could not do without this diluent—but a negative one. But what more could be expected of an inert gas?

There is, however, a much more important part played by nitrogen in the economy of nature. It is abundant in organisms. It forms a large proportion of our frame and tissues and is most abundant in the atmosphere. Lastly, as shown by Magendie, when animals are deprived of food containing nitrogen, they die. Let us start from this well-established fact, that nitrogenous food is necessary to maintain life in animals—in higher animals at least. This nitrogenous food is, in the long run, provided by plants. While a few plants—lentils, for instance—yield fruits containing a large proportion of nitrogen, the greater number furnish nitrogenous food only by undergoing the transformations which animal digestion effects upon vegetable food—grass, hay, leaves, etc. Some animals require nitrogen in the form of meat, while a greater number are content with that contained in plants; but, upon the whole, nitrogen is always primarily provided by plants. Now, as nitrogen is essential to all animals, how do the plants which provide it manage to incorporate it? Where do they get it?

The soil contains some amount of nitrates, a proportion of which it is quite certain that plants absorb, for cultivation always impoverishes the soil, deprives it more or less of nitrogen, as chemistry shows, and in order to restore its fertility nitrogen must be added to it under

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which are found in the blood, in the urine, etc., are produced by the cells of the tissues after circulation has entirely ceased, when air and oxygen are no more brought to them. The inference is that animal cells are, according to circumstances, aerobic or anaerobic.

the form of nitrogenous manures. But notice must be taken of the following facts. In the first place, forests—whose age is often very great—go on growing, although for centuries no manure has been added to the soil on which they grow, and the same is true of pasture land. Again, it is a well-known fact that if soil is manured with any nitrogenous manure, it yields more nitrogen in the crop than was given to it in the fertilizer. These facts, ascertained by Boussingault many years ago, suggested the idea that atmospheric nitrogen might play some part in the nutrition of plants, and that in some way or other they might borrow nitrogen from the atmosphere which contains such an amount of this substance.

To be sure, the atmosphere contains some ammonia (nitrogen and hydrogen combined), but the amount is very small. Mayer, of Heidelberg, while cultivating in the open air plants whose roots were immersed in nutrient solutions from which nitrogenous compounds were excluded, and protecting them against rain so as to exclude the influence of such nitrogenous compounds as exist in rain water, obtained a crop containing exactly the same amount of nitrogen as the seeds from which the plants grew—not a milligram more. This shows that the amount of ammonia, or other nitrogenous compounds, which may be borrowed from the atmosphere by plants in a direct manner is quite insignificant. But while plants may obtain very little or nothing from the atmosphere by direct process, the case is entirely altered when indirect processes are allowed to operate. Under such circumstances atmospheric ammonia when combined with the elements of the soil, plays an important part, as shown by Berthelot. Instead of remaining useless, as when contained in the atmosphere, it then becomes useful, and is utilized by plants. This process by which atmospheric ammonia combines with soil elements is not a spontaneous one such as that by which hydrogen burning in oxygen forms water—there is no unavoidable chemical reaction—it is effected by the agency of definite micro-organisms. While a specimen of soil left to itself under normal circumstances acquires more nitrogen, the same specimen remains unaltered (neither loses nor acquires nitrogen) when it has been previously sterilized by subjecting it to a heat above 105° or 110° C., by which all micro-organisms are killed. Again, M. Schloesing and Müntz have shown that it is by different micro-organisms that the nitrogen contained in nitrogenous organic matters of arable land is made to combine with other matters, and to form nitrates. One generates ammonia; another transforms ammonia into nitrous acid, which forms nitrates by combining with basic elements, and lastly a third micro-organism transforms the nitrites into nitrates; and this triple process is what is called nitrification—an operation fully investigated by Munro, Winogradsky, and Frankland.

Thus, by one means or another, atmospheric ammonia may be put within reach of plants and be used by them. But ammonia is however a very small proportion of the nitrogenous contents of the atmosphere.

Is there no other supply, and especially, is there no method by which pure atmospheric nitrogen may be also utilized by plants? In view of the considerable amount of nitrogen contained in atmosphere, the matter is one of great importance to plants.

The question has been answered by Hellriegel.[1] After twenty-five years' investigation, the learned director of the agricultural station of Bemberg has finally proved conclusively that certain plants at least have the power of assimilating atmospheric nitrogen. These plants belong to the leguminous family. While cereals, for instance, need to be provided with nitrogen under the form of nitrogenous compounds mingled with the soil, or under the form of nitrates or ammonia salts, lupines, pease, clover and such plants do very well without such compounds. And yet they contain nitrogen; moreover, agriculturists know that they not only do not require nitrogenous manure, but that after they have been grown on a soil they contain more nitrogen than the soil could possibly have furnished; hence the name of "bettering plants." If they are buried in the soil, they not only restore the amount of nitrogen which they may have derived from it, they add to it an excess which they have obtained elsewhere; that is to say, from the atmosphere. Plants grown in a soil totally deficient in nitrogen contain much more of it than the seeds from which they spring—provided, however, one condition is fulfilled. This condition is that the roots possess certain peculiar outgrowths or small tumors—nodules, as they are commonly called—in which a special sort of bacteria is found. If the bacteria are wanting, the plant does not grow well; it remains puny and deficient in nitrogen, but if watered with water to which has been added a culture of the requisite species of bacteria it becomes thrifty and yields an amount of nitrogen amounting to a hundredfold the weight contained in the seed.

It seems that in different species of leguminous plants the active and important species of bacteria are different. That which is adapted to acacia, for instance, although it does not suit pease, works well with beans, and vice versa. Are we to draw the inference that each species of this family has its own special bacterium? Nobbe is not of this opinion; he thinks there is only one species, which he calls *Bacterium radicola;* but that within this species a number of races or varieties has been evolved, each one specially adapted to a sort of communalism with a particular species of plant. For instance, if one individual of this bacterium lives in the nodosities of one particular plant, its progeny becomes specially adapted to life on the same species, and does not thrive on another species. Such is Nobbe's view briefly summarized, and it would explain many curious facts noticed by

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[1] Hermann Hellriegel, born 1831, died September, 1895. This important work was accomplished with the cooperation of Mr. Wilfarth, and was made known in 1886 at the Naturforscher-Versammlung in Berlin. Varro and the old Roman farmers had noticed that beans, lupines, and vetches render the soil more fruitful, but Hellriegel and Wilfarth discovered the reason.

agriculturists and horticulturists concerning sympathies and antipathies between plants, and like matters.

The quantity of nitrogen which leguminous plants can obtain from the atmosphere by means of the bacteria which live on their roots may be very considerable; it may amount to 100 or 150 kilograms per hectare (2½ acres). Hence, it is an excellent plan with soils deficient in nitrogen to grow and turn under leguminous plants. It follows also that if a given soil seems unfit for the culture of a particular leguminous plant, this may be because it does not contain the necessary bacteria, and under such circumstances all that is required is to inoculate it. A culture is not required; it is enough to sprinkle some earth taken from a field in which leguminous plants of the same species have grown and thriven. The bacteria abound in that earth, and at once multiply in the field. This is no matter of mere laboratory experiment; the process has been tested on a large scale at Meppen in Germany, by M. Salfeld, with the best results, the crop having been then doubled and trebled.

This inoculation may be performed in another manner. M. Bréal, of the Paris Museum of Natural History, grows two lupines in separate pots, filled with sterilized earth. He inoculates the roots of the one with a needle dipped previously in a culture of the appropriate bacterium, while the other is not inoculated. The result is that the former thrives, while the latter remains puny and perishes.

Besides, Schloesing and Laurent have shown that if different leguminous plants are cultivated in a confined atmosphere the amount of nitrogen in the air decreases.

The general result of the very important labors of Hellriegel and Wilfarth, of Nobbe, of Sir John Lawes and Sir Henry Gilbert is, then, the discovery that different plants of the leguminous family—belonging in particular to the papilionaceous division—are endowed with a very special mode of nutrition, quite different from that of other phanerogams. By means of the cooperation of a few micro-organisms which dwell in and on their roots, they are enabled to draw free nitrogen from the air; not ammonia, nor any other form of combined nitrogen, but free nitrogen, which is used as a nutriment. And thus it happens that that enormous quantity of nitrogen which goes to make a large proportion of the atmosphere, instead of being useless as it seemed at first, is of very great importance to plant life. The probabilities are that it is even greater than it now appears. We feel it difficult to conceive that only a small proportion of plants are able to avail themselves of this source of nitrogen, and physiology teaches us that so far as the principal functions of life are concerned there reigns great similitude in the processes by which they are effected. That papilionaceous plants only, of the whole host of the vegetable world, should be able to acquire nitrogen in the manner described seems unlikely, and thence the opinion that a similar process and a similar function must obtain among other families of plants. This is but an hypothesis, however, and no definite statement can yet be made concerning this attempted generalization. Some facts, indeed, go against it, and show that certainly not all plants have the functions which we have noted in the papilionaceous family. Messrs. Schloesing and Laurent infer from experiment that some species at least are unable to make use of atmospheric nitrogen, and require to have it provided to them under the form of different compounds contained in the fragments and débris of other plants, which thus play the part of manure and food. While the lion and tiger eat the sheep and deer, some plants eat, so to say, their congeners, and exhibit a form of cannibalism. The latter obtain nitrogen from the atmosphere, and after death their remains serve as food for other plants. Such is the case with mosses and many cryptogams. So, observe the gradation: Inferior plants[1] draw nitrogen from the atmosphere; superior plants feed upon the remains of the lower;[2] and, lastly, animals feed on other animals or plants. Man eats both animals and plants, and crowns the edifice of life, as he supposes; but the solid substructure upon which all the building rests is merely an agglomeration of humble unnoticed forms, often invisible to the naked eye, whose functions are to provide the animal and vegetable kingdoms with an essential part of their food. Whether there is here a plan is not for me to decide, but most assuredly the connections and interactions are of interest.

This exposition may seem somewhat long, but it was necessary. It shows that certain plants, at least, can either directly or indirectly fix atmospheric nitrogen without having recourse to the nitrates of nitrogenous manures. Here again it is shown that air is indispensable to life. A gas that at first seems inert and useless is found, after careful investigation, to play a most important part in the nutrition of living organisms. Without nitrogen there would be no plants, no food, no animals, no mankind, in brief, no life at all. And if atmospheric nitrogen were to disappear, life would soon be extinguished. Who, then, will consider this element of the air as useless?

We now come to carbonic acid.

We all know that it is an essentially noxious compound, and doubtless there is little in its history to redeem its reputation. One-half of our respiratory function is concerned especially with the task of ridding

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[1] And some superior plants also, such as those of the papilionaceous group; but even with them the process is indirect, as it is through very low organisms (bacteria) that nitrogen is brought to them.

[2] When Melchior Treub visited Krakatoa after the disaster of 1884, in order to investigate the floral repopulation of the island—seeds being brought by currents and winds from the surrounding parts in abundance—he noted that the first plants to appear were algæ and lichens. And it was only some time after the latter had taken a foothold, and, so to say, prepared a suitable soil, that higher plants were seen, and lastly phanerogams. This progression is quite in accordance with physiological facts.

our body of this substance, which is unceasingly generated in our tissues. It is not fit for breathing purposes, and all animals and plants perish in a confined atmosphere when the proportion of this gas rises above a very limited ratio. An atmosphere which contains one per cent carbon dioxide has evil effects upon most organisms, and when the ratio is ten per cent, life is endangered and death only a matter of time. Carbonic acid is of no use at all to the tissues, and when we breathe in an atmosphere where this gas is abundant, the blood corpuscles are not able, in the lungs, to get rid of the carbon dioxide they have collected in the body; so they keep it, and, keeping it, they can not take with them the amount of oxygen necessary for the cells and tissues. It may be asked why they keep the former. The reason is that gas exchanges between the blood and the atmosphere depend upon the amount or tension of the gas in both media. As soon as the tension of carbonic acid in the atmosphere is greater than that of the same gas in the blood, the blood corpuscles retain their carbonic acid. If the amount of carbonic acid in the atmosphere is increased, its tension becomes at some point superior to that of the same gas in the blood corpuscles. These, then, retain the noxious gas which takes the place which should be abandoned to oxygen. The result is death by asphyxia. Before death supervenes a condition of anæthesia is induced, which Bichat specially investigated by means of an ingenious experiment, through which the venous blood—well provided with carbonic acid, of course—of one animal was made to pass into the carotid and cerebral arteries of another, so that the latter had its brain irrigated with asphyxic blood, and was brought to a condition of anæsthesia. Even when applied locally to the surface of the skin, carbon dioxide induces a state of local and temporary insensibility, a fact which seems to have been long known and frequently utilized. Pliny relates in his Natural History that marble (carbonate of lime), when mixed with vinegar and placed upon the skin, puts the latter to sleep, i. e., renders it insensible, so that it may be cut and burned without inducing pain. In this case the anæsthetic agent is carbon dioxide, which is set free by the action of the acetic acid of the vinegar upon the carbonate of lime.

When carbon dioxide acts upon the entire organism, as when it is inhaled by the lungs, it induces general anæsthesia. This has been investigated by a number of physiologists, and one among them, M. Ozanam, has found it so satisfactory that he feels no hesitation in commending it as a substitute for ether or chloroform. His advice has never, to my knowledge, been followed by surgeons or physiologists, and some doubt may be expressed as to the expediency of using for surgical or other purposes so dangerous an agent. Some cases are known in which man has been deeply under the influence of carbon dioxide without fatal results. In such circumstances, anæsthesia has been complete. The patients relate, at least some of them, that before becoming unconscious there occurs a delightful condition during which they seem to be surrounded by a host of very brilliant lights, while exquisite music is played by some invisible orchestra. But this state is of short duration, and total unconsciousness soon occurs, which, if the toxic gas keeps on accumulating in the blood, is rapidly converted into eternal sleep. Cases of death by carbonic acid are not infrequent; they are met with particularly in the vicinity of fermenting liquids, such as brewers' vats or wine cellars; in places where carbon dioxide is naturally exhaled by "gas springs;" by thermal springs in some caves or grottoes, and in all ill-ventilated rooms where a proportionately large number of men or animals are gathered. In lecture and assembly rooms, which are often crowded, air vitiates rapidly; in theaters, in schools, in lecture halls, as much as 10 parts per thousand of carbonic acid has been observed, and in Alpine stables, as before referred to, where animals and men were crowded together, each seeking some warmth in the close vicinity of his neighbor, the ratio of 21 parts per thousand has been recorded.[1] Such atmosphere is toxic,[2] and proofs thereof are not wanting.

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[1] M. G. H. Richards, of the Massachusetts Institute of Technology, has, during nine years past, made some 5,000 analyses of the air of lecture rooms. The normal average proportion of carbonic acid in external air is between 3.7 and 4.2 per 10,000. In buildings, the proportion increases according to circumstances. For instance, in empty rooms it is higher by 0.5 on the average in consequence of the decomposition of organic matter, which always remains after the passage of any number of human beings, in the cracks of the floor, on the walls, etc. In the parts of the building where people come and go, without stopping for any considerable time, the ratio is a little higher, and becomes 5 per 10,000. In lecture rooms things are at the worst, as might be expected, and the ratio is 6 or 8 and occasionally 10 or 12 volumes of carbonic acid per 10,000 of air. If such proportions are exceeded, work becomes difficult and unprofitable. Each adult exhales, on an average, according to Andral and Gavarret, some 22 liters of carbon dioxide per hour, so that a man breathing in a confined space 3 meters long, 2 meters high, and 2 meters wide would in twenty-four hours transform the whole of the air of this space into an air having exactly the composition of that exhaled from the lungs. It must not be forgotten that each gaslight, on an average, produces 128 liters of carbon dioxide per hour, and 10 grams of candle produce 14 liters. Under such circumstances no one can wonder that the atmosphere becomes so soon vitiated in rooms where any considerable number of persons are assembled.

[2] It is toxic in its natural condition, by which is meant, if oxygen is present in it only in the usual proportion. But, experimentally, such atmosphere may be prevented from becoming dangerous if its composition is altered by an addition of oxygen. Regnault and Reiset have seen dogs and rabbits live in an atmosphere containing 25 per cent carbon dioxide, 30 to 40 per cent oxygen, and about 40 per cent nitrogen. Even without increasing the ratio of oxygen, animals may live a short time in an atmosphere containing a large proportion of carbon dioxide—30 per cent, for instance, oxygen being 16 per cent (Le Blanc); and Snow has seen birds withstand some time the effects of an atmosphere containing 21 per cent oxygen, 59 nitrogen and 20 carbonic acid. But these experiments can not have any considerable duration, and the average limit of respirable atmosphere is set by the composition of expired air. An atmosphere containing 4 per cent carbon dioxide, 16 per cent oxygen, and 80 per cent nitrogen is inadequate to long maintain life. A lamp is soon extinguished in such an atmosphere, but man may live in it for a short time.

To avoid any danger of the vitiation of air, hygienists are agreed that more is

For instance, during the wars in India, 146 prisoners were one evening at 8 o'clock shut up in a small room. Out of the number only 50 were still living at 2 o'clock next morning, and at daybreak only 23, all dying. Again, after the battle of Austerlitz, out of 300 prisoners confined in an ill-ventilated cellar, 260 died in a few hours through asphyxia, induced by an excessive proportion of carbon dioxide. And at the celebrated Oxford assizes (the "fatal" or "black" assizes in 1557), the high sheriff and 300 other persons died suddenly in court from asphyxia induced by the same means. It may be that in these cases some other influence was also at work, and that some exhaled substance similar to that which Brown-Séquard and d'Arsonval thought they had detected, added its influence to that of carbonic acid; but the existence of this substance has not yet been proved, although it seems probable.

Other cases of poisoning by carbonic acid are met with in natural conditions. Men and animals are occasionally killed by such gas, exhaled by neighboring springs and accumulated in hollows or small valleys. Such "death valleys" have been described by many travelers. No plant is seen, not a blade of grass, not a shrub or tree. The soil is bare, stony, and as if struck with death. Here and there a skeleton is perceived bleaching in the sun—a skeleton of bird, mammal, or even man. Ignorant of the fatal properties of the valley, animals or men

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required than the 16 to 20 cubic meters of air per individual per hour, that was formerly considered as sufficient. In the best ventilated hospitals of Paris 100 cubic meters are provided, but under normal conditions 60 are quite enough for persons in good health. As a rule, the atmosphere of a room may be considered as vitiated as soon as it begins to smell close. When this happens, however, it must not be considered as due to the smell of carbonic acid itself, which is scentless. The smell of close air is due to organic substances—hitherto undefined, or only partly known—which are exhaled by men and animals, and probably more by the skin and its impurities than by the lungs themselves, and generally the amount of these substances is considered as roughly proportional to the amount of carbon dioxide met in the air. Smell is considered as indicating approximately the unhealthiness of the atmosphere as regards respiratory purposes, and is a safe enough criterion. When a room becomes close, it should be thoroughly ventilated, and in such case a draft should always be established, two doors or windows, on different sides of the room, being opened. One is not enough; both are required in order to completely expel the close air and replace it by pure. Generally servants—and masters as well—are content with imperfect ventilation. Such is especially the case in winter, when air is often vitiated by the presence of a gas, carbon monoxide, which is given off in very small quantities by different heating apparatus, stoves especially. Although this gas is never present in any great quantity, it is a source of considerable danger; and in countries where slow-combustion stoves are used, it is each year the cause of many deaths. Carbon monoxide has even greater affinities for hemoglobin than has oxygen, it therefore combines with it and thus there is no place left in the blood corpuscles for oxygen, and the blood then carries no more of the latter gas to the cells and tissues of the body. This gas is also found in the air of mines, but in the open air is not met with, or exists in such small quantities that it can not be detected by present methods.

have wandered there while in pursuit of food, and in the lower part, where the influence of wind is the least and where the heavy gas naturally accumulates, asphyxia rapidly ensues. None who enter come out alive, and the bird of prey soaring in the heights, whose keen eye perceives the victim in the death struggle, and who pounces down upon this welcome opportunity, is vanquished in turn and rises no more.

Fatal to animals as well as plants, expelled by both from the organism as soon as it is produced, carbonic acid appears to all under the feature of a death-dealing agent, as a gas whose toxicity is unquestionable. The only word that can be said in its behalf is that at the moment of death it may act a kindly part. Death in the majority of cases, as a consequence of disease, is induced by asphyxia. During the death struggle respiration fails gradually, becomes slower and more superficial, with the inevitable result that carbonic acid accumulates in the blood. It is probable that when man is about to fall into his last slumber, when the body is on the point of entering that final stage of dissolution and disintegration which we call death, carbonic acid intervenes and plays its part, slowly drawing the curtain, gently putting intelligence to sleep, rendering it unconscious, deaf to sound, insensible to pain, and by beneficial and kind anæsthesia easing the final act of physical life. This may well be so, and this gas which some physiologists consider one of the agents by which each of us is brought into the world by stimulating the contractions of the maternal womb, thus also assists us out of it.

This function, however, is not the only beneficial one which carbonic acid fulfills, and concerning that very unwholesome and toxic constituent of the atmosphere much remains to be said. The unfavorable features have been put in full light; it is but fair to do the same for the redeeming traits, and this shall proceed to do.

All animals directly or indirectly feed upon plants, and plants draw from the soil the greater part of their mineral constituents. Nitrogen and oxygen they borrow from the atmosphere. But what about carbon? The matter is important, as their frame and tissues contain a large quantity of this substance. Two sources are available. Carbonic acid—carbon combined with oxygen—is present in the soil, where it is to be found combined with different substances in the form of carbonates, and in humus, the superficial layer of the soil, made up of fragments of leaves, of branches, of roots dead and decomposed, of mosses, dead ferns, etc. But we can not take into account the carbon which exists in humus, as the first plants which appeared could not have made use of it. There remain the carbonates of the soil, and it would seem to follow that this must be where plants obtain the larger amount of the carbon they use, as Mathieu de Dombasle and many other agriculturists after him supposed. A number of experiments by Sprengel, De Saussure and others, have shown, however, that the part played by carbonates is less important than was thought, and more recently Liebig has established the fact that plants grow and thrive quite well in a soil whence all carbonates have been expelled. Where then do they get their carbon? We know now that they take it from the atmosphere. It is their privilege to decompose the carbonic acid contained in air and to liberate its elements; that is, oxygen which is exhaled and carbon which is retained in their tissues. And the cultivated area of France—some 41,000,000 hectares—absorbs by this means some 60,000,000 tons of carbon each year. This important operation can, however, be performed only under three conditions. As only green parts are capable of taking carbon from the air, the plant must be provided with chlorophyll—that green substance, which is the cause of the color of leaves, and must be exposed to the rays of the sun and to a favorable temperature. Chlorophyll can decompose carbonic acid only under the influence of light and moderate heat; in darkness and under too great or too low heat it no longer acts, and the result is that plants suffer and die, victims of inanition. For it must be clearly understood that the chlorophyllian function is one of nutrition, quite distinct from the respiratory function. In the latter function plants, like animals, absorb oxygen and exhale carbonic acid; in the former the reverse obtains. The one goes on during night and day, the other is in operation by daytime only, and the function of nutrition lasting less time must necessarily be more active than the respiratory process; otherwise the equilibrium would be destroyed and the plant would lose more than it acquires and consequently suffer.

It is by the leaves mainly, and by the roots in a lesser degree, that atmospheric carbon dioxide is absorbed; but in both cases the gas must be brought to the leaves, to the parts containing chlorophyll, because these parts only can use it—can take the carbon and expel the oxygen.

Hence it follows that this violent poison, this gas which is harmful for all organisms, and which kills them as soon as it accumulates in the atmosphere even in small proportions, is essential to all terrestrial life. If it were to be destroyed, if air were to contain no more of it, all plants on the surface of the earth would die within a short period—some weeks at most. After this, as a matter of course, herbivorous animals would die, and this would not require more than a month. Carnivorous animals would hold out a little longer, as the stronger would feed upon the weak, but after a few weeks they also would go in turn, and only a few miserable, half-starved specimens of mankind would be seen feebly struggling from one rotting carcass to another, amidst as barren scenery as can be observed by looking at the moon through a telescope, and they, too, would have to die soon after, notwithstanding cannibalism or such other extreme methods which dire necessity might suggest. In a few months all nature would be dead.

While carbonic acid is a poison, a substance which endangers life greatly, it is also a necessity for life, and in the proportions in which it exists in the atmosphere it is just as much a necessity as it would become a fatal danger if it were to be present in larger quantity.

Such are the relations between air considered from the chemical standpoint and life as it exists on earth; between air in its normal, unvitiated, average constitution and life as it manifests itself under the present circumstances.

IV.—BIOLOGICAL INFLUENCE OF THE ATMOSPHERE CONSIDERED FROM THE PHYSICAL POINT OF VIEW.

We must now discuss another side of this complex question, we must deal with air considered as a physical substance, and especially as a substance having weight which presses upon all living organisms. This point of view is not less important than the preceding, and deserves some attention, by reason of the relations which exist between life and atmospheric pressure.

The atmosphere, as previously noticed, being a physical substance, possesses weight, and exerts a pressure upon the earth and all beings that inhabit it.[1]

As long as men or animals keep near sea level, or do not climb to exceedingly high altitudes, the normal average variations of pressure, as indicated by the barometer, are of small influence, and the much more considerable variations which are encountered when one ascends mountains or goes up in a balloon are not harmful as long as they do

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[1] The average pressure of the atmosphere varies, as before stated, according to the altitude of the locality, and also in the same locality at different times. At the sea level this average pressure amounts to a little over a kilogram per square centimeter, hence the total weight supported by an average man is about 18,000 kilograms. At Mexico the average weight per square centimeter goes down to 793 grams; at Quito, to 752; at Antisana, to 639; and it is no difficult matter to obtain the figure which represents the weight supported by man in such localities, when one knows that the skin surface of an average adult is somewhere between 1,400 and 1,500 square centimeters. The physicist Haüy, explaining and commenting upon the calculations by means of which the average pressure exerted upon the body is ascertained, remarks: "And that is the weight which those philosophers of old had to bear and resist who denied weight to the atmosphere."

This weight or pressure is considerable, but we do not feel it, as all the interior parts of our body exert the same pressure and therefore resist successfully that from the outside. It does not crush us any more than it crushes the soap bubbles, however thin they may be, because in both cases the resistance of internal air or tissues exactly counteracts that of external air. There are very few places in the body where the pressure from within outward does not exactly counteract the opposite pressure, in order to leave all movements perfectly free. Two exceptions, however, must be referred to—that of the pleuræ, between which no counter pressure exists, so that they are compelled by atmospheric pressure to keep strictly in contact, and that of certain articulations, where the head of a bone so exactly fits into a corresponding cavity that there is place for no air between, with the result that the atmospheric pressure forces the former into the latter and keeps it there with sufficient force to resist the counteracting weight of the limb.

not exceed certain limits. But beyond these limits danger exists for both animals and man, and while the effects are not exactly the same for all species, and do not occur at exactly the same altitude with all species, or even individuals of the same species, the general fact remains that at high altitudes, or under very low pressures, life is more or less endangered from different causes. In order to ascertain these causes it is not convenient to take men or animals into high altitudes, as the experimenter would be apt to be also influenced by the diminution of pressure, in consequence of which the value of his observations might be considerably reduced. A better method, easily available, is that used in laboratories, of providing large or small air-proof chambers in which the pressure may be increased or diminished at will, so that, without going out of the laboratory, the same patient or animal may be subjected by turn to the pressure which reigns at the bottom of the deepest mine, or even to far higher pressure, amounting to 800 or 1,000 atmospheres, and to that met on the top of the highest peak of the Himalayas, or at twice or three times that height in the lightest of balloons. With such instruments observation becomes easy, and is effected under the most favorable circumstances, as the operator is able to obtain at a few moments' notice exactly the amount of pressure he wishes to have.

The influence of those extreme pressures, high or low, where life becomes endangered, was very fully investigated by Jourdanet, and afterwards by Paul Bert, and those investigations have taught us by what means they become dangerous. The limits of pressure within which no harm occurs are variable according to species. All terrestrial and aquatic animals may and do resist certain variations in pressure, whether above or below the average. Man, for instance, can work at a kilometer below the sea level without any injury, and he can travel to the height of 5 or 6 kilometers in the atmosphere without being necessarily affected by the decrease of pressure. It is the same with birds and mammals, and surface or shore fishes may go pretty deep in the seas without experiencing any unpleasant effects, while deep-sea fish may travel upward for some time before reaching the danger line, so to speak. But for all organisms there are limits in the variation of pressure which can not be transgressed with impunity; there are limits beyond which life is destroyed.

How is death induced in such cases? We must consider the two different cases in turn, and shall begin with the effects of diminished pressure.

Four hundred years have now elapsed since a Jesuit missionary, Acosta, left us an excellent description of the accidents which attend ascensions in high mountains, or important diminution of pressure. "While ascending a mountain in Peru," writes Acosta, "I was suddenly affected by so strange and so mortal an evil that I nearly dropped from my horse to the ground. * * * I was alone with an Indian, and asked him to help me to keep on my animal, and I was taken with such pain, sobbing, and vomiting, that I thought I should die, and, moreover after having vomited food, phlegm (mucous matter), and bile, yellow first and afterwards green, I even threw up blood, such pains had I in my stomach; and I am sure that if it had lasted longer I would certainly have died. As it was it lasted only three or four hours, till we had reached a much lower region. And not only men, but animals also were affected." And further on, "I feel confident that the substance of the air in such places is so subtle and thin that it is unsuitable for human respiration, which requires it thicker and better adapted." This was written three hundred years before the time of Priestley and Lavoisier, and yet the expressions used by Acosta are really most happy. Atmospheric air in the altitudes is too thin, too rarefied, too subtle for the respiration of superior organisms. The evil described by Acosta is that which, in different countries and places, is named *puña*, *soroche*, *veta*, *mal des montagnes*, *mountain sickness*, *balloon sickness*. It has been more recently and fully described and investigated by Tschudi, Lortet, and many others; each has noticed the vertigo, vomiting, anxiety, and fainting which characterize it; and exact experiments—those of Lortet and Chauveau, among others—have shown that respiration is diminished and at the same time accelerated; intense muscular pains have been noticed, and also circulatory and nervous symptoms, which end in paralysis and death if the perturbations continue, as in case of the *Zenith* catastrophe.

While it would be quite superfluous for our present purpose to review the opinions which have at different times been entertained concerning the cause of these dangerous perturbations, we may briefly summarize the explanation thereof recently given by Paul Bert and others.

This is quite simple. The symptoms and death are due to a diminution in the tension of oxygen, which is itself due to the rarefaction of that gas. As everyone will understand, if the same volume contains in high altitudes less weight of air than in low altitudes or at the sea level, it follows that in the former condition there is less air available, less of each constituent, less oxygen. In the heights of the atmosphere air is made up of the same elements as below, but they are less in quantity although the proportions are the same; air is dilated, rarefied, thinner, less dense, and of the essential element—oxygen—a smaller quantity is inhaled at each respiratory movement, although the volume of inspired air is the same. Under such circumstances, as Paul Bert's investigations go to show, decrease of pressure kills, not mechanically, but by a chemical process. High altitudes kill because they induce a state of anoxyhæmia, a state in which the blood is deficient in oxygen. The animal—or man—in rarefied air, dies for the same reason that one dies in a confined atmosphere; in both cases there is an insufficiency of oxygen.

Another cause also operates, in the case of fishes or other aquatic animals that live at great depths, when they happen to rise too near the surface, thus coming from high to low pressure. The gases of the body, dissolved in the liquids (blood, etc.), have a higher tension than the outside pressure, and the result is that these gases expand and burst the tissues within which they are contained when the exterior pressure becomes less than that which reigns in the interior. The case is exactly that of a bladder inflated with air placed in the receiver of an air pump; if the air of the cylinder is gradually exhausted, the bladder swells until it explodes. This is an extreme case, which hardly occurs under natural conditions, but other accidents of a similar nature, which are explained by the same mechanism, often do occur in man or animals, as we shall show further on.

We can not leave this subject without adding a few words concerning mountain sickness. It is a well-known fact that at the same altitude different aeronauts or tourists are not equally affected. Of course this statement refers only to moderate altitudes, between 3,000 and 4,000 meters. At the very same place, on the same day, one person is a victim to mountain sickness and another is not. As only individuals of the same species are compared, the reason of the difference can only lie in personal or individual peculiarities; no specific physiological differences can exist such as those met with when one compares the influence of one and the same agency or poison, etc., upon individuals of different species; there is no evident and tangible cause such as that which one detects when comparing the resistance of the duck and of the common fowl to submersion, when the greater resistance of the former is due to its greater amount of blood, and consequently more considerable provision of oxygen. There are doubtless physiological differences of real importance between different individuals belonging to the same species, and between different varieties of the same species; considered *in toto* those differences are more important and more frequent than commonly supposed, and probably more important than those external morphological characters which are the bases of classification at present. But such important differences can not obtain between two individuals belonging to the same species, and the fact that they may occur one day and be wanting a week later, shows that they are merely accidental and temporary.

Mountain sickness is due to a condition of asphyxia, as already noticed, and this fact explains the differences referred to, as an ingenious experiment performed by M. Paul Regnard amply shows. This experiment was suggested by the proposal, made by a company, to build a lift by which to reach the top of the Jungfrau, the well-known Alpine peak. Before setting to work, it was desirable to ascertain whether the passage from low to high altitude would not produce unpleasant symptoms in the tourists using the lift,[1] and to show that

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[1] The lift was to be established in vertical shafts from a horizontal tunnel at the base of the mountain to the top.

under the circumstances attending the excursion, mountain sickness was not to be feared. M. Regnard's experiment answers this question. As far as physiologists are concerned, the question was settled, but the general public required to be satisfied upon this point. The experiment is easily repeated in any laboratory, and it is quite unnecessary to ascend Mont Blanc or the Himalayas for the purpose. All that is required is a glass bell jar, an exhausting pump, and a pair of guinea pigs. The bell jar must be rather wide, and it is placed—inverted—upon a smooth and even surface, such as that which can be afforded by a thick pane of glass.

The edge of the jar is smeared with tallow, so that when placed upon the pane the access of air is entirely prevented. Under it are the two guinea pigs. One is free and does as he chooses; the other is placed in a small treadmill where he is compelled to exert himself somewhat in order to preserve his equilibrium, as the treadmill is made to turn round by means of electricity. The two animals represent, the first, an aeronaut, or a person quietly sitting in a lift where no exertion is required; the other, a mountain climber, who has to expend energy, and to work if he wants to get to the top; and now both must be placed in a condition similar to those which obtain in high altitudes. A few strokes of the air pump connected with the bell are enough to bring the pressure to correspond exactly with that which exists at 2,000, at 3,000, at 4,000 meters height, and a manometer shows the pressure produced. So this experiment begins, and the atmosphere within the bell is slowly rarefied, as would happen in the case of a slowly ascending lift or mountain climber, and because, also, rapid decrease of pressure would be most dangerous. Up to the decrease of pressure which corresponds to a 3,000 meters altitude both animals remain quite well, the one who works his way up, so to say, as well as the other who keeps quiet or only walks a few paces to the right or left. The process is continued and the rarefaction increased. Before the pressure corresponding to 4,000 meters altitude is attained, however, the "working" guinea pig manifests evidence of physiological discontent. Now and then he stumbles, and does not exactly keep pace with the treadmill; he even rolls over and is clearly out of breath. When the manometer shows the pressure to be that which corresponds to a 4,600 meters altitude (210 meters less than the altitude of Mont Blanc), this guinea pig is entirely disabled. He can walk no more; rolls on his back, and is rolled by the treadmill; he moves no longer. In fact, he seems quite dead. Life is not extinct, though, and the animal moves when air is again let into the jar. The other animal is in an excellent state of health. At no moment has he presented the slightest symptoms; he nibbles at cabbage, and seems quite unconcerned with the experiment. It does not affect him in the least.

It may then be considered as settled that the quantity and quality of the air contained in the jar are quite sufficient; that they are adequate to maintain life. And if one of the guinea pigs exhibits symptoms of asphyxia, these are not ascribable to the nature of the atmosphere. If the experiment is pursued and air further rarefied, it is not until the decrease of pressure corresponds to that which obtains at the top of some peaks of the Himalayas (8,000 meters, the altitude attained by Glaisher, but in a state of unconsciousness) that the hitherto unaffected guinea pig shows symptoms of asphyxia. Such symptoms were certain to occur, since the quantity of air was decreasing all the time and must at some moment become insufficient. And now the experiment has proceeded far enough, as there is no necessity at all for killing the animals, and death must surely be the result if the experiment is allowed to continue; air is now let in slowly. Both animals recover entirely, the latter in shorter time than the former.

Now, what does the experiment show? It shows that in itself altitude or the decrease of pressure corresponding to altitude within the limits of 3,000, 4,000, 5,000 meters or even more (under 8,000 meters) is not sufficient to induce asphyxia and the symptoms of mountain sickness. The proof thereof lies in the fact that the inactive guinea pig exhibited no asphyxic symptoms at such altitudes. At 8,000 meters these made their appearance. They were unavoidable. They might have begun a little earlier, they might begin a little later—that is, at rather lower or rather higher pressure—according to the species and individual; but it is certain that for all organisms there is a limit in the heights of the atmosphere above which air is too rare and tenuous to maintain life, and asphyxia must ensue. This first fact, however, was already known, and M. P. Regnard's experiment proves nothing new in that line. What it shows is that muscular effort hastens the production of asphyxia or mountain sickness, and of this the active guinea pig provides an excellent demonstration. Now, muscular effort hastens asphyxia or mountain sickness because it is itself a cause of relative asphyxia. The organism that works and expends energy uses more oxygen, and therefore needs more than that which keeps quiet. The panting which follows running, or is the consequence of rapid muscular work with the arms, legs, or whole body, of violent exercise, proves that the body requires more oxygen, and if the expired gases are analyzed it is shown that carbonic acid exhalation is increased, and it is clear, therefore, that more oxygen is required, since the oxygen contained in carbonic acid is borrowed from the inhaled air.

M. P. Regnard's guinea pigs are exact representations, the one of the aeronaut or of the person in the lift, the other of the Alpine climber; and since muscular exertion alone induces a state of incipient asphyxia it is to be expected that in rarefied air, which itself tends to the same end, that condition should occur quicker in the organism which by its activity goes, as one may say, to meet it.

Practical conclusions are easily drawn from this demonstration. There is no reason for the persons who may be carried up the Jungfrau in the projected lift to fear the effects of altitude. The example of the inactive guinea pig assures them of immunity, and except in some almost impossible cases of anæmia or weakness they will experience no discomfort. On the other hand, incipient alpinists must perceive that the advice commonly given by guides has a solid foundation. The example of the active guinea pig shows them that ascensions must be performed slowly, without haste, without great exertion, without getting out of breath. To be out of breath means incipient asphyxia, and asphyxia means mountain sickness. So the excursionist must learn to climb slowly, with careful and measured step.

In brief, high altitudes must unavoidably bring on asphyxia and mountain sickness, but at moderate altitudes both are avoidable by reducing the exertion; they may be brought on by increasing one's efforts, and it is only by assuming the nearly perfect immobility of the aeronaut that one can hope to attain without discomfort the highest altitudes, since it is during such immobility that the organism needs least air.

Having considered the case where an animal or man passes gradually from a low to a high level, we must now turn to another, that in which the change is sudden or extremely rapid. This is not exceptional, but does not occur in the course of mountain climbing, for obvious reasons; and in the case of balloon ascents, where it would seem to be of common occurrence, we rarely hear of any serious inconvenience experienced, although the balloon often seems to rise very rapidly. The truth is that it rises rapidly to a moderate altitude only, and that it gets into really high altitudes only after a lapse of time quite sufficient for adaptation. To encounter cases of rapid decrease of pressure, we must turn in another direction, and we find examples where men work under high pressure, for instance, in diving bells, under the surface of the sea or of a river, to explore a wreck or build the foundations of a pier or bridge. Here, in order to counteract the great pressure overhead, that of the water added to the normal sea-level pressure—and every ten meters in depth of water adds the pressure of one atmosphere—air must be forced into the bell or diving apparatus, and the men are subjected to a total pressure amounting to three or four atmospheres. As it sometimes accidentally happens that the passage from this high pressure to the normal air is very rapid, the study of the results is instructive for the present purpose. These are often most unfavorable and death not uncommonly ensues. The same occurs when an animal in a bell jar is rapidly subjected to a decrease of pressure, or when, in a bell jar, where an animal has been placed and the pressure gradually increased by forcing air into it, the pressure is suddenly decreased merely by allowing the air to escape into the atmosphere. In both cases, and in fact in all cases where the passage from relatively high to comparatively low pressure is rapid or quite sudden, symptoms arise which are generally fatal. The animal falls on its side and dies, even if the final pressure is one which, if brought on slowly, would not be injurious to life. The danger lies only in the rapidity of the change.

Post-mortem examination of the victim affords a clue to the cause of death, and makes all symptoms clear and intelligible. We find gas or air in free condition under the skin, in the tissues, in the blood vessels; this we never observe under normal conditions. These gases are the cause of death. All tissues, and the blood, of course, contain at all times gaseous matters—oxygen, nitrogen, carbonic acid—either dissolved in the liquids or combined with hemoglobin in the blood, and the amount of these gases varies according to external pressure, according to the tension of atmosphere. Now, if the atmospheric pressure decreases gradually, the tension of the gases of the organism decreases accordingly; and they escape gradually into the atmosphere without making any trouble. But if the decrease is sudden, this gradual escape can not be effected; the liberated gases have no time to escape; the result is that they accumulate in all parts of the body, and in the circulatory system they obstruct small vessels and paralyze the heart.[1] Such accidents are not uncommon among the workmen referred to, and this is the reason why they are always advised to come up slowly to the surface, and the deeper they have been the slower the change should be. They have little to fear from working in compressed air at 2, 3, or 4 atmospheres; the danger lies in the decrease of pressure, which, if sudden, is generally fatal. As they say in their own language, "You have to pay only when you come out."

So much for decrease of pressure, rapid or slow. In the one case it injures by a deficiency of oxygen, by anoxyhæmia, and the only way to counteract its effects is to be provided with a supply of oxygen of which small amounts may be inhaled now and then. Aeronauts intending to attain very high altitudes can not do without such a provision, and it is their custom now to always take with them a supply of oxygen. In the other, the injury is the result of a quite different process, purely mechanical, the sudden liberation of gases in the tissues and especially in the blood, where they immediately interfere with the circulation, and stop the heart's action. When moderate pressure suddenly follows high pressure, anoxyhæmia plays no part, and only the mechanical effects occur; if low pressure follows moderate and sufficient pressure, anoxyhæmia alone occurs if the passage is slow; anoxyhæmia and the mechanical liberation of gases ensue if the passage is rapid and sudden. In both cases, decrease of pressure interferes with life.

Let us now consider the reverse case, that of an increase of pressure.

Under normal circumstances such increase is always unimportant.

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[1] Just as air, even in very small quantity, drawn in the circulatory system through some lesion of the venous system near the heart induces death in a few seconds, as all physiologists know.

Even at the bottom of the deepest mines, although pressure is appreciably increased, this increase can not be considered as exerting the slightest evil influence, and its physiological effects are practically nil. The increase of pressure is much more important in the case of diving bells, and it is among workmen who are engaged in the building of piers and wharves, or in the exploration of wrecks, that we must search for information concerning the effects of high atmospheric pressure, unless we turn to animals experimentally subjected to such condition in bell jars connected with forcing pumps. When the increase is slight, the effects are also slight. Some buzzing in the ears, some bleeding at the nose, and a slight numbness in the limbs are those which are most appreciable. But, at the same time, the respiration and circulation are slower. In some cases there occurs an abnormal excitation of the nervous system similar to that observed during acute alcoholism. Such accidents are quite naturally ascribed to an increase in the tension of carbonic acid, which accumulates in the system and determines incipient asphyxia. This interpretation is correct as long as the increase of pressure is moderate. But when the increase of pressure is considerable, when we have to deal with pressure of six or more atmospheres, the case is altered, and the cause of the symptoms is different. This is shown by Paul Bert's various experiments. In order to delay the effects of increase of pressure, he added pure oxygen to the atmosphere inspired by the animals experimented upon, expecting by this means to prevent the toxic influence of carbonic acid. He was, therefore, considerably surprised when he perceived that this had no other result than to hasten the fatal issue. He then proceeded to a careful analysis of the symptoms and phenomena, and perceived that when the pressure is over 6 atmospheres the oxygen contained in the atmosphere, acquiring a high tension, becomes a poison. And none can wonder at this. An increase of the proportion of oxygen under normal pressure is attended by toxic symptoms; an increase in the pressure of oxygen, which amounts to the same thing, must exert the same influence. And the proof that oxygen is the only culprit lies in the fact that an animal can perfectly well endure a pressure of 20 atmospheres if the air is poor in oxygen, if oxygen, being less in quantity, has, in the mixture, a tension which does not exceed that which the normal amount of oxygen, in normal air, possesses under normal pressure. Under increased tension, as well as in increased proportion—for both conditions are identical as far as physiology is concerned—oxygen is a poison, and a very dangerous one, and this is the reason why man and animals die in a normal atmosphere, when the pressure exceeds certain limits. Be it rapid or slow, considerable increase of pressure kills through the agency of oxygen and of its toxic properties, by reason of oxygen being dissolved in the blood serum. If we leave out of consideration those cases where the variations of pressure are rapid, and where, as is the case with rapid decrease of pressure, a purely mechanical element comes into play, one sees that gradual variations operate, not physically nor mechanically, but in a purely chemical manner, by putting the organism under the influence of an atmosphere too rich or too poor in oxygen.

It must be added that in this case, as well as in many others, adaptive phenomena occur. The Indians and animals of the South American Cordilleras are unaffected by mountain sickness which attacks the unaccustomed traveler, and animals of the abysses of the sea live and thrive under pressures which no terrestrial or shore animal could endure.

This fact of adaptation to altitude, which is confirmed by the other fact that there are villages or cities permanently inhabited by man at 3,000 and 4,000 meters above sea level, has long been well known. It has especially attracted the attention of a French physiologist, Dr. Jourdanet, who discovered most of the facts which Paul Bert investigated later, but the mechanism of the phenomena has been only recently explained. Jourdanet supposed that the inhabitants of low levels, when transferred to high levels, meeting with low pressure and consequently a small proportion of oxygen, became affected by anoxyhæmia, a state characterized by the inability of the red blood corpuscles to absorb a sufficient proportion of oxygen—in brief, incipient asphyxia.

In that he was right; he also thought that adaptation is effected in the following manner: If the evil is not unbearable, the system begins to produce a larger supply of blood corpuscles; these can absorb only a small proportion of oxygen to be sure, but then they are more numerous and by this means the balance is restored, and the system may absorb a sufficient quantity of oxygen. Here, again, he was right, but he did not succeed in establishing his hypothesis on a firm basis. The latter task was achieved by Paul Bert, who examined specimens of the blood of Peruvian llamas and vicunas, and proved that the blood of such of these animals as live on the highlands contains a larger proportion of hemoglobin and of oxygen than that of those of the same species living on the plains at lower levels. For instance, 100 cubic centimeters of blood of llamas or vicunas living on the highlands contain between 19 and 21 cubic centimeters of oxygen, while the same amount of blood in animals of the same species living on the lowlands contains only 12 to 15 cubic centimeters.

These results have been very positively confirmed by the investigations of MM. Viault, Muntz, and Regnard. M. Muntz has shown that in common domestic rabbits allowed to go wild upon the heights of the Pic du Midi, in France, the blood, after ten months' sojourn in the mountain, contains much more hemoglobin than that of rabbits belonging to the same breeds released for the same length of time in the plains at Bagnères de Bigorre. But it may be objected that this experiment is not as conclusive as it seems to be, owing to the fact that the rabbits of the Pic du Midi may have been surrounded there by different environmental conditions other than those of altitude which may have produced the observed effects. In order to meet this argument M. Paul Regnard has devised an experiment which affords a very precise and unassailable demonstration. In this experiment the only difference is a difference in pressure. If the increase in the respiratory capacity of the blood that occurs in consequence of life at high altitudes is occasioned solely by diminution of pressure, it is clear that such diminution ought to produce the same effect at any altitude whatever. So M. Paul Regnard took two guinea pigs belonging to the same litter, placed one in a bell jar, where a special apparatus not only provided the necessary decrease of pressure (by exhausting the atmosphere to the requisite degree), but effected the necessary ventilation, while the other lived in the same laboratory under normal pressure. The decrease of pressure in the bell jar and the density of the atmosphere corresponded exactly to those which obtain at Santa Fe de Bogota, at 3,000 meters above sea level. Both animals were killed after a month, and the result was that the blood of the guinea pig under decreased pressure absorbed 21 cubic centimeters of oxygen (per 100 cubic centimeters blood), while that of the other animal living under normal pressure absorbed only 14 to 15 cubic centimeters of oxygen at the most. The fact is quite clear; the experiment most convincing. By some means not yet ascertained the blood of creatures living at high altitudes, and able to withstand the first unpleasant sensations, acquires the power of accumulating a large proportion of oxygen, and thus their systems are enabled to resist that incipient asphyxia which is the result of a smaller proportion of oxygen in the atmosphere.

This is an important point, from the practical side. It explains the beneficent influence of high-level stations (such as St. Moriz, in Switzerland) upon anæmic or tuberculous patients. It shows that in cases where the organism is weakened and physiologically impoverished, and particularly where the blood has lost some of its vitality, the patient will be benefited by living for some time in mountain resorts, even at comparatively high altitudes, his blood will acquire new life, and become more apt to fulfill its functions, owing to the increase of respiratory capacity that results from decrease of pressure.

It is evident, however, that the patient should begin with moderate altitudes, 1,500 meters, for instance; with altitudes which do not overtask the system, which do not palpably increase the physiological tendency toward asphyxia, and one should not forget that decrease of pressure which, if moderate, is beneficent, becomes invariably fatal if it exceeds certain limits. Man does not seem to be adapted to live permanently at altitudes over 4,000 or 5,000 meters, and if other animals are able to do so, it is quite certain that even for these also there is a limit upon which they can not trespass without dangerous results. The differences are only of degree, and upon the whole they are of small amount.

MOVEMENTS OF THE ATMOSPHERE.

We must now consider another side of the general topic of the physics of air. I refer to the movements which unceasingly occur in the vast ocean of gas which surrounds our planet. They are familiar to all. It is these that swell the sails of vessels and carry them across the oceans, that give the impulse to the old-fashioned windmill, that lift the waves and send them rolling from continent to continent; these, also, that, with cyclones and tornadoes, uproot trees, blow down houses, destroy crops, snap the giants of the forests like mere twigs, raise clouds of dust, and spread ruin and death on every side. Breeze or tempest, it always is air in motion, and in this case as well as in others air is both beneficent and maleficent. Concerning the cause of this motion, be it gentle or be it violent, it is enough to remind the reader that the main if not exclusive cause is in difference of calefaction, and that the wind blows from cool areas to warm ones.

What part can these movements of the atmosphere play in the life of our planet? What is their influence? A superficial glance is enough to show that this is manifold.

In the first place, they help to intermingle the constituents of the atmosphere. To be sure, the general constitution of air is the same everywhere, no considerable difference existing. But we have referred more than once to the numerous local causes of alteration. Consider, for instance, a large industrial town or a volcano. Both exhale an enormous amount of obnoxious gases which are poured into the atmosphere—carbon dioxide, carbon monoxide, and a hundred other substances, toxic or inert; at all events undesirable for breathing. A few figures have been given above concerning the amount of such gases produced by mankind, by combustion, etc., and we all know that in cities the composition of air is less pure than in the country; that Manchester, Birmingham, Chicago, Pittsburgh, etc., are less healthy than their surroundings. If there were no winds, most certainly things would be much worse than they are, and, the very fact that city air is inferior to country air, substantiates this assertion. Without winds all these gases would accumulate about the place where they originated. Of course some diffusion would take place, but the process would be a slow one, and a much too great proportion of unhealthy gases would at all times be found in the air of such places, which would thus be more insalubrious than they now are. Without winds locally vitiated air would remain such, just as is the case with the atmosphere in a closed room where men or animals are assembled; wind is the cleanser of the atmosphere, the great purifier, which mixes and purifies it, which chases it over lands and seas, over fields and forests, from pole to equator, and from equator to pole, thus dissipating in the whole mass those elements which, for one reason or another, are produced in greater abundance at some points; it maintains the purity of the atmosphere, or at least its homogeneity. If the atmosphere were motionless, the air in cities would be perpetually vitiated, and all the carbonic acid which originates there would be delayed in its travel toward the country, the fields, and the forests, in whose biology it plays so important a part; the vicinity of volcanoes, and even of cities, would be uninhabitable, and life in cities impossible.

Again, from a biological standpoint, the movements of the atmosphere are useful in another way. They prevent the air from remaining excessively dry in some regions and inordinately damp in others. The air which has accumulated a large amount of humidity while above an ocean, a lake, a river, a forest, does not remain there. It travels farther, and carries the aqueous vapor it contains inland, up mountains, and over plains. It transports the clouds, and carries the water drawn from the Pacific Ocean to fall in rain on the American continent; through the same agency the water drawn from the Atlantic falls on Europe, and the water of oceans is carried through the atmosphere to enormous distances to provide the continents with the rain essential to plants, animals, and man, both that immediately used and that which, sinking through the soil, comes to light again, sometimes at considerable distances, under the form of springs, which help to make the streams and rivers. If winds did not occur as they do, if the aerial ocean were motionless, the vapors which arise above the oceans and masses of water would not travel so fast, so far, nor in such quantity, and a great part of our globe would be condemned to drought and sterility. The other part would hardly be pleasanter; in an atmosphere saturated with vapor, as that would be, perspiration evaporates most slowly, and if the temperature were even moderately high, man would lead a sluggish life, shunning effort as inducing an uncomfortable condition, and living in a laziness and *far niente* which have never conduced to moral, mental, or physical advancement. Truly wind is no unimportant agency in civilization and in the general evolution of mankind.

Again, the movements of the atmosphere play an important part in the regulation of temperature, as they do in the regulation of humidity. If they did not occur, air would be perpetually warm in some places and perpetually cold in others, the radiation and diffusion of heat acting but slowly. The wind is beneficent in that it carries warm air to cold regions and cold air to warm ones, tempering the climate of each.

To end this chapter, a word must be said of the part which wind plays in the biology of many species of plants, by providing them with important means of dispersion. Many plants possess light seeds, which are, moreover, provided with appendages in the form of wings, or of feathery hairs, and such seeds are very easily carried to considerable distances over plains, over rivers, and even over narrow sea channels. Through the wind's agency, these species are transported to new habitats, where they may settle and thrive, spreading gradually over large tracts. Numbers of insects and birds are thus carried to great distances by storms, and are thus enabled to obtain a foothold upon islands or continents to which their own forces could not have brought them. And micro-organisms, last but by no means least, as far as importance, not size, is concerned, make great use of atmospheric movements. They possess no means of locomotion, and have no limbs to carry them to a distance; but the wind makes good this deficiency, and takes good care to scatter them far and wide. There are many epidemics propagated from city to city, from country to country; there are death-working as well as beneficent microbes scattered over the whole face of the earth, and thus air is again an agent of death and of life by its contents, no less than by its essential constituents. But air contains also a large proportion of non-living matter, of dead dust as contrasted with the living dust just referred to. Such dust also is scattered far and wide, and there is no doubt but that it may be carried from China to North America, and from the New World to Europe or Africa. This dispersal of dust may be of some importance in agriculture; at all events it plays no insignificant part in geology, and all have heard of the influence of winds in the formation and migration of dunes on the seacoasts. This influence is often important. In France, in the region at the south of Bordeaux and in certain parts of Brittany, the wind has brought so much sand from the dry shores at low tide that man has been compelled to retreat and to desert his villages. These, gradually covered by the particles carried by the winds, have finally been entirely engulfed and buried, as were Herculaneum and Pompeii of old under the cinders of Vesuvius, and the only remnant of a once inhabited and prosperous hamlet is a spire which sticks out of the plain of sand. Analogous phenomena are to be observed in all countries. In 1889, according to Mr. George P. Merrill, a storm occurred in Dakota during which the soil was torn up to the depth of 4 or 5 inches, and the particles accumulated easily in recognizable sand dunes. In the western plains of North America, also, the same event occurs, and these dunes, when once formed, travel and migrate from place to place. Some miles north of Lake Winnemucca (Nevada), Mr. Russell found a series of such dunes, 40 miles long, 8 miles wide, some of which were 75 feet high. Near Alkali Lake other dunes are 200 and 300 feet high, and on the eastern shore of Lake Michigan similar dunes have advanced upon forests, which they have invaded, smothered, and destroyed, and the tops only of the trees, dead as a matter of course, emerge above the hillocks of sand.

It should be observed that particles of sand driven by the wind exert an erosive influence. They act as files, and gradually wear away the rocks which they unceasingly batter, and thus the wind works in two ways toward the leveling of the globe; indirectly cooperating with water and with frost it helps to disintegrate the elements of rocks; and when they are broken down it carries the particles, which are the ultimate result of such disintegration, to the plains and to the sea.

If one observes that besides this work wind is capable of tremendous effort; that it wrenches from the soil the strongest trees; that it scatters to the ground in crumbling ruins the most solid monuments or buildings; if one considers that it could also effect a much greater amount of work than that which is at present effected, by driving sailing vessels or windmills, one can not forego the conclusion that in wind we have an enormous source of energy which is hardly utilized from the industrial point of view.

This is undoubtedly true. Wind is a most powerful force, whose limits can not possibly be estimated; that it could be utilized for man's benefit could hardly fail to suggest itself. Many centuries have passed since the first endeavor, and although some progress has been made, and has been satisfactory enough during a long period, no one will venture to assert that nothing more can be done.

Wind has been used on land and on sea; windmills have been invented in most lands, and few savage tribes have failed to become aware of the great help sails are to navigation. For centuries civilized nations were content with sailing vessels, and some of the latter were truly splendid achievements, able, it must be remembered, to cross the Atlantic—under favorable circumstances—in eleven days, which is still the duration of the trip for average steamships. But for three-quarters of a century steam has been used and defeated sails for long distances. The best steamers of the transatlantic lines are able to run from Queenstown to New York in five days and a half, and from New York to Havre in six days and a fraction. Wind has been defeated by steam on land also, and coal has taken the first place as a source of energy. But coal supplies are not inexhaustible, and thoughtful minds are concerned with the important problem of drawing upon those other resources which the movements of the atmosphere still provide, and which are by no means used as much as they might be. Coal is decreasing, and no fresh strata of the precious store are in process of formation as far as we are aware. It is burned at the rate of millions of tons each year, and mines are being steadily emptied of their contents. Forethought demands that future generations be not caught unawares, and that even now the problem of providing fresh sources of energy be considered. These are not wanting. The application of electricity to general uses has developed important possibilities, and provided us with a method by means of which energy may be obtained, transformed, and carried to a distance with the result that with proper apparatus the energy of rivers, of winds, of tides, of solar heat, may be utilized. Some important steps have been made in the required direction, and much has been done to utilize the energy contained in rivers under the form of falls, in Europe as well as in the United States, where the Niagara Falls are the best known instance. But concerning the power contained in wind, little has been done to take advantage of it. Sailing vessels are always numerous, to be sure, but windmills are, on the contrary, on the decrease, and no new method has been devised of late to increase the quantity of force derived from this source. M. Maximilian Plessner, however, has done good work in trying to call public attention to the matter.[1] Wind is doubtless very irregular, by turns strong or even violent, and a short time afterwards very gentle, and even ceasing. But a great deal depends upon localities. There are places and large regions where the wind is quite regular enough, as far as strength and constancy are concerned, and near the seashore it seldom fails. In the subtropical regions, also, trade winds are very constant, and in most parts of the globe the regularity of the wind increases with the altitude. The latter fact has been well shown by a continuous series of observations made at the Eiffel Tower, in Paris, since 1889. This amounts to asserting that, upon the whole, a considerable part of the globe is perfectly suited for investigations upon the best methods of deriving power from the winds. M. Plessner has calculated that a wall or curtain 1,000 meters high placed upon the fifty-fourth parallel between the twenty-fourth and thirty-eighth degrees of longitude, would receive, through the impact of the wind, a total sum of 100,000,000 horsepower, and 130 such walls would provide 13,000,000,000 horsepower, which means the power of 1,000 Niagaras. Of course no such apparatus could be erected and used, as the first storm would destroy the whole fabric; but this helps us to realize the tremendous amount of energy which speeds over our heads. The first requisite is some sort of motor driven by the wind, and an accumulator to store the energy and yield it at the required moment. M. Plessner has no admiration for the old windmill; he does not find therein the motor which engrosses his thoughts or dreams. The æolian wheel would be more suitable, but this also is below his requirements, and he is rather inclined to look upon sails as affording a possible solution of the problem. "The utilization of the power of winds," he writes, "and its transformation into mechanical work, are possible only by means of sailing vehicles, driven by wind upon a circular railway, the power generated by such rotation being transmitted to an axle, and thence to machinery." He therefore proposes a circular railway, at ground level, or, better still, elevated upon trestles. On this railway a circular or annular train, made of small cars coupled together, each carrying a mast and two sails at right angles with each other, is driven by the wind. These sails are automatically trimmed, and automatically, also, they expand or contract, or rather take in the wind or withdraw from it. As long as the wind blows, the train continues rotating, and if it is connected with a central axle, the latter may work dynamos and charge electric accumulators. A similar apparatus might be arranged in water, boats taking the place of the cars, and since the wind power

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[1] See his book: Ein Blick auf die grossen Erfindungen des zwanzigsten Jahrhunderts—Die Dienstbarmachung der Windkraft für den elektrischen Motoren-Betrieb, Berlin, 1893.

is transformed into electricity the latter may be stored and kept in reserve, or transferred to a distance to perform 10, 20, 50 miles away any work that may be required.

Such is, in its main features, M. Plessner's project. Whether it be this or some other which is accepted, there is no doubt as to the necessity of trying to utilize a small fraction of the tremendous energy that produces the movements of the atmosphere, and is one of the results of the action of solar heat on our planet. There are certainly many ways in which the problem may be solved. For instance, a very simple method would be the using of wind power to force water into a reservoir at some height from which it might, at will, be let out to work turbines. In mountainous regions, and near the sea, in all places where water and wind are available, this system might be of service, however imperfect it may seem. At all events a great field is open to inventors, and a great harvest may be reaped by those who will work it with patience and skill. M. Plessner's investigations will prove very suggestive, and they may also find much that is useful in Mr. S. P. Langley's memoir on The Internal Work of the Wind. The facts referred to by Professor Langley are perhaps of more importance for the problem of aviation, or flight, and for the explanation of the soaring of the larger birds, which all have oftentimes seen sustaining themselves during whole hours, without apparent fatigue, or effort, but they are certainly very suggestive in the realm of aerodynamics. Mr. S. P. Langley has succeeded in proving that the force of the wind is not by any means as constant and uniform as is commonly supposed. It does not impart an approximately uniform movement, but a succession of short, rapid waves or pulsations of varying intensity, and fluctuating in direction on either side of the general course of the wind. He considers it as certain that an inclined or suitably curved surface, heavier than air, and free from all attachments whatsoever, may be uplifted and indefinitely supported in the air by means of "internal work," without any further expense of energy than that which is demanded for changing the inclinations of the plane according to the pulsations. It seems quite certain that under special conditions such a plane might advance against the wind, not only comparatively, but in the absolute sense. These data are very valuable, and may prove most useful for practical purposes.

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Having considered the general relationship between living organisms and the elements, pressure, and movements of the atmosphere, we must now proceed to illustrate the relationship between the physical contents of the air and living beings.

Air contains many elements that are accidental, temporary, and of minor importance. Some are gases; such as, for instance, carbon monoxide, carbureted hydrogen, and many others, for the most part obnoxious and toxic. Of these substances we shall say nothing here, because of their scarcity and irregular occurrence. They are not normal constituents of the atmosphere, and we may say that every substance known to chemistry may at some time or place be accidently present in the air. Only such bodies deserve notice as are normally present in the whole atmosphere, although they may be of minor importance. Under this head must be mentioned aqueous vapor and different solid materials, inanimate or animate, excluding those which are of volcanic origin, and dust, natural or artificial.

Aqueous vapor is always present in the atmosphere under the form of fog or clouds, and also in an invisible form. We will especially refer to the latter. It has a dual origin. The one part comes from evaporation, under the influence of heat, of the water of oceans, rivers, lakes, and moist soil. The amount of vapor produced depends upon the amount of heat, and also upon the amount of vapor already contained in the air. For each degree of temperature air can only contain a quite definite amount of vapor. The other part comes from living organisms, by transpiration through the skin and pulmonary surfaces of animals, by the evaporation which occurs from the leaves of plants. This production of aqueous vapor by living beings is very variable, and circumstances affect it greatly. An animal or man in dry air produces a large amount, since the expired air is quite saturated with it, but in moist air hardly any is produced, and that which is expired hardly does more than restore to the atmosphere the moisture taken from it. The whole of mankind pours into the atmosphere a total amount of some 15,000,000,000 kilograms of water per twenty-four hours, but a large proportion of this is merely returned; it has not been generated by man. Similarly, plants yield but a small amount of moisture if the air is already nearly saturated; they yield a very large amount if it is dry. It has been calculated, for example, that a wood of 500 adult and vigorous trees yields nearly 4,000 tons of aqueous vapor during the twelve hours of daylight. By night the amount is less considerable, and is only about one-fifth of the diurnal evaporation. This instance is enough to show that plants are most important producers of vapor. And if one only considers that in the United States, as an example, the total surface of plant leaves is at least four times that of the soil surface, one perceives how important must be the part of plants in the function we refer to. Physicists have estimated the total quantity of aqueous vapor in the atmosphere at 72,000,000,000,000 tons or cubic meters of water.

This vapor, which is very unequally diffused (since the maximum amount depends upon the temperature of air), and which varies in quantity according to the time, locality, and other circumstances, plays an important biological part. Air, when too dry irritates the respiratory organs; when too moist it impedes transpiration and its beneficent effects; *in medio virtus*, and the best condition is that in which air is neither very dry nor very moist.

Another more important part is played by this aqueous vapor in that it forms a sort of protecting screen, that, by day, tempers the solar heat by absorbing a portion of it and preventing it from scorching the vegetation and the soil, and at night, conversely, prevents excessive cooling of the earth's surface by radiation. It does not prevent the passage of luminous calorific rays, but absorbs a large amount of the dark thermic rays—whatever their source—and experiments by Tyndall, and especially Pouillet, and others, have shown that the atmosphere, by reason of the vapor it contains, absorbs about a quarter of the sun's heat, so that only three-quarters reach the earth proper. If this screen did not exist, our summer days would be much hotter and also much cooler. In the full glare of the sun the thermometer would stand higher than it does, and in the shade the temperature would be lower. We have an exact illustration of what would happen in what occurs on high mountains, or in balloons at great height. The higher we ascend the thinner becomes the layer of vapor interposed between the sun and ourselves. Under such circumstances the sun is scorching; its rays, nearly unopposed, exert a stronger influence upon persons and things and heat them highly, while the surrounding air is cold, as there is hardly any vapor to absorb solar heat. This fact has been well observed by Professor Langley during his ascent of Mount Whitney, and all alpinists have had experiences more or less similar. If, then, there were no vapor in the atmosphere, our summer days would, as is the case in high altitudes, be torrid and frigid at the same time—torrid in the sun, frigid in the shade, where the thermometer would certainly fall very low.

At night atmospheric vapor moderates radiation. During the night the earth gives off part of the heat it has received during the day, and this heat radiates into interplanetary space. When the sky is very clear and dry, radiation is considerable, and at all seasons a clear night is colder than a cloudy one, and night is colder in high altitudes where the overlying sheet of air and vapor is thin and rare, than in the lowlands, with a thicker atmospheric layer overhead. Radiation is unavoidable, because the temperature of celestial space is exceedingly low, probably inferior to 100° below zero (centigrade); but it is more rapid, and offers greater intensity when the air is dry and contains but a small quantity of vapor, because then the absorption by the atmosphere (by vapor, to be precise) of dark calorific rays radiated from the earth's surface is very slight. If there were no aqueous vapor in the air, a considerable cooling would begin as soon as the sun set, and such cooling does occur on high mountains and at high levels—in Thibet, for instance, which is both high and dry, and also in deserts, where the atmosphere is generally dry. In Sahara, after the hottest days under a scorching sun, the nights are generally very cool, and the thermometer runs down some 30° or 40° in a few hours. Such radiation and cooling must be very harmful, and most animals and plants could certainly not endure it. Vapor thus exerts a most beneficial influence, as it moderates the heat of day and the cold of night, and acts as a sort of regulator, by means of which some uniformity is established under antagonistic and conflicting conditions, and in spite of contrary influences. Quite certainly, if vapor did not exist, the physiology of the animals and plants of the lowlands would be different, or they would perish.

The parts played by the numerous solid particles found in the atmosphere are as varied as is their nature. Physically pure air is a myth and can only be obtained artificially, in laboratories, and when great care is exercised. Even at the greatest heights, where micro-organisms as well as vegetable or animal fragments are few and often totally wanting, mineral dust is always found. These particles are very small, to be sure, and their origin varies; some are of volcanic origin, and after important eruptions, such as that of Krakatoa, volcanic particles are very abundant in the atmosphere and may be years in settling or falling on land or sea; others are merely dust which the wind has swept off the surface of the planet, and a large proportion consists of minute fragments of aerolites which have fallen into the earth's sphere of attraction from interplanetary space.

Professor Newton has attempted to form some estimation of the number of such aerolites, and he comes to the conclusion that our atmosphere receives the enormous total of some 20,000,000 meteorites per twenty-four hours, each of which is large enough to produce the phenomenon known under the name of "shooting star." However small these fragments may be—and yet in order to become visible because of the heat evolved by friction against the atmosphere they can not be so very minute—they certainly bring to our planet a considerable amount of foreign matter, a large proportion of which remains some time suspended in the atmosphere before falling. In all places where the requisite observations have been made, and where instruments have been placed for collecting the mineral contents of the air, there has been obtained an abundant harvest of meteoric particles, easily recognizable by their form and structure, and the mud which slowly accumulates at the bottom of the sea contains a large number of these extra terrestrial bodies. As a matter of fact, mineral particles of foreign source are constantly pouring through our atmosphere in the form of a dry and invisible rain. A large amount of terrestrial dust is also found in this rain. Von Richthofen speaks of the particular aspect of the atmosphere in a part of China, where the sky is yellow and opaque. When the wind comes from the direction of Central Asia, all things are covered with a yellow dust which is brought by the wind from vast regions whose soil is covered with a layer of ochreous dust, which is driven to great distances over the Pacific. In Australia, rains of a sort of red mud have been observed—rain made into mud by the admixture of dust, the latter having been transported by the wind and storm from considerable distances. Such a rain has been noticed to fall over an area of 2,500 square miles. In the United States, a similar phenomenon has been observed. Prof. S. P. Langley, during the ascent of Mount Whitney, noticed that the middle strata of the atmosphere contained a large amount of red dust which was visible from above the level of these strata, while below, from the plains, no trace of it was detected by the eye. This dust had, perhaps, its source in China. The Krakatoa volcanic dust remained many years in the atmosphere and traveled many times entirely around our planet.

All this dust becomes easily perceptible to the naked eye, when we look at a ray of light in a dark room. But in order to well ascertain its origin, to know exactly what it is, microscope and aeroscope are wanted. By means of these instruments a very interesting microcosm is revealed. All sorts of particles are to be found in the air—small desiccated animals, such as worms, rotifers, vibrios, infusoria, fragments of insects, of wool, scales from the wings of butterflies, particles of hair, feathers, vegetable fibers, spores of fungi, pollen grains, flour, dust from the soil, and microbes. From our present standpoint many of these particles are of but slight interest to us, although it is a curious fact that volcanic dust may remain for years in the atmosphere at considerable altitudes, and travel around the earth with the winds, inducing those curious phenomena of light and color at sunrise and sunset which physicists and the public at large observed after the Krakatoa eruption. It is also a very curious fact, well illustrated by T. Aitken's investigations, that these particles are favorable to the production of rain. Under certain circumstances they play the part of a nucleus around which the vapor of the atmosphere condenses, and each particle becomes then the central part of a drop of rain.[1] What is of interest to us, from the biological point of view, is the presence of pollen grains, which explains how an isolated female plant may bear fruit even at a great distance from male plants of the same species; the presence of spores of fungi, which favors the dispersal of species; the presence of light seeds, which may be carried very far, and then fall to the ground, and develop an individual in a region where the species was never seen before. Again, the presence of microbes, to which we have previously referred, and which explains how many diseases are carried far and wide by the agency of the winds, such microbes being specially abundant in cities and in the vicinity of dwellings. At the Montsouris Observatory in Paris, M. Miquel finds between 30 and 770 microbes per cubic meter of air, according to winds, seasons, etc.; in the center of the town, Rue de Rivoli, the air contains 5,500 per cubic meter; in hospital wards, between

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[1] Such being the case, in order to induce artificial rain, instead of trying to change the state of the atmosphere by means of explosions it would seem more rational to send dust into the heights. But at all events, the essential requisite is the presence of vapor, and this feature seems to have been sadly neglected in recent experiments. Nature provides rain by means of vapor and changes in temperature, not by explosions which can hardly have any influence.

40,000 and 80,000, while at 7,000 meters altitude, and above the sea at some distance from the shore, none at all are found. These figures are enough to show how the air under certain circumstances is a dangerous agent, and serves as a vehicle of death.

As we have seen, air is fraught with life as well as with death. Each of its constituents is essential to life, and each is also a cause of death. The one that appears to be the most vivifying of them all, becomes under certain conditions and doses, a fatal poison; the most useless, the most harmful is, when carefully investigated, an essential basis of the whole structure of life. And the general conclusion is that none could disappear, none could exist under a different form or in markedly different proportions, without soon altering the features of our planet and changing it into a naked and barren globe on whose surface no living being, of the present type, could be found.

If we study the subject more attentively we become aware of another fact. We perceive, to use again J. B. Dumas's very happy phrase. that all living beings are, at last analysis, nothing but condensed air, Plants exist mainly by reason of the existence of air, and animals and man can not exist without plants. The elements of plants are air, and animals live upon plants; the connection is direct and intimate, and man, therefore, is also only condensed air. And as this air, since the centuries during which mankind has existed, has been unceasingly migrating from generation to generation, from individual to individual, now part of some of our human ancestors, later returning to the atmosphere, and thus perpetually pursuing its cycle, our present organism is made of the same elements as that of our ancestors. Their substance is also ours. And this substance, which is also that of past animals and plants, goes on through space as an untiring wave. To-day or to-morrow a flower or a fruit, it will unite at one time to form a portion of a sluggish mollusk, at another to help build the brain of a Descartes, a Newton, a Pascal, a Shakespeare, a Helmholtz, a Joan of Arc. The cycle is never interrupted. No human eye witnessed its beginning; none will witness its end. It seems to be infinite and eternal—although, doubtless, it is neither—and alternating from life to death, as old as the world and yet as young as the newborn; if consciousness were among its attributes it would have gone through all that life may give—the highest joys, the deepest sorrows, and all emotions, the noblest as well as the basest.

The breeze which gently moves the leaves, the wind which moans through the high forests, is the sum total of all life that has been. It is the material of all that has had existence, of those that came before us, of those that are no more and for whom we weep. Now it becomes part of ourselves and to-morrow, perhaps, it will go on, pursuing its way, unceasingly metamorphosed from organism to organism without choice or favor, according to law, till the time comes when our globe, no longer heated by the cooling sun, shall slowly die. Then all the substance of past living organisms will rest and return to earth; mortal cold and darkness will reign; the curtain will drop upon the tragedy of life, and that which remains will be a frozen and gigantic tomb, rolling silent and desolate through the unfathomable depths of the darkened heavens.

> I will encounter darkness as a bride
> And hug it in my arms.
>
> (*Measure for Measure.*)

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THE ATMOSPHERE

IN RELATION TO

HUMAN LIFE AND HEALTH.

BY

FRANCIS ALBERT ROLLO RUSSELL,

Vice-President of the Royal Meteorological Society, Fellow of the Sanitary Institute of Great Britain, Member of the Royal Institution of Great Britain.

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THE ATMOSPHERE IN RELATION TO HUMAN LIFE AND HEALTH.

By FRANCIS ALBERT ROLLO RUSSELL,[1]

Vice-President of the Royal Meteorological Society, Fellow of the Sanitary Institute of Great Britain, Member of the Royal Institution of Great Britain.

[Memoir submitted in the Hodgkins Fund Prize competition of the Smithsonian Institution, and awarded honorable mention with a silver medal.]

PART I.—CONSTITUTION AND CONDITIONS OF THE AIR.

The atmosphere has been compared to a great ocean, at the bottom of which we live. But the comparison gives no idea of the magnitude of this ocean, without definite bounds, and varying incessantly in density and other important qualities from depth to height and from place to place.

Uninterrupted by emergent continents and islands, the atmosphere freely spreads high above all mountains and flows ever in mighty currents at levels beyond the most elevated regions of the solid earth. What is the composition of this encompassing fluid, and what its character? The work of the present century has gathered in a rich store of knowledge to answer the inquiry.

The atmosphere consists in the main of two gases, oxygen and nitrogen, and these are intimately mixed in the proportion of about 20.9 of oxygen to 79.1 of nitrogen by volume, and 23.1 of oxygen to 76.9 of nitrogen by weight.[2] These gases, which are each of them chemical elements, are not chemically combined with one another, but only mixed; each preserves its qualities, modified only by solution in the other. Gases have the property of diffusing among each other so completely, that no portion which could be conveniently taken, however small, would fail to represent the two gases in a proportion corresponding with that which they maintain in the whole atmosphere.

Another valuable constituent of the atmosphere, though varying greatly in amount at different times and places, is of no less impor-

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[1] Author of "London Fogs," "Epidemics, Plagues, and Fevers; their Causes and Prevention," "The Spread of Influenza," "Observations on Dew and Frosts," etc.

[2] M. Leduc gives the weights as follows: Oxygen, 23.58; nitrogen, 76.42. Dumas and Boussingault give the density of nitrogen as 0.09725. (Comptes Rendus, 1890.)

tance to mankind than the two elementary gases which make up by far the greater part of the volume and weight of the whole. This is vapor of water, the result of the process of evaporation of those vast watery surfaces which are always in contact with the lower strata of the air.

Deprive the air of any one of these three main constituents and human life becomes impossible.

Next in rank from the human point of view is carbon dioxide, or carbonic acid gas, which, though comparatively very small in amount, exists throughout at least all the lower ranges of the atmosphere, and has the same close and necessary relations with plant life as oxygen has, or rather as food has, with the life of animals. It presents on a great scale an example of the wonderful law of gaseous diffusion; for, though much heavier than air, in the proportion of about 2 to 1, it diffuses under natural conditions nearly equably through every part, whether the region of its origin be near or distant.

Stated in tons, the following are the calculated weights of the chief substances composing the whole atmosphere:

	Billions of tons.
Oxygen	1,233,010
Nitrogen	3,994,593
Carbon dioxide	5,287
Vapor	54,460

In addition to the above, we find in the air a variable and very small quantity of ammonia, chlorides, sulphates, sulphurous acid, nitric acid, and carburetted hydrogen, but some of these depend, where detected, to a great extent on manufacturing operations and on aggregations of men and animals.

Liquids and solids in great variety are also very important, widely diffused, and constant ingredients in the atmosphere. The solids are everywhere present in the condition of very minute microscopic or ultramicroscopic motes or dust, composed chiefly of sea salt, or chloride of sodium, sand, or fine silicious particles, various dusts derived from volcanoes, factories, towns, and the remains of meteors set on fire in their passage through the upper air. Some of the most beneficent functions of these microscopic and invisible motes will be considered later. Other solids present in the upper air over a large part of the globe and in the lower strata, especially in the Arctic regions, are small particles of ice, condensed either in clouds or in air which appears nearly clear. Explorers in high latitudes relate that on fine cold days the air is frequently sprinkled with shining crystals of ice which seem to fall from a blue sky, and, on the other hand, in heavy gales and stormy weather the lower air is filled with a fine icy dust, resulting from the freezing of the spray torn from the sea waves. In temperate climates very much of the rain which falls on the surface of the earth has existed previously at high levels in the state of snow or ice particles. The experience of mountaineers and balloon voyagers, and, in a mountainous country, the sight of peaks covered with fresh snow after a day's rain on the low ground, prove how commonly rain is melted ice or snow.

Other solid particles always present in great numbers in the lower air, and of great importance in relation to human, animal, and plant life, are various kinds of microbes, fungi, molds, and spores. At certain seasons the pollen of plants is very abundant. In some countries the air is thick in the dry and windy season with the dust of the soil. Agricultural fires cause a thick haze over parts of Germany, the United States, and other countries at certain times of the year. After great volcanic eruptions the air over many thousand square miles has been affected by a dense haze. This was notably the case in the summer of 1783, when, after an eruption in Iceland, terrestrial and celestial objects were dimmed by "dry fog" in western and central Europe during several weeks. In 1883, on the other hand, after the eruption of Krakatoa, near Java, the upper air, between 40,000 and 120,000 feet in altitude, was overspread with a semitransparent haze of a very remarkable character, consisting mainly of finely divided, glassy pumice. This haze stratum in the upper sky extended over all known countries and remained visible for several months.

Cloud globules are the most obvious and widely present liquid ingredients of the atmosphere. They possess properties of great interest in connection with the recently discovered ubiquitous atmospheric dust, with optical phenomena, and with the formation and distribution of rain.

The other familiar forms of water in the air are dry and damp fogs, mist, and rain. Haze is in most instances, at least so far as the present writer's observations go, in the south of England, a phenomenon depending on very small particles of water and on the presence of dust particles as nuclei.

Ozone, an allotropic and unstable form of oxygen, has been found to be constantly present, in very small quantities, in the open air in natural conditions, but can not be traced in the impure air of great towns, and is no doubt always greatly diminished where dwellings are thick together. Ozone consists of molecules, each supposed to contain three molecules of oxygen.

Peroxide of hydrogen is also supposed to exist in slight traces in the general atmosphere.

Minor impurities, arising from animal life, from manufacturing processes, and from the combustion of coal, are mostly not perceptible to the senses, except in the neighborhood of places where they are given off very abundantly.

The principal functions of all these various elements and substances of which the atmosphere is composed, may now be regarded in detail with special reference to their influence upon human life and welfare.

OXYGEN.

Oxygen, that wonderful element which constitutes very nearly half of the solid crust of the globe, combined as most of it is with the metallic and other elements of the earth, forms also, in union with hydrogen, the great body of water which covers three-fourths of the terrestrial surface. Water consists of two volumes of hydrogen and one volume of oxygen chemically combined. Stated by weight, out of nine parts of water eight are oxygen. But water, as we know it, always contains other matter, and chiefly atmospheric air, which is dissolved in it, and to a considerable extent changes its character. For the service of man, water, deprived of air, would have lost several important characteristics. Oxygen is dissolved in water to the extent of 2.99 volumes to 100 of water at 15° C., an amount sufficient to support the existence of fishes and hosts of other aquatic creatures, and to oxidize and render innocuous some of the common impurities which result from animal and vegetable processes and decay. Probably its power when dissolved in the liquid is greater than in the atmosphere, and it must be compressed into a smaller space. Fresh charcoal absorbs eighteen times its volume of oxygen, and a much larger bulk of organic vapors, especially ammonia; in this condensed state the oxygen acts so powerfully as to unite with hydrogen to form water vapor, and with sulphur to form sulphur dioxide. We may thus assume that water, as we use it and drink it, has important effects upon the body which would not take place if robbed of its contained oxygen. As an instance of the value of the air contained in water for many domestic purposes, its assistance in the making of tea may be mentioned; if the air be allowed to boil out of the water the beverage is spoiled. Recent observation, however, shows that oxygen is not altogether removed from good water by the process of boiling.[1]

Oxygen has a very strong chemical attraction for the elements; only one is known with which it does not combine. Hence, "to burn" in common language means combination with oxygen, and most substances in the crust of the earth are already burnt, or combined with oxygen. In its ordinary form it has no color, taste, or smell, according to most observers, but recently a faint blue color has been detected as belonging to it, when seen in sufficient quantity. It has a small refracting influence on light, and exhibits a magnetic property, especially strong in the liquid form, to which it has recently been driven by intense cold and pressure. The degree of cold required was − 140° C. under a pressure of 320 atmospheres.

The proportion, by weight, of oxygen in the air has been determined by Leduc as 23.58 per cent.[2]

The volume of oxygen in the air in different localities and conditions has been tested by various observers. On the western seashore of Scotland the percentage was found to be 20.991; on the tops of hills, 20.98; in a sitting room (close), 20.89; at the backs of houses, 20.70; at the bottom of shafts in mines, 20.44.

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[1] See Comptes Rendus, 1890. M. Muller.

[2] Comptes Rendus, 1890. A. Leduc.

The accurate determinations of Bunsen of the oxygen in the general air gave a mean of 20.93 per cent. Two hundred and three analyses by Reiset gave nearly the same result. Hempel found the amount at Tronso to be 20.92; at Dresden, 20.90; at Paris, 20.89. These amounts must be received with qualification, because in comparing one town with another more depends on the position in the town than on the situation of the town.

The average proportion of oxygen in the open country or at sea may be stated at about 20.95 per cent. In large, open spaces in London the amount of oxygen is nearly normal; in the streets, about 20.885; in Manchester, in fog and frost, 20.91; in the suburbs in wet weather, 20.96 to 20.98. These figures are merely approximate.

In the air of mines an average of 20 has been observed, and in extreme cases the amount was no higher than 18.6.

In the midst of vegetation on open ground, especially in the daytime, there is an excess of oxygen.

Angus Smith and others found the following quantities of oxygen in air in different situations:

On the Atlantic (Regnault)	20. 918
In the Andes on Pichincha, about (Regnault)	20. 949
Tops of hills, Scotland	20. 98
Northeast shore and open heath, Scotland	20. 999
Stockholm (Petersson and Högland)	20. 94
Suburb of Manchester, wet day	20. 98
Middle of Manchester, inclosed space	20. 652
Manchester, fog and frost	20. 91
Manchester, backs of houses and closets	20. 70
Manchester, dense fog	20. 86
Heidelberg (Bunsen)	20. 924
Low parts of Perth	20. 935
Swampy places, France and Switzerland	20. 922 20. 95
Bengal Bay, over bad water (Regnault)	20. 387
Sitting room, rather close	20. 89
Small room with petroleum lamp	20. 84
Gallery of a theater, 10.30 p. m	20. 86
Pit of a theater, 11.30 p. m	20. 74
Court of Queen's Bench	20. 65
Chemical Theater, Sorbonne, before lecture	20. 28
Chemical Theater, Sórbonne, after lecture	19. 86
In cow houses	20. 75
In sumps or pits in mines	20. 14
Worst in a mine	18. 227
Very difficult to remain in many minutes	17. 2

Recent experiments by Messrs. Smith and Haldane on impure air contained in a leaden chamber showed that with oxygen 20.19 and carbon dioxide 3.84 two men instantly got headaches on entering.

Oxygen is the breath of life, the element without which no human being could exist for a single hour. Brought into contact by every inhalation of the lungs, it revivifies the loaded blood, spreads over the body the warmth resulting from its combustion with the carbon contained in the blood and tissues, and gives to the whole physical being a vigor and freshness which is impossible where the element is deficient. Thus to mankind it is life-giver, warmth-maker, and purifier. Unlike food, which may be taken irregularly and at long intervals, oxygen is a necessity at all times and in all conditions, in every hour of the day and night; and upon its reaching or approaching the normal quantity in the air around us, our health and enjoyment directly depend.

By the law of diffusion of gases, which causes the interchange of position of gases separated by a thin porous partition, the carbonic acid gas brought by the blood to the lungs passes out and is then exhaled, while the oxygen breathed into the air cells passes in through the walls of these cells to the blood. The heart sends the impure blood derived from the circulation through the body to the lungs; this dark blood is loaded with carbonic acid gas; the lungs return the aerated and purified red blood through their blood vessels to another division of the heart, which again drives the vivifying blood through the system. Experiments have shown that a similar change in appearance from dark to bright red blood can be caused by passing a stream of oxygen through the dark venous blood of an animal. That a process of combustion, or, otherwise put, chemical union, goes on at the same time, is shown by the fact that the blood is raised one or two degrees by its contact with oxygen. The oxygen in its course through the body combines with the effete or waste products presented to it by the tissues, and so the heating effect of combustion maintains the temperature of the whole body at the normal, about 98.6. The waste gases given off by the lungs consist of carbonic acid gas, water vapor, and a very small quantity of ammonia and other organic matters.

The average volume of air breathed in at each breath is about 30 cubic inches, and the volume of air which may be easily breathed in by an effort, and by expanding the chest, is about 130 cubic inches, or about four times as much. After a very full inspiration about 230 cubic inches can be expired by a man of average height and in good health. The total capacity of the lungs, however, is much more than this—about 330 cubic inches. Thus in ordinary quiet breathing we only fill about one-tenth of the available air space of the lungs. After every outbreath, or expiration, a quantity of air is left in the lungs. This residual air amounts to about 100 cubic inches.

An adult at rest breathes about 686,000 cubic inches in the course of twenty-four hours; a laborer at full work, about 1,586,900 cubic inches—more than double. The amount of air passing into the lungs has been estimated at 400 cubic feet in a state of rest, 600 in exercise, 1,000 in severe exertion. The number of air cells in the lungs is estimated at 5,000,000 or 6,000,000, and their surface at about 20 square feet. The epithelium or membranous film between the blood and air is exceedingly thin, and in many parts the capillaries are exposed, in the dividing walls of cells, to air on both sides. The weight of air inhaled in the course of the day is seven or eight times that of the food eaten. The mechanical work of breathing represents energy expressed by the lifting of 21 tons 1 foot in 24 hours.[1]

From every volume of air inspired about 4½ per cent of oxygen is abstracted, and a somewhat smaller quantity of carbonic acid gas is at the same time added to the expired air.

Experiments on animals show that the amount of oxygen absorbed is very little if at all increased by an excess in the air surrounding them.

OZONE.

Ozone is an important constituent of the atmosphere, greatly contributing to its purity and freshness and to the vigor of human life. It is a form of oxygen in which the molecule is considered to be composed of three molecules of the gas.

Although existing in small quantity in the air, rarely exceeding 1 part in 10,000, the activity of ozone is so great and its function so beneficial that its presence in normal quantity is, in ordinary surroundings, a fair guaranty of the purity of the air and of healthy conditions so far as breathing is concerned. No ozone is found in the streets of large towns, in most inhabited rooms, near decomposing organic matter, and in confined spaces generally. In very large, well-ventilated rooms it is sometimes, though rarely, detected. Ozone is found in very small quantity a little to leeward of a large town. Even at Brighton, a town of about 110,000 inhabitants, ozone was barely discoverable on the pier when the wind blew from the town, but abundant when the wind was from another direction.

Ozone has the power of oxidizing to a much higher degree than oxygen, and vigorously attacks organic matter in a fine state of division. It is therefore a strong disinfectant. Its oxidizing power is the reason of its absence from confined spaces where organic matter, dust, or smoke is present, for such matter quickly uses up the small portion of ozone which enters with the fresh air. The walls, furniture, etc., are also covered with fine dust, which the ozone attacks. The difference we feel in going from a furnished room, however large, into the open air, is thus partly accounted for. There is somewhat more ozone on mountains than on plains, and most of all near the sea. Water is said by Carius to absorb 0.8 of its volume of ozone. An examination of sea water with a view to detect the amount contained in it would be difficult, but might give interesting results. A great excess of ozone is destructive to life, and oxygen containing one two hundred and fortieth part of ozone is rapidly fatal. The ordinary quantity even has bad effects in exacerbating bronchitis and bronchial colds and some other affections of the lungs.

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[1] Professor Haughton, Carpenter's Principles of Human Physiology.

Ozone is formed by the passage of the electric spark, and especially of the brisk discharge through oxygen, and is therefore found in unusual quantity after thunderstorms. It may also be formed by the slow oxidation of phosphorus, and of essential oils in the presence of moisture; also by the decomposition of water by a galvanic current. When formed by electric discharge in air, it is quickly turned back again into oxygen, either by further discharges or by the action of high temperature, about 230° C.; at the temperature of boiling water it is slowly decomposed in moist air. Its pungency of odor is said to make it easily perceptible when only present to the extent of 1 volume in 2,500,000 volumes of air, and the smell may sometimes be noticed on the seabeach. It has been liquefied at 100° C. under 127 atmospheres pressure. In this form it shows a dark indigo-blue color; gaseous ozone looked at in a tube 1 meter long also shows a blue color. Thus there can be little doubt that, in conjunction with oxygen and fine dust, it contributes to the azure hue of the sky.

NITROGEN.

Nitrogen, the gas which constitutes four-fifths of the volume of the atmosphere, takes no direct part in the sustenance of human life, but has two great functions to perform: first, the dilution of oxygen to the proper and tolerable strength for respiration, and secondly, the supply of food material to plants.

Although life is possible for many hours in pure oxygen, it is hardly conceivable that the human constitution could be so modified as to endure for long an atmosphere of so actively combustible a character. At any rate, nitrogen is indispensable in present conditions to the human race. Plants, with few exceptions, do not absorb nitrogen from the air, and, indeed, in the case of most of these exceptions the supply of nitrogen is in a transitional compound form. Nitrogen is brought to the plants in general by processes of decay, and by the action of microbes in the soil, which rearrange organic elements, forming nitrates and nitrites. These nitrogen compounds are largely applied to the roots of plants as manure. Only one or two classes of plants can take up nitrogen from the air. Certain low algæ, freely exposed to light and air, seem to absorb nitrogen directly. Leguminous plants, such as peas, vetches, lupins, beans, clover, etc., absorb nitrogen from the air in a very curious way. Nodules or swellings are found on the roots; these contain minute fungi or microbes; the bacteria absorb nitrogen from the air, and, probably at the expense of the energy of the carbohydrates, etc., which they oxidize, supply this nitrogen in the form of compounds to the plant. These recently discovered facts open out the prospect of obtaining scientifically from the air, in some cases at least, the nitrogen which is now applied in combination with oxygen, soda, etc., as manure. If by the aid of special bacteria parasitic upon the plant we can systematically obtain the chief element of manurial stuffs from the atmosphere itself, a great advance will have been made in agriculture and in the cheapening of food.

CARBON DIOXIDE.

Carbonic acid gas, or carbon dioxide, is found in small quantities everywhere in the air, and in about the same proportion at 11,000 feet as at the sea level. It is a colorless, transparent gas and does not support combustion or animal life. At 0° C. it may be liquefied under a pressure of 38.5 atmospheres. When liquefied and then allowed to escape it freezes into a snow-white solid in the air, and in a vessel under the vacuum of the air pump freezes into a transparent mass like ice.

One liter of carbonic dioxide at 0° C. and 760 mm. pressure weighs 1.97714, nearly double the weight of air, taken as 1.

At the ordinary temperature and pressure water dissolves about its own volume of the gas. Dissolved in rain it exerts in the course of time a very powerful disintegrating effect on rocks and minerals, so that the crust of the earth is greatly modified by the constant action of the solution.

The chief sources of carbonic dioxide in the air are the respiration of animals and the burning of fuel. A large quantity emerges from the earth in certain places, as in the Poison Valley of Java, and in many mineral springs, where it effervesces out of water escaping from pressure.

Saussure found the amount per cent in a wood near Geneva to be 0.0504 in the day and 0.0576 at night; in January, 0.0423; in August, 0.0568. In Geneva he found an average amount of 0.0468, compared with 0.0437 in the wood.

Schulze, Reiset, Levy, Armstrong, and Muntz, in different places, made several thousand observations, and the mean of all these shows during the day 0.0299, and during the night 0.0317. Reiset's long continued observations in the country 4 miles from Dieppe gave an average of 0.02942; and in June, above the crop of red trefoil, 0.02898; in July, above barley, 0.02829; near a flock of sheep, 0.03178.

Thorpe's very carefully conducted experiments agree well with the above values, and give for the air over the sea 0.03011. Armstrong, at Grasmere, obtained during the day 0.0296, and during the night 0.033. At the Montsouris Observatory the mean during 1877–1882 was 0.03.

In an unventilated barrack the following amounts have been recorded as the result of careful observations: 0.1242, 0.189, 0.195; in a hospital at Netley, 0.06 to 0.08; in the General Hospital, Madrid, 0.32 to 0.43; in a boys' school, 4,640 cubic feet and 67 boys, 0.31; in a crowded meeting, 0.365; in a schoolroom at Madrid, 10,400 cubic feet and 70 girls, 0.723; in a stable at Hilsea, cubic space 655 feet per horse, 0.1053.

It is not easily explained why the normal amount of carbonic dioxide in the free air has been so long assumed in scientific articles and textbooks as 0.04 per cent, or 4 volumes per 10,000, when the best recent observations show an average not exceeding 0.0317 per cent, even at night, and a general mean of about 0.0308, or 3.08 volumes in 10,000. All the most recent works on hygiene, however generally accurate, repeat this error.

Considering the value of small quantities in these measurements, especially where they affect human life, it is most desirable that the standard should be taken rather as 3 than 4 volumes per 10,000.

Although carbon dioxide does not itself support animal life, and we could do very well without it in the atmosphere so far as breathing is concerned, it is necessary to the growth of plants, and therefore through them an indispensable substance for the existence of the human race. The vegetable world not only needs a supply of this gas for its own sustenance, but by the selective action of its leaves keeps the air continually pure enough for the life of animals. Under the influence of sunlight every green plant absorbs the carbonic dioxide at its surface, breaks it up into carbon and oxygen, and returns some free oxygen to the atmosphere. In this way the two great kingdoms, the vegetable and the animal, mutually contribute, each to the other, the elements of life. The carbon drawn from the air, together with hydrogen and oxygen, forms the wood of the tree, the stalk of the plant, and the flesh of the fruit, and these, when burnt or eaten, again result in carbon dioxide and water.

The change from the compound gas to carbon and oxygen is brought about by small openings or pores filled with a green substance, chlorophyll, which during the daytime has the power to extract the carbon and set free the oxygen. At night, on the contrary, there is a slight expiration of carbonic dioxide, so that there is a real reason against keeping large green plants in a bedroom during the night. But the amount is very small compared with that exhaled by one person.

It is now known that plants, like animals, breathe oxygen from the air, while they use the carbonic acid as food.

About 1,346 cubic inches of carbonic dioxide are exhaled by a healthy man per hour. An adult gives off in repose about 0.7 cubic foot, and in active work about 1 cubic foot per hour. (Pettenkofer.)

It is a remarkable fact that this amount is much reduced when the air is already fouled with this gas; experiments showed that where the same air was rebreathed, as it often is, the reduction was from 32 to 9.5 inches per minute. Thus it appears that the elimination of waste products from the system is seriously checked by the presence in the air breathed of an excess of carbonic dioxide. Otherwise stated, air in crowded places may continue to sustain life while it fails to remove any but a very inadequate portion of the poisons with which the blood is charged.

The general surface of the skin of the body also gives out a considerable quantity of carbon dioxide, though, of course, very much less than the lungs.

About 67,200 cubic feet of carbon dioxide[1] are given off by the burning of every ton of coal. Since about 405,480 tons are burnt daily in England on an average (the quantity is much larger in winter), the air over the country receives daily about 24,728,256,000 cubic feet of the gas, or 1,200,000 tons.

The perfect burning of ordinary coal gas gives rise to 200 cubic feet of carbonic dioxide for every 100 cubic feet of gas consumed. Practically every cubic foot of gas burnt vitiates as much air as the respiration of one person. So that in a large town during the evening hours in winter the vitiation of the air is in main streets and in rooms many times larger than during the daytime.

Angus Smith, whose methods were not quite so precise as those later in use, found the following amounts of the gas in air in the situation described:

Hills in Scotland, 1,000 to 4,406 feet high	0.0332
Bottom of same hills	.0331
In the suburbs of Dundee at night	.028
In Dundee at night	.042
In London parks	.0301
On the Thames	.0343
Where fields began around London	.0369
In the streets in London in summer	.0380
In Manchester in usual weather	.0403
In Manchester in fogs	.0679
In workshops	.300
In the chancery court, 3 feet from the ground	.203
In the Standard Theater pit	.323
In very ill-ventilated Cornish mines	2.50

It appears from these figures that hill air, like that of the open country and of the seaside, contains little carbonic acid, but is not superior in this respect to the air of the central parts of large parks in towns. In the streets of a town the amount is decidedly larger by about 1 in 10,000 than the average amount of the country. During the prevalence of fogs, streets and confined places in towns often contain double the natural amount. The condition of the air of workshops, theaters, and crowded places generally is evidently foul and dangerous to health.

In the central parts of London, within the city, Dr. W. J. Russell found a mean of 0.0422 for three winters, and 0.0379 for two summers. During fogs the amounts were much higher, giving an average of 0.072, and on one occasion a measurement of 0.141 was recorded. The lifting of a fog was followed by a rapid decrease in the excess. On still dark days the amount was large. On fine days, in strong winds, and on holidays, the quantity was below the average.

The deficiency of oxygen and excess of carbonic acid, which are common to nearly all rooms, schools, churches, theaters, and workshops where many persons are gathered, are very favorable not only to the spread of various infectious diseases, but to the maintenance of a number

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[1] **Reduced to about the average temperature of the air in England, 50°.**

of minor ailments; and where the exposure to foul air is prolonged, as in workshops, offices, and mills, to a continued depression of vitality. Various artificial means have been tried for improving the air of crowded rooms, and some are successful, but, on the whole, the direct admission of plenty of fresh air in currents directed upward and the removal of bad air by flues of sufficient diameter give in the long run the most satisfactory results.

The worst condition of air to which people are often exposed would probably be found in closed railway carriages. The capacity of an ordinary third-class compartment in England may be put at 240 cubic feet; it is certainly not greater. Containing 10 persons, it provides for each person 24 cubic feet of air at the beginning of a journey. Supposing the air to be unchanged, in the course of one hour each person will have breathed 17.7 of these cubic feet. Therefore, at the end of one hour 177 cubic feet out of 240 in the compartment will have been breathed out of the lungs of its occupants. Since an average man breathes out 0.6 cubic feet of carbon dioxide per hour, the amount of excess of this gas in the compartment at the end of an hour is 6 cubic feet; or otherwise stated, the amount in the air, instead of the normal proportion of 0.03 per 100 cubic feet, is 2.53 per 100 cubic feet. At the same time the oxygen is reduced and a quantity of organic poison and vapor is taken in with every breath. Practically, however, we must take into account the facts that from the first minute every person in the compartment breathes not a fresh parcel of air at every breath, but an already contaminated product, and that an excess of carbon dioxide has the effect of at once diminishing the quantity expired. Thus the amount of carbon dioxide would not be so large as that calculated, but may be estimated at one-half—1.26 per cent. But the deficiency in the carbon dioxide breathed out tells of carbon and other matters remaining unoxidized in the human system. The case of the compartment supposed air-tight is an extreme one and not quite exemplified in practice, but some approach to the condition described occurs in thousands of railway compartments on every calm, cold, winter morning and evening. Again, in traveling to the south of Europe in the winter of 1893 it was noticeable that 48 persons were shut up in one long carriage with a communicating passage between the compartments and without any efficient ventilation even through a hole or chink, the windows and doors all being made to fit closely. Twelve hours of breathing the same air would be likely to bring the occupants to a worse condition than where ten persons sleep in one small bedroom, which is about the worst case actually occurring in large towns. Moreover, these carriages are largely used by invalids and consumptives, and must become sources of infection to delicate persons.

Experiment by means of the sense of smell has shown that air in a room seems fresh when the carbon dioxide does not exceed 0.05999 per cent, a little unpleasant when the proportion is 0.08004 per cent, offensive and very close at 0.12335, and extremely close, when the sense of smell can no longer differentiate, at 0.12818. In a railway compartment this amount is often greatly exceeded.

It is recognized by the best authorities that in order to keep the air in a room in a state good for respiration every person should be supplied with 3,000 cubic feet of fresh air in every hour. Thus, in an unventilated railway carriage occupied by one person, the whole of the air would require to be changed thirteen times an hour, and if occupied by ten persons, one hundred and thirty times an hour. Plainly, the ventilation provided by ventilators or by 2 or 3 inches of open window is incompetent to do this, and falls very far short of what is required when the wind blows in the same direction as that in which the train is moving, virtually resulting in a calm.

A space of 750 to 1,000 cubic feet in a room is properly required for each person, when the whole of the air is renewed by imperceptible and even ventilation about three times an hour. This standard is commonly not approached when several persons occupy a small room and windows and doors are closed. In a railway compartment the space for ten persons should be on the same scale—7,500 cubic feet, at least—and the air should be changed completely three times an hour, at least. As a matter of fact, the space is only one-thirtieth of this desirable quantity, and the whole air may in many cases be changed not more than three times an hour. Since the space can not well be increased, the alternative must be taken of largely increasing the flow of air through the compartment. Small, fixed openings above the windows and a ventilator in the roof would be the most efficient means of replacing foul air by fresh. The openings might be made to diminish in size in proportion to the strength of the wind encountered, and should be so situated as not to cause a perceptible draft. In rooms there is no better cheap ventilation for a mild climate than that obtained by thickening the lower part of the frame of a sash window so as to leave a space between the two sashes by which air enters and diffuses itself through the room, escape being provided by the chimney. Tubes of rather large size communicating directly with the outer air, and with their interior openings directed upward about 4 feet above the floor, are very satisfactory, and by means of a valve or damper can be regulated so as to admit more or less air, according to weather.

For large houses and cold climates, where more expensive apparatus may conduce to ultimate economy, a thoroughly satisfactory arrangement is the provision in the basement of a coke boiler with a system of hot-water tubes contained in a chamber into which fresh air passes, and is thence led through flues into the upper parts of the various rooms, where it becomes cooled and flows away with the products of respiration through openings near the floor into pipes connected with a shaft next the kitchen chimney, and so upward into the open air. But the boiler and stove require much attention, and the substitution of gas for solid fuel would sometimes be preferable.

Gas fires are good if the products of combustion are not permitted to mingle with the air in the room, but carried off by the chimney, as with coal fires. The poisonous gases, etc., generated by combustion are very apt to cause sore throats, headache, and other ailments, and may favor the incidence of diphtheria. Carbon monoxide, which is given off by charcoal, coke, and gas fires in small quantities, is a strong poison.

VAPOR OF WATER.

The atmosphere of vapor of water coexisting with and interpenetrating the atmosphere of nitrogen and oxygen is of no less importance to human life. Its physical properties are very different and its characteristic is variety of state, while that of the dry air in which it floats is uniformity of state. Air is solid at —328° F. under a pressure of 1,000 atmospheres; vapor of water is solid at 32° F. under a pressure of 1 atmosphere. Recent researches have proved that cohesion, the force by which bodies are held together, increases as temperature is reduced. At the exceedingly low temperature of 328° F. metals and other solids are firmer than at any higher degree. Heat is therefore a force by which the molecules of substances in general are driven further asunder in the whole range of temperature. The force of cohesion is less in gases than in liquids and solids; and, indeed, is not manifested at all at ordinary temperatures and pressures. By great cold and great pressure, however, all gases but one have been brought to the liquid condition, wherein cohesion obtains the advantage over heat, and it is almost certain that by still greater cold all gases would be enabled to exist as cohesive solids. The habitable state of our globe depends on the adjustment of temperature and atmospheric density so as to permit the elements of life to maintain their appropriate gaseous and liquid forms. It is the large diversity of melting and boiling points in different substances which makes life possible. Uniformity, or even an approximation to it, would be fatal.

Water vapor, instead of being nearly homogeneous and of equal density at equal heights above the earth, varies greatly in quantity at different times and in different places. Like a gas, it tends to diffuse itself uniformly through the atmosphere as in a vacuum, but the resistance of the air has the effect of retarding the rate of diffusion. Owing, moreover, to the never-ceasing operation of unequal condensation and evaporation, the distribution of vapor is very unequal, both in time and place. The average quantity near the sea level in most countries is from 60 to 75 per cent of that required for complete saturation.

While air is always a mixture of gases in a fixed proportion, very far beyond any possible cause of liquefaction or solidification, vapor is never far from its condensing point; that is, however high the temperature and however low the pressure, a moderate amount of cooling will always bring it into the condition of water or ice. The repulsive force in the perfect gas, or in air, is sufficient to keep it gaseous at the lowest conceivable temperatures in natural conditions; the cohesive force in water is sufficient to keep it, except to a comparatively small amount, in the state of a liquid. Yet this small proportion which flows through our atmosphere reaches the enormous weight of 54,460 billions of tons. Lighter than air, transparent, almost impalpable, vapor has an immense work to do in the sustenance of all that grows and breathes upon the surface of the earth. Like a good genius, it enables the air, the sunshine, the earth, to bring forth their riches, to cover the globe with verdure and gladness, and truly to make the desert blossom like the rose. Without vapor in the air, there would be no streams, no lakes, no wells. The land would be uninhabitable by man, except so far as fresh water might be condensed from sea water by machinery, and plants for his use be grown by the seashore. Even then the human system would hardly tolerate the parching influence of a perfectly dry atmosphere.

Water vapor, having a low temperature of condensation, was one of the last substances to fall, during the cooling of this globe millions of years ago, from the vaporous into the liquid condition, and consequently remains as a covering between the rocks, which were early solidified, and the air, which was not solidified at all. Water covers about three-fourths[1] of the whole area of the terrestrial ball. It has the remarkable property of being capable of existing in the gaseous, liquid, and solid states within a small range of temperature, and even of existing in all three states under ordinary conditions at temperatures which are common in winter over a large area, and which are easily borne by human beings.

In every cubic inch of water are many thousands of millions of millions of molecules, and all of these vibrate more or less rapidly under the stroke of heat. Some molecules, as a result of collisions among themselves, which are very numerous in every second, and as a result of their situation on the surface of the sea, are propelled with such velocity that they leap above the general surface, get beyond the retaining power of cohesion, and are taken up by the wind or by rising currents and carried aloft. The vapor rising from the water surface is warm, has in fact become vapor owing to being in more energetic vibration than the average of the particles of water. Moreover, vapor is lighter than air. So the lowest stratum of vaporous air near the tropical sea becomes lighter than the air above it for three reasons: First, by being in contact with the warm water which has absorbed the sun's rays; secondly, by being mixed with vapor which is lighter than the air it displaces, and thirdly, by this vapor coming from the warmest or most strongly vibrating molecules on the water plane.

The force of gravitation, it should be observed, is often of very little account where small particles such as these molecules of water are to be considered. A slight charge of electricity would be enormously more powerful in directing the motion of a single molecule. The reason

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[1] The proportion of water to land is about 145,000,000 square miles to 52,000,000 square miles.

of this is that gravitation diminishes regularly with the size of particles of the same substance; but electricity, since it resides on the surface, diminishes at a much slower rate. It is likely that electricity would often cooperate with heat differences in driving the vapor from the surface in an upward direction. Evaporation is increased by low barometric pressure, so that an area of depression to some degree on this account tends to maintain itself.

By the beautiful law of the diffusion of gases, according to which each gas spreads itself through a space as if that space were a vacuum, subject only to retardation of the rate of diffusion by another gas already permeating the space, vapor diffuses itself through air, not with great rapidity, but so as to produce a fairly equable mixture in the same locality. The molecules of vapor have to encounter thousands of molecules of air in every inch and millions in every second of their progress, and if weather depended on diffusion, without the bodily transferences of large quantities of air horizontally and vertically owing to perpetually changing distributions of heat, the conditions of climate would be extreme and intolerable.

A very common form of exchange set up where the heat and moisture are not excessive by contrast with neighboring masses is by thin streams, filaments, or spirals of lighter vaporous air rising into the upper region, while colder filaments descend toward the earth or sea. This movement occurs under placid conditions, with cloudless sky, and when observed in temperate climates may be taken as a sign of considerable stability in the disposition of the atmosphere.

At other times, also commonly in fine weather, the warmer, lighter strata below break during the daytime into the upper strata by means of small columns, of a good many yards in diameter. These are often capped with rounded cumulus clouds where they attain an elevation and refrigeration beyond their dew point.

Occasionally, but rarely, the lower air breaks suddenly in a large torrential eddy, which may be several furlongs in diameter, into the upper region. The disturbance may give rise to a cyclone, whirlwind, or tornado. This occurs when the condition is abnormal, the lower strata being very moist and warm and the upper relatively cold and dry, and when from some cause, such as the prevalence of superposed winds, the interchange of differing air volumes has been delayed. The conflict of currents from different directions near the surface may then give rise to an eddy, and this will be a favorable occasion for a rush of light air, as through a chimney, toward the high level. Air flows in from all sides, but can not easily reach the center, owing to the earth's rotation, the onward movement of the whirl, and centrifugal force. In the present writer's opinion, a cyclone may be started or maintained by the strong wind, of 100 miles an hour or more, which often blows at a great elevation in the tropics and neighboring parts. At one observatory in the United States a velocity of 180 miles an hour has been registered. The effect of a strong horizontal wind on a "chimney" of hot vaporous air would be to increase greatly the force of the upward torrent, as has been proved by anemometric experience with tall chimney shafts and domestic fires. The effect of the violent wind is exceedingly destructive, especially when the tornado is of small diameter. Some towns in the United States are particularly subject to these storms, and, as they generally come from one direction, the effect of building a perpendicular wall of 200 or 300 feet high on that quarter near the town, in order to break or divert its course, would seem worth trying.

Returning to the more normal conditions of the atmosphere, we may imagine the vapor, whether from land or sea, to have mixed much but not uniformly with the overlying air. The differences in the humidity of different masses or parcels of air, and the viscosity, friction, or resistance of the lower strata, where the pressure is 15 pounds to the square inch, prevent the interaction from being continuous and uniform, and consequently the ascending currents are local and variable, but when once fairly started, generally persist for a considerable time, moving all the while with the prevailing wind. When the vapor streams reach a certain height, they begin to condense, first and chiefly because they expand, and in expanding cool themselves, according to the laws of heat, and, secondly, because they mix with cooler strata. If the vapor be supposed to have ascended to a height of 3,000 feet, the pressure upon it has diminished from about 30 to 27 inches of mercury, or by about one-tenth, so that it swells, allowing for contraction by cold, to a bulk nearly one-tenth more than it had at the sea level. This is sufficient to produce a large diminution of temperature and the molecules vibrate so much less rapidly that some of them cease to maintain the condition of vapor. The vapor must condense, according to recent discoveries, not in contact with mere air, but upon very minute solid particles, motes, or dust, which may consist of ultramicroscopic sand, sea salt, or other material. So a cloud takes form. For each amount of curvature of a liquid surface there is a definite vapor pressure, and the pressure necessary for precipitation is greater as the surface becomes more convex, so that precipitation takes place more easily the larger the water globule in the presence of vapor. And so great is the pressure required for the condensation of vapor in free air that condensation can not take place except upon those small nuclei of dust which, more or less, are present throughout the lower atmosphere. Solid surfaces exposed to gases contract a film of gas upon their surfaces. Now, the dust of the air, owing to its minuteness, presents an enormous surface, and is moreover largely hygroscopic. so that the tendency to gather a film of vapor of water upon its surface becomes very important and effective. Without this fine dust in the air the world would hardly be tolerable or even habitable by the human race. The vapor would condense, not in the sky and in the form of clouds, but on the earth, on mountains, trees, houses, and clothes, so that the sun's rays would strike down upon us oppressed with an air cloudless and saturated, and all objects would be perpetually streaming with moisture. An approach to such a state of things sometimes actually occurs on high mountains when the air is saturated and at the same time remarkably free from dust.

Clouds are often caused and maintained by mixture of winds or currents at different temperatures, the colder current reducing the temperature of the other below the dew point. Such clouds may be very wide in extent, but are not often dense, except in sudden and violent disturbances.

Radiation from a stratum of highly vaporous air may produce a cloud, and, when once formed, every cloud which has a clear sky above it radiates strongly and tends to maintain its existence by the consequent deposition of vapor upon its particles which it induces. The intensity of radiation into space depends largely on the dryness of the air above; and since dryness increases rapidly with height, the radiation from a high cloud is much more rapid than from a low one. Otherwise high clouds would dissolve much faster than they do in the rather dry air about them. If the heat of the sun's rays falling upon a cloud exceeds the loss by radiation, the cloud diminishes in bulk and density. Thus a fog frequently dissipates toward the middle of the day. But the farther the fog or cloud lies from the surface of the earth, the less is the heating effect of the sun, for loss by radiation proceeds faster and is not compensated by terrestrial warmth.

Sometimes, but rarely, cumulus clouds may be seen to precipitate fine rain suddenly, about sunset, owing to the sudden, uncompensated loss of heat by radiation. The appearance may be compared to a veil suddenly let fall which does not reach the ground. An example of this phenomenon occurred in the south of England on April 13, 1894.

The edges of clouds are always changing, and, in fact, a cloud is in constant process of formation and solution. Sometimes, especially in fine weather, or with a strong wind, the edges are hard, rounded, and well marked. This may be owing to a property which has recently been discovered to belong to aggregations of very small drops when moderately or slightly electrified—they attract one another. The higher regions of the air are strongly electric, especially in stormy weather, and the particles are held in proximity by mutual attraction and by the attraction of the mass of cloud.

Fog and clouds of a stratiform character, and cumulus clouds, and cirrus may commonly exist without rain, and in most countries there are many days in the year wholly overcast but rainless. This happens most often in quiet and uniform conditions of weather. There is no strong disturbance in the upper air; horizontal currents of somewhat differing temperature give rise to a stratum of cloud about their borders, and this soon evaporates when carried into the drier air above or falling into the warmer air below. Cumulus may often be seen to sink and vanish at sunset, and stratiform cloud by itself is commonly the expression of moderate condensation under quiet conditions insufficient to precipitate vapor rapidly.

A cloud layer may continue for some days with strong wind, being caused by (1) a gradual ascending movement of the lower air so as to precipitate a small quantity of vapor continuously by expansion; (2) by contact of the upper surface of the lower current with a colder currant at a higher level; (3) by radiation from a rather moist stratum through dry upper air; or (4) by a warm, moist wind arriving, after a long passage, in cooler latitudes, and gradually becoming cooler by radiation and mixture.

In showery weather cumulus clouds are very often seen to consist of two or more masses at levels wide apart, and the upper mass, which is harder and firmer-looking than the lower, seems to move much less fast. Such clouds, even though heavy-looking, may pass over without rain, and it is generally, only by the appearance of rain in the air and landscape under them that they may be distinguished as actually shower-laden. Rain is, however, far more probable in these cases when the clouds are in tiers or separate layers; indeed, a single cumulus mass, simple and uncillified, seldom precipitates at all.

What, then, are the causes of rain; and why does it fall from some clouds more than from others?

The simplest and a very common cause of rain is the sudden elevation of moist air to a higher level, with the consequent chill by expansion. Standing on a mountain between the west and east ends of a loch in Perthshire, when a west wind is blowing, one may see showers frequently falling among the mountains westward, and failing to reach the flatter ground toward the east. The wind, even before it reaches the mountains, is tilted upward by the pressure of air in front of it, is consequently cooled, and precipitates moisture upon their western slopes. When the air descends in a drier and warmer condition toward the lower ground, the clouds quickly dissolve and thin out. The cloud-forming and the shower-forming effect is in general roughly proportional, between certain limits, to the height and steepness of the mountains. The great cliff called Slieve League, on the coast of Donegal, and the cliffs of Hoy, in the Orkneys, both about 1,800 to 2,000 feet high, cause clouds to be thickly formed sometimes fully half a mile to windward. Whether rain falls, and how heavily, depends chiefly on the moisture of the air and the coldness of the stratum into which it is forced.

A similar but little recognized effect is caused by opposing masses of air. Thus, let a moist warm southwest wind meet a cold northeast wind; the southwest wind is forced upward, especially over certain localities, and flows over the northeast wind, expanding very largely and rapidly and precipitating moisture heavily. The production of heavy thunderstorms may be fully accounted for by the local eddies and conflicts between opposing winds, which occur in summer when the moist warm air-mass is lifted to great heights.

Generally, we may state the formation and amount of rain to be dependent on the following conditions:

(1) The height to which the lower air is forced upward.

(2) The amount of vapor in the lower and upper air, respectively.

(3) The relative coldness of the stratum into which the lower air is projected.

(4) The freedom from vapor strata and from cloud of the upper air, allowing free radiation from the rain cloud.

(5) The electrical condition of the air and cloud.

Where mountains are high, the air warm and moist and blowing toward steep slopes, very heavy rain falls either continuously at certain seasons, or in thunderstorms, according to the character of the winds, the heat of the sun on the earth, and to a less degree the temperature of the upper air.

The ranges of hills south of the Himalayas, the Himalayas themselves, the mountains of eastern South Africa, and the Andes give examples of such effects. High mountains have the power of precipitating as rain or snow even the rather small quantity of vapor which has passed over a continent, and thus the central areas of countries remote from the sea are provided with perennial fountains which flow down from the high ground and pass through the land as fertilizing rivers.

Another cause of rain is the radiation into space of the heat of vapor and of water particles at a height. Recent discoveries have revealed the fact that vapor does not condense into cloud globules in ordinary conditions without the presence of a very fine dust which floats in the atmosphere. When this dust radiates freely and moisture is deposited upon it, and when a cloud is formed, the upper surface of the cloud parts with more heat than the surrounding air, and the cloud globules grow in size by contact with vapor.

Now, throughout the process of increase in size, electricity is accumulated more and more densely on their surfaces, for the electricity of each molecule or particle resides on its surface, and the relative surface of a globule diminishes as the size of the globule increases. If the condensation be rapid, the particles formed are very unequal in size. Since surfaces only increase at half the rate of bulk, electricity is much denser on the large drop. Now, it has been found by experiment that large drops attract small ones when similarly electrified, and each addition further increases the attractive power of the drop. The large drops fall through a cloud at a much greater rate than the small particles and collide with many more droplets in the same time. In the course of a fall of 10,000 or 15,000 feet through cloud, the drops may greatly increase in size.

The sizes of drops vary from 0.0033 inch to about 0.1 inch. An ascending current of 3 miles an hour would sustain small drops;

only a very strong upward wind would sustain the largest. A hailstone of 2.58 inches in diameter would be kept at a height of about 15,000 feet by an upward blast of hurricane force, 100 miles an hour. Drops can never reach the size of a hailstone, for the resistance of the air has the effect of breaking them up. The smallest drops would take about six hours and forty minutes in falling from a cloud 10,000 feet high, but we know that this scarcely ever, if ever, happens. In reality the smallest drops falling on the earth are nearly always derived from a slight elevation and very small drops falling from a great height would, except in an extraordinarily saturated state of the air, evaporate in their course. Ordinary small raindrops take about six minutes or somewhat less in falling through 10,000 feet.

Raindrops are perfectly globular in form. This we know in two ways—first, from the rainbow, which can only arise from the regular dispersion of white light by transparent globules; and, secondly, by means of instantaneous photographs. The sphere is the figure of smallest volume which can be assumed, and consequently we find that free liquids under the influence of cohesion, surface tension, or gravitation, are always spherical.

Since a raindrop is an aggregation of cloud particles it contains a number of solid particles or invisible motes, and generally a very small quantity of sea salt. Besides this "dust" it attaches to itself soluble gases contained in the air, the result chiefly of animal life, of decomposition of organic matter, and of manufacturing processes. Thus, ammonia, nitric acid, hydrochloric acid, sulphurous acid, and a little air and carbonic acid, are found in rainwater. Brandes found an average of 26 kilograms of residue in every million of rain evaporated, the amount being greatest in January (65) and least in May (8). The residual substances were chlorine, sulphuric acid, soda, potash, magnesia, ammonia salts, organic matter, lime, carbon dioxide, oxide of iron, and oxide of manganese. The solid matter amounts in France to about 147½ to 156 kilograms per hectare. The importance of these minute traces of gases and other substances in rain is enormous, especially in relation to the nutrition of plants and the disintegration of rocks. But no less important to mankind is the function of rain in clearing the atmosphere of these ingredients. Clouds and rain are at the same time purifiers, filterers, and nourishers. In the words of the ancient declaration, "the clouds drop fatness," and "the water returns not void." The upper layers of earth have a remarkable power of purifying water, so that what is useful to vegetation is retained near the surface and the purified water passes down into deeper ground, where it may be drawn from wells or emerge in springs. The process, first of washing the atmosphere and then of self-purification, is so complete that though the mold swarms with organic life the water which has passed through this upper earth may be described as practically pure and free from organisms.

Not only is the raindrop a composition of solids, liquids, and gases, but it is of unequal consistency if the inner be compared with the outer part. Every drop surrounded by air is compressed into the spherical shape by an outer film of water which partakes of the character of an elastic skin. In the free air cloud globules and small rain can not easily coalesce on account of this elastic film enveloping them. They may impinge against each other, but unless the concussion be forcible they rebound. Similarly the drops falling from a fountain may be seen to run along the surface of the water like pearls before they unite with it. So also small drops of water falling from an artificial jet rebound and do not unite on collision. But let a stick of sealing wax be rubbed on flannel and held at a distance of several feet from the thickly falling drops; they at once cease to rebound, they unite into large drops, or else the jet keeps falling as a continuous stream and does not separate into drops as before. Again, let the drops be strongly electrified, they do not unite but repel each other.

Large drops attract small drops similarly electrified, and drops unequally electrified attract each other. The weak charge of similar electricity, which causes the globules to approach each other forcibly, is sufficient to break the enveloping film, but a stronger charge produces repulsion of the drops. In these observed facts we have what seems a very satisfactory explanation of some of the phenomena of thunderstorms; for example, the sudden heavy downpour and sudden cessation, and the apparent effect of flashes of lightning on the rain or hail. Finely divided water exhibits another property which is of great importance in the formation of rain, hail, and snow. Down to a very low temperature, 10° to 20° or more below the freezing point, according to the size of the particles, it resists congelation. This property is of immense effect throughout nature, and the life of plant and animals to a great extent depends upon it. When globules of water below the freezing point are touched by a frozen drop or by a snowflake they are instantly frozen. A crystal of ice is the most powerful of all substances in congealing water below the freezing point. Very many falls of rain, hail, and snow are due to this cause. The minute crystal as it descends through dense cloud gathers particles on its way until it has grown to be a large snowflake; and whenever the lower air is warm enough, snowflakes thus formed melt and fall as rain. Rain is much more often than we suppose melted snow. The minute flakes which would melt and evaporate if they did not meet with the water cloud, grow rapidly in the cloud, which would of itself be incompetent to precipitate.

When a flake of snow or kernel of ice falls through dense cloud, such as the towering cumulus which stacks itself to a great elevation in a thunderstorm, it electrically attracts the particles of unfrozen water, below the freezing point, through which it passes, and every particle attached and instantly frozen adds to the electric charge, so that more particles are attracted with ever-increasing strength. In this way, in addition to mere impact, in the course of a fall of 10,000 or 15,000 feet,[1] are formed those large hailstones which devastate crops and kill animals· Taking Aitken's observations of the number of particles of water or droplets of fog, falling upon a square inch in a minute in a dense fog, as a criterion—say, namely, an average of about 10,000 droplets—and assuming that these drops fall at the rate of not more (it is probably much less) than 10 feet a minute, a hailstone falling through 10,000 feet of dense cloud would encounter if it began as a snowflake, 1 inch square, about 10,000,000 droplets, by mere impact. Some hailstones may result from the attraction of small spicules of ice and particles of water alternately as the nucleus passes through different strata, and these show concentric bands alternately opaque and clear. Similar bands may be formed by the passage of the hailstone through alternate spaces of thick cloud and of clear, unclouded, but saturated air. The latent heat brought into the sensible condition by condensation and congelation has been supposed to make such an accumulation in clear, saturated air impossible, but actual observation indicates that the rapid passage of the hailstone through very cold air speedily and continuously dissipates the heat thus set free. The appearance of spaces between successive tiers of dense cumulus cloud and the almost invariably excessive display of electric phenomena are characteristic of great hailstorms. It is very probable that between the dense clouds lie masses of saturated, or even supersaturated, almost dust-free air. A cold hailstone falling through these would accumulate ice in clear, alternate zones surrounding the nucleus. Large hailstones are generally spheroidal, small ones conical, with icy bases and a softer apex. The large hailstones are probably more dependent on electric attraction, and the small on the impact of descent, for their form and icy accumulations.

In a thunderstorm or shower, the lower clouds are generally negatively and the upper positively electrified. Before a hailstorm clouds of great significance may be observed, which may be described as turreted cumulus or cumulo-stratus. They are quite distinctive of hailstorm weather, though of course the hailstorm may not occur in the district where they are seen. They consist of hard-looking, sharply defined, generally white, and rather small masses of cloud, with projections towering upward and rather broader at the top than at the base, or equally broad. These peculiar clouds are worthy of note with the view of forecasting the probable occurrence of hailstorms.

Vapor, when it ceases to exist as a gas in the air, assumes several

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[1] The height of cumulus cloud may often be well observed and measured not only from the plain, but on mountains. The tower of cumulus cloud often exceeds 10,000 or 15,000 feet, and in great storms may be 25,000 to 40,000 feet from base to summit. Both observations from the earth and balloon ascents supply evidence to this effect.

different forms which are only obscurely understood. There seems to be a stage between the gaseous and the misty in which vapor is condensed into very minute transparent motes or into a condition corresponding to the critical state, the viscous interval, observed by Andrews in carbon dioxide under great pressure. Just above this critical point this gas behaved to some degree like its vapor and liquid below it with regard to pressure. The behavior of water vapor under varying pressure and when near saturation at different temperatures would be an interesting though difficult subject for research. Dry vapor is regarded by some experimental observers as diathermanous, like air; yet we certainly find that what seems to be invisible transparent vapor does largely arrest radiation from the earth. Therefore, it would seem much of the vapor of the air, when near saturation, must be in a condition bordering on mist or finely divided water. Only beyond a certain size, maybe, or when dust is thick, do the particles become large enough to give the effect of haze. It often happens that a thermometer freely exposed to the sky on a fine night suddenly ceases to fall, and rises several degrees without any apparent cloudiness or diminution of the luster of the stars, but this rise, in the present writer's experience, is a good indication of approaching rain after dry weather. Whether the screen in the upper air which reflects the radiation from the earth be a thin cloud or else vapor in a state of inchoate condensation, has not yet been ascertained.

Haze, fogs, and clouds are caused by the tendency of vapor to condense upon solid particles below a certain temperature. A change of state from vapor to liquid or liquid to solid occurs much earlier in the presence of "free surfaces" of other bodies than where these are absent. Saturated air, as we call it, can hold no more vapor in ordinary conditions, but apart from solids and dust particles it could contain much more vapor without precipitation. Similarly, if water could be heated by itself apart from solids and contained gases, it would rise high above the boiling point without boiling, and would eventually explode; so also the droplets of a cloud do not freeze, though many degrees below the freezing point, until they touch a solid object. Dust in the air offers the free surface which is required for condensation. Different kinds of dust differ greatly in the power of compelling deposition. Sulphur, magnesia, and common salt are, in the laboratory, at any rate, powerful fog producers. In the open air sulphur seems to have little appreciable effect; but salt, which is hygroscopic, or damp-attracting, and pervades the atmosphere, plays an important part. Smoke, again, or finely divided tarry matter, greatly favors fog formation, owing, probably, to its strong radiative capacity and to its coating the water globules so as to prevent evaporation.

Suppose the motes of dust or salt in heterogeneous air to be radiating freely, and therefore to be colder than the air, and suppose each of them to be frequently brought in contact with filaments of air and vapor at a higher temperature than the average, then it is conceivable that momentary deposition and reevaporation may occur. The result would be haze. With fairly homogeneous masses of air, as with a west wind, the contact of warm and cool air occurs here and there on a much larger scale and at once produces massive clouds, owing to the quick growth of particles in a moist air brought in block below the dew-point by ascent or otherwise. The interchange between differing air masses is in this case by large columns instead of by infiltration and filaments. The steam leaving the escape valve of a boiler at high pressure is at first invisible, then bluish and semitransparent, like haze, then opaque and white, like cloud. The influences which cause haze maintain the vapor in the second stage; it passes perpetually from molecular invisibility to the verge of particulate visibility and back to invisibility by swift evaporation. Clouds, on the contrary, result from cooling in large masses, as by ascent, and the humidity is too great to permit so rapid a return to the condition of vapor within their borders. When they evaporate they become invisible at the edge without perceptibly passing through the stage of haze.

Why the process of change of size of the particles differs so much in different states of weather is by no means clear.

Haze has long been a meteorological problem. If it be vapor, why does it so frequently occur in the driest weather? If it be dust, why should dust continue to affect the atmosphere in such excessive quantities during particular periods, often in calm weather, and with a gentle wind from uninhabited areas, either sea or land? The moistest winds are generally the clearest, the driest are the haziest.[1] Moreover, there is a thick haze which sometimes persists for many days in spring or summer in England, and neither increases nor diminishes perceptibly during the night, when radiation is active. In such weather the air is dry, and the wind, if any, commonly a light air from between east and north. Since neither the sun's heat nor the nocturnal cold affects it, we must ascribe it to one of two things—the presence of a large quantity of dry dust in an unusual state, or the development of vapor condensation in some unusual way, so as to depend little on the general temperature. On the top of Snowdon, 3,300 feet, the present writer has observed haze as thick as on the ground level, and extending 1,000 or 2,000 feet above the summit. It was similar, though less in degree, to the obscuration described in the annals of last century as having covered Europe for months after the great eruption of a volcano in Iceland in 1783. Mr. Conway has recently observed high above the Himalayas a sudden haze overspreading the sky like the smoky haze seen near a large city in England. The explanation probably is that the haze depends on the relative temperature of mixed portions of strata of air, and much less on the general air temperature.

Aitken has shown that when the wind blows from inhabited places

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[1] In England.

there is both more haze and more dust than when it blows from the sea or from uninhabited country, and in Switzerland a thick veil of haze seemed to hang in the air between the observer and the mountains on all days when the number of particles was great, and it became very faint when the number was small. When the wind blew from the plains the air was thick; when from the Alps, clear. Similarly, at Ben Nevis, on the northwest coast of Scotland, a northwest wind was clearest, a southeast wind haziest, and the dust particles were generally more numerous according to the amount of haze. "Of 'purifying areas' the Mediterranean gave for lowest values 891, the Alps 381, the Highlands 141, and the Atlantic 72 particles per cubic centimeter. Dampness of the air was found to increase the effect of dust, so that nearly double the number of particles are required to produce the same amount of haze when it is dry than when it is dampish." When the depression of the wet-bulb thermometer below the dry bulb was 2° or more the transparency was roughly proportional to the wet bulb depression; that is, to the dryness of the air. "The nearness of the vapor to the dew-point seems to enable the dust particles to condense more vapor by surface attraction and otherwise, and thus by becoming larger they have a greater hazing effect." The number of dust particles in square centimeter lengths of 10 to 250 miles required to produce complete haze in air giving different wet-bulb depressions was calculated to be as follows:

Wet-bulb depression.	Number of particles to produce complete haze.
Degrees. 2 to 4	12, 500, 000, 000
4 to 7	17, 100, 000, 000
7 to 10	22, 600, 000, 000

Since more particles are required to produce haze in dry than in damp weather, it becomes the more remarkable that thick haze is so common in dry weather and generally absent in a moist atmosphere.

The observations of the present writer for many years have shown that haze is most apt to occur when there is infiltration or mixture of differing air currents, and indeed that it generally expresses the juxtaposition and mixture of winds. A steady wind extending to the upper clouds is very seldom hazy, and, on the other hand, haziness may be taken as a sign of the existence of another wind above that prevailing near the ground, or of variable currents. So much is this the case that in southern England a hazy or misty east wind signifies generally a rather short period of its prevalence, but a clear east wind means continuance. Of course care must be taken to be situated on the windward side of thickly inhabited districts in making such forecasts. It seems, therefore, that when haze is not due to a large amount of dust, it must arise from some effect of the mixture of different currents. A wind from the Atlantic on the west coast of Great Britain generally has a west wind above it, and is fairly homogeneous, but an east wind generally has to encounter and drive back a westerly or southerly wind, and has an opposing current within 3 to 7 miles above. There must in these cases be a great deal of mixture of portions of air of different humidity, temperature, and electrical tension. The contiguous parcels of air produce at a number of points momentary deposition of vapor on dust particles, and the resulting effect is haze. The dew point is attained in the molecular environment by momentary contact of cold, dry, dust-bearing with moist, warmer, less dusty air.

It is well to bear in mind the large extent and small depth of the whole of the lower region of winds. Currents of air, say within 25,000 feet of the surface, extended over a territory 400 miles square, would be represented by a layer of water an inch deep in a basin 80 inches square.

On the east coast of Scotland an east wind often brings a thick haze which may last two or three days, and is followed by rainy weather. But a much less thick blue haze prevails during fine weather, with light or variable easterly breezes, both in Scotland and England. The density of the haze in these conditions depends less on the number of dust particles than on the mixture of differing currents and on the moisture and warmth of the one current, the coldness and moisture of the other. There is no reason for supposing that a wind blowing from the polar regions and over the breadth of the North Sea is heavily charged with dust, yet the haziness is as great looking seaward as over the land of Berwickshire or Fife.

The clear air of continental climates, such as the European and North American, is partially explained by the moderate amount of dust, the infrequency of a condition approaching saturation in the lower air, and the absence generally of local winds such as are produced by a varied distribution of land and sea. Haze is very often the result of the passage of air over water of a lower temperature, and the difference of the temperatures may decide whether the obfuscation shall be haze, fog, mist, or fine rain. No amount of dust is in general competent in a dry, uniform air to produce apppreciable haze beyond what is due to its own particles. Thus in Colorado there is often a great deal of dust in the air, but the air is clearer at such times than it commonly is in England; in the Punjaub dust winds obscure the air for a long distance; in the Sahara Desert there is often thick dust, but the hazing is not great except with strong wind; when, however, this dust is blown far out over the Atlantic, the haze becomes very considerable, and is a common phenomenon about the Cape de Verde Islands. Towns, again, such as Paris and Pittsburg, which produce a great deal of dust, by the test of the dust counter, are not affected by haze in clear, dry weather, and even London, in some states of the air and very often at night, is only covered by a barely perceptible light haze. But coal smoke, commonly has the effect of causing a very persistent haze, and this, in the case of London, spreads conspicuously with the wind to places distant 100 miles or more. Coal smoke, we must remember, is accompanied by a good deal of water vapor and sulphurous acid. Gas and wood, when burned in large towns, produce no fog and very little haze, though the dust counter might show as many particles as where coal is burned. Dust in general may therefore be acquitted of taking an important part in producing any but a light, thin haze, except where there is a mixture of currents at different temperatures, and then some haze would in most instances be produced in any case by the normal average amount of very fine dust which exists everywhere in the atmosphere. In clear, homogeneous air, even near saturation, much dust or smoke may be added to the air without causing haze; in dry, hazy air much dust may be added without much intensifying the haze. In certain conditions of wind and weather much haze may exist without an abnormal quantity of dust, and, except on rare occasions, there is always enough dust, maybe of almost molecular dimensions, in the lower strata of the air to admit of precipitation of moisture where conditions are otherwise favorable.[1] A great deal of this dust probably consists of chloride of sodium, or sea salt.

The following instances may serve to show how haze and cloud are successively formed by a conflict of differing currents of air. St. Fillans Hill is a small, steep, isolated, conical hill about 300 feet in height, standing in the middle of the valley of the upper Earn, in Perthshire, about 2 miles from the lower end of Loch Earn, and flanked by mountains about 2,000 feet high on each side of the valley. The author was on the summit about 5 o'clock one evening in August,[2] when the breeze, which had been blowing freshly from the west, with a clear air, suddenly began to slacken, and in about five minutes dropped altogether. Then down the valley, eastward, a blue haze began swiftly to climb the glens tributary to Strathearn, and the whole air eastward grew obscure. The calm only lasted a little more than two minutes, and then suddenly a strong wind from the east set in, and soon the air westward as well as eastward had turned thick. The east wind continued, and in a few minutes the tops of the hills rising precipitously from Strathearn to a height of about 2,000 feet were obscured with cloud banners which grew continuously, and descended till in about two hours not only the hills above a level of about 1,000 feet, but the whole sky, was covered with gray clouds. The duration of the neutral calm corresponded with the time usually occupied, according to my observations in the neighborhood of London, by a moderate east wind in driving back the opposing current. At Richmond, and between Richmond and London, such a

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[1] These observations are derived from many years' attention to the conditions of prevalence of haze and fog in and near London.

[2] About 1877 or 1878.

change is signalized in the neutral band of calm by a dense yellow haze, producing great darkness in winter, the result of a banking up of smoke to some altitude, together with the condensation of vapor by the mixture of currents differing in temperature. The darkness in such a band lasts much longer with lighter winds, and I have known a west wind to prevail at Richmond simultaneously with an east wind in London, both without fog, while at Wandsworth a calm continued for many minutes with dense, almost nocturnally black smoke fog, the pressure in each direction being apparently equal.

FOG, SMOKE, GASEOUS AND SOLID IMPURITIES IN THE AIR.

FOG.

Fog is the result of one or both of two principal causes. The first is active radiation into space from the earth and from the air contiguous to it, and the second is a mixture of winds and currents, or of vapor and air at different temperatures.

1. Radiation fogs occur commonly when the atmosphere above the lowest stratum is cold, dry, and nearly still, and when the lowest stratum is greatly cooled by contact with the cold radiating earth, and therefore precipitates vapor into the form of minute globules of water. These globules themselves have a large radiative capacity, so that they tend further to reduce the temperature of the air in which they float, which has no such capacity. The stratum of fog so formed, not extending very many feet above the ground, fails to reflect much of the heat radiated from below, and quickly disperses, by radiation into space, whatever heat it absorbs. Thus earth and fog continue rapidly to part with their heat through the clear sky into space. The stratum of fog often grows in height and density through the night, and continues till about noon of the following day, or disperses in the late hours of the morning. If extended over a plain and watched from a height above the upper level, a fog of this character, in somewhat damp and not typical radiation weather, may be seen gradually to move irregularly upward under the influence of the morning sun, and in various directions to present prominences like those of the upper edge of cumulo-stratus. Smoke issuing from a tall factory chimney rises through and above the fog, but in a very short time falls back upon its surface and meanders like a dark river on a white ground.[1] The persistence of the fog depends upon the coldness of the ground, which is shielded from the sun, and upon the very large difference of temperature, sometimes 10 degrees or more, between the fog and the stratum of air a few feet above it. When, however, the sun's heat absorbed by the water particles exceeds the heat lost by radiation, the fog lifts, that is, its uppermost stratum rises, owing to diminished specific gravity, and

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[1] These observations were taken during the prevalence of a ground fog, in the country surrounding the Malvern Hills, in February, 1890.

either clears at once or remains for some time as a light blue haze.[1] The strata below it, submitted to the same influence, successively rise and take its place, and the evaporated moisture mingles with the general air.

Fogs of this kind locate themselves in low-lying valleys, basins, and plains, for the air, chilled by contact with the radiating ground, sinks by gravitation into such situations and in them is least likely to be disturbed. Sometimes a white fog may be seen pouring down an open and rather steep ravine like water.[2] Slopes of hills, especially their southern sides, some hundreds of feet above the plain, are comparatively free from these fogs, and are much drier and warmer during their prevalence than lower places in the neighborhood. Such an elevation is more favorable on this account to the human constitution; both the daily and yearly thermometric range is much smaller. Dense fog and frost often remain throughout the day on the northern side of hills when the southern slope is bathed in sunshine. This has been observed on several occasions on Hindhead, Surrey, the air in the fog keeping much colder than the air above it and on the southern slope.

In the still air which precedes and accompanies radiation fogs the number of dust particles is high above the average, owing partly to their becoming gathered by undisturbed precipitation into the lowest strata. On several occasions when the dust particles were counted they amounted to between 45,000 and 80,000 per cubic centimeter. Each of these is a nucleus for the deposition of vapor. The water particles are so small that they evaporate before touching solid objects during the daytime, the objects being warmer than themselves. For this reason these fogs have no wetting effect. In a fog, when objects were invisible at 100 yards distance, 19,350 droplets sometimes fell on a square inch per minute, but the average was much less than this, and the smallest number about 1,900 per minute.[3] The large number of particles favors the formation of fog. Considerable numbers of living organisms no doubt exist among the water particles of the fog, but are not known to be a cause of ill-health in the country remote from towns. Nor is great cold combined with fog productive of much illness in the country. In smoky towns the case is far different. Thus, in London the death rate was raised in a single fortnight, from January 24 to February 7, 1880, from 27.1 to 48.1 per thousand. The fatality and prevalence of respiratory diseases were enormously increased. The excess of deaths over the average in the three weeks ending February 14 was 2,994, and in the week ending February 7 the deaths from whooping cough were unprecedentedly numerous—248—and from bronchitis numbered 1,223. At least 30,000 persons must have been ill

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[1] This haze may be taken to be caused by the aggregated nuclei of dust left after evaporation of the water which condensed upon them.

[2] This was seen by the author with remarkable distinctness near Alum Bay, in the Isle of Wight.

[3] Aitken.

from the combined effect of smoky fog and cold. The present author was in London during the whole period, and noted especially the unusual number of days during which the darkness and stillness continued, and the tenacity with which the fog clung to the cold ground on the shady sides of squares and streets, when a warm, gentle current from the south improved and cleared the air above a height of 20 or 30 feet.[1] The large excess of carbonic acid, of sulphurous acid, and of micro-organisms and effete organic products was partly concerned in these ill effects, but the factor of greatest importance was the finely divided and thickly distributed carbon or carbonaceous matter, which irritated the breathing passages and lungs. The results corresponded rather closely with the more gradual ill effects of dusty trades. The lungs of a man who has spent his life in London or Manchester are found, post mortem, to be choked with black matter. In some parts of London there is sometimes no more light at noon than in the darkest night. After a fortnight of dense fog the deaths in London for one week, ending January 2, 1892, exceeded by 1,484 the average number, being at the rate of 42 per 1,000. Increases took place in the following diseases: Measles, 114 per cent; whooping cough, 173; phthisis, 42; old age, 36; apoplexy, 58; diseases of the circulatory system, 106; bronchitis, 170; pneumonia, 111; other respiratory diseases, 135; accidents, 103.

These results are in the main attributable to the concentration of the ordinary constituents of London air, with moisture and intense cold to help their deadly work. The majority of the fatal cases were in weakened constitutions, though many were among the robust. The experience of large towns always is that the power of recovery after illness is much less within their confines than in the country. In the fog the evil influences of town air are many times multiplied. The blackest fogs, which are local, are the result of variable or opposing currents which carry up the discolored mass to a height of hundreds of feet, where they condense their moisture in a stratum of unusual thickness or height. By a converging flow of currents, a huge column of blackened fog particles rises vertically to a height where it may remain or whence it may move slowly from place to place. A fog need not always be resting on the ground, but may hang after the manner of stratus cloud at some level, often a few hundred feet above it. This happens when the ground is not much colder than the air. The smoke of a steamer may be seen sometimes thus to form a dark streak, remaining about the same level for an hour or more. That domestic fires at least rival manufacturing works in the production of dark fogs is proved by the intense darkness which has prevailed in London on Sundays, and once on Christmas Day. Factory fires are out on Sundays, but domestic fires are larger and more numerous. Smoky fogs invade houses and even warm rooms, showing that many of the nuclei are solid particles large enough visibly to obstruct light even when dry.

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[1] London Fogs. R. Russell. Published by Stanford, London, 1880.

At a distance of 10 miles from London, the smoky particles are small and show quite a thick haze in a room with a fire, when a gentle current is moving from the town. Professor Frankland has shown that if a little smoky air be blown across the surface of water evaporation is retarded 80 per cent. The water globules may be similarly coated with tarry matter, which hinders the warmth of the sun from evaporating them. Moreover, every particle of carbon is a good radiator and in the early morning tends to increase the cold in the air around it; moisture is deposited upon it, in the opinion of the present writer, and can only with difficulty evaporate, so long as radiation is active and while the heat and light of the sun are stopped by smoke. The effect of finely divided carbon in stopping light may be tested by holding a piece of glass for a few moments above the flame of a candle; the black film deposited enables us to look at the sun easily, and it appears well defined, like a red orange, as in a fog.

The imperfect combustion of coal is the cause not only of fogs being specially dangerous to life, but of their persistence in duration far beyond those of the surrounding country. The removal of coal smoke would mean much less fog and much less evil in that which remained. Cities which use wood as fuel, or anthracite, or gas, or oil, are no more visited by fogs than the surrounding country, although the fine "dust" above them is, according to Aitken, very greatly in excess of the normal.

Pittsburg had a black climate till it used natural gas, and thenceforward has had a clear air, and no special liability to darkness and fog. In London, of 9,709,000 tons of coal used annually, about 1 per cent escapes into the air unburnt and 10 per cent is lost in other volatile compounds of carbon. The bright sunshine, compared with that of Kew, 9 miles distant, was, in the four years 1883–1886, 3,925 hours, against 5,713 at Kew, and about 6,880 at St. Leonards, about 80 miles distant. From November, 1885, to February, 1886, inclusive, the sunshine in London was 62 hours, at Kew 222, and at Eastbourne 300.

Town fogs contain an excess of chlorides and sulphates, and about double the normal, or more, of organic matter and ammonia salts.

During the last fortnight of February, 1891, the previously washed roofs of the glass houses at Chelsea and Kew, the former just within, and the latter just outside, London, received a deposit from the fog, which was analyzed and gave the following results:

Substances.	Chelsea.	Kew.
	Per cent.	*Per cent.*
Carbon	39	42.5
Hydrocarbons	12.3	4.8
Organic bases (pyridines, etc.)	2	....
Sulphüric acid (50_3)	4.3	4
Hydrochloric acid (HCE)	1.4	.8
Ammonia	1.4	1.1
Metallic iron and magnetic oxide of iron	2.6	....
Mineral matter (chiefly silica and ferric oxide)	31.2	41.5
Water, not determined (say difference)	5.8	5.3

The weight of the deposit was at Kew 30 grams in 20 yards. At Chelsea the same area gave 40 grams, which is equivalent to 22 pounds to the acre, or 6 tons to the square mile. A large proportion of the deposits of fog in smoky towns clearly arises from the imperfect combustion of coal. On plants the deposit is sticky, like brown paint, and is not washed off by water. A country fog is harmless in a greenhouse; a town fog most destructive, killing soft-wooded plants, and greatly damaging others. A very large number of plants will not thrive in smoky towns. In Manchester, the deposit collected from aucuba leaves gave 6 to 9 per cent of sulphuric, and 5 to 7 per cent of hydrochloric acid, mostly in a state of combination. Three days' fog deposited per square mile 1½ hundredweights of sulphuric acid and 13 hundredweights of blacks.

Among the results of smoky air in towns may be mentioned: The discouragement of cleanliness and ventilation; the constant deficiency of light; the damage to plant life, so that only a few trees and plants can live; the destruction and disfigurement of stone, cement, iron, paint, wall papers, clothing, etc., and the depressing effect of dirt and blackened streets on the people; losses to artists of all kinds who depend on light; the lowered vitality of a large portion of the population, and a contributory influence toward the rapid degeneration and extinction of town families.

In London the extra expenditure entailed is about £1 a head, or more than the value of all the coal burnt in houses. The extra washing, painting, and repairs, and the loss of unburned carbon, etc., are among the principal items in the account.

The intensity of the ground fog depends largely on the amount of cooling which the earth has previously undergone. At the beginning of February, 1880, the ground in London was hard frozen with the intense frost which had prevailed for some days. A moist southerly current supervened and the temperature rose several degrees above the freezing point. On the shady side of squares the fog then produced between the ground and 10 or 20 feet above it was so dense that at 10 a. m. a lamp-post 4½ yards distant was invisible. In an ordinary thick fog, such as that of January 11, 1888, objects are visible at thirteen times that distance. Above the shallow stratum of ground fog the air was nearly clear and the smoke escaped.

Such fogs are due partly to radiation into space, but also largely to the mixture of the warm current with air which has become cold by contact with the ground, and to radiation toward the ground.

All radiation fogs disperse or greatly diminish when the sky becomes clouded and reflects some of the warmth radiated from the ground. They are not formed under a cloudy sky.

2. Fog is frequently produced, sometimes on an enormous scale, covering an area exceeding that of the British Isles, by the mixture of opposite currents of small velocity. The condition of atmosphere often

resembles that which produces haze in summer; a slow infiltration of currents of different temperatures brings different laminæ into contact. A cold earth and a sky clear above the low clouds increase the intensity of such a fog, but are not necessary to its existence. A southerly wind is too warm to produce fog by itself unless it meets with a cold surface, and a northerly wind is too dry by itself to be reduced below the dew-point. When, however, two opposite currents, one of which is colder than the other, diffuse into each other slowly, as when the colder current over an extensive area sinks into the warmer current below it, a fog may be produced which is less thick than a radiation fog, but may continue with little change through several days and nights, and commonly declares its character by the height to which it extends and by its moisture. It deposits much more moisture on trees, etc., than most radiation fogs, and, though no visible mist or rain may fall, the ground under trees often becomes very wet. Thus precipitation of moisture is increased in forests. In cold climates or at high levels every exposed object accumulates ice. A wet or mixture fog disappears under cover, and is thinner in large towns than in the country, for the particles of which it is composed are almost pure water and evaporate when the air is a little raised in temperature. On mountains in Great Britain wet fogs are very common, and may occur with strong wind; moisture or ice is deposited on the windward side of all objects. Continuous damp mist may be produced in Great Britain by a northeast wind blowing beneath a damp southwest or south current, and such mists produce very disagreeable weather. In September and the first half of October, 1894, southern England was immersed for weeks in a mist so produced. The northeast wind was not of very distant origin, and, not being dry, its mixture with the very damp southerly current overlying it produced dense mist, cloud, and occasional rain.

Many fogs, such as those over rivers or valleys, and over the cold ocean current near the Bank of Newfoundland, are due partly to mixture and partly to radiation. The sea fog originates in the cooling of air by contact with the colder surface of water and by mixture with the cold air which lies near the water. At many coast places on a hot summer day a sea fog frequently comes up on a cool breeze which mixes with the warm air above it from the land. On the other hand, when a sheet of water is much warmer than the air above it, a thick mist or fog may be formed, which is largely condensed steam.

Fog is less common in summer in the interior of continents or of large islands than on the coast, but in winter, owing to the greater loss of heat by the surface of the earth than by the surface of the sea, fog is more common inland. In many countries in the temperate zone the stratum of cloud or fog does not lie often upon the ground, but at a height of hundreds or thousands of feet; the sky remains quiet and overcast for days and weeks together. The elevation of the cloud, which would be fog on the ground, depends on the height at which the dew-point of the air is reached, or else on the height of the boundaries of a lower and upper current differing in temperature. The lower air is too dry to permit the condensation of vapor within its borders. A warmer and moister upper current condenses vapor by contact with the cold upper boundary of the lower air. The cloud canopy prevents excessive loss of heat from the surface of the earth.

A mist, in the usual meaning of the term, is the name given to very small rain, or to a cloud of which the globules are large enough to fall perceptibly. Near the surface of the earth it seldom, if ever, grows from radiation fog or from the haze of anticyclonic conditions, but very frequently is a result and direct growth from wet or mixture fogs. It may be considered as fine rain, which falls from a cloud undergoing cooling and consequent aggregation of particles. In hilly country near the sea, where the wind arrives after having blown over a large breadth of warm ocean, misty rain is very common.

At Kingairloch the number of dust particles was always very low in such weather, showing that the majority were being used up by the mist. The transparency of the air, or "visibility," so often preceding rain is due first to the paucity of dust particles brought by an ocean wind which is made purer than it otherwise would be by the clouds and rain of the area from which it blows; secondly, to the homogeneity of the air and the tendency to form large cloud globules or drops of rain when near saturation, the proportion of vapor to dust particles being high.

In quiet winter weather, a long-continued damp mist or else a very fine steady rain has, in the present writer's experience in England, preceded intense cold, and may be supposed with great probability to be caused by the gradual descent of very cold air upon the lower strata.

PARTICLES SUSPENDED IN THE AIR.

The atmosphere contains an immense number of substances suspended in it in the form of visible and invisible dust, but only a small proportion of these require attention as affecting human life. Deserts, dry and sandy tracts, and wind-swept plains yield a continual supply of fine motes of silica, aluminium silicate, calcium carbonate, calcium phosphate, etc. Volcanoes pour forth sand, fine mud, sulphur, sulphuric acid, silicon glass, etc., into the upper air, by which they are carried over all quarters of the globe. Meteors and small aerolites burn up as they daily pass through the high and rare atmosphere at heights from 30 to 200 or even 300 miles, and the products of their combustion, iron oxide, magnesia, silica, or other fine dust, fall impalpably toward the ground Clouds of unburnt carbon perpetually rise from towns, factories, steamships, and scattered houses; in manufacturing districts and towns particles of iron, steel, stone, and clay are abundant; so are fragments of vegetable tissue, cotton, hair, wool, skin, and starch. Even coal gas, which shows no smoke in its combustion, fills the air where it is burnt with millions of particles in every cubic foot. The whole atmosphere is pervaded by particles of salt derived from the spray of the seashore and of ocean waves. In summer, pollen seeds, odors of earth, trees, flowers, and hay, and the spores of an immense variety of fungi float on every breeze. Most of these have no special interest, but some of the spores and pollen are capable of setting up great irritation in the human system, almost amounting to diseases. Hay fever is the result of the action of grass pollen on the breathing passages.

LIVING GERMS IN THE AIR.

Much more important are the living germs, the microbes, bacteria, fungi, and molds, which are found very unevenly distributed, and especially abundant at low levels in populous places and habitations. Miquel found in a cubic meter at Montsouris Observatory, near Paris, 85 of these organisms in spring, 105 in summer, 142 in autumn, and 49 in winter. On other occasions the numbers were 70, 92, 121, and 53, respectively.

In the Rue de Rivoli, in Paris, the number was about 5,500. In air collected at 2,000 to 4,000 meters high (about 6,300 to 13,600 feet) no bacterium or fungus spore was found. Pasteur exposed 20 flasks of clear broth in the open country of Arbois, 20 on the Lower Jura, and 20 near the Mer de Glace, at a height of over 6,000 feet. Of the Arbois flasks, 8 developed organisms; of the Jura, 5; and of the Mer de Glace, 1 only.

Miquel's experiments proved that microbes were much more abundant in the town than in the country. In rooms the number was eight times, and in hospitals twelve times the number in the open air. These experiments refer to hospitals in Paris only. In hot countries, after a prolonged period of dry hot weather, microbes diminish. In M. Miquel's view the places where there are most microbes are centers of infectious disease; the curves of mortality to a great extent correspond with the curves of the number of microbes and follow them after a short interval. In 1 gram of the dust of his laboratory he found 750,000 germs, and in that of a room in Paris 2,100,000. In the air of hospitals microbes of suppuration have been found. Devergie found an "immense amount" of organic matter in the air in the vicinity of a patient with hospital gangrene. Dr. Dundas Thompson found, in the air of a cholera ward, starch, woolen fibers, epithelium, fungi, or spores of fungi, and vibriones. Scaly and small round epithelia are found in most rooms, and in large quantity in hospitals. The dust of a hospital ward at St. Louis contained 36 to 46 per cent of organic matter, largely epithelium cells. Parkes similarly detected large quantities of epithelium in the air of barracks and hospitals. In 1 gram of dried earth Miquel found 800,000 to 1,000,000 microbes. Recent research shows the number is especially great on the surface near dwellings, and rapidly decreases with depth, so that at 1 meter down there are few. Ninety per cent of these soil microbes are bacteria, chiefly in the form of spores. It is easy to understand how these may be carried into the air, especially in dry weather, as dust by wind and by evaporative forces.

It has been calculated that in a town like London or Manchester, a man breathes in during ten hours 37,500,000 spores and germs.

In Berlin an investigator found 3 colonies of bacteria and 16 molds in 25 liters from an open square, and 37 colonies of bacteria and 33 molds from a schoolroom just vacated. Professor Tyndall exposed for a short time 27 flasks containing an infusion of turnip, etc., to air on a ledge of rock above the Aletsch glacier in Switzerland, an altitude over 8,000 feet, and then carried them to a kitchen stove with a temperature of 50° to 90° F. In the same way 23 flasks were exposed to the air of a hayloft near the same altitude and placed with the others in the stove, due precautions being taken in all cases to prevent the kitchen air from contaminating the flasks. Of the 27 flasks opened in free air not one showed a sign of organic life; of the 23 opened in the hayloft, 21 were invaded. Many other experiments in London and elsewhere convinced him that the air of an ordinary room swarms with germs of life, and that if infusions of flesh, fish, or vegetable be exposed even for a short time to the dusty air they become turbid and putrid within a few days. Exposed for months to air "optically pure," that is, deprived of dust, they remain clear and sweet for months, in fact, do not putrefy at all. Some of the germs or spores in the air have a very remarkable resisting power and will germinate after several hours' boiling; others are killed in five minutes. The spores of bacillus subtilis, which is common in hay or in the air of haylofts, is not killed by prolonged boiling. But bacilli themselves, which are soft and unprotected, are killed by boiling water within a few minutes. The small size of the germs and bacilli may be to some degree realized when we note that in Tyndall's estimation the number in a single drop of turbid infusion is probably 500,000,000 "many times multiplied." The evaporation of such a drop would then conceivably permit the launch into the atmosphere of more than one thousand million organisms. The natural processes of decay in most places on the surface of the earth must be incessantly nourishing immense numbers of microbes in very great variety, and wherever drying or heating takes place quantities of colonies of all sorts which can flourish in daylight must be raised into the air and widely disseminated.

Percy Frankland counted the number of microbes falling on a square foot in one minute in several situations, with the following result:

Roof of Science Schools, Kensington, March	851
Roof of Science Schools, Kensington, when the wind was stronger	1,302
Roof of Science Schools, Kensington, after rain	60–66
Roof of Science Schools, Kensington, during thick fog	26–32
Burlington House, during Conversazione	318
Burlington House, on following morning	109

Natural History Museum, Entrance Hall, Whitmonday	1,755
Hospital for Consumption, morning	18
Hospital for Consumption, afternoon	66
Railway compartment, open window, 4 persons	395
Railway compartment, window 4 inches open, 10 persons	3,120

In experiments made with the object of finding the number of microbes in a certain volume of air, he found at a height of 300 feet on Norwich Cathedral, only 7 in 2 gallons; on the gravel near the cathedral, 18; at the top of Primrose Hill, 9; at the foot, 24.

Dr. Fischer found, in experiments made at sea, that at 120 miles from land, in eleven out of twelve experiments, the air was quite free from germs; that at 90 miles from land, in seven cases out of twelve, there were germs, but very few. Practically it appears that at 120 sea miles distant from land the air is pure and free from microorganic life.

Angus Smith roughly calculated the amount of organic matter, living and dead, to weigh, in pure air on high ground, 1 grain in 209,000 cubic feet; in a bedroom, 1 grain in 64,000 cubic feet; in a closely packed railway carriage, 1 grain in 8,000 cubic feet.

He obtained some curious results by shaking up air in different places with water. The air of a cowhouse gave an effect only produced by fifty to one hundred times the quantity of good air, and contained a mass of débris, hairs, etc. The air behind houses in streets was worse than in front of them.

Moisture collected from the air above marshes has been found by Italian observers to contain multitudes of seeds of algæ and of microscopic infusoria. The condensed dew exhibits a surprising quantity of spores and sporangia.

Other observers agree in noting decaying organic matter in abundance, vaporous and solid, together with living minute forms of animal and vegetable life, floating in the air; these consist of algæ, diatoms, fungi, bacteria, and other microorganisms.

The subtilis, or hay bacillus, is always present in the open air, but the bacilli generally keep to low levels and do not extend so high as the mold fungi.

Cunningham, at Calcutta, found spores and other cells constantly present in the free air, usually in considerable numbers. The majority were living, capable of growth, and seemed independent of moisture and direction of wind.

Mr. Greenleaf Tucker found that outside the City Hospital of Boston 10 liters of air contained on an average 10 colonies of bacteria, 7 of molds, in November; 13 of bacteria and 3 of molds in January. The number of bacteria was less on rainy days. The hospital itself contained few bacteria, owing to constant care and cleanliness, but the number was much increased after sweeping and bedmaking.

Carnelley found in clean one-roomed houses 180 bacteria per 10 liters; in dirty houses, 410; in very dirty, 930; in schools, from 300 to 1,250, according to ventilation; in the Royal Infirmary, Dundee, 10 to 20.

The greater part of the dust of clean habitations, consisting of motes derived from mineral, vegetable, and animal substances, has little apparent effect upon health. But it certainly tends to reduce vitality by some small amount, and gives extra work to the breathing organs. Consequently, to invalids and delicate persons it is important to reduce this dust by all reasonable means. A beam of strong light, sunlight or the electric lamp, shows the air of most inhabited rooms to be so crowded with dust as to be almost opaque to vision. Aitken found 41,000,000 particles in the cubic inch in a room where gas was burning. Rooms with polished wooden floors, painted hard plaster, glazed paper, or wood-paneled walls, and not containing fluffy fabrics, evolve much less dust. They are more healthy not only on this account, but chiefly because they provide much less pabulum and protection for the growth of noxious microorganisms.

De Chaumont found in the air at Paddington and in University College Hospital particles composed of the epidermis of hay, of pine wood, linen, cotton, epithelium, charred vegetables, and minerals.

Tichborne, of Dublin, found in a street 45.2 per cent of organic matter, and at the top of a pillar 29.7 per cent. Most of it was finely ground manure.

The spores and mycelium of *Achorion schonleinii* and of *Tricophyton tonsurans* have been found in the air of a hospital for diseases of the skin.

The surface of the ground in streets, squares, courts, and gardens, and the sweepings of dwellings and stables, contain swarms of the germs of the bacillus of tetanus, a disease fatal to man. These chiefly infest the droppings of various domestic animals, and may be carried through the air to wounds; commonly they infect by contagion and not through the air. Drying, light, and putrefying matter do not kill the bacillus, nor does a temperature of 80° to 90° C. Tetanus has caused great mortality among soldiers who have lain wounded at night on the field of battle, probably owing to the lifting of the bacillus by emanations from the ground and its deposit on open wounds.

SEWER AIR.

Sewer air contains molds, fungi, bacteria, and animal and vegetable débris. The microbes do not exceed about 6 per liter in a good sewage system. In ordinary drains, however, they are much more numerous, and are borne into the interior of houses in company with highly poisonous gases. The gases of sewers are sulphuretted hydrogen, ammonium sulphide, carbon bisulphide, a very little marsh gas, compound ammonias, with traces of ptomaines and leucomaines.

AIR OF MINES.

The air of mines contains only a few molds, fungi, and bacteria.

GROUND AIR.

Ground air contains microorganisms in abundance, according to locality and conditions, but has hitherto been little examined. It contains an enormous quantity of carbon dioxide, which is at its maximum from July to November. The foul air of cesspools is sometimes drawn into houses through 20 feet of earth.

When organic substances decompose in the air, they are first attacked by molds, then by bacteria. These last cause odorous gases to be emitted, which are oxidized by the air. If the air has access to the substances, aerobic organisms multiply; if only slight access, as in masses of filth in a drain, anaerobic multiply, such as those of putrefaction, of tetanus, and of malignant œdema.

ORGANISMS, ETC., IN THE OPEN AIR.

The open air in populous places contains much dust of suspended matter and many living organisms. Débris from wool, silk, fibers, hair, feather particles, dried epithelial cells, epidermic scales from the skin, pus cells, pyogenic microorganisms, fragments of insects, and fecal particles are among the former, and living minute ova or infusoria, minute amœbiform organisms, etc., which may even *grow* in the atmosphere, are among the latter. All these are of animal origin. Of vegetable origin are the following: Soot, fibers, hairs, cells, starch, straw in powder, spores of molds, fungi, diatoms, and bacteria; living pollen seeds, spores of fungi, molds, diatoms (which may live and grow in the atmosphere), and, rarely, mycelium of fungus, algæ, bacteria, and their spores. In woods in September basidiospores are abundant. Of mineral matter, sodium chloride, or common salt, is always present.

MICROORGANISMS IN ROOMS.

Many living microbes float in the air of all dwelling houses, but in rooms which are old, overcrowded, and dirty, the numbers are very much higher. These come for the most part from the sides and floor, and not from persons, but they are much more numerous when the dust is disturbed than when the room has been quiet for a short time. In schools, large numbers of microbes find a nidus under and between the boards of the floor if these are not close-joined. Bacteria chiefly abound, but many mold and yeast fungi are also present. The latter belong more to the external air, the bacteria to the internal air, and since the bacteria are the heaviest, the air of a room which is left quiet contains a preponderance of molds and yeasts. Pathogenic or disease germs are nourished to a great extent by the floors and walls of rooms, and for this reason the material should be smooth and easily washed. In schools and places which are frequently crowded, cleansing should be frequent, and no opportunity of extensive growth of bacterial colonies should be tolerated. An inquiry into the relative impurity of air in differently constructed buildings would be useful.

The clothes of scholars should be clean and washable, and there should be no crowding together in the class rooms.

SEWER AIR.

Sewer air in sewers of good construction, in good order, and at ordinary temperatures, contains very few living organisms discoverable by the usual methods. Microbes are not easily given off from sewage unless it be in a state of fermentation, and those which escape soon attach themselves to the wet surfaces of the sewer and drains. Yet there may be microorganisms which are not capable of cultivation and observation by means hitherto tried, but which are the agents concerned in the putrefactive and disease-causing changes set up in organic substances exposed to sewer air.

Moreover, the presence of a very few pathogenic microbes may be sufficient, when inhaled with the noxious gases in which they float, to set up typhoid and other dangerous disorders.

It is well to guard against the assumption that negative evidence proves anything in these cases. The bacilli or organisms of smallpox, measles, whooping cough, malaria, etc., are either undiscovered or very difficult to see and to identify. Drinking water which may be clear, bright, and pronounced by microscopic analysis to be pure and excellent, may poison by the invisible germs of typhoid which it contains. Analysis of water and of air is sometimes a less trustworthy arbiter than the senses, or than knowledge of suspicious circumstances.

Often a family lives in a badly drained house for a long time without suffering anything worse than headaches, diarrhea, sore throat, or loss of appetite. These ailments may be due either to habitual inhalation of the poisonous gases, or to the gases joined with slightly virulent microbes. Depressed vitality gives a strong presumption, if other conditions are wholesome, that drain air enters the house.

When drains and sewers are out of order, or fermentation is going on, or where there is old sediment, it is probable that a large number of microbes of a disease-producing kind are evolved and carried by the gases and air into houses. The process of decomposition and fermentation sets free small bubbles of gas in the liquid and on the wet surface, and these bubbles in bursting scatter a number of small particles into the air. The force with which liquid particles are scattered upward may be observed in the breaking of minute bubbles such as those which rise to the surface of a glass of effervescing water. Experiments on various drying and putrefying liquids could hardly fail to furnish interesting results. There seems to be great probability that bacteria or their spores are thrown in quantities into the air from viscous putrefying or fermenting liquids. Certainly a fermenting brewer's vat scatters multitudes of yeast germs into the air, and the case seems strictly comparable.

VAPOR AND ORGANIC MATTER FROM LIVING BODIES.

The lungs and skin together give off about 30 ounces of vapor in the day, or about 550 grains an hour, enough to saturate about 90 cubic feet of air at 63° F. Estimates naturally differ as to average amounts, but Professor Foster states that the water given off from the lungs in the day is about 1.5 pounds and from the skin 2.5 pounds. Vapor in a room ought not to exceed 4.7 grains per cubic foot at 63° F., or 5 grains at 65°. This vapor is practically not pure, for it is associated with minute portions of organic gases and solids, and condenses with them upon the walls, ceiling, and furniture, whence it emerges again with organic dust when these are warmer than the air of the room.

Organic matter is given off from the lungs and skin, of which neither the exact amount nor the composition has been hitherto ascertained. The quantity is certainly very small, but of its importance there can be no doubt. It darkens sulphuric acid, decolorizes permanganate of potash, and makes pure water offensive when drawn through it. Collected from the air by condensation of vapor in a hospital, it is found to blacken platinum and to yield ammonia; it is therefore nitrogenous and oxidizable. It has a very fetid smell and is only slowly oxidized by fresh air. It is molecular or particulate; it contains epithelium and fatty matter from the mouth and pharynx, sometimes effluvia from the stomach. Damp walls, moist paper, wool, and feathers are capable of largely attracting or absorbing it. Experiment shows that it bears a nearly constant proportion to the carbon dioxide in inhabited rooms, so that this gas is conveniently taken as an indicator of the amount of the organic matter in the air. Since this organic matter has been proved to be highly poisonous,[1] even apart from carbon dioxide and vapor, we may safely infer that much of the mischief resulting from the inspiration of rebreathed air is due to the special poisons exhaled from the body, their fatal effect being accelerated by the depression of vitality caused by the gaseous products of respiration and by the want of oxygen. Air thus organically vitiated and confined in places long inhabited, which are subject to continual condensation on their surfaces, without proper cleansing, appears to play a very large part in the propagation of disease in man and animals.

The quantity of particulate organic matter given off has been estimated at 30 to 40 grains for each adult. This is certainly sufficient for the nutriment and sustenance of a very large number of micro-organisms, which may grow, in the presence of moisture, upon it and upon other dust deposited upon the walls, floor, and ceiling. Water through which breath has been passed, and kept at rather a high temperature, gives off an unpleasant smell, and putrefaction is set up.[2] It does not appear to be definitely ascertained whether the breath and

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[1] Dr. A. Ransome and others.

[2] Carpenter; Douglas Galton.

skin actually and normally emit in good health living microorganisms, either pathogenic or harmless, but the probability is considerable when we remember that the mouth and air passages are inhabited by various species, and that warm evaporating surfaces exercise a repulsive force on minute particles. Foster states that the aqueous product from the breath is very apt to putrefy rapidly, owing to the presence of microorganisms. It is not generally assumed, however, that living microbes are exhaled to an appreciable extent. The subject is an important one and demands inquiry, but the ultra microscopic minuteness of the germs may defeat direct observation. As to the frequent emission of a deadly particulate poison, however, no doubt whatever can exist.[1] It is a dangerous and pernicious element in all aggregations, and, combined with carbon dioxide, produces, when in moderate quantity, depression, headache, sickness, and other ailments; when in large quantity, as in the Black Hole of Calcutta, and in various prisons of which there is record, rapid death in the majority and fever in the survivors. Its action upon the development of living germs when deposited upon outside objects has not been ascertained. Probably it may be favorable to some and unfavorable to others. Some of the most deadly human and animal diseases certainly are capable of virulent growth in their presence, and of passing more easily in a potent condition through air in which they are abnormally concentrated.

ORGANIC EMANATIONS FROM THE SICK.

Hospitals, when not well ventilated, contain a very large quantity of organic matter floating in the air and deposited on walls and floors. This gives rise, in the most impure air, to hospital gangrene and erysipelas, increases the severity of many diseases, and prolongs convalescence. Gangrene having once appeared, is very difficult to get rid of. Thorough ventilation and hygiene of the building where the sick are received and treated prevents these evils from arising.

ORGANIC EMANATIONS FROM THE SKIN.

Sweat contains salt, lactate, butyrate, and acetate of ammonium; calcic phosphate, ferric oxide, volatile fatty acids, e. g., sometimes valerianic and caproic acid, and sometimes leucin. Perspiration gives off into the air a large quantity of vapor, about 2 pounds in the twenty-four hours and a little over 1 per cent of this quantity of solid organic matter. Fatty acids, inorganic salts, neutral salts, ammonia, and particles of epidermis are constantly passing from the skin into the air. In the sick the matter emanating from the skin is often largely increased and is very offensive.

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[1] Some recent experiments of Smith and Haldane seem to show that carbon dioxide is the only element of mischief, but the conditions of ordinary life are so various and so difficult to imitate in experimental investigation that the inquiry needs to be widely extended.

The poisonous matter emanating from the skin of healthy people and animals, if thrown back upon the body by accidental or artificial means, causes death in a short time, not only in the case of rebreathing, but in cases where the pores of the skin are stopped, as by gold leaf or plaster of paris. Sheep have died in large numbers after being dipped in a resinous compound. The poison returned upon the body by the stoppage of the pores by finely divided soot may be a cause of the excess of cancer in chimney sweeps. Dirty bedding used after having been rolled up for two months has given fever.

The relation of the organic matter of respiration to disease can not be doubted, and, indeed, it seems probable that much of the mortality of infant and adult life may be due to the rebreathing of poison excreted by breath and skin. These are known to be, mediately or even sometimes directly, a great cause of consumption, pneumonia, and bronchitis. The recent experiments on the development of typhoid fever by the respiration of sewer gas lead naturally to the inference that other poisons besides that of sewer gas may play a very important part in laying the system open to the attack of disease germs either from within or from without the body. The chemistry of the expired breath deserves full investigation in many different cases and circumstances.

Gaseous emanations from sewers, drains, cesspools, and foul refuse cause diarrhea, vomiting, and prostration, or a low state of health. Children are more susceptible than adults, and when they breathe the gases largely diluted may suffer from languor, sore throat, and diarrhea. These results may be due simply to chemical or inorganic poisoning. Where the specific organism is present, typhoid, epidermic diarrhea, or diphtheria may result. Well-managed sewage farms do not seem to cause illness in their neighborhood. Sodden and neglected farmyards, on the other hand, are both common and pernicious. A great deal of illness, affecting both man and animals, arises from them. Thus "circulation," as in sewage farms, versus "stagnation," as in farmyards, shows its great superiority, even where other circumstances are apparently adverse.

The air close to certain crowded burial grounds has had a very bad effect on people living near them; it has greatly aggravated any disease from which they suffered.

The effluvia from decomposing corpses produces dysentery, diarrhea, or a low fever, and in some circumstances diseases of a more severe character.

SULPHURIC AND HYDROCHLORIC ACIDS.

Sulphuric and hydrochloric acids exist to a small amount in the atmosphere, but are not easily discovered except when brought down to the ground dissolved in mist or rain. Hydrochloric acid is one of the most soluble gases known, water at ordinary temperature absorbing five hundred times its volume. At Rothamsted, about 23 miles from London, the sulphates in rain were 0.0027 in the summer and 0.0032 in the winter; the chlorides were much less in summer than in winter. The average of sulphates in a certain period of thirteen months was 0.004, of chlorides 0.0033. Seven samples collected near Horsham, in Sussex, gave sulphates 0.0048, chlorides 0.0041. A sample collected on Dartmoor during a gale from the southwest gave the following results: Sulphates 0.0005, chlorides 0.0087. Proximity to the sea evidently increases the chlorides and reduces the sulphates. At St. Bartholomew's Hospital, in central London, the sulphates were 0.0388, the chlorides 0.0179, and the amounts were greater in summer than in winter. The quantities of these impurities in the air of a large town are much above the average of the country. The rain does not give acid reaction, but wherever it is contaminated with soot it becomes distinctly acid after a few hours. Soot, then, being acid and becoming moistened by rain, must play an important part in the corrosion of buildings and other materials on which it has been deposited. Experiments were made by Dr. Russell by means of a conical vessel filled with ice, to ascertain the amounts of impurities condensed from air in London. The results were remarkable; sulphates 0.1344, chlorides 0.0506, ammonia 0.006; and in fogs the amounts were 0.2480 sulphates, 0.1215 chlorides.

ARSENIOUS ACID IN RAIN.

A gallon of rain in the city of London has been found to contain 0.00021 grain of arsenious acid.

AMMONIA IN THE AIR.

Ammonia is always present in the air in minute traces, either free or combined. It is a chemical compound of 14 parts by weight of nitrogen and 3 of hydrogen, and arises from the decomposition of organic matter. It is lighter than air in the proportion of 8.5 to 11.47. Although the quantity rarely exceeds 3½ parts in 10,000,000 of air, this is sufficient to be of very high importance to the growth of vegetation, for the gas is soluble to quite an extraordinary amount in water, and is thus continually being brought down from the atmosphere in rain and dew. Brandes found, by evaporation of rain, in each million kilograms from 8 (May) to 65 (January) kilograms of residue, of which ammonia salts formed a considerable portion.[1] Rain, according to Boussingault, contains about three-fourths of a milligram of ammonia per liter, equal to 7 kilograms per hectare per annum. Dew contains about 6 milligrams, equal to about 29 kilograms per hectare per annum; fog, about 50 milligrams, and in Paris, 138 milligrams. Water dissolves from 700 to 1,000 times its volume of ammonia, according to the temperature. Representing the quantity of ammonia in rain at Valentia, in Western Ireland, by 1, the quantity inland in England was 5.94, at Glasgow 50.55. The albuminoid ammonia was: Valentia 1, Manchester 7.38, London 6.23.

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[1] Pierre.

In summer the amount in the air is highest, in winter lowest. In large coal-burning towns it is considerably more abundant than in the country, and is deposited with carbonaceous, sulphurous, and organic matter on exposed surfaces during the prevalence of fogs. Foggy air in these towns contains an excess of sulphates and chlorides, but a still greater excess of organic matter and ammonia salts, often double the normal. The ammonia contained in the deposit on glass roofs in Chelsea and Kew after fogs was respectively 1.4 and 1.1 per cent. The processes of combustion, both in manufactories and in domestic fires, of coal and of coal gas, give rise to ammonia.

Only traces of ammonia are evolved from the lungs, and a little from the skin and in perspiration.

The smell of ammonia is distinguishable in most stables, but where strong we may be sure that ventilation is deficient. Main streets, especially where wooden pavements are used, often smell offensively of ammonia; on still, dry days the ammoniacal dust is thick in the air, and in windy weather is blown about in clouds. Analysis has shown that 95 per cent of the dust from wooden pavements in main London thoroughfares, consists of horse dung. This is breathed into the lungs and often produces sore eyes and sore throat. Such pavements should either be kept scrupulously clean throughout the day or be properly watered, in order to reduce harmful dust, and an occasional coating of tar would not only prevent the emanation of noxious matter, but would preserve the wood.

Ammonia, being everywhere present in the air and extremely soluble in water, may truly be said to be attached to all exposed surfaces where moisture is also present; in the neighborhood of human habitations and decaying animals or vegetable matter it has been found on all objects; in a room, if a perfectly clean glass be suspended, traces of it appear after an hour and a half. Evolved in small quantities from the skin and lungs, it must be deposited with condensed vapors on the walls, ceilings, and floors of dwelling houses.

NITRIC ACID IN THE AIR.

Nitric acid also pervades the air in minute quantity, and, with ammonia, plays a great part in the development of plants. It results partly from the combination of nitrogen and oxygen in the atmosphere caused by thunder storms and partly by the oxidation in loamy soil of the ammonia of decomposing organic matter. It seems probable that many forms of bacteria or molds may be favored in their growth by the presence, with moisture, of these two nitrogenous substances. Within human habitations, cow sheds, etc., we must regard the walls, and all surfaces as covered with a thin top-dressing of moist organic dust and ammonia. Within the soil ammonia appears to be oxidized to nitrites by one set of microorganisms, while another set oxidizes nitrites to nitrates. To the latter the presence of ammonia is a hindrance.

LOCAL GASEOUS IMPURITIES—SULPHURETED HYDROGEN—SEWER AND DRAIN AIR.

When certain animal and vegetable matter undergoes decay, the small quantity of sulphur which it contains combines with hydrogen and forms the gas, sulphureted hydrogen, which, even in mere traces, is very offensive to the sense of smell. It also forms some offensive organic sulphides. The sulphureted hydrogen gas set free often bears with it germs of disease, so that it has been treated as a danger signal. Drain or sewer air, however, does not always contain the gas in appreciable amount, when dangerous germs are being given off, and the faint smell of an old filth deposit may exceed in morbific effects the unpleasant odor of fresh putrefactive processes. Nor does sewer air, even if it be poisonous, often contain virulent germs of disease. Dogs and horses are rapidly prostrated by 1.25 to 4 volumes of sulphureted hydrogen per 1,000 of air, but men can breathe a larger quantity. In large doses, nausea, headache, convulsions; in small doses, low febrile symptoms follow its inhalation. The frequent inhalation of small doses produces chronic poisoning; 1 per cent is at once destructive of life.

The air over some of the most pestilential marshes in Italy contains an unusually large quantity of the gas. In mines it produces convulsive, narcotic, and tetanic symptoms.

SULPHUROUS ACID.

Sulphurous acid in the air of cotton and worsted manufactories apparently tends to produce bronchitis and anæmia. It destroys vegetation in the neighborhood of copper works.

CARBURETED HYDROGEN.

Carbureted hydrogen, breathed in small quantities, as in the air of some mines, does not seem to cause ill effects, and experiment has shown that for a short time it can be breathed in the proportion of one volume to four of air.

HYDROCHLORIC ACID.

Hydrochloric acid vapor is very irritating to the lungs. In some processes of making steel this gas, with sulphurous and nitrous acids and chlorine, cause bronchitis, pneumonia, destruction of lung tissue, and eye diseases among the workers. It destroys vegetation for a long distance when given off in large quantities from manufactories.

CARBON BISULPHIDE.

Carbon bisulphide vapor, given off in vulcanized india-rubber factories, produces, in those exposed to it, headache, giddiness, pains in the limbs, nervous depression or excitement, and complete loss of appetite.

Carbon monoxide is a very poisonous gas arising from the consumption of coal, coke, coal gas, and especially charcoal. Less than 0.5 per cent is fatal to animals. Fatal consequences from the use of charcoal stoves where ventilation is defective are common in some countries.

Carbonic oxide is given off by iron works, brick fields, copper furnaces, and cement works. It is dangerously present in the cheap illuminating gas known as "water gas."

ORGANIC VAPORS.

Organic vapors of various composition are given off by marshes, wet forest ground, "made soil," soil containing organic matter under warm sand, and by many manufactories for the conversion of animal refuse, etc. The effluvia from tanneries, glue and soap works, slaughter-houses, pigstyes, etc., are apt to lower the health of people living near them and to aggravate disease.

SOLID ARTIFICIAL IMPURITIES.

Many severe forms of disease, especially of the respiratory organs, are caused by the dust inhaled in various trades and occupations. These are generally proportionate to the sharpness and angularity of the dust and its quantity. Coal dust is among the least harmful. Among lead miners, bronchitis and lead poisoning; in copper mines, gastric disorders; in pottery works, in stone cutting, steel grinding, in flax and cotton factories, in shoddy works, and in metal polishing, lung diseases are common, and the death rate is high.

Thus the comparative mortality of file makers was 300 compared with 108, that of gardeners; of earthenware .makers 314, compared with 139, that of grocers; of cutlers and scissors makers 229, compared with 129, that of paper makers. The dust of soft woods and of flour seems to have little bad effect.

As regards phthisis and lung diseases the figures of several trades are as follows, when compared with fishermen, 100: Carpenters, 170; bakers, 201; cotton workers, 274; file makers, 396; stone and slate quarrymen, 294; pottery makers, 565; northern coal miners, 166. The injuriousness of the dust in cotton mills is increased by the use of mineral substances for sizing. The mortality of cutlers, etc., from these diseases is almost as great as that of fishermen from all causes put together, including accidents. The comparative exemption of colliers in well-ventilated coal mines deserves investigation, for there would appear to be some ground for the supposition that it may be owing to an inhibitive action of this particular dust upon the development of tuberculosis; on the other hand, it may be simply through living in fairly good air of an even temperature, where the specific germs of phthisis are few or absent. The homes of the men are generally comfortable, and much larger fires are kept up than in the south, so that their rooms are dry and well ventilated.

PART II.—CLIMATE, AIR, AND HEALTH.

MALARIOUS AND INFECTIOUS DISEASES: THEIR CONNECTION WITH AND DESTRUCTION BY THE ATMOSPHERE—THE INFLUENCE OF CLIMATE ON NATIONAL HEALTH.

The spreading, infectious, or epidemic diseases in the animal world and in mankind depend to a very great extent upon aerial influences.[1] Microscopic fungi or microbes, the prime causes of these disorders, are sensitive to dryness, moisture, heat, cold, and sunlight, and a study of their relations to the atmosphere has led and will lead to results of the very highest importance to human welfare. Many of them reach the living body, upon which they lodge, through the air; many are partly nourished outside the body by the gases and moisture which the air brings to the seat of their growth. But as a whole the pure atmosphere works energetically and unceasingly for their destruction; dry air and sunlight deprive most species of disease organisms of their vitality. This great generalization may best be appreciated by a brief review of the principal endemic, epidemic, and pandemic maladies to which the human race is subject, dealing especially with the manner in which they are developed, restrained, diffused, or annihilated by the qualities of the air.

Microbes have been divided into two main classes, aerobic and anaerobic, the first growing best in the presence of air and the second growing best in substances and in positions to which free air has no access.

Some of the first class, such as the hay bacillus (subtilis), grow best only with a copious supply of air; some grow better when the air supply is not large than when free air is admitted; some of the second class can grow in the absence of free air, but thrive more when some air is admitted; and others, which are fully anaerobic, grow only when free air or oxygen is shut off. Examples of these last are the bacillus of symptomatic anthrax, of tetanus, and of the malignant œdema of Koch.

A large class of bacilli or bacteria are killed by dry air, by light, by artificial heat, and by prolonged intense cold, but are capable, when adverse influences act upon them, as by deficiency or inappropriateness of the nutritive medium, of forming spores, minute germs which are scattered abroad in a condition of far stronger defense, and capable of resisting for some considerable time prolonged exposure to sunlight and even to boiling water, to drying, to various antiseptic chemicals, and to any possible natural cold. The spore-bearing faculty belongs to a variety of species of bacilli, both pathogenic and harmless.

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[1] "The atmosphere is the most universal medium or vehicle" of their poisons to the breathing organs and intestines. (Professor Corfield, medical officer of St. George's, Hanover Square, London.)

Spore formation takes place at temperatures between 16° and 45° C., and these are in general the extreme limits. Bacilli which do not form spores—for instance, those of typhoid fever, glanders, and fowl cholera—are easily killed outside the body by a number of natural and artificial agencies. Among these agencies the most efficacious are drying, exposure to dry air and oxygen, high temperature, sunlight, the presence of other species of microbes, the poisons evolved by themselves or by other species, cold weather, exhaustion of their appropriate nutriment, and various inimical substances which inhibit growth or actually kill. In the very fatal diseases of cattle known as anthrax, and when transferred to mankind, as wool sorter's disease, the bacilli which infect the blood of the dead animal are killed by mere drying, without exposure to air; but if the blood be for some little time exposed to the air, spores are formed which may remain upon the pasture, or upon wool, or hides, or elsewhere, and infect fresh cattle or human beings at some distant date. The putrefactive process in the carcass also kills the bacilli, but will not kill the spores if these are allowed to be formed.

Anthrax is known to be in many cases communicated through the air from one animal to another or to man, and among wool sorters, butchers, and others enters the body through a wound, or by the lungs, or by the alimentary canal.

Spore formation is generally favored by a copious supply of oxygen. It is a process by which the degeneration and destruction which takes place in a colony of nonspore-bearing bacilli is prevented, and by which the seeds are set adrift, to be planted and grow again into bacilli in more favorable surroundings.

The process of growth from a spore into a bacillus has been experimentally observed in favorable conditions to be completed in periods varying from half an hour to two hours. The bacillus introduced into an appropriate medium multiplies by fission at an enormous rate, so that, for instance, 248 microbes of the pathogenic species *Staphylococcus pyogenes aureus* in a cubic centimeter increased to 20,000,000 in twenty-four hours, and 20,000 bacilli of fowl cholera multiplied in the blood of a rabbit to about 1,200,000,000 in twenty hours.

Microbes vary greatly in size not only between classes and species, but between individuals, according to the medium and circumstances of growth. Ordinary dimensions lie between about 0.5 and 5 micromillimeters in length and 0.1 to 0.5 in breadth. The spores are in many cases much smaller. Clearly, an organic living dust of less than one thousandth of a millimeter in diameter is capable of existing in great numbers on very small areas, even on small, almost invisible, dust, and of being wafted long distances by gentle aerial movements without sinking. In perfectly still air inclosed in a box in the laboratory Tyndall found that all visible dust sank within three days, and nutrient media then exposed were unaffected by bacterial growths, so that the microorganisms originally present must have settled down. But in nature not only is such a calm unknown, but processes are continually taking place which launch fresh organisms into the atmosphere. Moreover, there is good reason to suppose that several disease microbes or their spores are still lighter than those which have been subject to similar experiments. The influenza microbe is extremely light. Its length has been given at $\frac{1}{50000}$ and its breadth at $\frac{1}{250000}$ of an inch. Disease microorganisms have in the laboratory passed from room to room through the air, and accidentally infected animals inoculated with other kinds. Light dust falls at so slow a rate through the viscous air that even in a room the downward motion is scarcely perceptible; yet in a few hours all the grosser particles are deposited if drafts, movement, and shaking of the room are prevented. Most pathogenic microbes are carried down with this dust or sink of their own gravity, and soon subside, but in ordinary conditions there is too much disturbance to permit effective purification by subsidence. The light dust of the volcano Krakatoa, which was visible as a haze, took a year to fall even out of the rare upper strata, and many disease microbes are equally small, and fall still more slowly through the dense strata near the ground. Particles of smoke may perhaps be compared with the spores of bacteria, and tobacco smoke not only floats long in the air of a room, but passes through passages and through chinks into rooms above and below.

Among animal diseases of an intensely infectious character and disastrous to agriculture, cattle plague, pleuro-pneumonia, and foot-and-mouth diseases are perhaps foremost. Two, at least, of these are communicated not only by infected articles, but by transmission through air for a short distance of particles derived from an actual or previous case. These diseases, or some of them, have formerly been widely held to come from some unusual epidemic constitution of the air, but they are now thoroughly proved to be preventable by the admission of plenty of external air and rigid precautions against contact or proximity of infected articles. They are frequently spread by attendants passing from one herd to another without complete systematic disinfection; frequently also by imperfectly disinfected sheds. No animal plague has been proved to be capable of passing effectually through a long stretch of atmosphere, and the free atmosphere in all cases tends to diffuse and destroy the poison. There is reason to regard certain low alluvial lands and swamps as the original breeding grounds of the saprophytic microbes which cause some of the worst animal plagues, for these plagues have followed immediately the subsidence of floods and the drying up of marshes. Since the neighborhood of these places is not exempt, the organisms concerned must be capable of transport in a potent state for a short distance by moist air. The filthy condition and foul, unventilated air in which cattle are kept have also been shown to be the cause of their gravest maladies. Tuberculosis in animals depends to a very high degree upon the absence of proper ventilation and upon proximity to each other. In the open air and wild life it does not seem to occur. It has been well ascertained that the microbes of cattle plague may cling so persistently to infected places that whitewashing, scraping, and ordinary disinfection may be insufficient. Similarly, tuberculosis of cattle occurs again and again in particular stalls, showing that the infective matter remains in a virulent condition on the walls, floor, or ceiling, and probably infects not only by contact, but through air. The breath of the animal condensed on the walls would no doubt form pabulum for the increase of any remnants of a former multitude which might light upon them or emerge from the pores of the material. In France, epizootics greatly increased after the introduction of railways, owing to emanations from and contact with incompletely disinfected cattle trucks, yards, sheds, etc., and the diffusion of infectious cases by increased movement.

INSUFFLATION OF ANTHRAX, ETC.

The inbreathing of the bacilli of cowpox, anthrax, clavelee, and suppuration is sufficient to give each of these diseases to sheep and cattle. But there is no evidence to show that any animal plague is transmissible through any long distances of air or by the general atmosphere; on the contrary, animals are in thousands of instances kept within a mile or less of others which are stricken, and with due precautions remain well.

TUBERCULOSIS.

Many of the epizootic diseases which occur in animals may be transmitted to men, but they often occur in a modified form and are either more or less severe. Some may have been originally human maladies. Fifteen at least are said to be thus interchangeable. The most important, widespread, and fatal of these is consumption, phthisis, or tuberculosis. The bacillus tuberculosis kills about 1 in 8 of the population of Great Britain and America, and about an equal proportion, one-seventh, according to a very high authority (Hirsch) of the people of the majority of other civilized countries. It is the greatest and most constantly present plague of man. It has been considered ineradicable, constitutional, hereditary, and attributed by many authorities to some vice in the atmosphere. Now, we know that it is a nationally self-inflicted, unnecessary, and preventable pestilence, of which the great and certain prophylactic is pure air in plenty; no foul air, foul dwellings, and overcrowding. Overcrowding, the rebreathing of expired air, dirty, dusty dwellings, moist or organically polluted walls, floors, ceilings, and furniture, and the careless habit of spitting account for a very large part, perhaps the majority, of cases of consumption. The breath in fetid air, the emanations from cultures of the bacillus on the walls, curtains, carpets, etc., and, most potently, the dust of the dried sputum itself of consumptives, may infect healthy persons, but mostly those who have some tissue delicacy or predisposition. But another very common cause, especially in the largely fatal tuberculosis of infants, is the use of milk from infected cows. Now, these cows are themselves diseased through media very similar to those which disarm the human subject, rebreathed foul air and dirty places; in fact, want of cleanliness, and, above all, want of fresh air.

Well-ventilated cow sheds, and immediate separation of sick animals, prevent the spread of tuberculosis among cows; thus children are saved from the danger of tuberculous milk. The breath of the consumptive in well-ventilated rooms may be considered harmless. Animals have been infected by breathing the dust of sputum disseminated in the air, and no doubt the same mode of infection is very common among mankind, but only in close association with the sick or in stuffy apartments. The State board of health of Maine has issued valuable instructions to prevent the practice of expectoration except in spittoons, which may be wooden or pasteboard, and should either be burned daily or cleansed with boiling water and potash soap.

The reduction of consumption by such means and by better regard for ventilation is not only probable, but certain. In England the death rate has considerably declined with sanitation. From 1851 to 1860 it was 2,679 per million per annum. In 1888 it was 1,541. In New Hampshire, United States, the deaths from the several diseases named were as follows: From 1884 to 1888, consumption, 4,039; diphtheria and croup, 983; typhoid, 750; scarlatina, 187; measles, 160; whooping cough, 109; smallpox, 2. Here the very large proportion of deaths due to consumption, and the importance of effecting a reduction, are strikingly shown; but a similar proportion exhibits itself in every thickly inhabited State, both in Europe and America.

Rooms occupied by consumptives should be periodically disinfected and always kept clean. The danger is there, but it can be averted. The experience of the Brompton Hospital shows that with proper hygienic precautions cases of infection from patients are very rare. Koch has shown that enormous multitudes of bacilli may be distributed on the ground and in the air from only one patient, and how infection is explained by their long survival in a moist or dry state. Cornet showed how the walls and carpets, cornices, etc., retain them still potentially virulent. Thus certain houses remain for a long while centers of infection, and newcomers are attacked out of all proportion to the cases among neighboring uninfected dwellings.

Prisons, barracks, etc., which when crowded and badly ventilated were very fatally affected with consumption have been rendered wholesome by thorough ventilation and greater cleanliness. Out of an average prison population of 4,807 in the year 1890 in England, only 9 died of phthisis, excluding cases in which sick prisoners were removed home.

The mortality of the British army in barracks from consumption in the ten years 1837 to 1846 was 11.9 per thousand. After the report of a royal commission in 1858, ventilation and air space were greatly extended, and the mortality immediately and rapidly fell; in 1888 the consumption rate was only 1.2 per thousand.

The disease prevails more on wet, cold, clayey ground and damp places generally than on high and dry sites, and all causes of chills and colds give an opportunity to the infection of the specific bacilli where they are present in sufficient numbers and strength.

Cold countries are rather less subject to the disease than temperate and warm climates, but everywhere the most important factors are the habits of the people. A moist atmosphere, with wide daily range of temperature, favors its prevalence. In Greenland, Labrador, Iceland, Spitzbergen, Nova Zembia, Finland, Siberia, and the northern parts of North America the disease has been rare; also especially on mountain ranges, high plateaus, and little-visited districts, such as the Soudan. In Algeria the nomad Arabs were free from it. The Bedouins who exchange their tents for stone-built houses suffer to some extent. Many uncivilized tribes are exempt until they adopt the clothes and way of living of civilization. Outdoor life in the free air, and clean, spacious sleeping quarters almost or quite annihilate consumption if animal sources are excluded. Soldiers on campaign, fishermen, hunters, engine drivers, gardeners, and farm laborers are least attacked; workers in gritty stone or metallic dust, in hot, close, crowded, and damp rooms or factories or mines, and dwellers in damp houses, back-to-back houses, and close courts furnish the largest number of victims. In the old town of Havre, with its airless, narrow streets, the mortality is three times as great as in other parts of the town.

It has been shown that in proportion as a population, male and female, is drawn to indoor occupations, the death rate from consumption increases.

An elaborate investigation for official purposes by Dr. Ogle showed the mortality from phthisis and lung diseases of men from 45 to 65 years of age working in pure and vitiated air in England, to be as follows:

	Phthisis.	Other lung diseases.	Total.
Pure air:			
Fishermen	55	45	100
Farmers	52	50	102
Gardeners	61	56	117
Agricultural laborers	62	79	141
Confined air:			
Grocers	84	59	143
Drapers	152	65	217
Highly vitiated air:			
Tailors	144	94	238
Printers	233	84	317

From these figures the effect of the breathing of foul air on respiratory diseases is conspicuous. But the differences represented would have been much greater if the class described as living in pure air had not been subject, during that part of their lives which was spent within doors, to the bad air of close apartments or cabins, and to the occasional infection of places of assembly and resort.

That demonstrable bacilli are given out by the breath of persons suffering from consumption and other diseases, has been proved by Ransome and others. The possibility was doubted by Cornet and other authorities on the grounds that nonvolatile substances can not be exhaled, that many good observers have failed to find them, and that where observed errors may have crept into the experiments. But Cornet himself has shown that the bacilli are exhaled in small numbers by patients, and that they and their spores are given off in great numbers from handkerchiefs, bed linen, furniture, floors, etc., of rooms in which consumptive persons live.

Klein has shown that guinea pigs exposed to a spray of tubercular matter in the air, or else kept in the shaft of a ventilator in a consumption hospital, acquire the disease. It has been proved by Straus that nurses of consumptive patients have tubercle bacilli deposited on their breathing organs. These last experiments are not proofs of the exhalation of the fatal microbes. But we have the most convincing proof in everyday facts of the possibility of the exhalation of the bacilli or germs of several infectious maladies. The breath is one of the most common vehicles of transference of infection from person to person. Moreover, Ransome finds much indiffusible organic matter, such as epithelial scales, in the condensed aqueous vapor of the breath. The breath of consumptives, however, contains very few bacilli, and the particles of sputum which fall from the mouth in expectoration or in speaking are more dangerous.

Tuberculosis has been produced in animals by causing them to inhale air vitiated by subjects of phthisis. Glass slides, wetted with glycerin, show the presence of tubercle bacilli in the air of consumption hospitals. Tuberculous particles inhaled are found to be more capable of infecting than particles swallowed. The air does not often, at any rate, convey infection from the mere breath of a patient in an ordinary clean room, and the temperature must be rather high to maintain the vitality of the germ. In hot climates, under similar conditions, the danger is greater, but generally the better ventilation reduces it.

Consumption and leprosy are caused by similar microbes, and have much in common in their behavior. In phthisis the contaminated air conveys the bacillus to the air passages, and in scrofulous glands to the nearest sore; in leprosy the exposed parts, hands, face, and feet, which have received some scratch or wound, are first attacked. As leprosy has been got rid of not only by improved conditions of living, but by segregation of the victims, so consumption and tuberculosis will be exterminated wherever the utmost care is taken in providing for fresh air, good and well-cooked food, clean dwellings and clean byres, and in segregating or specially controlling and caring for affected individuals. Close courts, back-to-back houses, damp cottages, tuberculous meat and milk, overcrowding, and dusty occupations in heated air deserve either total condemnation or most rigid precautions. Rooms should be constructed so as to be easily and frequently cleaned and constantly aired. The habit of wetting envelopes, ledger pages, etc., from the mouth should be prohibited. Notification of cases should be required as in other infectious diseases. Light, air, space, exercise, and cleanliness should be made easy of attainment and common to every human being.

TYPHUS.

Another disease intimately associated with bad air and with crowded dwellings is typhus. It does not arise at all among persons living in the open air and in well-ventilated rooms, but spreads with fatal effect in the crowded, dirty apartments of the poor, in filthy jails, ships, and lodging houses. The disease was formerly very destructive in England, infesting the prisons, and was sometimes communicated to judges and lawyers into whose presence prisoners were brought; but better conditions of living, greater cleanliness, and more regard for ventilation have resulted in its almost complete extermination. So sensitive is the microbe to fresh air and disturbance of foul surfaces that the crowding and dirt which remain, bad as they are, are scarcely sufficient to maintain its virulence. Typhus is not conveyed far by the air, and as a rule only infects those who are very near to the victim. All the staff of the Fever Hospital, in London, were attacked at some time through this infection, but during eight years no case occurred among the staff of the Smallpox Hospital, which was in close proximity. Even the attendants in typhus wards run little risk when these are spacious, well ventilated, and not overcrowded. Poisonous microbic emanations from the lungs and skin are thus in an almost incredible space of time rendered harmless by the action of fresh air.

The winter has generally been the season of greatest prevalence of typhus, owing probably to the greater distress and crowding in the cold months. The infection remains for some time on clothing, walls, etc., so that the air does not apparently disinfect or destroy where the organism has sufficient moisture and nourishment.

THE PLAGUE.

The plague, a very severe pestilence which has been common in the East and in North Africa, and has visited Europe with the most appalling mortality, arises in districts where filth abounds to the most extent, where dwellings are overcrowded, and where famine and undernourishment are frequent. It is both miasmatic and contagious. In 1603 it hardly ever entered a house but it seized all living there. Prolonged breathing of the sick-room air was the most effectual means of infection.

A moderately high temperature is most favorable to the breeding of this pest; above 86° F. it declines. Moist, alluvial soils; the banks of great rivers, such as the Nile and Euphrates; a warm, humid air; great accumulations of putrefying animal and vegetable matter in the vicinity of dwellings; dwellings surrounded by heaps of manure and almost hermetically sealed—these are conditions favorable to the growth of plague. Once started, it spreads by infection much after the manner of typhus. Care for the purity of air in and around dwellings abolishes plague altogether, as has been proved locally in the Himalayas and generally in the retrogression of the disease from Europe.

CHOLERA.

Cholera is to a great extent a disease of air poisoning. It arises from the soil in certain districts of India, where it is endemic, and from which it occasionally has the opportunity, through favoring climatic influences and the movements of travelers, of invading temperate regions, in which it may cause great mortality in a few seasons, but can hardly establish itself permanently in the soil or water. It does not, as was long supposed, travel from place to place through the air, and has no epidemic existence beyond its breeding places apart from human agency. The cholera microbe, the comma in all probability, thrives in a damp, organically polluted soil, such as that of the delta of the Ganges and the flat lands around Madras, Bombay, and Shanghai; of the valleys of the Brahmaputra, the Nerbudda, the Tapti, the Indus, and the Euphrates, and in a temperature of from 25° to 40° C. In the delta of the Ganges the temperature of soil and air appears to be so favorable that it never dies down; at Shanghai it regularly infects the air and water after the heat of July and August. It is aerobic. A freezing temperature prevents its growth, but does not destroy it. Kept moist, it may live for months after growth has ceased; dried for a few hours, it dies. In temperate climates it is spread by the entrance into water and air of the organisms derived from growth in the dejections of cholera patients, some cases being only recognized as diarrhea, but still being capable of spreading the poison. The destruction of the dejecta is, therefore, the safeguard in all cases. The power of extension of cholera through the air alone in the neighborhood of cholera patients where due hygienic precautions are observed is very small, but every article used must be washed or sterilized. The general atmosphere does not convey it either from person to person or from soil to soil, unless, possibly, in rare cases and for a short distance. In fact, free air, unless very humid, soon kills it. The atmosphere of the Gangetic delta, the chief endemic area of cholera, is remarkably damp. There are probably a number of places in India where the soil is to some extent infected, but where mischief arises only in certain seasons.

The conditions of soil and air favorable to the growth and exhalation of the cholera germ may be concisely summed up as follows;

Permeability of soil to air, moisture of soil not excessive, average soil heat at 6 feet deep about 79°, a moderate amount of contained organic matter, and little putrefaction or ordinary decomposition; mean annual temperature of air about 72° F. The minimum water level, otherwise the maximum of soil ventilation, and the maximum of cholera coincide. Dry or saturated soil are unsuitable for the continuous growth of the bacillus.

DIARRHEA.

In an inquiry conducted about thirty-five years ago[1] regarding the prevalence of diarrhea, a disease which in England is fatal to very large numbers of children, it was found that there are districts in which endemic diarrhea is unknown, and others in which it prevails extensively every year. The excess of mortality coincided in all cases with one of two local conditions, the tainting of the atmosphere with the products of organic decomposition, especially human excrement, or the habitual drinking of impure water. Since the time of the report a large amount of evidence has accumulated which goes to prove that summer or infantile diarrhea is caused by the infection of air and food by emanations from a damp organically contaminated soil raised above a certain temperature. Houses built on or near a subsoil containing decomposing organic matter, or where sewers leak, are particularly subject to diarrhea. The nature of the soil is important. Sand, loose fine gravel, deep mold, and permeable soils generally, where organic matter is abundant, are productive of the disease; houses built upon rock, without fissures, are generally altogether exempt. "Made ground," containing organic rubbish, on which so many houses in the outskirts of large towns are built, emits products of decomposition into the interior of houses and is a fruitful source of suffering. The practice of building on rubbish heaps should be made a criminal offense. The absence of free ventilation within and around houses greatly increases the mortality from this cause. Deep drainage has been followed by a marked fall in the prevalence of the disease. Paving, impervious flooring in houses, cleanliness in the storage of food, with ventilation, are important measures for its reduction. Purity of air, indeed, in this as in so many other cases, is the remedy to be sought.

Diarrhea in the epidemic form arises under conditions very similar to those of cholera. It may be in fact a very near relation of that microorganism, but is milder in its effects and has the quality of developing at lower temperatures. When polluted, damp soil at 3 or 4 feet deep reaches about 56° to 60° C., as it generally does in England in June or July, the cases of diarrhea mount up rapidly, for the diarrheal microbe is then multiplying in the subsoil and emerging through the upper stratum, and may indeed be developed in decaying organic matter on the surface. Settling upon articles of food and drink, such as vegetables, water, and milk, it multiplies and develops the poison

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[1] Second Report to the Privy Council, London, 1859.

which belongs to fungoid growth. When ingested with food, and even when breathed with the air, it causes the disease. The air of that part of a town which was subject to diarrhea has been proved to contain germs which cause the disease, and to contain 2,000 to 7,000 bacteria and micrococci in the cubic meter. The deaths in this part of the town, containing one-third of the population, were 216 out of a total of 256. The remedies for diarrhea are principally draining the ground to a considerable depth, paving, ventilation of dwellings and of places where milk and food are kept with air from some height above ground, cleanliness generally, and a good water supply. Cows, farmyards, and dairies need similar attention. Diarrhea is much less common among the Irish population of large towns, owing to their infants being almost invariably suckled by their mothers and not from the bottle.

The general air soon nullifies the danger from strata near the infected ground, and the germ seems to be incapable of enduring conveyance in a potent state through any considerable distance in the free atmosphere.

TYPHOID FEVER.

Typhoid fever, like cholera and diarrhea, depends to a great extent on the growth and cultivation in neglected human refuse by human agency (unwilling but effectual) of germs which thrive in damp, polluted soil or in foul water. Warmth and exclusion from free air favor the development of the bacillus, supposed to be the cause of typhoid. It can grow, however, in the presence of free oxygen, and then develops the saprophytic habit and great resistant power. In direct sunlight it is killed in six to seven hours, and in diffuse daylight growth is very slow. The mode of entrance of typhoid is both through air and water contaminated with the products of the intestinal discharges of persons sick with the disease.

During twenty years preceding 1883, the average annual number of persons who died of typhoid in England was about 13,000, the number of those who suffered from it about 130,000. In many continental cities, the proportion is much higher. Although bad water accounts for a large number of cases, bad air, the emanations from drains through defective traps and waste pipes, also infects in very many instances. Recent experiments of great interest have shown that sewer air is capable of so poisoning the system as to lay it open to the attacks of the typhoid bacillus, which is doubtless frequently present either in the foul air or in the intestines. In this way many outbreaks are caused by the combined influence of drain air and specific microbes. The condition of farmyards near dairies whence milk is supplied to cities is too often so filthy that both air and water are poisoned. Milk has a remarkable power of absorbing gases and vapors, and is also a cultivating medium of various fungi and bacteria.

Typhoid germs, like so many others, are soon rendered innocuous by mixture with fresh air, and there is some evidence to show that oxidation by the air in running water has a good effect where the noxious matter is largely diluted and the stream pure. In London, New York, Paris, Berlin, and perhaps the majority of places in the northern temperate zone, typhoid fever is most prevalent in the late summer or autumn, when the ground at a little depth, and water in shallow wells, are at their highest temperature. In India it occurs mostly in the hot, dry months before and after the rains, and may in part be attributed to the wind blowing up the dust of filth deposited in the fields, but chiefly to the same conditions as prevail in England and to the introduction of the virus, often from slight and unsuspected cases.

The great majority of houses in civilized places resemble inverted, slightly ventilated bell jars, connected with a system of pipes on which deadly organisms may grow, and from which they may be conveyed by the poisonous gases to the bodies of the inmates. It should be a primary object to make the entrance of these gases difficult and of the outer air easy. The bacillus concerned in typhoid fever is probably widely diffused, but, whether often present or not in an innocuous form in the human intestines, does not attack life where air and diet are pure. With the aid of impure air from drains, middens, and foul sinks it acquires deadly power. Cleanly disposal of refuse and abundance of fresh air are the great securities against this disease.

MALARIA.

Malaria is the most general, constant, and destructive of endemic diseases in tropical climates and over a very large proportion of the inhabited globe. Millions die of it every year in India, and in Africa and South America it is terribly prevalent and fatal. Vast numbers of people are crippled and diseased for life in consequence of the fever, and in many districts the whole population looks debilitated and anæmic. It depends on the emission of living organisms, probably amœbiform, from warm, damp soil, rich mold, sand, or other suitable ground containing a little organic matter. It haunts open and narrow valleys, dried water courses, the country at the foot of many mountain ranges, sandy coasts in certain climates, mangrove swamps, deltas, marshes, and even in certain districts dry, sandy plains at a considerable elevation. The organism appears to exist either in an active or latent form in nearly all hot countries where the soil contains sufficient organic matter, and that need not be much. Where soil is efficiently drained, naturally or artificially, malaria is rare or absent; and where irrigation works increase the dampness of the soil, there also malaria increases or develops itself. Cultivation, with the exception of rice growing, in general diminishes or abolishes malaria within the area cultivated. Lowering of the water level and aeration of the soil reduce malaria notably. Drainage in East Anglia has almost extinguished ague, which is a similar or the same disease. Some sandy, semidesert districts, such as Western Rajpootana, are subject to malaria, although the water is several hundred feet below the surface. But here the sand is found to be damp a short distance below the surface, and probably the same condition prevails elsewhere in sandy tracts where malaria is present. The rainfall is scanty, but the great range of temperature probably causes a good deal of dew-condensation on the sand.

Sometimes, though rarely, rocky surfaces emit malaria, but probably the habitat of the organisms in these cases is in clefts or disintegrated rocky detritus. The efficiency of attack on the human body depends in great measure on the concentration of the organisms within a few feet of the surface of the earth in the evening hours, the difference between day and night temperature, the high temperature of the soil, and the suddenness of the fall of temperature. Although the strongest men in the best of health may be stricken, yet, in most malarious countries, the avoidance of fatigue, of indigestion, and of any chilling of the surface of the body, is an important safeguard. The conditions in which malarious germs are emitted from the soil and concentrated in the nethermost strata of the air are further considered in relation to the emanation of vapor from the earth and the deposition of dew.

YELLOW FEVER.

Yellow fever results, in all probability, from a fungoid or microbic growth, but the particular microbe concerned has not been certainly identified. It prevails habitually in the West Indies and on the coasts of the Gulf of Mexico, and these have been regarded as the original breeding grounds. But it has also long been endemic on the west coast of Africa, especially at Sierra Leone. It is easily capable of transportation, especially in the case of particular outbreaks and in particular seasons, and it has in several years, like cholera, attained almost a world-wide prevalence. When transplanted to favorable places (and these are mostly seaports with very poor sanitary conditions) it takes root and breaks out in succeeding years as if it were multiplying on the polluted soil. As a matter of fact, it thrives on damp organically contaminated soil, on the walls of houses, and on the wood of ships, in foul holds. It haunts the vicinity of drains, banks of rivers occasionally dry, harbors, and crowded rooms or houses. The manner of its growth a good deal resembles that of cholera, but its areas of prevalence are smaller, and it is more largely communicated through the air, each case of yellow fever becoming a focus of prevalence in tropical and foul conditions. It requires a high temperature for its propagation, and is arrested, but not destroyed, by frost. Strangers are much more liable to attack than residents, but residents are not always immune. The living cause of the disease clings with great tenacity to ships, walls, etc., for a long time, and is conveyed, in very many instances, by the air to persons who approach the infected object. The organic poison seems to multiply outside the body, upon foul surfaces, and thence to infect. It is not transported by the wind—at any rate to a distance—but depends on human movements, on overcrowding, neglected refuse, and absence of proper ventilation. It seems probable, from its persistence on the coast, on the banks of tidal rivers, and on ocean-going ships, that it finds a favorite pabulum in slightly saline deposits.

DIPHTHERIA.

Diphtheria, now one of the most fatal maladies of children, both in Europe and America, is equally preventable by purity of air; but since it is commonly caught by infection, and susceptible persons are attacked through slight doses, absolute prevention is difficult. Its propagation depends to a great extent on schools and close aggregations of children, some of whom may be affected by the disease in a mild form, such as slight sore throat. Some cases arise from a disease of the cow, which is not easily identified, but the great majority of cases of the disease are certainly due to the emission into confined air of the microbes from persons already suffering with sore throat or diphtheria, and therefore the great majority of cases would not occur if schools and dwelling houses were well cleansed and ventilated, and if children with suspected throats were as far as possible isolated. The gradual growth of diphtheria in villages and towns and its frequent recurrence indicate an infection of the air in houses either from a contaminated surface soil, from floor or walls, or from the breath of persons who have had the disease and in whose throats the microbe lingers after their recovery. Diphtheria does not occur at all in clean, dry places, unless introduced by some person or imported article carrying the infective organism. The germ is certainly not present in a potent condition in the outer air. Newly inhabited countries and places have always remained free from diphtheria until the germ has been introduced by human agency.

Diphtheria and scarlet fever are among the most widely and constantly prevalent, and most fatal, of all diseases in temperate climates. They are both communicable through the air in proximity to a patient, and this is a very common mode of conveyance. But they have never been known to pass across any considerable space through the outside air. The evidence leads very strongly to the conclusion that they are rarely if ever caught by exposure to infected air which has been very largely diluted in the free atmosphere. Predisposition to diphtheria, and probably to a less extent to scarlet fever, is favored by drain air, sewer air, and the emanations from heaps of decaying animal or vegetable matter, dust heaps, and by the various causes of sore throat. And it is probable that the microbe of diphtheria, which has been identified, frequently infects the surfaces whence the foul emanations proceed. It is certainly present in very many places, especially in houses and localities where the disease has formerly prevailed. Measles are often followed by diphtheria, though no source of infection can be discovered. Many persons after recovering from diphtheria are still capable of giving infection by the breath, for the bacillus may remain for months in the mouth and throat. Cases of sore throat which may be slight often communicate to other persons, in consequence of aggregation in foul air, severe sore throats and diphtheria. It seems that the disease may be a slight one until by the effects of rebreathed air it develops fatal virulence. For this reason, and owing also to the opportunities of ordinary infection in confined air, diphtheria is a disease which largely depends on schools for increase and propagation. It haunts the surfaces of objects which have been exposed to it, and thorough disinfection is required to remove it. The autumn and winter season, damp dwellings, damp soil, dirty farmyards, privies, etc., favor its development; but its continual increase has been due to increased school attendance, meetings, etc., and to the increase in the number of infected places, and in the means of quick traveling. Ventilation, much more thorough than any now generally practiced, combined with the better disposal of refuse, must be the principal hygienic measure to reduce its prevalence. Investigation of the conditions under which it survives in places and houses, and of the effect of ventilation and proper space in schools in preventing its propagation, is much needed.

PNEUMONIA.

Two or more different diseases are known under the name of pneumonia. The temperature of the air is an important factor in its production, but all countries are subject to it. The maximum number of deaths from this infection occur in December, the minimum in August. Cold is a strong predisposing, but not the ultimate cause. Overcrowding, the want of ventilation, emanations from sewer and filth, play an important part in epidemic outbreaks. Certain bacilli or micrococci are concerned in the production of epidemic pneumonia, and possibly the commonest form of pneumonia is due to the opportunity given by cold or by foul gases for the attack on the body of an organism frequently present in the breathing organs. There is little evidence as to the exemption of persons living entirely in the open air and thoroughly well-ventilated dwellings, and not exposed to infection from others, but the probability appears to be that many persons have in themselves a cause of a certain sort of pneumonia which may attack them through a chill, but that the breathing of purer air and the prevention of infection through the breath would greatly reduce the number of victims. The typhoidal character of some forms of pneumonia and their mode of origin and spread suggest a connection with soil poisoning and contamination of superjacent air. On these points investigation is needed.

Pneumonia is very apt to occur after colds, measles, typhoid, malaria, and especially influenza. If it be due to a particular micrococcus, the organism must be very widely disseminated. But probably several different organisms are capable of thus affecting the weakened constitution, and the disease named pneumonia is the result of different causes which need more distinct classification than they have yet received.

Dusty trades and smoky fogs favor the incidence of pneumonia.

BRONCHITIS.

Bronchitis, one of the most prevalent and fatal of all diseases in cold and temperate climates, is often directly due to the effect of cold and of a sudden fall of temperature. Although much less common and fatal among people living in healthy conditions, it nevertheless often attacks strong constitutions, even in the purest atmosphere. Fatigue predisposes. A great deal of preventable bronchitis results from imprudence in clothing and in diet—for instance, alcoholic excess—but much also from breathing dusty and smoky air. A smoky fog of some days' duration in cold weather in London causes a heavy mortality, while a fog in the country has little effect. Much bronchitis results from weakness and chill following illness and fatigue. Changes in the blood and accumulation of waste products are apt to follow excessive exertion. The importance of warm clothing and of breathing air free from smoke and dust, especially the dust given off in the manufacture of hardware, pottery, lead mining, etc., is great in the prevention of this disease. Close rooms where gas is burned contribute largely to bronchial attacks, and in general purity of air is one of the first conditions tending to immunity. But cold and damp seem to be quite sufficient to produce bronchitis in some constitutions, and in young children and old people, apart from anything like infection from outside. Indeed, it seems likely that an excess of ozone, or else a cold, bracing air, often determines an attack, and these qualities are beyond doubt sufficient greatly to exacerbate symptoms resulting from a slight cold or chest weakness. A soothing, soft, warm, damp air, on the contrary, quickly ameliorates the condition of a sufferer from bronchitis, cold, or cough; the extraordinary power of a whiff of cool, fresh air to increase the malady, and the ill effect of even a glass of cold water, seem to show that the bronchial tubes, capillaries, and air passages are in a highly sensitive state and that temperature is a matter of extreme importance. Experimental investigation of the temperature and condition of air most tending to rapid recovery from bronchitis might disclose facts of importance in the connection of inflammatory states with the atmosphere. It seems not unlikely that an absence of ozone, deficiency of oxygen, and excess of vapor of water, and of nitrogen or carbon dioxide, might prove favorable.

RHEUMATISM AND RHEUMATIC FEVER.

Few diseases are more common or cause more suffering than rheumatism, acute or chronic. A great deal has still to be discovered respecting its external causes. It prevails much more in some districts than in others, and certainly in many cases the mischief is brought into the human system through the air. Damp and cold in soil and air, and chill in the body, especially when feeble or fatigued, are main factors. As in so many other maladies, the specific cause in rheumatic fever may be the entrance of a micrococcus or other germ by means of a chill, either in hot or cold weather. An inquiry into the distribution of rheumatism, with regard especially to soil, climate, air, and dwellings, and eliminating as far as possible predisposing human habits, would furnish results of much value. There is some indication, as in the case of malaria, that air near the ground in low places has much to do with the incidence of the disease. Damp dwellings and clothes conduce to an attack, and to the chronic form. It seems very probable that it would be found that persons removed from ground air, as in the attics of high buildings, are exempt from attack, except through food and drink.

MEASLES AND WHOOPING COUGH.

Measles and whooping cough are spread chiefly through the air to persons in the immediate neighborhood of the sick, and of articles, especially clothing, which have been exposed to the infective matter. Segregation, ventilation, and avoidance and disinfection of materials which may disseminate the disease are effective in prevention, where they can be carried out. In the early stage of measles, as of influenza, even while the symptoms are slight, the germs of the disease may infect through the air, and therefore measures of precaution are difficult. The best preventives against widespread and severe attacks are habitual regard for sufficient air space and warmth and immediate isolation.

DENGUE.

Dengue is a disease somewhat resembling influenza in its symptoms, but prevalent only as an occasional epidemic in tropical countries. It is apparently spread by infection in the air from case to case, but not through the general atmosphere. The reason of its failure to extend beyond hot climates is quite obscure, but it would seem as if it required, like yellow fever, a high temperature outside the body in order to grow and disseminate germs fitted for infection.

SMALLPOX.

Smallpox has been ascertained by several careful investigations to be capable of passing through long distances, at least half a mile or a mile, of fresh air without losing its power of infecting susceptible persons. The experience of hospitals in London and Paris is well known. Recent observations on the spread of smallpox from a hospital near Leicester, containing 49 patients, showed that a number of cases which occurred in a suburb about 300 yards distant were in all probability due to transport by the wind. The epithelial scales and dust of smallpox cases are rather peculiarly protected from atmospheric influences, and the conditions of the survival of exposed germs need inquiry.

INFLUENZA.

No disease of the epidemic character has seemed to depend more on the constitution and infection of the general atmosphere than influenza. Its rapid spread, its apparently capricious outbreaks at places wide apart, the almost simultaneous attack, as it seemed, upon a large fraction of the population of a country, masked the true method of progress. But when its track and behavior were carefully followed, these facts became clear—that it never traveled faster than human beings; that many mild cases existed in every large town long before it was generally recognized; that it took at least six weeks to attain its maximum after the occurrence of the first cases; that its rapidity of advancement from east to west and from town to village corresponded roughly and generally with the rapidity of means of transit; that large numbers of people not exposed to personal infection escaped; that islands unvisited through the period, deep-sea fishermen, and lighthouse keepers escaped, except in a very few instances where they had been ashore or received communications from infected places; that susceptible persons very easily caught the pest within a few days after exposure to infection in the ordinary sense; that infection was sometimes conveyed by parcels, letters, clothing, etc., from patients or infected places; that ships which had cases on board were the means of starting it in islands at which they stopped; and that in previous epidemics the spread was often so very slow as to be quite unaccountable by any atmospheric quality. Moreover, when the bacillus of influenza was identified, it became easy to comprehend how the countless multitudes of exceedingly small organisms alive in the sputum and saliva might be disseminated in the air of buildings and of public conveyances and transmitted from place to place by commerce and the post. The general atmosphere either diffused them to harmlessness or killed them, for there was no evidence of influenza reaching an isolated community by means of wind blowing from a place where it was prevalent. But in confined or foul air they were capable of passing through many feet without losing their capacity of infection. They were experimentally shown to thrive abundantly on the gum of an envelope,[1] and since many patients wrote letters, this must have been rather a common mode of transmission, the organic motes flying upward to the breathing organs of the recipient on his breaking the fastening. There is no difficulty in explaining the quick diffusion of an epidemic having the qualities of influenza among a susceptible population. The minuteness of the bacilli, their vast numbers in the breathing organs, the short period of incubation, and the early infectiveness, and in modern times the immense daily communications between distant places, have to be taken into consideration. If examination of matter of the

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[1] Dr. Klein, British Medical Journal, February, 1894.

tenuity of smoke particles, or of the minutest microbes, could be undertaken, with a view to determine the rate and extent of its diffusion by human communications, it would probably be found that very few districts in the country are out of microbic touch, as it were, with all the chief centers of population for a single day, and none for so long as a week; and certainly the air inclosed in a packet from an infected place, when suddenly liberated, would be likely to bear with it active seeds of mischief. But the great majority of cases of influenza were due to proximity to a person already attacked. Most people in the course of a day come into association with ten or twenty others in more or less confined spaces of air. If only one in five catches the influenza, and so on in the same proportion, a fourth part of a large city may be struck down in a very few weeks. In general, one-half or three-fourths escape, being insusceptible, or less susceptible than others, or less exposed to the virus. Where large numbers of persons work together in one ill-ventilated building, the proportion of attacks is much higher, other things being equal, than where people work at their own homes. But the frequent opportunities of infection at meetings, social gatherings, public houses, in public conveyances, churches, and chapels tend to reduce the inequalities which would otherwise be conspicuous. The distance of air through which influenza can strike has not been well ascertained, circumstances being very different, and some forms, such as the catarrhal, being apparently more easily diffused than others. The maximum distance in the recent epidemics, for susceptible persons, could hardly have been less than 100 feet in close air, and 4 feet in the open. Isolation, where practiced, was successful in so far as it was strict. But the intercourse of ordinary life makes isolation impossible for the general population when once an epidemic of influenza has been allowed to attack a number of centers. Strong measures against importation from other countries and immediate isolation and supervision of the few cases which would occur might succeed in staving off a national infliction, for the precautionary measures would not need enforcement beyond the brief period of its prevalence in neighboring countries. Not only the high mortality, but the enfeeblement of millions of breadwinners for months, years, and even for life has to be considered in connection with the expense of preventive measures. This expense would only be a small fraction of the losses incurred by permitting the pestilence to rage unchecked.

As regards weather and climate, cold is distinctly conducive to the spread of influenza, probably for several reasons: (1) The stillness which often prevails in frost; (2) the closing of windows, etc., and the closer association; (3) the greater prevalence of colds, bronchitis, etc., laying open the breathing organs to attack. The first epidemic in London, at the end of December, 1889, was ushered in by fog and frost, and apparently rapidly reduced in severity by the mild and strong winds of the latter half of January, 1890. The epidemics in succeeding years were much more severe, although they came upon a population to some extent protected. At the same time there can be no doubt that an epidemic may occur in any climate and in any weather. The tropics are not exempt. An instructive instance of the subtle diffusion of influenza occurred in a village of Central Africa, which was attacked immediately after the arrival of two natives from an infected place far distant. But outdoor life and less constant communications prevent the quick diffusion and wide prevalence which belong to civilized nations in temperate climates.

The manifest, at present the only practicable and yet difficult, measures for preventing these great and very destructive epidemics are: Precautions against the introduction of the pest by travelers and by articles sent from infected districts; immediate compulsory notification, without fee, of all cases occurring in a district to the medical officer of the district and through him to the central board; isolation so far as can be arranged of all the early cases in a district at the homes of the patients; prohibition of attendance of infected persons at any assemblage; and publication of the importance of ventilation, and of living, warmly clothed, as much as possible in the open air, unless actually stricken. During the period of illness, and for some time after recovery, the greatest care is required to avoid chill, which often induces pneumonia or other evils. The fresh outer air can only be safely breathed when the symptoms have subsided and when the strength has partially returned. It is remarkable that cold air alone, however pure, seems capable of causing a relapse when the system has been greatly enfeebled and the breathing organs left in a highly sensitive condition.

COLDS.

Colds and sore throat have never received the attention they deserve from an etiological point of view, owing probably to the slight character of the majority of cases. Yet they are important, first for their wide diffusion, endemicity, and frequency, and secondly for their effect in giving opportunity for the attack of more serious disorders, among which may be mentioned diphtheria, measles, pneumonia, bronchitis, and consumption. Close observation for many years has led the present writer to the conclusion that though primarily a chill, that is exposure, insufficiently clad, to a draft or cold air, is very frequently sufficient to give a slight cold or sore throat, or the feeling of one, yet severe colds are caught in general either (1) in marshy or low and damp situations, or in conditions somewhat similar to those which produce malaria; or (2) by infection from persons after the manner of other infectious diseases. It would appear as if the microorganism, or one species of microorganisms, which sets up a sore throat and severe cold, inhabits the upper layer of earth, especially in damp or marshy places, where decaying vegetable matter abounds, and passes into the air, especially in summer and autumn evenings when the earth and water are still warm and the air is rapidly cooling. When the microbes are dense in the humid and misty low stratum of air, and when the human body is being quickly chilled, they are able to attack successfully. The microbe is probably a very common and widely diffused one, and may be present in comparatively small proportion and in less vigor in the lower air generally over the land. At sea it would be absent, and indeed there is good evidence that it does not bear long transport in a virulent state in the free air. Colds are scarcely ever caught on the open sea, even if the clothes be wet with salt water, and breezes straight from the Atlantic do not seem capable of inducing sore throat or cold. But, of course, to make an experiment crucial, previous life in the open air, disinfection of clothes and if possible of the breathing organs, would be necessary. It is not improbable that the microbe of colds, like that of pneumonia, may be frequently present in the mouth. The experience of St. Kilda,[1] which used to be absolutely free from colds until the annual boat arrived from the mainland, points to the ordinary presence of the infective particles on clothes or in the breath. The islanders were nearly all struck down with severe colds within a day or two after welcoming their visitors. Probably a similar dose of infection would be quite insufficient to prostrate persons on the mainland who were accustomed to the petty assaults of the microbe, and protected by scarcely noticed symptoms of catarrh.

An exactly similar thing occurs in the case of influenza. Hundreds of instances were observed in which the proximity of persons who had had influenza or had been near cases of influenza gave it to others, and often persons lately arrived in a place which had passed through the epidemic were struck down while the great majority of the resident population remained protected, at least for some months.

Colds protect against their own recurrence in most people for some months. Severe colds go through a house after the manner of an infectious disease, and can be similarly guarded against by isolation. The air certainly conveys a cold for several feet through confined air, and in a closed railway carriage susceptible persons who have been free from colds for some time are easily infected. An attack is often attributed to a chill felt at the beginning of the infliction, but in reality the cold has usually been caught some hours or a day or two before, and the feeling of chill is simply the beginning of the disorder, as in other infectious maladies. On the other hand, there may be a real chill, which gives opportunity to the microbe to make its attack and produce a feverish cold in a day or two. Foul air and crowded rooms are eminently conducive, especially if combined with drafts, to disseminate colds.

Persons arriving in town from the pure air of the country or from a sea voyage are very apt to catch cold. They have been living apart

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[1] And other islands. See Darwin's "Naturalist's Voyage." Report of the Local Government Board; Epidemic Influenza, London.

from the constant presence, and, as it were, the vaccinating influence, of the germs in bad air. From similar reasons horses, when brought from the country to London stables, very frequently fall out of sorts to the extent, it is said, of 95 per cent, and sheep, when placed among imported apparently healthy sheep, often fall sick. Texas cattle fever is caught from apparently healthy cattle. The first intercouse between Europeans and natives is attended with the introduction of fever, dysentery, or other diseases.[1]

SEASONAL AND GEOGRAPHICAL DISTRIBUTION OF INFECTIOUS DISEASES.

Many of the spreading diseases are more or less wont to rise toward a maximum and to fall toward a minimum at certain times of the year, and these seasons are generally nearly the same in similar climates in the same hemisphere, but there are many particular instances of variation.

Scarlet fever is a disease chiefly prevalent in the northwest of Europe, moderately prevalent in Russia, North America, and parts of South America, the coast of Asia Minor, Italy, Turkey, and Greece, and quite uncommon in Asia and Africa. It is not frequent in Australia. Its maximum in London occurs in October, its minimum in April. In New York its maximum is in April, its minimum in September. In England, generally autumn is the time of maximum prevalence. In the whole of Europe and North America 29.5 per cent out of 435 epidemics are recorded as having occurred in the autumn, and 21.8 per cent in the spring, the period of minimum; the remaining 48.7 per cent took place in summer and winter. A dry air with little rain seems to increase the prevalence of scarlet fever.

Measles, in London, has two maxima, one in December and a lesser one in June, and two minima, one in September and one in February. Measles occurs nearly all over the world since the great extension of commerce, and seems to be little affected by climate. Cold weather, however, favors it, as might be expected, since it infects through the air of close rooms.

Influenza, typhus, relapsing fever, smallpox, whooping cough, croup, pneumonia, not only prevail most in cold weather, but in cold countries, where there is least outdoor life and least fresh air in rooms and most crowding. Diphtheria increases with the cold weather of autumn, but tends to decline in February, and is at a minimum during the hot months. Cerebro-spinal fever, which is a good deal connected with crowding in large numbers in institutions, etc., not only attacks most in cold weather, but in cold or temperate countries. The relation between the temperature and the disease seems to be indirect, and the causation and dissemination of the malady are obscure.

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[1] Williams, quoted by Darwin, "Naturalist's Voyage."

Consumption or tuberculosis is most prevalent where the air is moist and the daily range of temperature large.

Typhoid or enteric fever is most common in the autumn and much less prevalent in May and June. There is a sharp decline in its prevalence in London in December. In New York, and in large towns in Europe, the maximum is decidedly apparent in late summer or autumn. The variation of prevalence according to season seems to show a distinct connection between the development of the bacillus and the temperature of soil and water, and considering the long incubation and duration of cases the maximum of infection must take place at the very time when the temperature of the soil at 1 or 2 feet deep is about at its highest.

Cholera, diarrhea, yellow fever, and malaria, the poison of all of which arises from the soil and surroundings into the air, are much more prevalent in the hot season and in hot countries.

CONDITIONS OF INFECTION THROUGH THE AIR.

In order to obtain a true conception of the manner in which the virulent matter of infectious diseases may be conveyed through short distances of air, either directly from a patient or indirectly from objects which have become infected, we have to consider those cases in which susceptibility is greatest, for these afford the truest criterion of the capability of the survival of pathogenic microbes, and the best measure of the precautions which should be adopted to exclude not only persons of average susceptibility, but the most susceptible, from the area of danger. In cases of pyæmia, of puerperal fever, and of smallpox, not only ordinary measures of disinfection, but abstinence from attendance on susceptible persons for some time, is recognized as needful. In cases of influenza, diphtheria, and scarlet fever less care is exercised, except in regard to certain susceptible states. In all of these diseases, however, transmission is far too frequent, and as a matter of fact the required precautions are not duly observed. The strict regulations of dress and washing enjoined upon nurses are almost equally applicable to medical attendants, and the use of clothes of a washable material and smooth surface by all persons in the presence of infectious cases would give greater security to all patients visited, and, indeed, to the general population. A square inch of cloth can easily hold upon its surface 10,000,000,000 microbes of influenza, so that it is quite conceivable that a man may carry on his clothes many more of these organisms than there are inhabitants on the globe, and that many scores of thousands of these pass into the air of every room which he visits.

Similarly, in the cases of other diseases which pass largely by the breath and by deposited particles, there must always be a certain number on every person who visits the sick room, and although the majority of people fall victims only to rather large numbers or a high degree of virulence, still, in order to avoid the setting up of fresh centers in susceptible people, disinfection and washing are indispensable.

The most remarkable instance of immunity from infection of a maternity hospital is that of the Grand Duchess Catherine, at St. Petersburg, one of the most carefully regulated in the world. Every utensil, instrument, and article of clothing is rendered aseptic and kept so. A vacated room is at once stripped and disinfected. The floors are mosaic concrete, the walls tiles and parian cement. Floors and walls are thoroughly washed. The result of this extreme care was that during three years there was only one case of puerperal fever, and that was brought in from outside.

A boiled vegetable or animal infusion in a test-tube may be kept an indefinite time without change or fermentation when ordinary air and objects are excluded, but a mere touch of the finger or of some object which has been lying in a room infects with microbic life and the fluid goes bad. The comparative infrequency of the conveyance of some of the infectious diseases from one to another by means of a third person is less due to the absence of the germs than to the average resisting power of the human body. The precautions taken to prevent the spread of foot-and-mouth disease in sheep and cattle well illustrate what is necessary for the protection of human beings. In an outbreak in England in 1892, a strict watch was kept to prevent the passage of any infected article, and no one was permitted to come in contact with cases of the disease excepting those persons who were provided with a proper dress, which could be easily disinfected. If these and similar measures had been customary for some years for the prevention of epidemics in man, the belief in an "epidemic constitution of the atmosphere" or in "aerial transmission" by wind for long distances could hardly have survived. The recent pandemic of influenza has given occasion for the revival of these hypotheses, which were successively overthrown in relation to consumption, the plague, cholera, yellow fever, smallpox, and even rabies or hydrophobia. Recent investigations have, however, proved beyond all doubt that the atmosphere does not, except possibly in the rarest instances, convey the virulent matter of epidemics from place to place, and that there is no security against infection so great as life in the open air and good ventilation. In fact, the atmosphere is the great reservoir of purifying agents and the most important of all disinfectants. In close places the air, deprived of some of its oxygen, filled with moisture and the impurities of respiration, can not exercise its beneficent function, and in crowded rooms infection becomes easy. So, also, cholera and other infectious matter retains its virulence in packages or stored clothing. Under the open sky and in pure air few species of pathogenic germs can pass many feet unscathed.

Consumption is typical of the class of endemics which can be caught either directly from a patient or indirectly through infected objects in close air. People who live entirely in the open air and in well-ventilated, clean places do not suffer from it, except in the few cases where it may be inherited or introduced from without. It is a disease of civilization, and many countries have been unaffected until the virus has been brought by human agency.

Soil is not concerned in the prevalence of most endemic and epidemic diseases, though many may have originally sprung from the soil, and some have located themselves in certain areas from which they spread over the globe. The small part played by soil emanations in the great majority of spreading diseases is exemplified by the extension of epidemics and of endemics like consumption, diphtheria, measles, and whooping cough, in countries which are covered with snow and congealed with frost. When once introduced they pass among the population whose habits are favorable to their growth. In islands, again, when an infectious disease, such as measles or influenza, is introduced, it spreads as fast as in countries where the soil might be supposed to nourish the bacillus or micrococcus independently of the human body. On board ships and in isolated institutions where opportunities are given by association, many infectious diseases spread just as they might in inhabited places, whatever the soil. At the same time endemicity is largely a matter of soil and habitation. Infection from person to person, and to a great extent through confined air, may thus be separated off as the main condition of prevalence of infectious diseases.

Diseases capable of transmission for a short distance through the air may, for present purposes, be divided into the following classes:

(1) Those which arise from damp soil or subsoil in alluvial plains, deltas, valleys, mangrove swamps, certain sandy coast districts, and other situations. Malaria, intermittent fever, and ague are the chief diseases of this type, and are in general not transmissible from person to person. They are transmissible a few miles through the air from the locality of origin. Colds and sore throats probably arise from similar conditions, and are infectious through a short distance of air to susceptible persons. Forms of dysentery and certain diseases of the liver, etc., seem to be due to conditions largely corresponding with those of malaria.

(2) Diseases which arise in somewhat similar conditions, but seem to have required not merely vegetable matter, but a large population and neglected filth in the soil and water for their development. Cholera belongs to this class, and depends to a great extent on human filth in the soil and befouled water. Cholera is infectious from person to person through the air, but only to a slight extent, and depends for its existence beyond its habitat on access to filthy soil, water, or places where it grows, multiplies, and infects the air, as well as other matter, which gains access to the body. Typhoid grows on damp human filth and may infect persons who breathe the air arising from such filth, especially in houses and confined places. The air in the neighborhood

of a typhoid case does not appear to convey the disease, apart from excremental matter exposed to the air. Yellow fever seems to grow in conditions somewhat resembling those which are favorable to cholera—filthy, damp surfaces in great heat—and infects the air in the neighborhood of its growth, especially banks of rivers, harbors, holds and bilges of ships, and dirty, dark, crowded streets. It sometimes infects direct from a patient. These three saprophytic or semisaprophytic diseases may be supposed to be propagated a short distance from place to place through the air without the intervention of a human subject, but have never been known to be carried far independently of human transporting agency.

(3) Diseases which arise from deposits of organic matter from the lungs and skin, and also probably from other excrementitious filth. Typhus and the plague may be named in this class, but other conditions of filth are powerful in their genesis. Plague is both miasmatic and contagious, and, where concentrated, seems to be capable of passing through several hundreds of yards of air. Prolonged breathing of the sick-room air both in plague and typhus is the most effectual means of infection. Damp, alluvial soils; streets, walls, and floors with damp organic deposits sticking to them; carcasses and refuse lying unburied around houses; in these situations the plague fungus flourishes. Diphtheria arises probably from somewhat similar breeding places, from heaps of house refuse, from middens, drains, ash heaps, and polluted ground, floor, and walls, and is transmitted a short distance through the air, probably seldom more than 10 or 20 yards. It is very often, probably in the majority of cases, carried by the air from person to person through a short distance, most easily in damp, close, or confined air, like so many other infections. The diphtheria fungus, when it has been once introduced, sticks to certain places, damp houses and damp organically polluted sandy soil seem to favor it. It is improbable that it is ever conveyed far from place to place through the air to persons except by human agency and the movements of domestic animals. Pneumonia may possibly depend on somewhat similar conditions, and may be caught by one person from another through the air. Consumption, phthisis, or tuberculosis, depends to a very great extent on conditions similar to those of typhus, and is spread through the air a short distance in the dried matter of saliva and sputum.

(4) Scarlet fever, measles, whooping cough, influenza, and dengue arise from conditions outside the body which are unknown, but decaying organic matter may provisionally be assumed to have been their original breeding ground. They are now almost entirely dependent on transmission from person to person, and to a very large extent on transmission through a short distance of air. It is very seldom that these maladies are caught in the open air, so that the medium of transmission is the confined and more or less foul air of schools, houses, churches, and theaters. They are never caught in isolated positions in

the open air, in islands to which no infection is brought by human agency, and in well-ventilated institutions where every possible precaution against infection from without can be rigidly maintained. Even the Isles of Scilly, near the southwestern coast of England, were free from measles, scarlet fever, and smallpox for ten years, the only district exempt out of over seven hundred in the whole country. It was also one of the seven districts in which no death from diphtheria occurred.[1] Since communication has become frequent, owing to a great increase in trade, the immunity does not continue, and influenza broke out there only a few weeks later than on the mainland. Another island, Alderney, was affected early by influenza through the examination of goods by custom-house officers, who caught the infection soon after the arrival of the steamer.

PREVENTION OF SPREAD AND PREVALENCE OF VARIOUS MALADIES.

Prevention of the spread of these various classes of disease, the reduction of some and the extinction of others, may be effected by the following means:

1. *Malaria class.*—Drainage, cultivation, planting, proper disposal of refuse and carcasses. In places where a small area of moist ground or small marsh gives off the dangerous exhalations, the surface might be covered with a film of crude petroleum to prevent the escape of the germs. Other experiments on the treatment of the surface of the ground with antiseptic mixtures might lead to valuable results. Powdered charcoal, and lime, might be tried.

2. *Cholera class.*—Proper disposal of refuse, drainage of soil, cleanliness and airiness of streets, houses, quays, ships; prompt disinfection and cleaning of places where first cases occur; prevention of overcrowding. Where any damp surface, as in a midden, pool, or drain, is suspected of giving off dangerous emanations, crude petroleum might have the effect of imprisoning the germs by an impervious film. Experiments are needed on means for the exclusion of living organisms from the air, where they are numerous, by treatment of the surface soil; also on substances inhibitive of their growth, which might be used on a large scale.

3. *Typhus class.*—Cleanliness and good ventilation of dwellings and of their surroundings and avoidance of overcrowding in houses, schools, etc., prevent this class of disease from arising, but ordinary personal infection has to be attacked also by isolation on the occurrence of the first symptoms. The inside walls, floors, etc., should be of some impervious material, easily and frequently washed. A dense cement or hard wood may be suitable; but, whatever the material, liberal ventilation and cleansing are required to prevent deposition of organic matter and growth of fungi. In schools, etc., the walls should be of smooth cement,

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[1] Public Health Reports. Sir John Simon.

glazed ware, glass, or metal, and the floors of close, hard wood or common tiles. The bacteriological examination of various wall and floor surfaces, and of the air inclosed within them, would be of great service with a view to the prevention of organic deposit and emanations.

4. *Measles class.*—Cleanliness of surroundings and ventilation are required as in the last class. Isolation on the occurrence of the first symptoms, use of glazed or washable materials for the room where a case is treated and for the outer clothing of attendants, absence of carpets and hangings, and frequent thorough sweeping, cleaning, and airing would greatly reduce the number of centers of infection. Where many people work or meet together, the air must be kept as fresh as possible. Influenza is best reduced by immediate isolation or segregation of the first cases in any place, and by avoidance of meetings in confined spaces. The distance of air, confined and open, through which various infections common among mankind and animals can pass should be determined by comparison of records and by actual experiments on animals.

The effects of the free air in healthy regions, neither very low nor very high, neither very hot nor very cold, may be summed up as supremely beneficial to human life and health. The most healthy class of people are fishermen, sailors, and gardeners, yet some of these are affected by close cabins, and others by surrounding zymotic diseases. The most healthy creatures are the birds and wild animals in fairly warm climates; a little less healthy are the sheep and oxen which are never stalled; much less healthy are the stalled cattle and horses; least healthy of all the higher orders of living beings are men in crowded places.

The conditions of greatest security against endemic and infectious diseases are also the conditions which conduce most to robustness, physical and mental vigor, and enjoyment. Outdoor life with sufficient work or exercise can not, with impunity to the race, be forsaken for purely intellectual and sedentary pursuits.

IMPORTANCE OF FRESH AIR TO HORSES AND CATTLE.

Mr. Fred. Smith, professor of the Army Veterinary School at Aldershot, has shown the great importance of fresh air to horses in stables. The air of buildings in which animals are kept has received very little attention except in the army, but the results obtained by better ventilation wherever tried are remarkable. Warmth derived from the animals only, in a cowshed or stable, is evidence of foul air; ventilation should be by good-sized opposite windows, and by roof-ridge exits; and if necessary, artificial heating should be employed. Cubic capacity per head should be 1,600 feet. The majority of preventable diseases among animals are traceable to food and feeding, but "certainly next to this comes impure air." By good ventilation and care for cleanliness glanders has been entirely got rid of, a disease from which hundreds previously died annually; pneumonia has been greatly reduced in prevalence and intensity; ophthalmia has nearly disappeared, and the animals are much less susceptible to colds and coughs. "Cattle plague, pleuro-pneumonia, variola, and probably tuberculosis are undoubtedly spread by the medium of the air in infected areas." This class of disease can therefore be absolutely stamped out, and there are other diseases, such as horse influenza and pneumonia, which, with better knowledge of atmospheric influences in connection with the specific cause, may come into the same category. Infected places should be treated as if in a state of siege.

Port inspection, as regards some of the worst animal diseases, it is impossible to estimate too highly; for instance, in the years up to 1886 the number of cases in Great Britain of foot-and-mouth disease was 1,993,149; since that year almost the only cases occurring have been those which had escaped detection at ports in a very few instances, and certain other cases which had been in their proximity. All these were traced and most severely isolated, so that the country is saved from great agricultural disasters by the constant vigilance of the central and port authorities. Since many animal diseases, including tuberculosis, glanders, foot-and-mouth disease, anthrax, actinomycosis, scarlet fever (a slight eruption in the cow), and diphtheria, are transmissible to mankind (some of them, but to a very small degree so far as is known, through the air in proximity), the immunity of animals from disease concerns not only the wealth, but the health of the community. Further inquiry is needed as to the transmissibility of horse influenza and pneumonia through the air, and as to the connection, if any, of these with human maladies of a like character.

THE INFLUENCE OF CLIMATE ON MENTAL AND PHYSICAL QUALITIES AND ON NATIONAL HEALTH.

The influence of atmospheric qualities upon the bodily constitution and health, upon the mind, and upon the enjoyment of life, is eminently worthy of consideration. When we come to examine closely into the manifold causes which contribute toward human happiness, we find that, upon the whole, comparing acclimatized races, the differences in the results in regard to all except extreme varieties depend at least as much on human, artificial, and removable causes as on climate and on atmospheric conditions. The peasant of Norway may be as healthy and as happy as the peasant of Italy, the native craftsman or the ryot of India as contented though not so vigorous as the woodsman or farmer of Canada, the African negro of the equatorial zone and the uncorrupted Greenlander may physically enjoy life as much as the English or American laborer. The peculiarities and tendencies of race can hardly be separated in the account from the effects of climate. Broadly speaking, however, we may safely affirm that, apart from the special and preventable evils of a high civilization, the most vigorous, flourishing, intellectual, healthy, and progressive people of the world are those which inhabit the temperate zones. Within the tropics the strongest and most energetic peoples, bodily and mentally, are those living in the mountains or at high altitudes. The inhabitants of low ground in hot climates are inclined to be listless, uninventive, apathetic, and improvident. They live for the day, shut their eyes on the future, and have a leaning toward fatalism. An equable high temperature with much moisture weakens body and mind. No long-established lowland tropical race is a conquering race in the widest sense of the term, or forward in the march of intelligence. But certain nations have the power of resisting, at any rate for a long time, the enervating influence of a moist, warm climate, with the malarious fevers which commonly belong to it. The Arabs and Chinese evince extraordinary power in this respect. The Arabs not only thrive in their own hot, dry country, but on the coast and in the interior of Africa, where the negroes are driven like sheep before them. The Chinese make excellent and most industrious laborers, even in the climate of Java, Sumatra, and Borneo, and where neither Malays nor Europeans persist in the hard work of cultivation. Their fare is rather scanty, and, as a rule, entirely vegetable. The Italians and Spaniards, again, can withstand hot climates better than most Europeans. The Spaniards have greatly multiplied in Cuba, the Portuguese do not desert the oppressive forest regions of Brazil. The natives of the South of France thrive in Algeria better than natives of the North of France. On the other hand, the people of northern Europe, if they do not themselves suffer much in the tropics, rapidly degenerate, and the race either becomes extinct or greatly enfeebled in a few generations. In Java, Europeans do not live beyond three generations. It was shown many years ago by a distinguished lady, and has now to some extent been long recognized by military and civil authorities in India, that a very large part of the excessive British mortality in India was owing in the first place to removable insanitary conditions, and in the second place, to faulty diet and personal habits. The realization by the governing authorities of the true and possible conditions of living in a hot climate has led to a large reduction in the rates of sickness and death. Stokvis has shown how in recent years Europeans have lived much better than formerly in the tropics. Even children to the number of one hundred or more, from the age of infancy to the age of 18 have grown up well in an institution in Calcutta, where they were carefully tended. The improper and excessive consumption of animal flesh, spirits and beer, and the disregard of simple hygienic rules, still continue to give to climate an ill name which fairly belongs to habit. Making full allowance, however, for these preventable causes of disease and degeneration, the fact remains that children can only with difficulty grow to due strength and capacity in the climate of India and the lowland tropics generally. They begin to flag after their fourth year. Common experience demonstrates the impracticability of colonizing the equatorial zone with the races of the cooler temperate regions. Even the high stations on the hills, where the temperature may not be above that of the home country, are not sufficiently favorable to the continuance of the family and to permanent settlement. The air, though cool at night and agreeably warm by day, is somewhat too much rarefied, and the sun shines vertically. At 7,500 feet the pressure and density of the air are lessened by one-fourth, and the sun's heat increased by many degrees.

Australia is not yet proved to be equal to the Mother Country as a permanent home for the Anglo-Saxon race; indeed, there is some evidence that the British standard is not maintained, but this is largely accounted for by causes which may be considered within human control.

Hot climates are not favorable to emigrants above 44 years of age or to children under 16, and field labor can not well be undertaken.

While Europeans visiting hot, moist climates are apt to be attacked in the bowels, the inhabitants of hot climates visiting Europe and North America are especially attacked by, and often succumb, to diseases of the respiratory organs. The cold countries are unfavorable to the establishment of tropical races. A similar relation seems to hold here between cold and respiratory diseases and heat and bowel diseases, as we have seen to prevail in winter and summer in temperate climates, but the effect is accentuated when the subject is unacclimatized. That the natives of tropical Africa can increase and multiply in subtropical or moderately warm climates is proved by their increase in the Southern States of North America.

Tropical islands are not in general well adapted for colonization by northern Europeans, for though their climate is more moderate than that of the mainland and tempered by sea breezes, fever often infects the valleys, and the moisture of the atmosphere has a relaxing influence. But many islands not considered wholesome would be far more congenial if proper hygienic measures were taken and the most suitable food and clothing habitually used. The Sandwich Islands are favorable for settlement, and may be compared with tropical highlands of moderate elevation.

The most remarkable instance of the permanent settlement of English people in the tropics is that of the inhabitants of the Barbados and of Tuagua, one of the Bahama Islands. The former are descendants of rebels sent from England for slavery between 1650 and 1700. They have survived through conditions of great misery and severe exposure. The islanders are now chiefly occupied in fishing. Deterioration there has been, but this may fairly be ascribed to poverty and improper food rather than to climate. In Tuagua the people, some of whom belonged to families settled there since the time of Charles II, appear to have maintained somewhat better health and physique.

It is noteworthy how in some circumstances a seemingly small change of climate does harm or good and in others a very great change has no ill effects. Invigoration immediately follows a change from southern England to the Alps, the Scotch Highlands, Norway, or the open sea; a change for the worse, and loss of vigor overtakes natives of the north of England or of Scotland who fix their abode in the Thames Valley or near cities in the south. On the other hand, English crews may winter in the Arctic regions, where temperature is 60 degrees below what they are accustomed to, and diet coarse and unvarying; yet they maintain perfect health. Food untainted and moderate in quantity and abstinence from alcohol probably have much to do with health maintenance in any climate.

Temperature falls about 1° F. for every 270 feet altitude on the average.[1] Other conditions being equal, a place at 6,000 feet high has a temperature fully 20° lower than the plain at the sea level.

Generally, the range of temperature increases from the equator toward the poles, from the coast toward the interior, and from mountains in the tropics to mountains in northern countries. Humidity is less at high levels, but relative humidity may be greater than at low levels, and saturation may prevail for long periods. In Europe the level of maximum rainfall is about 3,000 to 4,000 feet; in the tropics, also, the lesser mountain ranges have more rain than the highest, and the maximum rainfall is about 6,000 feet. Mountain valleys are less healthy than high plateaus.

The "vital" or lung capacity diminishes from about 266 to 246 cubic inches in the ascent from sea level to 2,000 feet, and the pulse beats faster by fifteen to twenty in the minute. At 2,000 feet the pressure of air on the chest is reduced by over 200 pounds. Since vital capacity is also diminished by high temperature, the hill station can not equal in this respect the temperate climate, but there is reason to believe that the lung capacity increases in course of time so as to be fully equal to its value at the low level. Evaporation from the skin and lungs increase, and digestion and sleep are generally good.

Strength is naturally greater in hill people. Life is hard, and the weaker members perish; the pure air invigorates; the changes of temperature refresh; good water is plentiful; the exertion of climbing and the deep breathing expand the chest and increase the lung capacity; the food is wholesome and not in excess; activity and alertness are generally expected. On the other hand, in high mountain valleys malaria is often found, also goitre, asthma, ophthalmia, inflammation of the lungs, and diseases of the kidneys. Dysentery, acute bronchial catarrh, typhus, albuminaria, and diabetes are rare; also the many zymotic and other diseases more or less dependent on aggregation.

In a period of thirty-four years the mortality of the Dutch-Indian army was, on low ground, 5.27 per cent, on high ground, 3.66 per cent.

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[1] The decrease would be less than this—about 1 degree for each 400 feet, up to 1,000 feet.

MENTAL AND PHYSICAL QUALITIES IN RELATION TO CLIMATE.

Distinguished observers[1] maintain that the white man can not flourish in the tropics, and will not work where an inferior race works; that in Ecuador and Brazil the white race dies out in the third generation; that in Southern and Central America, north of Uruguay, the colonies break up through fever and climate; that in Panama and other parts of Central America the air is so pestilential that even the Chinese succumb at an enormous rate, and that the most fertile parts of the earth, which are bound to be the most populous, can not possibly be the homes of the Aryan race, or of any higher race whatsoever. There can be no doubt that mental and bodily qualities are very largely affected by the atmosphere, with its various constitution of density, temperature, moisture, cloudiness, fog, wind, and organic pollution. Extended investigation of the effect of climate upon human health and welfare would lead to results of the highest importance. The inquiry might be directed, in the first place, to an historical examination of the movements of nations, races, tribes, and individuals, and of the effect upon them of change of climate, separating as far as possible the results due to preventable circumstances and change of habits, from results which might be regarded as necessary in the relations of the atmospheric and the human constitution.

Secondly, the fitness of various races for removal to various climates under modern conditions might be examined, and the effects of tropical highlands be compared with those of lowlands.

When we recollect the evil reputation of many localities and climates which in the first half of this century were spoken of as deadly, and when we consider that these have lost their bad name solely by the exercise of local and personal hygiene, we can not despair of the power of man for reducing the unhealthiness even of large areas and tropical climates. Last century a troopship, a prison, and a barrack may each habitually have rivaled the worst tropical country in sickness and mortality; to-day they are as healthy as a country village; the prison, indeed, is a model of salubrity.

The fact has been extensively realized that cultivation and draining may often do for a pestilential tract what cleanliness and ventilation do for an infected building. A scientific inquiry into the results of cultivation, draining, and irrigation in improving or harming the health of districts subject to malaria in various parts of the world would afford information of great value. The nature of the soil, the height of the subsoil water, the microbiology of the soil and of the superincumbent air, and the effect of atmospheric conditions should be tabulated and compared. We already have evidence of the frequent recrudescence of malaria through artificial irrigation in India, and in Egypt

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[1] Pearson, National Life and Character, Wiener's Perou et Bolivie. Orton's Andes and Amazon, Curtis's Capitals of South America.

the possibility of the revival of plague through irrigation can not be lost sight of. What malaria means in India is best realized by a glance at the mortality statistics, which show that 3,000,000 natives annually fall victims to this most fatal of all endemic diseases, and we know that where one dies many are enfeebled for life.

Looking at the available evidence, we may fairly infer (1) that the inhabitants of temperate climates are, on the whole, intellectually and physically superior, and that they owe this position largely to atmospheric conditions; (2) that in the tropics and commonly in the temperate zone the inhabitants of the mountains are physically the strongest; (3) that tropical countries are not favorable for rapid permanent colonization by the races of northern Europe and of the Northern States of America; (4) that the maintenance of healthy conditions in persons passing from one kind of climate to another very different climate depends to a great extent on the observance of hygienic method and a change of habit, but also on the time taken to make the move, rapidity of transition being inimical to health; (5) that tribes or races have moved from hot to cold, and cold to hot climates, occupying centuries or thousands of years in their progress, and have not invariably suffered or degenerated, and that therefore, and on other grounds, it is probable that fairly healthy hot or cold countries may in the course of centuries be colonized by races which have successively and slowly occupied lands warmer or colder than their own; (6) that people long subject to extreme variations of temperature, as between winter and summer, and day and night, are better able to colonize than those who are subject to more uniform temperature.

MODE OF ATTACK OF MIASMATIC DISEASES.

It is very desirable that the various diseases which affect the inhabitants of moist countries in the tropics should be traced to their original haunts, and their favorite channel of communication be ascertained. Is the condition known as tropical anæmia mainly a result of temperature or of an emanation from the soil in the air? Are dysentery, diarrhea, hepatitis, and liver disease due mostly to organisms swallowed in food or drink, or inhaled in the air overlying soil rich in organic matter, or are they produced by merely physical properties of the atmosphere acting on imperfectly healthy bodies, by means of over-fatigue, insolation, or chill? It appears likely that both air and water are capable, in the case of several tropical diseases, of conveying the poison. Thus, at Sierra Leone, improved water lowered the death rate, but it still remains high; in the villages of the Najagarrh hills in India, a drain-cut reducing the flood level by 3 feet greatly improved the health of the people, and splenic enlargement cases were reduced to less than one-sixth of their former prevalence; in the canal-irrigated country in India fever is both more prevalent and more virulent, and a great difference in the health of the people is observed between places where the water level is high and where it is low; the mere neighborhood of a swamp, without any pollution of water supply, is often sufficient to prostrate troops. There can indeed be no doubt that air infected from the ground very commonly causes a widespread epidemic of malaria. When the waters of a flood subside, the fever extends over a wide area and beyond the limits of the flood; and exposure to night air without any other source of contamination is a frequent cause of fever even to the robust. Considering the large number of varieties of bacilli residing in mold and in damp earth covered by sand, the relation of diseases to the air and vapor emanating from the ground is a subject worthy of national or international research.

All over the world there are indications, if not such evidence as amounts to proof, that where the air stagnates or is confined in valleys without exposure to frequent winds, the condition of robust health in a population is not well maintained. In certain valleys of Switzerland, of the Pyrenees, of Derbyshire, in England, and of parts of India goiter and cretinism have been common; in low-lying clay districts in England cancer has been shown to be prevalent above the average, and in limestone or chalk districts to be below the average. Valleys lying across the direction of the prevailing wind and not well ventilated are liable to an excess of heart disease. Whether these effects are in any degree due to stagnant or miasmatic air or wholly to difference in the water supply it is uncertain, and the subject demands inquiry.

Climate has often been credited, even by great writers, with effects on the human constitution which statistics have failed to indicate. Most people have supposed that suicide in England must be most frequent in November or in winter when the dark foggy air depresses the spirits. As a matter of fact, however, in England and in Europe, as a whole, suicides are most frequent in the summer half of the year, and especially in May and June, when the aspect of nature is most cheerful and the air bright and pleasant. A very distinct and considerable rise in suicides, crimes, and nervous diseases takes place in the spring and early summer. The first cold weather in autumn produces a temporary and smaller increase. Montesquieu assumed that the number of suicides is excessive in England, and attributed them to depression, caused by the dark, cold, damp climate. As a matter of fact, the suicides in England are not excessive when compared with France and central Germany, and the climate is not often dark and damp for long periods. Esquirol and Cabanis asserted that a rainy autumn following a dry summer is productive of violent deaths; Vilemais maintains that nine-tenths of suicides happen in rainy and cloudy weather. Quite a different order of things is revealed by a comparison of the figures for suicide, and especially for the suicide of insanity, for the different months. The quick increase of the temperature of the air, the dryness and sunshine of the spring have the effect of precipitating mental alienation and increasing nerve instability; the organism is least robust when the winter passes away.

Suicide predominates in the central part of Europe between latitudes 47 and 57 and longitudes 20 and 40. In the southwest and northeast of Europe the tendency is much less. Italy, Spain, and Portugal have a minimum number. The distribution appears to be little affected by climate, and very largely by mental advance and cultivation, so that the climatic factor, if existent, is concealed. But there is sufficient reason in Europe, at least, to attribute an excess of nervous diseases when other conditions are equal to periodic hot and dry weather and alternations of heat and cold. Countries either very hot or very cold are less subject to suicidal tendencies than the temperate region. But inquiry is needed to dissociate the climatic factor from the many others which confuse the evidence in civilized countries.

The influence of climate upon health and upon national character has never been very fully studied, and is worthy of the attention of Government and of science. The effect of change of climate has already been touched upon in another part of this essay.

The degree of cold which the human body can easily bear is surprising. A temperature of —70° F. with a dry and still air is less trying than a temperature of 20° with damp and strong wind. The present writer has had experience on a mountain in Italy of a temperature of 17° F., with sunshine, which was quite pleasant and not too cold for sitting out. Even invalids can sleep with windows open and sit out, without very heavy clothing, when the thermometer shows several degrees of frost. The purity of the air as well as the dryness seems to invigorate the frame and prevent the sensation of chill. Voyagers in the Arctic regions endure prolonged cold without in any way suffering in health if judicious in their mode of life, and mountaineers are seldom the worse for exposure unless they have greatly fatigued themselves or have been overtaken by rain or snow. The tolerance of heat is also very remarkable where the air is dry and pure and direct sunshine avoided. The temperature of the body rises about 0.05° F. for every increase of 1° F. above the ordinary temperature. The amount of air respired is less in hot than cold climates, in the proportion of 8.157 to 10 ounces of carbon. The total effect of heat and of cold on the human body has never been fully investigated. The net result, however, of a very complex series of changes induced by different temperatures on the inhabitants of different lands seems to show that a moderate or medium temperature is most favorable to health and strength, apart from telluric and constitutional factors, and from diet, training, and habits. Yet there can be no doubt that some race of mankind may attain very great strength and health in any nonmalarious climate.

PART III.—VARIOUS ATMOSPHERIC CONDITIONS AND PHENOMENA.

TEMPERATURE AND HEALTH.

The relation of the temperature of the air to health has already been noted in the case of various diseases. Thus malaria, dysentery, liver diseases, cholera, yellow fever, and dengue belong especially to hot climates. Anæmia and general enfeeblement affect the inhabitants of colder regions when stationed in the tropics. Hot weather in northern Europe increases the prevalence of several diseases, and with drought increases the death rate in towns and damp places. Diarrhea becomes prevalent, and in less degree scarlet fever and diphtheria. Diseases of the intestines increase. Cold, dry, still weather is generally healthy except in towns, and to old people, and to persons whose lungs are delicate. A cold winter in temperate climates increases the death rate, and a mild winter is healthy in northwestern Europe. Influenza, pneumonia, and bronchitis are more fatal in cold weather. Diseases of the circulatory system, heart disease, and phthisis are at their maximum of fatality. Cold, clear, still, frosty weather is, on the whole, healthy and much less fatal in towns than cold with fog.

The most favorable temperature to health in temperate climates is about 55° to 70° on an average; natives of the tropics probably thrive best at a temperature of about 65° to 80°.

DRY CLIMATES AND HEALTH.

A perennially dry air is almost universally favorable to human life, and dryness in a sparsely inhabited and well-watered country is wholesome in several ways, especially, perhaps, in its preventive effect on epidemic and lung diseases. In towns, dry weather without showers is much less favorable, in fact it is distinctly unfavorable. Very damp and rainy countries with moderate temperature are often healthy; for instance, western Ireland, western Scotland, Cornwall, and the lake district of England. The deaths from consumption, etc., are much fewer in these districts than in the drier districts which are more thickly inhabited, though not less, perhaps, than in equally sparsely inhabited drier country districts. That they are so numerous as they are depends probably very much on the tendency to aggregation and bad ventilation in the dwellings in bad weather. Tropical or warm countries, and warm seasons, in many localities, are unwholesome when there has been much rainfall, and this is succeeded by hot weather. Much moisture in a calm air helps greatly to spread various epidemic diseases and malaria. Dry air is favorable to the healing of wounds, and probably to the oxidation or death by desiccation of noxious living matter in the air.

The exemption of many tribes and races living in dry climates from phthisis and other disorders of an infectious nature may be, and probably is, partly due directly to the dry air which does not permit the growth of the bacillus on solid substances or soil, but must also be attributed to the migratory habits of the people, the outdoor life, and the absence of centers of infection. Arabs, who were exempt from phthisis and scrofula in their camps, died at the rate of 50 per cent when they were located in French prisons. This is only one of many instances which go to prove that the infective matter of consumption clings to solid surfaces and thence invades the human system through confined air.

HEALTH AT HIGH ALTITUDES.

The effect of living at high altitudes has been variously stated, but on the whole it seems probable that most persons become acclimatized to the rarity of the air, diminished pressure, lower temperature, lessened humidity, and increased sun power. Above 6,000 feet the pulse and respiration rates are slightly increased. Dr. Marcet gave as the chief outcome of several years' experiments on the amount of carbon dioxide and air expired at high altitudes the following statements:[1] The effect of altitude and cold combined increases the amount of carbon dioxide expired, but where the cold does not become appreciably greater, as on the Peak of Teneriffe, the amount remains the same as at the sea level. At altitudes above 10,000 feet the amount is lessened. Less air is expired at high altitudes. It appears that the blood more readily acquires oxygen at high altitudes than near the sea level. The body can gradually accommodate itself to altitudes much above 10,000 feet. Recent laboratory experiments by Dr. Loewy showed that the diminution of air density and pressure to about 17.717 inches is well borne, greater rarefaction being balanced by deeper inspiration. A similar compensation occurs when carbon dioxide is added to the air. Animals breathing air rarefied to half an atmosphere eject the same amount of blood from the heart as under normal pressure.

The expansion of the chest and increased action of the heart add to strength and vigor, and the mountain races, with the exception of people living in deep or flat valleys, are generally fine in build. In the tropics, Quito is an example of a large population doing well at a height of 10,000 feet. For some forms of consumption, consumptive tendencies, and several other diseases, such as anæmia, altitude is beneficial; for others, including nervous irritability and heart weakness, it is harmful. The elements which are concerned in these effects have not been identified. For old people and those who can not take much exercise, mountain heights are clearly not well adapted.

SEA AIR AND HEALTH.

Sea air is very beneficial to the great majority of people, and has a wonderful restorative power in many ailments and illnesses. It is free

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[1] Proc. Roy. Soc., 1878, 1879.

from all kinds of infective germs, and therefore epidemic diseases are unknown at sea, except in so far as they arise from the material, provisions, or water of the ship, or have been brought on board by crew or passengers. Much of the benefit which would otherwise be derived from a sea voyage is often counteracted by the small space and difficulties of ventilation of sleeping berths and cabins. The temperature of the tropics has a bad effect upon the crew and passengers of ships from colder climates, and loss of weight results; but, in general, the weight and strength of passengers are increased by voyaging in a fair climate. Much depends, of course, upon the accommodation and diet, as well as upon the atmospheric conditions.

THE IMPROVEMENT OF CLIMATE WITH SLIGHT ELEVATION.

From a certain number of experiments and from a review of observations taken by meteorologists of differences between temperature and humidity at different heights above the ground, the present writer came to the following conclusions,[1] shortly stated:

The mean temperature at a height of about 100 feet above the ground does not differ sensibly from the mean temperature at 5 feet, but seems to be slightly in excess.

The means of daily maxima at heights of 69 and 128 feet fall short of the mean maxima at 10 feet, and still more of the maxima at 4 feet. The means of daily minima at the greater heights exceed the mean minima at the smaller heights.

There is a certain altitude, apparently about 150 feet above the ground, at which, while the mean temperature is equal to that at 4 feet, the maxima are lower and the minima higher than at any lower point.

On an average of nineteen months, the mean of maxima was about 1.5° F. lower at 128 feet 10 inches than at 10 feet, and the mean of minima about 0.55° higher.

In cyclones the higher, and in anticyclones the lower, points generally have the lowest mean temperature.

The mean night temperature is always highest at the higher points, and the mean day temperature always lowest.

About sunset in clear or foggy weather, when calm, temperature falls much faster near the ground than at some height above it.

Equality of lower and upper temperature seems to occur about two hours before sunset and after sunrise, but varies with the season.

In clear weather and low fogs, between sunset and sunrise, temperature is always, or nearly always, higher at heights varying from 50 to 300 feet above the ground than at heights from 2 to 22 feet.

In bad weather the higher points are coldest by day and night. In foggy weather, especially with ground or radiation fogs, temperature is very much the lowest near the ground, and within the fog much lower than above it.

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[1] Trans. Sanit. Inst. of Great Britain.

The mean daily range at 128 feet approaches closely that of the English seacoast, and at 69 feet is about midway between that of coast and inland stations.

Mean humidity is more than 1° less at 69 and 128 feet than at 10 feet surrounded by trees. Humidity by day is a little greater, by night much less, 2° or 3°.

Places on hills or slopes from 150 to 700 feet above a plain or valley, especially with a southern aspect, have a much smaller annual range, and also a smaller daily range than places on the flat. At 545 feet a superiority of 12° or 13° in the extreme minimum has been registered. Thus we find that at a height about equal to that of the upper rooms of a high house a more equable and drier climate prevails than near the ground, and that conditions on sloping or well-chosen natural elevations are on the whole similar.

The importance to delicate persons, and indeed to the majority of people, of living at some height above the ground, especially in places which are damp, subject to fog, or to unwholesome emanations from the ground, has yet to be appreciated.

EFFECT OF IMPURITIES IN THE AIR OF TOWNS ON MENTAL AND BODILY HEALTH.

A dense population in manufacturing and other large towns is accustomed to breathe a compound mixture in the air which in course of time profoundly affects the health of the race. The oxygen is deficient, the ozone absent, carbon dioxide in excess, hydrocarbons, animal and mineral dust, sulphurous acid, chlorides, ammonia, and microorganisms in pernicious abundance.

The small tenements or crowded rooms produce the high death rate, an enormous proportion of deaths in childhood, and of diseases of the lungs at all ages. The best model dwellings, on the contrary, have a lower death rate than the mean of the town, although the population to the acre is dense.[1] In New York, about twenty-five years ago, 495,000 persons lived in tenement houses and cellars, most of them dark, damp, and unventilated. By hygienic measures, largely by ventilation, the death rate was reduced in twelve years from 1 in 33 to 1 in 38.

Townspeople spend much more of their lives indoors than the peasantry. At their work and in their rooms they breathe dust of many sorts, particles of skin, organic poisons, and often many pathogenic germs which would develop in their bodies if they had not already passed through the specific disorder. The air being deprived of its exhilarating power, they seek stimulants in food and drink, and go to mischievous excess in the consumption of animal flesh and alcohol. Hence many internal diseases. Children are never seen of the right sturdiness and color which is common in the country. Most children

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[1] The corrected death rate of infants in the dwellings, chiefly blocks, of the Metropolitan Association for Improving the Dwellings of the Industrious Classes in London, has been for some years past much below the average.

born and bred in the crowded parts of towns are sickly, pale, feeble, unnaturally sharp and wizened, their voices are of bad quality, and their height and weight deficient. The elder people become reckless, often depraved, dirty, and scarcely ever free from ailments. Their whole bodily, mental, and moral nature deteriorates. As a consequence, it is difficult for native townsfolk to obtain employment in competition with immigrants from the country. In general, policemen, laborers, domestic servants, and several other classes of employees are found to be most fitted for their duties if country born, and thus perpetual immigration is stimulated. The best and strongest people are constantly migrating to the great towns, bringing their health and youth to supply the demand for good work, and reducing the death rate, so that the true proportion of victims of town air and town conditions fails to be realized. As a matter of fact, it has been ascertained that very few families survive in central London for more than four generations, and that many die out in two or three generations. A true Londoner of the fifth and even of the fourth generation is rare. A very large proportion, probably the majority, lose the fine stock of health they brought with them from the country within two generations.[1] This is a matter of national and international importance, and the fact should be clearly understood by the public and by legislators that the desertion of the country by the best blood involves the rapid consumption of the finest physical, mental, and moral qualities.

We have, in fact, in our midst areas—climates, if we may so strain the term—of which the properties come into close competition with the influences of the tropics in bringing about the decline and extirpation of families. If the inner circle of a great city were to exclude immigration for a generation, the poverty of its health resources would stare it in the face, and the falling value of a day's labor would startle it into the promotion of hygienic reform. Room and space would be demanded as a necessity for the proper development of human beings.

The rate of mortality is greatly increased by the bad air of towns, and especially by the close, foul air of dwellings and workshops. But the rate of sickness is still more increased above that of the breezy country. In one part of the parish of St. George's-in-the-East, in London, there are nine cases of sickness to one death, but in the worst part of the same district there are twenty known cases of sickness to one death, and a sickness rate of 620 per 1,000. There is, in fact, no good health in the people of the crowded streets, unless it may be for

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[1] Defining a Londoner as one who habitually resides in London, with only few holidays, and whose great-grandparents, grandparents, and parents were Londoners, it is exceedingly difficult to find such a specimen among 5,000,000 people. Even true Londoners of the third generation are very disproportionately small in numbers and feeble in health and strength. These facts, however, do not prove that the inhabitants of large towns must of necessity decay unless recruited from without, for with better homes, houses, more air, reduced hours of work, more holidays, and better hygienic conditions of suburban as compared with central quarters, the prospect of continued vitality greatly improves.

a short time among newcomers from the country. "They are perpetually on the trudge to the hospitals, and get patched up again and again and live on."[1] Much of this most deplorable state of things may be owing to excess of alcoholic drink, but the excess is in many cases the result of a demand for a stimulant which pure air might have prevented. About 1,000,000 out of 4,000,000 persons are treated at London hospitals and dispensaries in a year, and probably this represents fairly well the sickness of great towns in general. A great amount of the lassitude and idleness of the lowest population of cities has been traced by Dr. Richardson to want of ventilation, in their own and former generations. "Tell them," said Mr. Chadwick, the great sanitary reformer, "that when they hear of that disease called consumption they ought to know that it comes constantly from bad administration, which permits dwelling houses to be built on damp and sodden and rotten sites, and which permits industrial workers to breathe, but not to live, in foul airs, gases, vapors, and dusts. Tell them that in model dwellings a death rate of 15 in the 1,000 has replaced one of 30 in the 1,000." Dr. Louis C. Parkes, medical officer for Chelsea, states that much of the anæmia, the pale faces and disordered digestions, and many of the wasting diseases of children in the great towns are to no small extent due to a condition of atmosphere which prevents the perfect action of the lungs and the complete oxygenation of the blood, and so lowers the tone of the body and the ability to repel disease. These facts ought to be impressed upon the population. In England it has been computed that the amount now annually spent on intoxicating liquors might double the actual house room for every family.

The causes of physical degradation in towns are no doubt complex, but that bad air and want of light are very powerful factors, is proved by the following considerations:

Children placed in every respect in equally good conditions in town as they have had in the country, with the exception of the difference of town air, in many cases lose health, grow pale and weak, and in fact do not thrive as they do in the country. Children brought up within the central area of large towns are less robust than children brought up in the country; the children of the poor especially suffer, for though they may have the chance of more flesh meat and often of more food, the air they breathe both without and within doors is inferior, and this affects them not only directly, but indirectly, as through loss of appetite. Very many children in towns have poor and unwholesome appetites. Children in small, crowded towns in various countries, e. g., Italy or Spain, where the streets are narrow and the air foul, often look unhealthy and feeble, and bad air alone, both in town and country, is known to give similar results. Children who are ailing or simply pallid and unhealthy, after the pattern of the alley, very soon gain in health and appearance when moved to country air. The experience of very many adults is similar to that of children, and they rapidly or

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[1] Evidence of a doctor in the East End of London.

gradually lose their accustomed vigor during a period of employment in crowded or badly ventilated places. The air of workshops, printing rooms, mills, etc., sometimes changes young, vigorous looking men almost beyond recognition in the course of one or two years. Outdoor work in towns is far less pernicious, and if houses and streets were more spacious, and work places more airy, the physical degradation would be much less perceptible. The mental and moral effect of living in bad air can hardly be estimated, mixed up as it is with the various other conditions which generally accompany it. The wits are certainly dulled when oxygen is wanting and carbonic acid in excess, but social contact tends perhaps more powerfully to sharpen them. Sharpness, cunning, and alertness increase in towns, but great work demanding sustained intellectual effort is not favored, but vitiated, by bad air. In schools, the loss of attention, the difficulty of keeping on long at a task, and the sympathetic weariness, are very frequently the result of bad ventilation. The schoolmaster has great power to improve the quality, or rather the scope, of his pupil's brains by the admission of plenty of air. School-masters and teachers as a class are not in the list of healthy occupations, although they are above the average of strength when they enter their profession. The air they breathe must be concerned in the disorders which especially attack them. Town air seems to tend to weaken the power of the will, the self-command, and the exhilarating sense of freedom and content which distinguish independent yeomen or the peasantry of the hill country, who breathe the vital atmosphere. But here again, we fail to discriminate between the effects of physical and of social differences. Since "self-reverence, self-knowledge, self-control" are among the highest human attributes, and most essential for future progress, the effects, direct and indirect, of vitiated air on character might with advantage form the subject of extended and carefully conducted scientific inquiry.

Intemperance in drink has been commonly attributed to foul air among other influences. There can be no doubt that many a man has become enfeebled by working in bad air, and has taken to drink in the vain hope of keeping up his strength, or with the deliberate intention, for the moment justified, of stimulating his faculties occasionally when they flag. Where the air has so little freshness, mind and body are more likely to crave for artificial and less wholesome sustenance. Whether on the whole the indoor workers consume more alcohol than the outdoor may be doubted, but the effect upon them, beyond question, is worse.

An investigation of the effect of air on mental qualities might be undertaken on the following lines: A number of schools in which ventilation is good to be compared with schools similar in class of scholars, etc., but with bad ventilation of less space, the character of the work and of the scholars to be compared; schools where great improvements in ventilation have been made to be examined as to any notable progress following the improvements; workshops of similar classes to be compared, respectively good and deficient in ventilation or space, the results as regards health, vigor, intemperance, and efficiency.

WIND FORCE AND HEALTH IN A LARGE TOWN.

In an inquiry made quite recently by the present writer, but hitherto unpublished, concerning the relation between the health of London in winter and the force of the wind, the conclusion was arrived at that on the whole, the mortality is greater in calm than in windy weather, and that there is much less variation in the death rate during the prevalence of strong winds than during the prevalence of gentle winds and calms. The period examined was from November, 1872, to December, 1893. In January, 1890, and in the first quarter of 1892, influenza greatly raised the mortality above the normal, but since this is one of the zymotic diseases, of which the prevalence is increased by calm weather, the figures for these periods have not been omitted. The months of October, November, and December, in 1879 and in 1889, were the least windy periods recorded, and each was followed by a high death rate. Several calm periods coincide with great cold and fog, and it is these in combination which have the worst effect upon health in a smoky town.

Further investigation is required to ascertain which diseases are most apt to spread in calm weather, and the relation of particular winds to particular diseases.

The following table represents roughly and approximately the rates of mortality in the periods mentioned:

Minima, hourly horizontal movement less than 11 miles.

Period.	Death rate.	Death rate in five weeks following.
December, 1873 (22 calm hours, cold and fog)	28.2	23.1
February, 1874 (33 hours calm)	24.6	23.1
November, 1874 (34 calm hours)	27.2	31.4
February, 1875 (no calms)	25.7	23.2
October and November, 1876 (no calms)	21.4	22.4
February, 1878	25.4	24.3
December, 1878 (36 calm hours)	28.1	26.8
October, November, and December, 1879 (131 calm hours)	26.6	31.2
January, 1880	31.2	31.7
November and December, 1885	20.64	22.5
February, 1886	24.9	26.9
January, 1887	21.8	19.3
December, 1888	19.8	23.2
January, 1889	20.3	18.2
November and December, 1889	19.48	28.1
December, 1890	24.7	28.5
Quarter ending April 2, 1892	28.2	....
October, November, and December, 1892	18.5	....
Total	24.42	25.25

Maxima, hourly horizontal movement more than 15 miles.

Period.	Death rate.	Death rate in five weeks following.
November, 1872 (no calms)	22. 8	24. 5
January, 1873 (37 calm hours)	19. 2	24. 8
February and March, 1876 (no calm hours)	24. 6	23. 4
January and February, 1877 (17 calm hours)	21. 6	27. 6
November, 1877 (no calms)	22. 3	25. 3
January, 1878 (24 calm hours)	26. 6	25. 4
November and December, 1880	21. 9	25. 0
November, 1881	21. 18	23. 1
November, 1882	21. 26	23. 5
January, February, and March, 1883	21. 9	23. 6
November and December, 1883	21. 23	20. 4
January and February, 1884	21. 22	19. 9
December, 1884	21. 6	23. 2
February, 1885	19. 6	22. 0
December, 1886	20. 9	21. 8
February and March, 1888	21. 2	19. 0
February, 1889	18. 2	18. 6
January, 1890	28. 1	21. 4
Total	22. 15	23. 1

DEW AND FROST—EXHALATION OF VAPOR FROM THE EARTH.

From an investigation conducted by the present writer during the two summers 1891 and 1892, the following were among the conclusions arrived at:

Calm or a light air is favorable to dew formation. Wind prevents the deposition of much dew and evaporates much of what is formed. Free radiation or an exposed situation is, on the whole, perhaps the most effectual cause of dew on very many nights of the year. In a level country those parts of a field which are least sheltered by trees and hedges gain most dew on perfectly calm nights. Those parts of any flat substance with the most exposure to the sky are on calm nights most bedewed. The tops of bushes, posts, railings, pans, etc., are on calm nights more bedewed than the sides. Greater cold by greater radiation in these cases produces greater deposition. Radiation from fine points, however, is often not sufficient to counteract in air which is not very humid the effect of the continual impact of air above the dew-point and higher in temperature. Close to the ground the case is generally different, for the movement of air is less and the humidity and cold greater. With fog or a very humid air the points are most bedewed. In dry weather the dew is deposited most on the leeward side, in moist air or fog on the windward side of objects.

Nearly all the conclusions of Wells were confirmed. But a very remarkable amount of evidence soon accumulated from the experiments that a great proportion of the dew formed near the ground is condensed from vapor derived from the earth. A large quantity of dew was invariably found on clear nights in the interior of closed vessels inverted over grass and sand, very little or none in vessels inverted over plates lying on the ground. The inverted glasses or vessels, however much their rims were embedded in the ground, gave similar results. More dew was found on the lower surface of plates of glass or earthenware or boards slightly raised above the ground than on the upper surface. The lower sides of stones, slates, glass, and paper on the ground were more bedewed than the upper sides. The lower half of stones lying or embedded in sand was more often bedewed and frosted than the upper half. The interior of closed vessels inverted on the grass and covered with two other vessels of badly conducting substance was thickly bedewed, and the grass in the three inclosures was also thickly bedewed. The deposit on the interior of vessels was much less over dry garden earth than over sand or turf. A great deal of dew was deposited on the interior of vessels over dry sand or dust, the earth being somewhat moist an inch or two inches below. Pebbles, etc., lying on a dusty road became quite wet underneath early in the evening, and over grass the underside of a square of glass is clouded soon after the grass loses the sunshine. A very great difference of temperature was found soon after sunset after hot days between the temperature of the soil at a depth of 2 or 3 inches and the temperature of the air close to the ground, just above the blades of grass. On one evening at 11 p. m. the temperature of the exposed grass was 36; of the soil at 15 inches, 60.5.

The author became convinced by these experiments and other considerations, that a great deal of dew comes from vapor from the soil and from plants, and at sea from vapor from the surface of the sea; that malaria and some other diseases are largely caused by emanations from the soil at night bearing organisms into the air, which are then retained by the damp air in a cold stratum near the ground, and that sand overlying damp earth permits air and vapor to rise easily through it. Also, it became evident that a great deal of soil-air may be drawn into houses through pervious soil, and that the neighborhood of damp ground may be thickly infected with organisms contained in the air and vapor which emerge from the soil. A dry covering of sandy earth is not only little impediment to the exhalation of vapor, but may serve to protect micro-organisms from the killing action of dry air and sunshine.[1]

EXHALATION OF GASES AND PARTICLES FROM THE EARTH.

It is generally assumed that evaporation or distillation of water gives rise to pure vapor and leaves behind all impurities, but, as a matter of fact, in many natural conditions this is far from being the case. When earth becomes heated, moisture forces its way as a vapor through a

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[1] The author has treated this subject more fully in Trans. Sanit. Ins. for 1892: The Exhalation of Vapor from the Earth.

porous superficial layer, and carries with it spores or minute organisms which have multiplied or germinated in the passages through which the vapor passes. A moderate degree of moisture and rather free aeration of the soil are favorable to the growth of many kinds of microbes. We know that cotton wool, unless tightly packed, will not stop the passage of microorganisms; sand and porous soil allow both air and water to pass without depositing all their particulate contents. The filter beds of water companies are efficient not by the action of the sand, but by the retention of particulate bodies in the slimy covering soon deposited above the sand.

Cold nights following hot days seem to favor very much the exhalation of vapor from the earth.

Wind may very likely have an effect in drawing out the gases from the soil, but this action is less important to human health, for malarious germs are dispersed and much less dangerous in windy weather.

Aitken has shown by his experiments on the formation of small, clear spaces in dusty air that bodies warmer than the air drive away dust from their surfaces and create the dust-free black envelope which surrounds them. He further showed that an evaporating surface has a similar influence, and that dust was driven more than twice as far from the wet part of an object as from the dry, the object being above the temperature of the air. The necessary conditions for the repulsive effect to be strongly shown are that the air must be acquiring heat and moisture from the surface. Very little heat with moisture gives a thicker dark plane than double the heat would do. Dust passes through small openings with surprising ease; "any opening which admits air allows the passage of the finest particles." The air contains enormous multitudes of particles so small that the concentrated light of the sun does not reveal them.[1] We may fairly infer from these facts that no inconsiderable part of the fine dust of the air, mineral and organic, is derived from below the surface of the ground. Some interesting experiments made a few years ago showed that the dust deposited in tightly closed cupboards is brought in by the movements of air induced by changes of temperature. Similarly, changes of temperature must draw in and expel fine organic dust from and to air and soil.

The present writer's observations led him to conclude that a great quantity of vapor issues from the earth even in dry weather, and when the surface down to 2 inches or more is dry and dusty that the emission is very large in the evening, but that the maximum appears to take place in the early hours of the morning in dry weather; that soon after sunset in England in summer the temperature of short grass and contiguous air may be 9° to 15° or 20° colder than that of the earth at a depth of 1 to 15 inches, and that about sunrise the temperature of the top grass of a pasture field may be 20° to 30° colder than that of the earth at a depth of 9 to 15 inches and lower, and that the emission of

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[1] Formation of clear spaces in dusty air. By John Aitken, Proc. Roy. Soc., 1877.

vapor is very much less through mold than through sand or dust. In hot climates, such as India and Italy, on bare sandy ground and in valleys it seems probable that the differences in temperature between soil and surface air may amount at night to between 30° and 40°, and in malarious places the flow of impure vapor toward the surface may be equal to the evaporation from a marsh. These facts have a very distinct bearing on the generation and prevalence of malaria, diarrhea, dysentery, and other diseases.

Herr Singer, at Munich, found that the maximum temperature of the soil (59.3) at 4 feet 3 inches, was reached on August 24, and Fodor's results gave a maximum temperature at depths between half a meter and 1 meter in August. Liebenberg observed that sand is warmed throughout more rapidly than clay and that the richer a soil in organic matter the greater its power of absorbing heat. Pettenkofer's observations show that a very large amount of air is contained even in firm soils and that effluvia from decomposing organic matter may pass for a long distance through very loose soils. Permeable soils are sandstones, loose sands, and chalk, and are generally healthy unless they contain much organic matter or are superposed upon a clay or other impervious stratum which holds up the water near the surface. Movement of subsoil water of course greatly affects the quantity of earth vapor given off during certain periods. The dried beds of water courses are well adapted for the evolution of malaria, for the superficial layer is usually permeable, the soil contains much organic matter, the water level is not far from the surface, cold air collects over the valley and is often moist and stagnant. In the dry regions of Australia it is well known that water may be found at a little depth below the dry channels of rivers.

Vegetable mold near the surface of the earth is very rich in saprophytic bacteria, and Flugge states that infusions made from manured fields and garden earth contain thousands of bacteria in every drop, though diluted one hundred times. But the observations of the present writer tend to prove that the retention of heat and moisture by this kind of earth is much greater than that of other soils, and that much less emission of vapor takes place from it into the air, so that the organisms which might be expected to invade in excess the air over cultivated ground may in reality be scarcely capable of entering it.

GROUND AIR.

The amount of air in the upper layers of the earth is very considerable, but varies greatly with the nature of the soil. Gravel and sand contain a large quantity of air, which has been estimated at one-third of its bulk. A bird has been experimentally inclosed in a glass cylinder with a solid bed of gravel below and above it, and was not affected, the air which passed through the earth being sufficient to maintain life. The proportion of carbonic acid, however, in some soils, especially where there is much organic débris, much exceeds that in the atmosphere, and would prevent the success of such an experiment. Ground air passes easily through earth, especially through gravel and sand, so that in the neighborhood of decomposing organic matter houses built on such soil are liable to invasions of poisonous gases. Carbon monoxide has been known to pass 20 or 30 yards through the earth into a house, causing severe illness. But the worst results follow the infamous practice which has been in vogue at the outskirts of large towns of selling turf and gravel on building sites, allowing the excavations to be filled in with rubbish and refuse, and building dwelling houses over these sources of disease. Probably many houses in towns where fever persistently breaks out owe their unwholesomeness to this cause. Even where the soil is natural and undisturbed beneath the foundations, there should always be a layer of impervious material, such as good Portland cement or rock asphalt, between the house and the ground; or else a good space through which the outside air may freely flow. Dwellings well raised above the ground escape many dangers associated with ground air, damp, and drainage. A damp basement is a frequent source of trouble. Hollow skirtings, casings for pipes, bell wires, etc., frequently give opportunities not only to rats and mice, but to deadly gases, to make their way into the apartments.

Inquiry is needed to discover the actual quantities of vapor emitted from different soils and subsoils, at different temperatures of air and soil, at different barometric pressures, at different times of day and night, and at different seasons, and at varying levels of subsoil water. An examination of the different species of microbes or amœba-like organisms emitted would also be of interest.

EMANATION OF ORGANIC PARTICLES FROM EVAPORATING FLUIDS.

The spread of infective organisms into the air from the surface of evaporating liquids is a subject worthy of investigation. It has been generally stated and assumed that an evaporating liquid contaminated with impurities leaves behind it all foreign ingredients and passes into the air as pure vapor. This is very far from being universally true, if evaporation be understood not as a laboratory process carefully conducted, but as a process subject to the various interferences which must occur in natural conditions. Evaporation from the sea may give pure vapor into the air, so long as the sea is tranquil and no bubble breaks on the surface, but the breaking of waves on the ocean and on the shore, and the evolution of gases from animal and vegetable life and organic decay cause evaporation to be accompanied by a considerable emission of sodium chloride, and of other substances in solution, into the air with the bursting of foam and bubbles and the tearing off of spray by the wind.

Marshes give off various gases, especially in the drying process, besides vapor. The upward movement of the air from the drying ground, the generation of gases in the viscous fluids and in the earth below them, the bursting of countless small bubbles and films, the development of electricity in the evaporation of an impure liquid, the repulsion of small particles by a warm evaporating surface, all help to carry into the lower air a large quantity of microscopic and ultramicroscopic dust. In a research made by the present writer into the diathermancy of thin films of water[1] he was much struck by the force with which the thinnest film snapped; a slightly soapy film of 1½ inches diameter and about one-millionth of an inch in thickness broke with an audible sound. In the viscous fluid of drying marshes there must be millions of thin films breaking and throwing their minute spray into the air which carries off the contained organic particles. Moreover, there must be a continual evolution of very small bubbles of gas from the muddy earth through the liquid above it. The scattering force of small bubbles is surprising. If a glass of effervescing water be watched, the minute bubbles which rise to the surface of the liquid will be seen to throw particles of water to a height of several inches in the air. The smell of drying marshes probably proceeds not only from gases, but from particulate products. Indeed, many organisms and vegetable and animal débris have been actually observed microscopically in the air above marshes. Many living germs are probably beyond the range of visibility. The manner in which spores are scattered from the hyphæ of molds, etc., may represent a similar process in the ejection from marshy surfaces of various microorganisms. The formation of gas bubbles by the *Bacillus coli communis* may be only one example out of many in which such action takes place. This characteristic of coli communis has been used by Klein as a mark of differentiation between it and the bacillus of typhoid.[2]

The influences, or some of them, which have been named as helping to carry small organic particles into the air over marshes may be capable of launching infective matter from the lungs and air passages of persons suffering from such diseases as scarlet fever, measles, diphtheria, and consumption. Certainly organic matter and living particles have been observed in the condensed vapor of breath. Thus walls on which the breath condenses may become culture grounds for disease germs which it contains.

PERMEATION OF BUILDING MATERIALS BY AIR AND VAPOR.

The ordinary materials used for floors of dwelling houses are quite ineffectual to prevent the permeation of gases and microorganisms from the soil into the air of the dwelling. By experiments made with several different materials used for flooring, with a view to determine the rate at which air would pass through them into the Torricellian

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[1] Proc. Brit. Association, Cardiff, 1881. Abstract.

[2] Journal of Pathology and Bacteriology, November, 1893; Centralblatt für Bakt. and Parasit., Vol XV, Nos. 8 and 9. Local Government Board Reports, 1892–93.

vacuum over mercury, it was ascertained that mortar is practically merely a coarse sieve and permits the rapid and easy passage of gases, that plaster of paris is also highly permeable, 75 per cent compared with mortar; roman cement permeable to the extent of 25 per cent, and portland and hygienic cement to the extent of about 10 per cent. The rate of diffusion of gases through porous septa is, by Graham's law, in the inverse ratio of the square root of their gravity. If the gases in the earth below the flooring be heavy compared with the air of the room, upward diffusion through the flooring material must be rather slow, unless other apertures for the ingress of outside air are insufficient to supply the draft of fires. When the ground is warm, as in autumn, and contains certain light gases and vapor, there may be considerable aspiration from the ground through the floor into the room. It seems probable that mortar and other porous material would permit the passage or penetration not only of gases, but of microbes, but that good cement would not permit the passage or penetration of microbes to any important extent. Asphalt is still better, and effectually shuts out both gases and germs. Coal gas has been known to pass a considerable distance through the earth under frozen ground and to enter a house through the flooring, and there can be no doubt that much ground air enters houses in this way, especially in autumn and winter. A good concrete layer, 4 to 6 inches thick, or asphalt, under every house would do much to diminish diseases caused by ground air. The reduction of two courses of bricks, which would be saved by diminishing the air space between floor and ground, would partly balance the additional cost.

MECHANICAL VENTILATION IN SCHOOLS.

From a paper by Professor Carnelley on mechanical ventilation in schools, Sir Henry Roscoe drew the following conclusions, briefly summarized:

By mechanical ventilation the microorganisms were reduced to one-tenth, the organic matter to one-seventh, and the carbon dioxide to one-half; the temperature was kept higher without draft, and cold drafts were excluded. In badly ventilated schools microbes increase up to a certain point with increase of wall space; in mechanically ventilated schools the microbes decrease with increase of space. Scrubbing or washing floors had no effect in reducing the emission of microbes into the air, and it was found that the infection of a school with these organisms takes place very gradually, old schools being much more infested than new buildings. Similar facts have been observed by Miquel as regards houses. It is clear that walls and floors and perhaps ceilings also should be faced with an impervious material, adapted for frequent washing, and without interstices. As regards mechanical ventilation, however, it has not yet been proved that proper natural ventilation can advantageously be superseded.

The floors and walls of rooms must often be very suitable culture grounds for the microbes of disease. Many fungi grow upon damp plaster, damp wall paper, the interstices of floors, and upon rough surfaces and ledges in empty and also in occupied rooms. The *Chætonium chartatum*, for example, develops on paper and on the binding and insides of books wherever they are near a damp wall. Paper and size are well adapted to the settlement and multiplication of molds and probably also of some pathogenic microbes.

Bricks, mortar, plaster, and paper are all highly porous, and admit the passage of air continually through them. A common brick can absorb a pound of water, and plaster is also hygroscopic. We have, then, this condition in a room, that it is surrounded by damp, porous material, largely contaminated with organic dust and gases from the interior condensed within the walls and in the flooring or carpets. The resemblance to porous, damp, contaminated ground which is a known source of disease, is sufficiently close to make it highly desirable that better provision should be made (1) against damp in walls, (2) against the penetration of organic vapors and dust into the material of walls and into the interstices of floors, and (3) for the easy cleaning of walls with soap and water, and of floors which should be without interstices, by dry rubbing or with paraffin or otherwise.

AERATION AND SELF-PURIFICATION OF RIVERS.

The oxygen of the air contained in water has been supposed to play an important part in getting rid of the contamination of organic substances and in diminishing the number of pathogenic microbes in the water of streams used for drinking. A large number of experiments have been made in different countries with the object of determining the degree of safety with which water may be used for public supply which has run in the open air for various distances after contamination with sewage and other impurities.

The investigation is by no means a simple problem, and where the bacteria are found to have greatly diminished in number in the course of a few miles, the result is often due to other influences besides aeration, of which gradual dying out of the organisms is one, and sedimentation commonly the most efficient. Frank's experiments on the River Spree, at Berlin, showed that, though in flowing through the city, the river contained hundreds of thousands of bacteria in the cubic centimeter, the water some miles lower contained only 3,000 to 8,000, about the same number as in its upper course. In the Isar, below Munich, the number fell from 15,231 to 2,378 in the course of 22 miles. In the Thames and the Ure, Frankland did not find any considerable diminution. The Massachusetts State Board of Health found in the course of 23 miles a diminution of free ammonia from 1,728 to 1,299, of albuminoid ammonia from 826 to 382, of total nitrogen from 3,000 to 2,156, and an increase of nitric acid from 218 to 457. Oxidation to an important degree is shown in this case, but the result is not altogether favorable to the efficiency of aeration. In observations made on the River Limmat before and after passing through Zurich the following were the results:

	Distance in kilometers.	Number of bacteria per cubic centimeter.
Outflow from lake	0	225
Station 1	1.86	1,731
Sewer outlets	2.175	296,670
Station 4	2.485	12,870
Station 5	2.796	10,892
Station 6	3.417	5,902
Station 7	5.903	4,218
Station 8	6.214	2,346
Station 9	8.078	2,110

Miquel found in the Seine above Paris a rate of 4,800,000 microbes in the liter; below Paris, 12,800,000; in sewer water, 80,000,000.

Instances of outbreaks of typhoid through the use of river water contaminated miles above the intake are not rare. Gloucester suffered by the poisoning of the river by Kidderminster, 20 miles higher up. A single case of typhoid produced the disease in a Scottish town by the drawing back up the course of the river, owing to the obstruction of a weir, of the sewage which had entered below. At Providence, R. I., an epidemic was caused by the very slight pollution of a large and rather rapid stream 3¼ miles above the intake. When Lowell, Mass., has had a fever outbreak, Lawrence, lower down, has had a similar attack a little later. The Merrimac River has given several instructive examples of typhoid following pollution, and the Schuylkill, which is contaminated many miles above the intake of Philadelphia, appears to be the chief cause of the prevalence of the disease in that city.

Experiments on the artificial aeration of water by the Massachusetts Board of Health, and on natural aeration below Niagara Falls by Professor Leeds, show that little or no diminution of organic particles, and no chemical purification, is brought about.

Dr. Percy Frankland has found that various disease-causing bacilli present no uniformity in their behavior in potable water. Many preserve their vitality for a considerable time—days and weeks—and some, which form spores, for an indefinite time. Gaffkey's typhoid bacillus preserves its vitality even in distilled water for about fourteen days.

Altogether, aeration can not be trusted as effectual in rendering polluted water fit for drinking, and the diminution of organisms which to some extent does take place must be attributed to other causes.

ACTION OF BACTERIA AND OF THE AIR IN CONNECTION WITH DECOMPOSITION AND PLANT GROWTH.

Bacteria, or microbes in general, of an immense number of different kinds are almost ubiquitous on the whole surface of the earth and on all exposed solids. The favorite habitat of most kinds is the moist surface of some substance of organic origin undergoing decomposition. But some sorts appear to flourish on almost any kind of solid exposed to the air. Thus panes of glass, rocks, metals, tiles, and sand will furnish a crop, the richer, no doubt, for any slight deposit from organic liquids or gases. The chief work, and a very vast one, of microorganisms is the transformation of dead organic matter into "inorganic" substances. All the dead vegetable and animal substance lying exposed or where air has access is being transformed into mineral matter by this agency. Decomposition generally consists of oxidation by a class of microbes which take their oxygen from the air, and then the transformation and use of the oxygenized products which sink deeper into the earth by another class of microbes, the anaerobic, which not only themselves detach oxygen from its new compounds, but allow of its being united with products which are formed by chemical changes as a result of their activity. The whole process converts the nitrogenous elements into ammonia, nitrous and nitric acids, carbonic acid and water, and produces also phosphoric acid. It takes place most readily in porous, somewhat moist earth and at a high temperature. It is a necessary preparation of the soil for the life of plants. The active bacteria of this decomposition, nitrification, or mineralization do not extend to any great depth, generally not so deep as 12 feet, below which the ground is sterile. The rapid oxidation going on near the surface leaves little free oxygen for the use of bacteria even at the depth of a few feet. The decomposition effected chiefly by the aerobic bacteria in the upper layers enables plants to draw nutriment from the new products, and thus the presence of air and bacteria in the mold are necessary conditions for the growth of vegetation. These newly discovered facts must have a very important bearing upon agriculture. The relation of air supply, soil, temperature, and moisture to the microbic life in the earth, and consequently to growing crops, will become a fruitful subject of research to chemists, bacteriologists, and scientific farmers.

Most of the diseases of plants are dependent to a very great extent on conditions of weather, and many are transported by the air to new situations where they spread as from a center. Thus they differ from the spreading diseases of animals, which are not, on the whole, mainly affected by the character of a season, and are not carried so far through the atmosphere. The number of plant diseases of an infectious kind, depending on fungi or microbes, is very great. The vine alone is attacked by more than a hundred species. Some species live in alternate generations on different plants; thus the rust of wheat requires the barberry plant for one of its stages of development. The spores of mildews and microscopic fungi are generally ejected in great numbers and with some force into the air, and are carried from plant to plant, or field to field, by the air, as, for instance, the potato disease, *Peronospora infestans*, and the mildew of the coffee plant. Heat and moisture, dew and gentle rain, are favorable to the growth and spread of most diseases of plants. The fungus of dry rot grows in damp, unventilated places on badly seasoned wood, and when about to produce spores, seeks the light; its sporangia dry up and discharge innumerable spores. The common ferment of grape juice, the *Saccharomyces ellipsoideus*, grows on the surface of the grape, and when it gains access to the fermenting vats develops enormously by budding and division; when its development is hindered, as by drying up of the liquid, spores are formed, which are capable of resisting dryness, high temperature, and various conditions without losing their power of germination. They may thus be carried alive to a new habitat. This action is characteristic of a great number of ferments, of minute fungi, and of microbes generally, and explains the transmission of many diseases both of plants and animals. The globular spore case of mold, such as appears on fruit, jam, bread, etc., scatters its spores in all directions, each spore being about one three-thousandth of an inch in diameter. These float in the air in great numbers. The spores of oidium, again, a vine disease, escape into the air as fine dust, and spread with extreme facility. The sudden appearance of potato disease in a field is due to the field having been sprinkled with the spores of the peronospora in dry weather, and to the quick development of the zoospores when favored by damp, either rain or dew. The smut of corn produces extremely light spores, about one five-thousandth of an inch in diameter; these float in the air, and have so strong a resistent power that they will germinate in water after having been kept for years in a dry place. The peziza of the lily disease fires off ascospores which are carried by the wind to rich soil where they germinate, produce hyphæ, bore into the tissues of the plant, and shed millions of spores around. A disease of the pine is associated also with the groundsel, on which the fungus spends a portion of its existence. The hop mildew is borne by the wind, and has been found to be to some extent averted from threatened fields by thick woods or large hedge rows.

A great deal of disease in plants and forests is produced through wounds, to which the air conveys fungi which accelerate decay. The decomposed organic matter becomes a suitable soil for the development of fungi, which are not parasitic on living parts, and spores from these are very abundant. The hyphæ of the disease fungus follow up the poisonous action of the juices of the mold fungus and spread into the contiguous wood. True wound parasites also alight on the damp surface of a cut or broken branch and extend their mycelium into the living tissues, gradually bringing about the death of the tree.

These and very many other spreading diseases in plants can only with difficulty be controlled when their spores are given off in large numbers, and when the vegetation on which they alight is damp or in a vulnerable condition. Various applications have been tried to save plants, such as potatoes and vines, from attack, and though partially successful, they involve much trouble. The best security is the prevention of the emission of large numbers of the disease spores into the air from decaying or affected plants, and to cultivate only those varieties of plants which are most immune from infection. The extent to which plant diseases are transmissible through the air has never been ascertained. It seems probable that, with the exception of wide-spread disease in exceptional seasons, the diffusive action of the wind would, in general, so disperse the germs as to render them harmless to healthy plants not too near together. If this be so, then the careful destruction of centers of infection as early as possible would very greatly reduce the prevalence and damage of the diseases of plants. The preservation of fruits, such as apples, is only successful where care is taken that they are not too near together, and that those attacked are speedily removed. But in damp, warm places the spread is too rapid for such measures to be effectual. Dry, sterilized air might be found a valuable means of preserving fruits, vegetables, and provisions generally.

INFLUENCE OF WEATHER ON INSECT PESTS.

The effect of a particular kind of season on insect pests is worthy of more attention than it has hitherto received. The importance of attacking in time and as far as possible destroying the insect life which, if neglected, inflicts incalculable damage on crops and gardens, has scarcely been realized, owing to the blight being generally regarded as a necessary evil, not to be foreseen or prevented. The development of insect pests is generally favored by dry weather. Stunting of the growth, and overmaturation of the sap of plants induce early changes in the maturing and structure of aphides; the insects multiply without the interference of the ordinary destructive influences of bad weather, and delicate maggots, etc., which are generally drowned in very large numbers by storms of rain, emerge unharmed. At the same time it may happen that corn and other crops may be enabled by earlier hardening of the case, stalks, etc., to protect themselves against attacks which in wet years would bring serious damage. In some countries, and in respect to some crops, it is customary to arrange the date of maturity with special regard to the protective power of the plant and the period of expected attacks from insects. The whole subject is at present too little under scientific observation, and great benefit might result if the following branches of inquiry were systematically investigated: (1) The influence of different kinds of weather in developing insect pests; (2) the time of appearance of crop insects in different seasons in relation to the weather, and the time at which crops are most open to attack in different seasons, according to the weather; (3) the treatment of the ground in drought with a view to destroy threatening pests in their early stages, and, in general, the conduct of agricultural operations with regard to the probable development of particular pests resulting from particular kinds of weather; (4) the issue of forecasts of insect prevalence, derived from a careful study of the habits of various species of insect pests, and of the weather of present and previous seasons.

ACTION OF PLANTS ON THE AIR.

Plants in general take up free oxygen from the air and during the night exhale a small quantity of carbon dioxide. They also give a large quantity of oxygen to the air by the breaking up of carbon dioxide into carbon and oxygen through chlorophyll. The oxygen is set free, while the carbon is retained. Experiments have been made on various plants with the object of ascertaining the amount of oxygen which they absorbed at different temperatures. The following are some of the results:

Five seedlings of *Tropæolum majus* absorbed 1.04 cubic centimeters carbon dioxide of oxygen per hour at 35° C.

Four seedlings of wheat absorbed 0.088 cubic centimeter of oxygen per hour at 15.4° C.

Each plant has its temperature of maximum absorption. Wheat evolved 37.6 milligrams of carbon dioxide per hour at 40° C. The maximum amount of carbon dioxide evolved at the temperatures does not correspond with the maximum of oxygen absorbed. Variations in the composition of the atmosphere do not interfere with the respiration of plants, and the relations of the amounts of these gases absorbed and evolved, unless those variations are extreme, and not occurring in natural conditions.

Plants have been placed under glass shades, with their roots immersed in water containing free carbonic acid and certain salts, and with their upper parts exposed to a north light in carbon dioxide, hydrogen, and nitrogen. In the carbon dioxide they did not thrive. Convolvulus throve very well in nitrogen, mixed with a third part of carbon dioxide, and after three weeks these gases were found to be mixed with so much oxygen as to approach the proportions in the atmosphere. The power of plants to produce in a closed space an atmosphere resembling that of the globe might well form the subject of research on a great scale.

THE INFLUENCE OF FORESTS ON CLIMATES.

The influence of forests on climate is now much better ascertained than it was thirty years ago, at any rate with regard to temperate regions. But the importance of preserving trees, woods, and forests is far from being recognized as it ought to be by Governments and by the people generally.

The annual average temperature within forests is slightly lower than in the open. The difference is greatest in summer, least in winter. The day temperature is less, the night temperature more, than in the open. In summer, a beech forest is more effective for cooling than fir or spruce. The soil temperature is lower in forests, especially in summer, when the difference may amount to 14° F. The mean annual relative humidity is from 3½ to 10 per cent greater than in the open. Nearly one-fourth of the rainfall is intercepted by the trees and evaporated or slowly conducted to the ground. Forests somewhat increase rainfall, especially on high ground. The humus formed from fallen leaves diminishes the evaporation from the soil by more than one-half. The whole effect of forests is to retain and more equably distribute the moisture throughout the year, so that streams flowing from them are not torrential, and not subject to heavy floods, but are kept well and moderately supplied. By the prevention of excessive heating of the soil by the sun, and by the diminution of range of daily temperature and of sudden changes, malarious fevers are reduced. The mitigation of strong winds, of hot sunshine, of blizzards, and intense frosts is favorable to health, and generally the shelter and amenity of well-distributed woods, copses, and forest trees are of great hygienic and agricultural importance.

CERTAIN PHYSICAL QUALITIES OF THE ATMOSPHERE.

It is a law of gases that the volume of a given mass is inversely as the pressure; otherwise stated, the density at a constant temperature is proportional to the pressure. The resistance to compression, then, is proportional to the pressure. Yet the law is not exactly true at various pressures and temperatures. Air follows it very closely. Air and nitrogen are, for pressures up to 20 atmospheres at least, more compressed than if this law were exactly true. Amagat, by a fine series of experiments with a tube of mercury extending about 1,000 feet into a deep coal pit, found that air is slightly more compressed up to a pressure of about 80 atmospheres, and then begins to be somewhat less compressed. At about 400 atmospheres the deviation on the side of less compression is nearly one-fifth of the volume, the value pv, or the pressure multiplied into volume, being 1.1897 compared with the original unit. For pressure diminished below that of the normal it appears, so far as experiment has hitherto gone, that the value pv is practically constant down to at least one eight-hundredth of an atmosphere. No determination has been fully verified for pressures below one-thousandth of an atmosphere. The air at a height of 90 miles is still sufficiently dense to set meteors on fire by friction, but can not exert more than one three-thousandth of the ordinary pressure, unless, indeed, the atmosphere be surrounded by some lighter gas. Both air and meteor are at a temperature below —180° C. before contact takes place. The experimental difficulties of ascertaining the values at these low pressures are exceedingly great.

PROPAGATION OF SOUND IN AIR.

The rate of propagation of sound in air is believed, on theoretical grounds, to increase in some slight proportion with the intensity of the sound. The mean velocity of the explosion sounds and air waves of Krakatoa, in the eruption of 1883, was about 700 miles an hour, or less by about 23 miles than the velocity calculated for sound in air at 0° F.; it corresponded with the theoretic velocity at between —20° and —30° F. How was the rate affected by the temperature of the upper air, and what mean value of temperature can be assumed in that total propagation? The rate of movement diminished in the second and third circuits of this great air wave round the globe; the rate for the first passage in one direction was 10.23 per hour; for the last, 9.77 per hour; in the other direction, 10.47 and 10.27, respectively; so that a diminution of rate with diminishing intensity does seem to have occurred. The high temperature of the tropics does not appear to have raised the rate, as might be expected, above the rate in the temperate zones. Nor did the air wave travel faster, so far as can be deduced, than ordinary sound, although, considered as a very low note, it might theoretically be expected to do so. The velocity of the wave in the tropics toward the east was retarded; in the extratropics toward the west was retarded toward the east accelerated; from the data available in the report of the Krakatoa Committee of the Royal Society of London it appears that in the tropics there was an excess of general movement of air from east to west of about 14 miles an hour, and in the extratropics an excess of 14 miles from west to east. Thus the propagation of the air waves throws some light on the mean air movement within and without the tropics. The effect of cold in the regions both of the South and North Poles was not what might have been expected; there was no discoverable retardation by the low temperature. All these results have yet to be interpreted, but may perhaps themselves contribute toward a better knowledge of the laws of the transmission of sound and great waves in air.

The sounds of Krakatoa, which were audible over an area exceeding twice that of Europe, were not very loud in some places in the immediate neighborhood of the volcano. It seems as if the mass of falling ashes, pumice, mud, etc., and the great variations of temperature and humidity in the midst of the hot materials must have exerted a powerful dulling effect. Striæ or laminæ of alternate hot and cold air seem to be very capable of diverting and reflecting sound waves.

With regard to the conveyance of ordinary sounds in air in various kinds of weather, Professor Tyndall and others have arrived at certain results of much scientific interest and practical importance. The condition of the air varies very greatly with regard to transmission of sound, and often without any apparent cause. Fog, rain, hail, and snow do not sensibly diminish sound. The most powerful cause of stoppage is nonhomogeneity of atmosphere, or aerial reflection by a number of currents, columns, or laminæ of different density. On one day guns and sirens were heard at 10½ miles; two days later were inaudible at 3 miles. Water in the state of vapor mixed with air, in nonhomogeneous parcels, acts powerfully in wasting sounds. Not only clouds, but layers of transparent air, may produce echoes both intense and long. The power of the particles of cloud to produce aubible echoes has been doubted by Tyndall; but we may observe that a grove of trees in leaf, even of larches and pines, has a very strong effect in reflecting sound and in heightening its pitch. Let any passenger by railway note the marked rise of pitch as the train passes between woods of beech or oak. The sound resembles that of a small cascade, or of wind among rustling leaves.

The blasts of the fog siren have hitherto been found to be most effectual of all sounds tried for prolongation, penetration, and small cost. Its audibility is good at a range of 2 miles under all conditions. Experiments are still needed in order to attain a higher efficiency in sound propagation for maritime and other purposes, and to ascertain the effect of air in various conditions. The transmission and collection of sound through a few miles by means of suitable exciters, polished funnels, and acoustic mirrors of large size has not been developed as it might be.

AURORA BOREALIS AND AUSTRALIS.

The aurora borealis or australis is very far from being understood. The height of the luminous arch has been variously estimated and calculated as between 33 and 281 miles, and no doubt greatly varies in different latitudes and in different displays. The greatest height estimated was 500 miles. But in high latitudes the aurora has been observed to emerge from the tops of hills and even as a rule from the ocean, but not from ice floes. Loomis has given much information concerning the distribution of the aurora over the globe in the Smithsonian Report for 1865. Near latitude 40 in the United States only 10 auroræ, on an average, are seen annually. Near latitude 42, about 20; near 45, about 40; and near 50, about 80 are seen. Between latitude 50 and 62 auroræ are seen almost every night, as often to the south as to the north. Farther north they are seldom seen except in the south, and from this point northward they diminish in brilliancy and frequency. Near latitude 78 the number is reduced to 10 annually. In the meridian of St. Petersburg the region of 80 auroras is found between 66° and 75°. The region of greatest auroral action is a zone of oval form encircling the North Pole. This zone resembles a line everywhere perpendicular to a magnetic meridian. In Europe auroræ are much rarer than in North America. Some auroral displays, such as the remarkable one of March 30, 1894, are visible both in Europe and America. It seems that an exhibition around one magnetic pole is often simultaneous with a similar exhibition around the other magnetic pole of the earth.

The aurora appears to be the result of the agitation and vibration of particles of air under the influence of the passage of an electric current, diverging from the magnetic polar regions. The current passes where the resisting power is least, that is, in highly rarefied air, dense air and a vacuum both offering too much resistance to be used for the course of the current. It strongly affects telegraph wires and corresponds with earth currents of uncommon intensity. It has been supposed by Sabine and others to be connected with disturbances in the sun, which, again, depend on the position of the planets. Sun spots and auroræ were considered to be at a maximum in periods of eleven years; auroræ and earth currents to be due to small but rapid changes in the earth's magnetism; the upper conducting strata of the air to behave like a secondary coil, and the sun to act like a primary current which produces magnetic changes in the core of a Ruhmkorff machine. There seems to be no doubt of a connection between the periods of sun spots, of the variation of the magnetic needle, and of auroræ.

Some observers have noted a connection between these lights and great cyclonic storms, but they are certainly not always followed by bad weather, and in North America have been associated with clear skies. Moreover, the height at which they traverse the air renders it unlikely that they should be either the cause or effect of disturbances in the lower air.

Occasionally the elevation of moisture and cirrus cloud to a great height may afford a readier than ordinary means of transit to electric currents. Generally, however, cirrus cloud does not extend to one-tenth of the calculated height of the aurora, and can hardly aid in forming a passage for the current. That some visible effect of induction may be produced on cirrus and high cirro-cumulous, which are themselves electrified, is not improbable. The present writer was once greatly struck by a very extraordinary arrangement of high cirrus and cirro-cumulus clouds in closely packed, detached, reticulated, and nearly rectangular compartments, covering the whole area of the sky overhead, from 9 to 9.50 a. m. on November 17, 1882, in London, and learned afterwards that at about 10 a. m. a great magnetic storm had occurred over the country. The radiant point was about north. The appearance of the clouds was represented on paper at the time, and the diagrams were afterwards submitted to members of the Royal Meteorological Society.

The simultaneous appearance of an aurora in northern Europe and in America rather discounts the supposed connection between this phenomenon and the weather, for changes very rarely take place about the same time and in connection with each other over this wide area. March and October, the months of maximum display, happen to be months which are often windy in England. The cause of the aurora is rather to be sought in changes which come within the scope of astronomical inquiry. The spectroscope has not given much information regarding the nature of the substances which emit the light. The appearance of the aurora greatly resembles the passage of voltaic electricity through Geissler's exhausted tubes.

Observation is much needed in relation to these matters. The aurora, from a meteorological point of view, is interesting as a proof of the great height to which the atmosphere extends. Estimates of the height of the phenomenon exceeding 100 miles have, however, not been fully verified.

METEORS AND AEROLITES.

Meteors, or shooting stars, are within the domain common to both astronomy and meteorology. The moment they enter the atmosphere they are objects of special interest to the meteorologist. It is known that they traverse the air, where it is dense enough to raise them to a white heat, at very great velocities.

Many calculations have been made of the height of particular meteors which have been observed over a wide stretch of country. The statement by one astronomer many years ago as to the enormous numbers[1] which enter the atmosphere daily has been repeated so often, without confirmation by the actual observation of others, that it would be well to obtain independent values for particular areas on which to base fresh estimates. The majority of shooting stars are probably telescopic objects and of very small dimensions, perhaps not larger than pebbles. Particles weighing only a few grains become visible to the naked eye if they enter the air at a velocity of 40 miles a second. Many nights pass in which, with a clear sky, only a very few shooting stars cross the field of view.

It has been suggested by a distinguished astronomer that meteors or aerolites are the products of terrestrial or lunar volcanoes, which have been shot out to so great a height that they escaped from the retaining power of the earth's gravitation. In remote ages the density of the air and the amount of vapor, and consequently the friction, must have been greater than at present; but meteorology offers no objection to the theory, and the problem of their terrestrial or extraterrestrial origin is rather one for geology to assist in elucidating.

ATMOSPHERIC TIDES.

There can be no doubt that large tidal effects are produced in the atmosphere by the sun and moon, but they are not easily detected, for the barometer only registers the weight of the air and not the height, and the weight of a column of certain height is diminished under the crest of a tidal wave. Practically, however, solar and lunar gravitation and their atmospheric tides have no important influence on weather. Provisionally, the barometric effect of the lunar tide has been calculated from observation to be from 0.003 to 0.004 inch. The interest of the question lies rather in its astronomical bearing. The range or

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[1] Four hundred million has been given by one computation.

differences of thickness of the stratum of air through which the heavenly bodies are viewed must be considerably greater at spring tides than at the opposite phases.

THE ZODIACAL LIGHT.

The zodiacal light still remains very much a mystery. It may be a reflection, by a multitude of exceedingly small and light solid particles driven off from the sun, of the solar beams, and, indeed, it seems highly probable that the development of electricity in the chromosphere may be sufficient to propel small particles with much greater force away from the sun than gravitation can exercise in restraining them. When the surface is large compared with the mass, as in the smallest particles larger than molecules, the electric forces need not be disproportionately great to exceed by many times the force of gravitation even of the sun. If the interplanetary spaces be filled with reflecting and nonreflecting motes derived from sun, and moving at a speed much exceeding that of aerolites, we must suppose that our atmosphere is always receiving within its borders multitudes of these particles which are instantly consumed by friction. Moreover, if such emission proceeds continually from the sun, a similar process takes place from the more distant stars, and the whole of recognized space is traversed by small elementary particles traveling at an enormous speed. The phenomena of the tails of comets tend to corroborate this opinion. In fact, considering the immense number of comets in space, it seems impossible that such small particles can be absent. Compared with their extension, their united mass may be very small indeed within the orbits of the planets. Like meteor swarms, they do not apparently affect the motion of comets or of planets. None the less, the part they fill in the economy of the universe may be considerable.

HEIGHT OF THE ATMOSPHERE.

Meteors which have been calculated to pass with ignition through air at a height sometimes as great as 300 miles; auroræ, of which the height has been estimated by careful observation sometimes to exceed 281 miles; and the duration of twilight, with polarizing effects of the sky, giving a height of 198 to 212 miles, agree in showing a much greater altitude for the extension of our atmosphere than was formerly supposed. First 5 and then 45 miles was generally stated as the outside limit. And we have to remember that at this great altitude of about 300 miles the atmosphere is dense enough to produce very palpable effects. It would be a bold proposition to assign a limit to the atmosphere within 1,000 miles.

ATMOSPHERIC DUST AND THE REFLECTION OF LIGHT.

Atmospheric dust, or particles large enough to arrest the movement of light waves, exercise a very important function in the illumination of the air and sky, which would otherwise be dark except in the direction of the sun, moon, and stars. The beauty of land and sea and of atmospheric effects would be vastly reduced if the reflecting particles were absent, and houses not facing the direct sunshine would be inconveniently dark. Ozone and oxygen molecules, in some state probably of aggregation, are concerned in the reflection of blue rays, so that an elimination of the coarser dust would not entirely darken the atmosphere. A complete removal of reflected rays would slightly diminish the terrestrial warmth derived from the incidence of light rays from the general atmosphere, and slightly increase that derived from the direct rays of the sun. Invisible, or barely visible, vapor particles are probably still more efficacious in producing similar effects.

SUNLIGHT AND THE EARTH'S ATMOSPHERE—ABSORPTION AND REFLECTION.

The light of the sun which reaches the earth has passed through two atmospheres, one of the sun and one of the earth, and each of these atmospheres robs the light emitted from the sun's body of some of its brilliancy and an unequal proportion of color, so that the original color of the sun is modified by the successive subtractions from parts of the spectrum before it reaches our eyes. The sun's atmosphere arrests more blue rays than red, and the light from the middle of the sun's disk is more blue than that which reaches us from the limbs, for it has to traverse less of the solar atmosphere. Prof. S. P. Langley has shown that the effect of the invisible solar atmosphere is so important that its diminution by a third part would cause the temperature of the British Isles to rise above that of the torrid zone. The earth's atmosphere, also, has the effect of scattering many rays, and principally those waves which form the most refrangible end of the visible spectrum and gives the impression of blue. By the use of an exceedingly delicate instrument, at a height of 15,000 feet, Professor Langley was able to show that at this elevation, where nearly one-half of the absorbing mass of the air was got rid of, the ray 60, near D, had grown in brightness in the proportion 2 to 3, that the blue end of the spectrum had grown in intensity out of all proportion to the rest, and that a very great length of invisible spectrum became recognizable beyond the visible rays below the red. The amount of energy in this invisible extension is much less than that of the much shorter visible end. The conclusions to which Professor Langley arrived as the result of his investigations on the solar light was that the sun is blue, that the solar heat is greater than was supposed, and that the total loss by absorption in the atmosphere is nearly double what had been estimated. The sun he calculates to be competent to melt a shell of ice 60 yards thick over the whole earth annually, or to exert 1 horsepower for each square yard of the normally exposed surface. The existence of life on the planet, and especially of the human race, must clearly be dependent on the capacity of the atmosphere for modifying and absorbing the radiant energy of the sun.

An investigation of the principal elements concerned in arresting and reflecting the sun's rays would yield results of much interest. The absorptive and reflecting capacity of vapor in the free air has not been determined. The power of any constituents of the air, e. g., ozone and ammonia, apart from dust particles, to scatter the rays of light, is not known. The reasons of the variations in radiation from the surface of the earth on different days when the weather continues clear and apparently unaltered have not been fully made out. Much information might be gained by regular observation at two stations, one on the summit of a high mountain and one on the plain below, of the radiation value by day and night, and by comparing the results with the weather, humidity, and any meteorological phenomena which might be connected with them. Thus, for instance, a comparison of the radiation from the stations on two clear days, one dry and the other humid, would give some idea of the effect of invisible vapor in arresting radiation. If true vapor in a dry state is found in the laboratory not to stop heat rays, the inference would have to be made that vapor in the air often exists in a different but still invisible condition.

WINDS AND TEMPERATURE AT GREAT HEIGHTS.

Balloon observations have shown that a variety of currents are often met with in ascending from the earth to 10,000 or 20,000 feet, and also remarkable changes of temperature, not always in the direction of cold. On September 15, 1805, the air near the earth was 82°, and at 23,000 feet was 15°. On July 27, 1850, after passing through a cloud fully 15,000 feet thick, 17.1° was noted at 19,685 feet, and —36.2° at 23,000 feet. On July 17, 1862, at 10,000 feet, 26°; at 15,000 feet, 31°; at 19,000 feet, 42°; then a little below this height only 16°. Thus it seems that the air may be not seldom divided into adjacent masses differing by 26° or more. On March 21, 1863, up to 10,300 feet the wind was east, between 10,300 and 15,400 feet, west; about 15,000 feet, northeast; higher still, southwest, and from 20,600 to 23,000 feet, west. The changes of humidity are also sudden and great. Rain falls sometimes 4,000 feet above falling snow, at 15,000 feet. At 37,000 feet the dryness of the air indicated an "almost entire absence of vapor," yet cirri floated high above this altitude. On July 27, 1850, the balloon passed through about 7,000 feet of ice-cold water particles, and ice needles formed only at —10°. On March 21, 1893, a small balloon with registering apparatus was sent up to a height much greater than any of which there was previous record, and a temperature of —51° C. was recorded at about 45,500 feet; the air at Vaugirard at the time being at 17° C. This very promising experiment of sending recording balloons to great altitudes seems likely to lead to valuable information on the condition of the air up to 50,000 or 60,000 feet in various kinds of weather.

RANGE OF TEMPERATURE AT GREAT HEIGHTS.

Observations by mountaineers on the Andes and in the Himalayas have shown that the difference between night and day temperatures, at heights about 20,000 feet and over, is extraordinarily great, and that changes are very sudden. The interposition of a cloud of ashes from a volcano produced on Chimborazo a fall from 50° to 15° F. in two hours. The effect of the shadows of clouds on the air and clouds below must be very considerable.

ELECTRICITY AT HIGH ALTITUDES.

Electricity is highly developed in the upper regions. The observations carried on for some years at Pikes Peak, Colo., 14,132 feet above the sea, and about 8,000 feet above the plain, proved that snow and hail are always accompanied by electric manifestations. That St. Elmo's fire, or the brush discharge, occurs when the air is damp with rain, snow, or hail, and that the sparks are often almost continuous in storms of snow and hail, the flakes and hailstones being highly electrified.

The appearance of cirrus suggests the shaping of this cloud by electrical forces, and there can be no doubt that the air above 5 or 6 miles is strongly charged with electricity, which has not yet been experimentally accounted for. The origin is generally attributed to evaporation, by which the evaporated water and the water surface take electricities of different signs, and there is some, but not sufficient, experimental ground for the hypothesis. Gases consist of a vast number of molecules which may be considered as separated from each other, and these can receive an electric charge in such a manner as to make the whole mass of a gas so charged electric. The minute particles of water floating in the air, being better conductors, become more highly charged and present comparatively smaller surfaces with a denser charge continually as they grow in size. In fine weather the air is usually positive, in broken weather more often negative. The upper air is considered to be positive and the earth's surface is negative. Electricity increases very rapidly with height; thus Sir W. Thomson found the potential to increase from 23 to 46 volts for a rise of 1 foot. Clouds in showery weather are strongly electrified and the change of sign is often rapid. In showers and thunderstorms streams of sparks run off from the end of an elevated collecting wire, and sometimes from telegraph wires. Valuable information for the forecast of storms and weather generally might be obtained from observation of the electric character and potential of clouds, obtained through instruments near the surface of the earth.

ATMOSPHERIC CURRENTS ABOVE 40,000 FEET.

The observations of extraneous matter in the upper atmosphere after the eruption of Krakatoa, showed that a current from east to west, of hurricane force (80 miles an hour), prevailed in August and September over the equatorial region, and that a slower movement of the upper air from southwest and west prevailed in autumn over the northern temperate zone. Investigation of the currents of the atmosphere at heights exceeding 40,000 feet is likely to lead to valuable results. Exploring balloons might even show the ultimate possibility of rapid communications between distant places by means of steady upper currents.

PART IV.—SUBJECTS FOR RESEARCH.

The following subjects for research seem likely to yield valuable results in connection with the welfare of man. The bearing of some of the points suggested may be slight or remote, but are not on that account altogether negligible:

The topographical features of different countries in relation to climate and weather, and a comparison of the effect on weather and climate of similar physiographical features and circumstances in different zones and climatic areas.

The influences of forests and cultivation on weather, on humidity, on atmospheric electricity, rainfall, thunderstorms, soil moisture, and the flow of rivers.

The influence of the radiation from different soils and surfaces on climate, as, for instance, of grass compared with fallow, and of sand compared with rock and clay.

The heat received by the soil from the sun in different climates and at different altitudes.

The intensity of solar radiation at different latitudes and altitudes.

The intensity of terrestrial radiation into space by day and night at different altitudes, and the temperature of small objects suspended at high altitudes in sunshine and at night. This might be obtained by exploring balloons.

The temperatures of clouds of different thickness and different character in their upper, lower, and central parts, and at a little distance outside them.

The causes of the down rush and increase of horizontal movement of the air often observed before heavy showers and hailstorms.

The dynamical and thermal consequences of the rising and falling of masses of air.

The action of air in motion, or wind, on calm or stagnant air near their bounding surfaces; the manner in which by friction and by impact masses of air influence other masses whether at rest or in motion, and the effects of the collision of meeting masses of different specific gravity and humidity.

The influence of clouds of various thicknesses and heights on the radiation from the earth's surface.

The nature of the vapor or invisible water screen which often arrests radiation on clear nights.

The capacity of vapor and water of existing in various states in the air, and the reasons for the great differences of state observed, whether as dry or wet fog, mist, haze of several sorts, clouds of many sorts, ice particles and snow crystals of very many different forms, snow flakes of various shapes and sizes, hailstones of various shapes, construction, and sizes, and soft hail, or graupel.

The temperature of fogs and of their bounding edges.

The climatic and geological effects of coverings of ice and snow.

The relation of the temperature of oceans, seas, and lakes to the climate of the neighboring parts.

The variations and ranges of temperature with height in different latitudes and climates.

The extension of soundings of the high atmosphere with thermometers and other instruments by small balloons on the plan recently successful in Paris or at Vaugirard.

The observation by means also of small balloons and recording instruments of temperatures at various heights above the ground in different kinds of weather, say at 2,000, 4,000, 6,000, 8,000, 10,000, 12,000, 14,000, 16,000, 18,000, 20,000, 24,000, and 28,000 feet. Such observations may give very valuable information for the purposes of forecasting, for there is reason to believe that certain kinds of stormy weather are characterized by very great differences between adjacent strata, especially in cold weather and at high altitudes, and that these differences are diagnostic symptoms in many cases. In fine, settled weather the changes are probably much more regular with increase of height.

The absorption, in air, of radiant heat of low refrangibility in different kinds of weather both along horizontal planes and vertically, and obliquely; and the relation of absorption to actual and following weather. The amount of absorption, which might easily be measured by a thermopile and galvanometer directly toward a constant source of heat, or by a bolometer, would be an interesting subject of inquiry in connection with obscure states of vapor and water in the air, and with the forecast of weather.

The loss of heat by drops passing through a known distance of air, both dry and humid, in a certain time. The relation of the rapidity of the loss of heat to the size of the drop, and the difference between the temperatures of the drops and of the air. Similar experiments could be made with ice bullets. The results might elucidate some points in connection with the evaporation and growth of raindrops and with the growth of snowflakes and hailstones. A high tower in frosty weather, or a shot tower, might be convenient for these experiments; or a cliff of sufficient steepness and height.

The effects of the mixture, on a rather large experimental scale, of masses of air of different temperatures, humidities, and electrical states, and of different electrical sign. The resulting humidity, fog formation, and electrical state.

The effects of mixture of invisible steam of different temperatures, of visible steam at different temperatures, and of each of these in different electrical states. The growth of size, and the color, of the steam particles and the effects of absence and presence of much dust or smoke.

The true results of the electrification of jets of steam or cloudy masses, the relation of the size of the deposited vapor particles to the electrification, and the optical effects of various degrees of electrification in air.

The effect of an electric field on the surface tension of drops of water, and the various effects of varying amounts and proximity of the electricity of the charged surface on drops of different sizes. When the electrical field is uniform the surface tension of the drop is only slightly diminished, and the diminution is independent of the size of the drop. Very small drops thus preserve their high surface tension in the neighborhood of an electric field. But when there are a number of charged atoms surrounding the droplets the effect is different; the diminution of surface tension which is brought about varies inversely as the square of the radius of the droplet. The whole subject of the electrification of gases, dry and moist, the electrification of drops of water and their behavior under electrification, and the relation of surface tension in cloud globules and drops to electricity in natural conditions, requires investigation. The "cloudy condensation" of steam, and the optical effects in electrified steam have hitherto led to conflicting inferences, and careful observation has not yet proved a diminution or increase in the size of the water particles or a recombination of dissociated molecules of oxygen and nitrogen. The question is of great interest in many respects, and may have a bearing on thunderstorms, rainfall, evaporation, and chemical problems.

Shortly stated, there are three principal views of the apparent action of electricity on steam. Mr. Aitken believes that the thick condensation, coloration, etc., of a jet of electrified steam is due to the prevention of the coalescence of the very small condensed particles which would occur without electrification. Mr. Bidwell believed that the effects were produced by the conglomeration under electric excitement of particles which would otherwise have evaporated unseen, not becoming large enough to cause visible obstruction of light. These views are related to Lord Rayleigh's discoveries on the behavior of drops under electrification; the drops coalesced when weakly, and repelled each other when strongly electrified.

Prof. Paul Carus holds a very different view, and considers that the condensation effects depend on the action on steam of exceedingly small particles of dust. "One may estimate," he says, "that pure dust-free, unconfined steam at 100° would require a pressure of 10 or more atmospheres to condense it. Add to this dust particles less than 0.000001 centimeter in diameter, and the pressure sinks to 15 centimeters of mercury; in the case of particles of 0.00001 centimeter diameter, to 1 or 2 centimeters of mercury, that is, to pressure increments certainly met with in steam jets. The fact that nuclei of a few hundred molecular diameters are needed is the very feature of these experiments, and explains why smoke and other coarse material is useless, and why the condensation-producing dust must be so highly specialized." Glowing charcoal and red-hot platinum produce effects similar to those of flame, owing, according to Professor Carus, to the escape of clouds of exceedingly minute particles from these objects. "Dust-stimulated condensation differs merely in degree, not in kind, from jet condensation in air," for air always contains fine dust. "Air nominally purified needs only a higher degree of supersaturation to evoke condensation running through the whole gamut of colors." Mr. Bidwell found the following substances active in the condensation of the jet: Air, oxygen, or nitrogen, in which the electrical discharge was occurring; burning and incandescent substances; fumes from phosphorus; hydrochloric acid; sulphuric acid vapor; nitric acid vapor; acetic acid vapor. The following were inactive: Air, etc., in which the electric discharge had ceased for about ten seconds; smoke without fire; bottled phosphorus fumes; ozone, steam, alcohol vapor; formic acid vapor; sulphurous acid. Finding that the effects of a discharge in nitrogen and in oxygen separately were the same as in air, Mr. Bidwell concluded that the action is due in some way to dissociated atoms of nitrogen and of oxygen. Robert Helmholtz suggested such an explanation, having discovered that flames and incandescent substances generally cause dissociation of the molecules of the surrounding air; and Mr. Bidwell hints at the possibility of the necessity of the presence of water, as in so many chemical reactions, to recombine dissociated atoms.

The whole subject is an important one to meteorology and merits a searching and full investigation.

The difference of weight in drops after falling through a measured height in different states of the air, dry and moist, and the relation of loss or increase of weight to size of drop.

The gain or loss in weight of drops similarly let fall, but previously strongly or feebly electrified. These experiments to be tried in saturated and in foggy air.

The increase in weight and bulk of particles and bullets of ice allowed to drop through saturated and foggy air and through misty rain at a low temperature. The ice bullets to be cooled, before falling, down to several degrees below 0° C., and the effect of electrification to be tried.

Similar experiments to be tried in the laboratory; e. g., frozen spheres of water to be rotated rapidly through freezing fog artificially produced in a closed space; the icy spheres and the fog to be electrified, and the gain in weight of the ice sphere to be noted, also the relation of rapidity in rotation and differences of temperature and electric state to the observed increase.

The development of large ice crystals to be attempted in the laboratory, such as sometimes form on the outside of hailstones. Electrification, saturation of air, and great rapidity of movement would seem needful.

The study of the movement of convection currents over a soil or surface heated to various degrees above the temperature of the air. Smoke might to some extent show the manner in which the currents rise and the height to which they reach in continuous streams. The effect of wind, at some height above the surface, in promoting or retarding the unbroken ascent of currents might be observed, in connection with such phenomena as showers, tornadoes, and the formation of cumulus. The effect of a calm above a moving air mass might similarly be shown on a small scale.

The radiation of air and of vapor, separately and together, and mixed in various proportions; also the absorption. Experiment might give information respecting the radiation and absorption of air and vapor in respect of light and of heat in general of various refrangibility.

The radiative and absorptive power of fog or cloud. Experiments might give useful results both in the laboratory and in natural conditions. The effects of dust and smoke mixed with the fog might be observed, and the comparative loss of heat in unit of time by dusty or smoky and dust-free air.

Observations are needed on the geographical distribution of thunderstorms and hailstorms, the influence of mountains, forests, and local winds, and on means of forecast and warning against damage.

The elaboration of plans for the mechanical use of wind power for pumping, irrigation, factories, mills, and traction or propulsion, and for the conversion of wind power into electrical energy. The geographical distribution of wind force, and the areas in which steady, strong winds blow continually or for long periods, need to be ascertained in order to place windmills in economically advantageous positions. The heights above the ground at which wind is strongest should also be ascertained.

Mr. Symons notes that the Hon. R. Abercrombie, in 1875, summed up the results of a study of the oscillations of the barometer in thunderstorms, and concluded that there are two classes of storms in this country—one in which the barometer rises, in the other it falls. The rise is always under the visible storm, and the greatest rise is under the greatest uptake, or ascensional column of air. Dr. Fines, of Perpignan, established a Redier baragraph in 1875, and in a memoir published in 1883 gave reproductions of the traces of several storms. He found that before heavy rain at Perpignan there is usually (1) a decrease of pressure and temperature; (2) with the rain, sudden increase of wind, rapid rise of barometer, and fall of temperature; (3) at the end of the storm rain, reversal of the last three phenomena.

It appears probable that a fall of the barometer before thunder or hail storms may be caused by the increased amount of vapor in the column of air above it, and the rise, in most cases, is simply explained by the condensation of vapor permitting drier air to flow in, and still more by the existence of a cold, heavy mass of air at some rather high altitude, which, indeed, is one of the main causes of the storm. The barometer may very probably in most thunder or hail storms be acted upon oppositely by the two coexisting conditions, a humid column of ascending air and a descending block of upper air colder than the average of its level. Hence the mercury is either stationary or oscillates within narrow limits. The rise under the ascensional column may also be frequently caused by the rapid ascent of a column of air which takes an appreciable time to expand to the lower density of the upper levels. A study of the temperature and barometric movements before storms of different kinds, and with different winds, might lead to a useful prognosis of the course and character of storms, tornadoes, and heavy rains.

Observations on the rate of change of ocean temperatures at different depths in relation to the temperature of the air and to the influence of currents are needed, and also of the rate of cooling and warming of air currents passing over a sea surface of lower or higher temperature.

Experiment is needed in extension of our knowledge respecting the amount of ground air and gases in various soils, their expansion under variations of atmospheric and ground temperatures, of atmospheric pressure, and of natural processes of decomposition. Smoking or scented substances buried in the ground might afford some useful information. Also, respecting the production of gases by bacteria in the soil, the movements and permeation of ground air or gases through various soils, the emission of microbes into the air at different seasons and hours, and the density of microbes in the air near the ground. Also, respecting the depth in various soils at which organic matter best undergoes harmless decomposition, so as not to give out noxious products to the air to a degree dangerous to health, or offensively, so as not to poison wells, and so as to be of maximum benefit in agriculture. The relations of ground air to the ground water.

The amount of dew derived from the earth, directly, in various temperatures, soils, and circumstances; the amount exhaled by various plants, and the amount of organic matter and microorganic life in dew in particular situations, such as malarious tracts and water courses. The depth from which dew may be derived, as, for instance, the measurement of the depth at which the soil begins to be moist on sandy elevated malarious plateaus, where dew vapor emanates from the ground, but the surface down to several inches is dry.

The discovery of some means of determining the amount of moisture belonging to dew proper and to deposition from very humid air on solids in certain states of the atmosphere.

The emission of solid exceedingly minute particles from wet evaporating and drying earthy and other surfaces at different temperatures of air and ground. The emission of organic particles from marshes and drying edges of pools, etc.

The amount of organic matter and number of microbes in the air in different situations, hours, and seasons, as, for instance, in malarious valleys and tracts, and on hills and house tops compared with a height of 3 or 4 feet from the ground, on sandy malarious plains on still evenings, in places subject to cholera, diarrhea, and rheumatism, in low meadows and by river banks at sunset in summer, in places some miles to windward and to leeward of great towns, in streets, in old and new houses, in crowded places, in railway cars and in cabins, and in schools.

An investigation of all the phenomena and physics of evaporation from liquid and solid surfaces. The development of electricity, the effects of differences of temperature, of surface tension of slight impurity and slight films of oily matter, the phenomena of the dust-free envelope, and the conditions of evaporation from the human body would be within the scope of the inquiry.

The determination of the resisting power (1) in pure fresh air, and (2) in foul or rebreathed air in a room, of the various microbes concerned in various diseases of an infectious nature. The effect of dryness of air, of sunshine, of the presence of a minute trace of organic matter, of the character of the material, whether mineral or organic, on which they rest. The effect of ozone, of nascent oxygen, and of the vapors of various antiseptic or "disinfecting" substances. The capability of growth of various disease microbes on culture material intended to imitate the organically contaminated walls or rooms, etc., and the discovery of means for preventing such growth and emission into the air of inhabited places. Examination and culture of microbes and experiment on microbes found on walls of closely inhabited rooms. Cultivation of microbes on size used for papering, and on paper, and on plaster. The observation of the number of microbes in air over various kinds of street pavement. Examination of systems by which the air of sewers and drains may be prevented from entering dwelling houses, and of means by which the drain may enter the sewer from underneath, so that the drain may effectually and permanently be sealed by contained water or sewage.

A very interesting branch of research, and one to which little attention has hitherto been paid, is the formation of ice crystals, snow, and hail. In the free atmosphere, beautiful crystals develop themselves in great variety, mostly hexagonal or six-rayed, but some few with three or twelve rays, and some of less regular shape. At least two hundred different shaped crystals have been observed and drawn, many of the most exquisite delicacy and regularity. Often a single shower yields several different species of snow crystals, but generally there is great similarity in the crystals which fall about the same time. The cause of the difference in shape has not been made out, and indeed is not likely to be fully accounted for by any means at our disposal, but the present writer has been led by many personal observations to the conclusion that the crystals are differently developed according to (1) the amount of dust or nuclei in the air, (2) the electric state, (3) the humidity of the stratum where they have their origin and of the lower strata, and (3) the suddenness or slowness of their growth. He found that in a clear air on a hill crystals on vegetation were clearer, simpler, and more glassy than in the rather foggy neighboring valley; that in the neighborhood (10 miles) of London, where the air was smoky, the crystals on trees were very much more feathery, branching, and opaque, and yielded smoky water on melting. The upper air varies greatly in the amount of contained dust nuclei, in free electricity, and in differences of temperature between strata. A moist southerly wind beating back a cold northeast wind in England generally yields broad, heavy, irregular, conglomerated flakes; a dry gentle wind, with uniform conditions, yields regular crystals, small and thin; a very dry and cold air in the early days of a severe frost sometimes gives showers of pellets of various sizes, roughly hexagonal or polygonal, very dense, thick, opaque, and like a number of superposed plates. In March, and sometimes in April, a soft hail or dense pellets of snow fall in showers with a northeast or north wind, and dry air, the showers alternating with bright sunshine. At great heights in the Alps, the snow in winter is small and powdery; in summer the flakes are much larger.

Hail is often the result of a sudden condensation of very warm, moist air by great reduction of temperature at a great height. The dust nuclei are soon all occupied by moisture condensed upon them, and as the vapor falls to and below saturation point in a high column, it has not sufficient nuclei on which to condense in cloudy form, and precipitation takes place at a great rate, either on the cloud globules or on the snow crystals which fall through from the upper part of the cloud. Since the whole or a great portion of the column of the topmost cloud is below the freezing point, the globules as they come in contact with the falling crystals instantly freeze, and so the crystal grows and falls ever faster, accumulating bands of ice and snowy particles according as the air is clear and saturated, or else densely cloudy, through which it passes. The electric charge being much denser comparatively on a large drop or crystal than on a small one, and the vapor pressure being less, the hailstones grow very quickly, and since they fall rapidly through very thick clouds, they add much ice by mere impact at their base. The radial structure so often observed indicates the origin of the hailstone from a radial snowflake or hexagonal plate. Hailstones of large size are produced in circumstances of great electric disturbance.

Sometimes a hailstone has been found with finely developed hexagonal ice crystals growing like stalactites from a matrix. Possibly the attachment of a flat hexagonal crystal at a certain stage in the fall of the hailstone and the action of electricity in the rapid passage through the air are sufficient to account for these large ice crystals, but they have not been observed in other conditions in nature. Small, long, clear crystals are formed on vegetation in a clear, moist air by radiation. It would be interesting to endeavor experimentally to produce ice crystals of large size by strong electric charges in saturated air below the freezing point and in rapid motion.

THE BEARING OF ATMOSPHERIC INFLUENCES ON PLANTS.

The connection between atmospheric conditions and the development of plants, especially of staple crops, is strongly realized by every farmer in countries where weather varies from year to year. But the subject is an immense one, and its branches extend in many directions, some of which have been little explored, and most of which have only recently come under systematic scientific inquiry in a few places. Most valuable work on agricultural meteorology has been done in the United States, in France, in Germany, and in England. The Climatology of the United States, by Louis Blodgett, published in 1857; The Signal Service Tables of Rainfall and Temperature Compared with Crop Production; the Compendium of Phenological Observations, by Ihne, in Sweden; the work of Lawes and Gilbert at Rothamsted, in England; Wollney's Researches in Agricultural Physics; Adamson's and Boussongault's various and interesting observations on plants; the great work of Sachs on temperature in connection with plant life; and Hoffman's extensive work in the same field afford an excellent ground for further researches, which ought to be based as far as possible on a common plan and to be both national and international.

As regards temperature, the following points may be considered to have been ascertained with respect certainly to a large number of plants of agricultural value. A particular temperature or a narrow range of temperature within certain limits is required for the quickest germination and most rapid growth of each kind of plant. Growth is retarded in proportion to the deficiency or excess of temperature. For each plant there is a minimum and maximum temperature and a temperature most favorable to growth. The sums of the temperature required for a certain growth of similar plants in two places are in proportion to the sum of the temperatures above zero at the places. Plants in high northern latitudes grow more quickly with the same temperature than the same kinds of plants in lower latitudes. Capability of resisting cold seems to increase with the age of the plant, and plants containing much water seem least capable of resistance. Seeds of northern-grown or mountain-grown plants germinate and develop earlier than similar seeds in warmer situations when both are planted together in the warmer place. There must be a maximum fruit formation and growth for some period of time best adapted to the plant or crop. Blossoming and ripening of certain plants, beets and potatoes, nowever early sown, coincided with that of the planting which took place when the minimum temperature of germination of the plant had been exceeded by the ground temperature. This result discourages very early planting. The highest results in Austria-Hungary were obtained from both beet and potato planted on May 1 as against earlier and later dates. When the necessary earth temperature has been reached, then the seeds should be planted.

The observation of ground temperature ought to be a very important branch of agricultural practice. The temperature at depths of 1½ to 3 inches should be taken daily, and in course of time, when observations and experience have been accumulated, and a classification made of the results for various crops, this will become a more useful and trustworthy guide to the farmer than the temperature of the air. The aspect or exposure, and also the character of the ground, have of course to be noted in connection with these inquiries. In dry ground temperature increases in some ratio according to the size of the particles up to a certain point, and then decreases. This holds good for the warm season. Oscillations of temperature follow in a similar relation. In moist ground the temperature also increases, up to certain limits, with the size of the earth particles, and the ground in a crumbly condition is warmer than in a powdery or fine state of division. In the cold season the coarser ground is colder and follows changes of temperature more quickly than the less aerated or firmer ground.

Fine earth can contain more water than coarse earth, but also evaporates more, and allows less water to sink through it. Penetrability and evaporation are frequently inversely related to each other.

Perhaps some results of ground temperature and moisture observations arrived at by the present writer may be here briefly alluded to, though they were on a small scale. When grass or earth is covered over at night by an impermeable material, the moisture from a little below the surface of the earth exhales, but does not escape, and is deposited on the undersurface of the material and on the grass blades. Plants might thus be kept moist, when desirable, by a covering which could be removed at any convenient time in the afternoon and replaced in the evening. Hollows, depressions, and sheltered parts near the hedges are much more bedewed on most nights, excepting the calmest, than fully exposed places, and the intensity of frost and the sun's heating effect a little below the surface is also generally greater—in fact, the daily and annual range of shallow-earth temperature is greater, but all these results depend on the amount of wind at night in the particular district. Dew, though copious under a close covering, is very much below the normal on the earth under loose coverings or under trees. Since moisture combined with frost is often fatal to plants when frost alone is not, it is important to discover the driest and airiest situations for delicate or early vegetables; if frost and fog with calm are probable, but if the climate is subject to frost, fog, and wind, or frost and wind, a more sheltered situation is desirable, according to the nature of the plant, for some suffer more by cutting winds and others by freezing fog. The southern border, even to some yards' distance, of a thick, high hedge of evergreen, such as holly, is much warmer than other situations, and is most warm on sloping ground. Pasture land, replacing arable, increases the cold due to radiation at night, and also the relative humidity near the ground, for the dew-point is quickly reached over grass. The difference of temperature between the top of moderately long grass (a few inches) and the surface of the earth or bottom of the blades is often very great in the evening and night, 10° or more occasionally, and at 2 inches deep in the ground the temperature of the roots of grass, even in England, may be 26° higher than that of the blades. The temperature close to the surface of the earth under grass rises very quickly immediately after sunrise. The temperature at 15 inches deep was high, 59° to 62°, and nearly uniform in August. These experiments were made on sandy soil, and in the mold of a pasture field.

The relations of the various qualities and conditions of the atmosphere to plant growth in various soils and situations have still to a great extent to be determined. Agriculture depends not only directly, but also indirectly on weather. A certain kind of season has a compound effect on a great number of crops, on each a somewhat different result, and this result has its effect upon the crops of succeeding years. It may be favorable to a weed or to a species of blight, mold, rust, or parasite, as well as to the crop attacked by such pests, and the net gain or loss for the present and future may not be easy to determine. If a particular character of spring is found to have a particular effect, either in hardening a crop for resistance or in developing a pest at some critical time, or in rendering the ground fit for some other crop than one of which the planting seems likely to fail, then valuable results will have been gained. The co-relation of a variety of plants, of birds, of insects, of fungi, with each other, and the relation of each of these to weather and season, have still, for the most part, to be made out. Accurate observations of the times of planting, the times of gathering, and the character of seasons, may render it possible for specialists to inform farmers with a large percentage of success of the best time for their operations in various localities. Weather conditions are exceedingly important in the cutting and carrying of certain crops—hay, for instance, and there must be a particular time of the summer which is most favorable for each district, in view of which grass should be sown and cut, without, of course, any interference with the individual judgment as to the right time, which must vary with the aspect of weather and crop. It would be desirable to use some standard method of obtaining the actual temperature of plants at a little height above the ground, as well as in their roots. The amounts of rainfall and the relation to plant growth in various soils should be systematically recorded. The amount of sunlight and "actinic" energy with relation to various crops has still to be investigated on a large scale; some valuable results have already been obtained.

ABSORPTION AND EMISSION OF WATER FROM THE LEAVES OF PLANTS.

M. Boussingault showed some years ago that plants absorb from the earth and exhale to the air an enormous quantity of water. He calculated that a field of cauliflower, 1 hectare in extent, can emit in twelve hours 20,000 kilograms. M. Deherain states that a young blade of wheat evaporates in one hour a weight of water equal to its own. *Eucalyptus globulus* is supposed to be capable of evaporating eleven times the rainfall of the area which it covers, provided, no doubt, that the rainfall is not excessively large. Oaks are also great evaporators and grow best in wet clay. M. Fautrat, inspector of forests, has found that the quantity of vapor in the air over forests is much greater than in the air over the open country. But exact comparative observations of the amount of water evaporated within and without forest areas in various climates are wanting. Forests have been planted in certain parts of southern France with excellent results in the improvement of health, and malaria has diminished in several instances in consequence of judicious planting. The question of planting in connection with human health is a very important one, and the influence of forests and trees on the steadiness of the water supply makes it very necessary that forests should be carefully guarded by the State in many countries. Vegetation, large or small, should never be hastily destroyed. Trees and hedges are very useful in breaking the force of strong winds, in giving shelter to animals, and promoting the growth of fruit trees and vegetables, and they add greatly to the amenity of the country.

The exact conditions of climate most suitable to each kind of useful crop, tree, or plant, have yet to be determined, though they are in many cases fairly well known. The development and selection of hardy specimens would be aided by trial of the effect of transplanting or obtaining seed from various climates of each species examined. The gradual acclimatization of plants might, under scientific inquiry, be found to be capable of furnishing better results than have hitherto been obtained.

The amount of water collected by trees from the air in misty and damp weather has not been determined, although in some districts, especially where warm, moist winds from the sea prevail, with frequent mist, it must be considerable.

The exact manner in which the spores of dry rot, potato disease, vine diseases, rust, and other plant fungi are conveyed through the air, and how far they may be carried in a potent state through dry and moist air, requires investigation; also the influence of ozone, of sunlight, and of drought upon them when deposited on their host.

The relation of the air supply, air temperature, and moisture to the microbe life in the soil, in connection with the growth of crops, with biological chemistry, with soil emanations, and with diseases.

The assimilation of atmospheric nitrogen by bacilli connected with certain plants; the results of the fermentation; the possible synthesis within the microbe cell of atmospheric nitrogen and nascent hydrogen, resulting in ammonia.

The influence of different kinds of weather in developing insect pests, especially those which are destructive to crops. The cultivation of crops in such a manner as to render them as far as possible proof against such pests, by choice of varieties best adapted for resistance and by planting and maturing them at times least adapted for insect attacks. The issue of forecasts of insect prevalence, derived from systematic study of the habits of noxious insects and of the weather of present and previous seasons.

Experimental investigation of the respiration of plants.

Germination of plants; its dependence on temperature in a great variety of seeds from different localities and latitudes. The influence of temperature of the air on the formation of chlorophyll, and the activity of assimilation and growth in artificial atmospheres differently composed.

The relation of wind to health, as regards force, direction, and duration, and with relation to temperature and moisture. The health of cities as affected by mean horizontal movements per hour and by the number of calms; different periods in the same cities to be compared, and the same periods in different cities. The relation of wind and calm to infectious and malarious diseases, taken separately, and to rheumatism, neuralgia, bronchitis, and colds. The generally better health of towns, villages, and dwellings in high situations; how far owing to difference of soil and how far to difference of climate, especially temperature, daily range, and wind. The comparative healthiness of the upper stories of houses, especially as regards diarrhea, typhoid, rheumatism, malaria, and tuberculosis. The bodily and mental conditions, such as breakdown, fatigue, or depression from overwork, anxiety, or other causes, and all cases of ill health, in which (1) a fine, placid climate and (2) a windy, changeable, moist climate is most beneficial. A comparison of the health and diseases of inhabitants of wild, windy climates, such as those of northern and western Britain, with the health and diseases of the inhabitants of calm, bright climates, if possible not far removed in latitude. A comparison of the health of sailors on board ships with good, airy quarters with the health of the same class of people in the country on shore in about the same latitudes.

MALARIA.

The relation of malaria to various soils, to the aeration of the soil, height of water level, ground respiration, and plant life, with its evaporative power and emission of oxygen. The distance to which malaria can be conveyed over land and sea, and over fresh water, by the air without losing its infective power. The dependence of the vitality of the organism on moisture in the air, on temperature of the air, on darkness or light. The effect of belts of trees, walls, and muslin screens in breaking its potency. The effect of dried air, as in a room with a fire, in enfeebling the organism and nullifying its power to infect. The effect of ozone and of nascent oxygen upon it, and the effect of antiseptics such as thymol, cinnamon, toluol, and aromatic vapors.

Inquiry into the infective power, if any, of malaria from person to person through the air, a few instances having been recorded.

CHOLERA.

The extent to which cholera may be regarded as endemic in parts of India and other countries, the nature of the soil over which air is infected, the most favorable amount of aeration and moisture of the soil, the atmospheric conditions most favorable to its growth and to its invasion of the air and of persons. The atmospheric conditions most favorable to its extension over Europe and America, and the special precautions needed to prevent the transport of the poison in such conditions. The possibility of a system of international warnings of the prevalence of the epidemic at any centers and of forecasts of seasons or types of weather in connection with its probable spread. The experimental use of some liquid, such as crude petroleum, for blocking the pores of earth where cholera is endemic, and preventing the emission of germs into the air. The effect of cultivation of various moisture absorbing and evaporating plants and trees in endemic areas.

YELLOW FEVER.

The transmissibility of yellow fever through the air from person to person and how far, and its dependence on moisture, temperature, wind, and other conditions of the air. The character of soil and surface on which the microbe develops, the aeration of soil, etc., and the possibility of checking its growth and emission into the air by spraying with petroleum or some viscous disinfectant or antiseptic. Since yellow fever germs seem to be aerobic and to grow largely on surfaces, the treatment of street surfaces, walls, ships, harbors, etc., in this way seems promising.

THE PLAGUE, TYPHUS, TYPHOID, AND PNEUMONIA.

The extent to which the plague, typhus, typhoid, and pneumonia are severally capable of passing through and infecting in outside air, and also confined air. Their dependence on infected soils and surfaces, and on aerated or nonaerated soils; on atmospheric conditions, especially temperature and moisture, and on the seasons. Their dependence on human habits and previous life, whether mostly in bad or in fresh air. The influence of breath poisons on the growth and spread of typhus, and of drain or sewer air and gases on animal and human vulnerability by typhoid and pneumonia. Cultivation of whatever germs there may be in stinking air from old drains, middens, putrid sink water, etc., and identification of disease germs if possible.

DIPHTHERIA.

Examination of air for detection of the diphtheria bacillus over polluted surfaces of sandy soil, over ash heaps, decaying vegetable and animal matter, and above drain outlets. Relation of the bacillus to atmospheric conditions where it grows on soil, organic matter, dirty floors, or walls, etc.; how far it is aerobic; how far it may pass through air in different conditions, and how much it loses virulence in dry air, in moist air, and in confined and open spaces. Effect of exposure or aeration in causing it to form spores, if any. Effect of sunshine on the bacilli, with and without air; the diphtheritic poison is rapidly weakened by air with sunshine, but only slowly by sunshine alone. Effect of coating a cultivation of diphtheria bacilli with a very thin film of oil or viscous disinfectant, so as to prevent growth and passage into the air. The favorable temperature, a rather low one, the exclusion from light and air, and the presence of certain other organisms furnish useful points of departure for an investigation of climatic and local conditions of prevalence of diphtheria.

SCARLET FEVER, MEASLES, WHOOPING COUGH, INFLUENZA, AND SMALLPOX.

Distance through which each of these diseases has been known to pass in air in various conditions. Experiments especially with respect to vaccine in relation to the conveyance of smallpox through long distances of outer air. Accumulation of experience and new observations on the virulence of the lymph in dry and humid air, and a comparison with the virulence of pathogenic bacilli of different kinds exposed to like surroundings. Dependence of most of these diseases on air in confined and ill-ventilated spaces for effective spread. How far can ventilation, and how far can diffusion of ozone, disinfectants, and various aromatic substances and vapors counteract the infectivity of the germs?

INFECTIOUS, CONTAGIOUS, EPIDEMIC, AND ENDEMIC DISEASES IN GENERAL.

A full investigation into the comparative health of persons living in fairly isolated places, such as islands or institutions having little communication with populous places, would lead to useful results. The occasions of any outbreak of disease could probably be accounted for and the medium of conveyance identified. The degree of human susceptibility to various infections could be much better made out than in ordinary situations. Moreover, those diseases, such as bronchitis, rheumatism, and cancer, which do not seem to depend for the most part on infection, but on constitutional or atmospheric conditions, could be better accounted for, the possible causes being few. The immunity of children living in several large and very well-managed institutions from the ordinary diseases of children is instructive, and, on the other hand, the frequent prevalence of ophthalmia in pauper schools indicates an effect of bad ventilation upon crowded children of poor vitality. A great sanitary authority demonstrated the enormous fall of mortality following ventilation of crowded places, and another fall following regular daily head-to-foot ablution and insistence on clean clothing.

A comparison of different atmospheric or climatic influences upon similar branches of the same race, through long and short periods. Thus the effect of moving northward to a colder region upon a branch of a race still established in low northern latitudes, and the effect of living at a greater altitude in several different parts of the world might be traced, and the particular elements in climate which produce a change in race characteristic might be to some extent ascertained. The effect of the same climate upon a number of immigrants from different climates; regard to be paid to direct atmospheric action on the constitution and to indirect action through induced change of habits.

An inquiry into the most suitable food for full health and mental efficiency in various climates, and the relation generally of amount and kind of food to climate. How far simple, unvarying food and temperate and active habits and how far a bracing air contribute to the vigor of mountain people.

The effect of sea and mountain air on the majority of civilized people and brain workers; the effect of pure country air on dwellers in large towns; of habitually breathed fresh air on bodily and mental health; and the possibility of greatly increasing the alertness and work power of a nation by better provision for fresh air in schools, offices, factories, workshops, and dwelling houses. The effect of good and bad air respectively upon tendency to alcoholic intemperance. A comparison of well ventilated with badly ventilated schools, and of schools before and after good ventilation, both as regards specific maladies and as regards mental brightness and progress.

The degeneration of the natives of temperate climates when settled in tropical countries, and the grounds for a belief that gradual migration in the course of generations from cold to warm countries may enable them to continue and flourish. The relative capacity of families from Great Britain, from Australia, from the Northern and from the Southern States of America, and from the West Indies of enduring tropical climates, such as those of India and Central Africa. The degree of toleration of hill climates in the tropics by Europeans, and the endurance of families.

How far the diseases of the bowels, liver, etc., which attack settlers from cold climates in the tropics, and how far diseases of the lungs, which attack settlers from the tropics in cold climates, are due to microorganic infection and the slow or quick poisoning resulting therefrom, or simply to hot and cold air, respectively.

The diseases resulting from chill, both in hot and cold climates, and the means of guarding against it.

The effect of climate, both direct and indirect, upon the tendency to nervous diseases and mental diseases, and upon the tendency to suicide.

The influence of climate, direct and indirect, upon national character. The effect on health of clear, dry, intensely cold calm weather, such as prevails in high latitudes and on high mountains, and the effect of dry, hot climates as distinct from moist. Both hot and cold dry climates seem to be healthy and tolerable. Separation of the malarious disease effects of hot, moist climates from the mere effects of heat and moisture of the air.

An investigation of the causes of the healthiness of cold, wet summers in western Europe, and of the means by which some of their beneficial results may be artificially imitated.

A comparison of the healthiness of the different seasons in the same and different portions of the United States, and of the relation of zymotic and other diseases to the condition of the air, and to the temperature of the soil and of the ground air. The variety of climate and extent of surface of North America, and the great system of the Signal Service make that country peculiarly adapted for such an inquiry.

The reasons of the arrest of certain spreading diseases, such as yellow fever and dengue, by lower temperature.

The climates and qualities of air most beneficial to persons suffering from nervous diseases, nervous irritability, and heart disease. An attempt at a classification of climates most suitable, in most cases, for each kind of malady or ailment, separating as far as possible the purely climatic from the human factors, such as accommodation, food, etc. The elaboration of a complete medical climatology, applicable not only to persons, robust or invalid, but to families and races, with regard to temporary or permanent settlement.

An examination of the conditions under which, in the crowded quarters of large towns, population deteriorates, so as to become in a short time, if not recruited from the country, physically and mentally enfeebled, and in a few generations almost extinct. The part played by the continual breathing of bad air, and by the crippling produced by attacks of various maladies most rife in crowded places and bad air.

Contrasted with country air, town air contains an excess of carbon dioxide, less oxygen, no ozone, many gaseous and solid impurities and vapors and an immensely greater number of motes of the finest dust. The air is also heated by pavements, etc., so as to become less bracing. The parts played by these various factors in diminishing vigor might be to some degree allocated.

The effects, direct or indirect, of daily or constant breathing of vitiated air on the mental powers, the will, self-control, and temperance.

The effects of vitiated air on the mothers of families, their ability to feed their infants, their strength, and the health of their offspring.

The diseases most prevalent during calm and during windy weather, respectively. The comparative wholesomeness of similar houses or streets in the most exposed and most sheltered situations in towns and country.

The normal aeration or permeation of walls and building materials by external air and by internal air with its impurities; the fitness of many porous contaminated substances lining dwelling houses for the growth of pathogenic organisms.

Research and experiment as to the best means of ventilation, natural and mechanical, for various climates.

The elaboration of a scheme of aero-therapeutics, including experiments in oxygenation, etc.

The effect, whether great, slight, or practically nil, of the aeration or exposure to natural oxygen of contaminated water, and also of various pathogenic microbes in rivers, lakes, and ponds or reservoirs.

The cause of milk turning sour in "thundery weather" and an examination of air at such times with regard to its microorganic contents, its putrefactive influence, and its effect not only on milk, but on various animal and vegetable infusions. Certain kinds of fungi or germs which affect milk may be enabled to survive in warm, moist air, when they would be killed by dry air; in that case the "thundery weather" would turn milk sour simply because the air is then commonly warm and moist.

Animal flesh and other provisions do not putrefy or turn bad for a long time in dry and desert air; apparently moisture is necessary in the air for the conveyance of live microbes and for their attack on the substance.

Wounds heal very well and rapidly in the desert, and disease is very rare among wandering tribes; inquiry seems to be needed to ascertain how far this is due to absence of microbic life in the air and on substances to which the air has access.

If some diseases and putrefaction and such changes as occur in milk and organic infusions are owing to presence of microorganic life in the air, then those changes and fermentations should not occur in mid-ocean, where care is taken that only air which has not been in contact with any part of the ship, etc., gains access; for the air on mid-ocean is considered to be practically free from living germs. Experiment might best be made on small islands or exposed rocks, such as Rockall, which may be assumed to be sterilized.

The antiseptic treatment of wounds is now recognized by the greatest surgeons[1] to depend less on the sterilization of the air about wounds than on the sterilization of all objects, including the hands, instruments, bandages, etc.; so that it seems that the open air is practically

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[1] See recent addresses of Sir Joseph Lister and others.

harmless to wounds, except, no doubt, in certain unhealthy situations and near the ground. This conviction agrees well with the realization by physiologists and by public health departments of the general rule that epidemics exist through the action of man and not of the atmosphere. "It is in the power of man," in Pasteur's opinion, "to cause the parasitic maladies to disappear from the face of the globe if, as I am convinced, the doctrine of spontaneous generation is a chimera."

The effect (1) of temperature and (2) of moisture in promoting the growth of various kinds of mold, fungi, saccharomycetes, and plant parasites. Ordinary mold seems to grow well at a low temperature, if the moisture be sufficient.

The influence of dry air in weakening various kinds of microbes or fungi in relation to plant and animal diseases. Their growth on various fomites in relation to qualities of the air and to light.

The relation of weather to diseases, not only to those apparently caused by microorganisms, but to a variety of other maladies. A certain climate or a certain kind of weather may give rise to an excess or maximum of a spreading disease by direct influence on the outside growth of a microbe, or by helping to spread the spores or germs, or by increasing the supply of some pabulum, or by effects on wells and water supply, or by affecting the human constitution so as to lay it open to attack, or by producing effects on human conduct which favor the spread of the disease. The contributory factors may be many, remote, or concealed, but such thorough investigation as is possible could hardly fail to give valuable results.

There is generally a main cause in each disease by attacking which much progress is made. The soil temperature in diarrhea and cholera, the dried sputum in consumption, the close air in typhus, have already been thus marked out.

The lesions, or quasi-lesions, by cold and chill, are exceedingly effective in disarming the resistent powers of the body, so as to give opportunity to such diseases as bronchitis, pneumonia, liver and kidney diseases, dysentery, malaria, and many others. The manner in which by clothing and otherwise these consequences of atmospheric variations may be guarded against might well form a subject for research. The rate of cooling of vessels at the blood temperature surrounded by various fabrics would give useful information. Some experiments of Mr. Garrod[1] showed that in a room at about the average annual temperature of the exterior air, when clothes are removed from the human body, the temperature very quickly rises in the axilla to a point 2° higher than before. The blood vessels are of course congested, and colds, etc., are then easily caught. The rise does not take place when the temperature of the room is above 70° F., and increases as the temperature of the air is less.

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[1] Proc. Roy. Soc., 1869, No. 112.

A temperature between 30° and 42° seems to be very favorable to chills, etc., possibly owing to the humidity and conductivity of the air being greater than at lower temperatures, to the absence of the sharp, bracing action of frost, and to the greater number and vitality of microbes in the air than at lower temperatures. Dry, cold winds may have a chilling effect equal to a calm, damp air of the same temperature.

With regard to all these matters of air and health, or season and health, a great deal might be done for the prevention of disease by the public issue of forecasts, or monitions, at appropriate times, showing the character of the maladies common at the season, or to be expected, and giving some plain directions. If this were done weekly, it is probable that the number of lives saved would be larger than those saved by the weather forecasts for coast purposes.

EXPLORATION OF THE ATMOSPHERE IN CONNECTION WITH WEATHER FORECASTS AND A MORE EXACT KNOWLEDGE OF ATMOSPHERIC CONDITIONS.

Captive balloons regularly used, weather permitting, at a number of well-distributed stations, would give valuable information in addition to the ordinary items furnished for the purposes of governmental forecasting. Mountain observatories have already been long enough established to give results which show a different distribution of temperature and pressure before different types of weather. But balloons might be fitted with instruments which would show the pressure and temperature at several heights in succession during ascent and descent, and this information would very probably be important in forecasts, if the height attained were sufficient. Balloon ascents have shown the atmosphere to be frequently arranged in blocks or masses of air of very different temperatures within a short distance of each other, and occasionally in an inverse order to that which might be expected from the law of diminution with height. Thus, on July 17, 1862, the thermometer on the earth was 59; at 10,000 feet, 26; at 15,000 feet, 31; at 19,500 feet, 42; but on descent a little below this height, the temperature fell with extraordinary rapidity to 16. Strata much below the freezing point may have a few hundred or thousand feet above them, currents of air at 40 or 42. The variations are often very large and rapid. The greater the height, within the limits of the cirrus cloud at least, the greater apparently are the differences between adjacent strata or masses of air. Irregularity of temperature and humidity distribution must have a considerable influence on the consequent weather, and a series of balloon observations for a term of years at a good number of stations would probably be of very considerable service both for theoretical and practical purposes.

Free balloons for exploration, such as have given good results in France, might be contrived to ascend to some desired height, and then rapidly to descend, so as to be again available. The hydrogen balloon might, for instance, carry a small vessel containing a substance which would combine with the oxygen and with the vapor of the air at an approximately known and arranged rate; the increased weight of the contents would reverse the ascent at a roughly calculated height, and, except with strong winds, the balloon would descend at no great distance. In calm weather its motion could be watched with a telescope and its approximate height noted. Intelligent persons in towns and villages should previously be instructed to secure the descended balloon and to take readings. Schoolmasters in France have received such instructions.

It is probable that the condition of air immediately preceding tornadoes, cyclones, and blizzards, and thunderstorms or heavy rains would frequently be of sufficiently remarkable character to give ground for generalizations from balloon records by which the advent of these phenomena could be foretold.

ELECTRICITY, CLOUDS, AND RAIN.

The connection of electricity with the formation of rain, snow, and hail requires much fuller investigation than it has yet received, and research in this field is sure to yield interesting results. The upper air is positive, the lower often negative, and the almost invariable necessity for two or more layers of clouds for the production of anything more than misty rain over level ground seems to point to an almost invariable coexistence of oppositely electrified clouds in the formation of heavy rain. Heavy showers and snowstorms always show a large development of free electricity, but of course this may be merely a *consequence* of the agglomeration of the drops, and in no important degree a *cause* of the precipitation. In the heavy clouds of showers there seem to be generally several zones or areas of opposite electricities. The observations on Pikes Peak show the large development of free electricity in the rain, and hail, and snow formed at great altitudes. Howard deduced from Reed's observations that snow and hail unmixed with rain are positive almost without exception. Probably if the snow and hail could have been intercepted in the upper air, it might have been said "without exception." On one occasion, when "a most awful darkness filled the atmosphere" and some rain fell mixed with hail, the positive charge became "as strong as it could possibly be."[1]

Experiment on the electricity of clouds, showers, etc., does not seem to have been continued in recent years, though much might be learned from it in connection with the other conditions of weather. On the other hand, laboratory experiment on the electrification of steam, of smoke, and of small drops has led to most interesting results. An electrified rod, at a few thousand volts, with brush discharge, in a

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[1] Phil. Trans., Vols. XXXI, XXXII.

vessel filled with smoke, widened the "dust-free coat" enormously, and the whole box was cleared of smoke. A discharge from a Voss or Wimshurst machine through smoke causes a very rapid aggregation in masses or flakes along the lines of force, and the soot is left on the sides and floor of the vessel. The most effect is produced when the air itself is electrified, but a knob acts less quickly than a point.

A piece of rubbed sealing wax held about a yard distant from a falling water jet broken into small drops causes the drops at once to cease to scatter, and unites them into large drops as of a thunder shower. A cloud of steam turns into "Scotch mist;" a spherule of water amalgamates with a large mass at the first opportunity; if there be the slightest difference in size or in electrification, the repulsion is exchanged for attraction before actual contact. The opposed surfaces come into collision with considerable violence, even when the relative motion of the centers of the masses is small. Surface tension is overcome, and thus violence of contact promotes the coalescence of drops.

The whole subject is of deep interest, not only in connection with the causes of rain and conditions of cloud formation, but with the physics of the atmosphere generally.

OVERCOOLING, ETC.

Other matters deserving fuller investigation than they have yet received, although they have been the subject of valuable memoirs by Dufour, Von Bezold, and others, are the capability of vapor existing in the atmosphere beyond the normal degree of saturation, "overcooling," as it has been termed; and, secondly, the degree of temperature and other conditions in which small drops of water and cloud globules can exist unfrozen. These questions are of great interest both meteorologically and in relation to physics in general.

With regard to the supersaturation of air, this has been proved to be possible in the laboratory to a remarkable degree when dust is absent, but has not yet been proved in the atmosphere. It seems highly probable that occasionally, especially in very moist air, when much rain and cloud has been long continued, or in the intervals between thunder clouds at a great height, there may be spaces of the atmosphere in which dust is so rare and moisture so large that the ordinary point of saturation may be passed. The accumulation upon drops or snowflakes passing through such a space would be heavy.

The latent heat of condensation from vapor upon cold drops of ice has been supposed, owing to its very considerable amount, to make the growth of such drops or hailstones to a large size by deposition from vapor impossible. But rapid passage through cold air may be found to dispose very quickly of the heat thus set free. Experiment is needed on this point.

With regard to the liquidity of droplets below the freezing point, the fact is fully proved, and clouds and fogs often seem to be still liquid at 12° to 20° F. below the ordinary freezing temperature of large drops. But the degree of cooling which may be borne without freezing, and its dependence upon the size of the globules in the free air, has yet to be determined. Observation of the sun and moon and the diffraction effects in clouds at ascertained heights would be the best available means, short of direct observation at great heights, of fixing the relation of size to congelation at various temperatures.

DISTRIBUTION OF VAPOR CLOUDS.

Experiments with kites and with electrometers have shown that transparent vapor is grouped in masses through the air like visible clouds, but less continuous, and astronomical observations seemed to show a distribution of the atmosphere not only into horizontal strata, but into vertically extended compartments differing greatly from each other. Brief perturbations of polarization, occurring at any hour of the day, have been ascribed to "clouds" of cirrus, etc., too faint to be seen. Recent experiments in the foehn and in other hill and valley winds have shown considerable differences of temperature at intervals of a few minutes. Delicate and sensitive thermometers, hygrometers, and electrometers might well be used for the further discovery of the varying states and divisions of the air in respect of temperature, humidity, and electric state and of the causes of differences.

There is much reason to assume that the atmosphere is divided, like the sea, into many large and small masses of unequal temperature. The great reluctance of waters of different temperatures to mingle, as seen in the neighborhood of Newfoundland and of the Gulf Stream, also at the head of the Lake of Geneva where the Rhone enters, and at the junction of the Rhone and Arve below Geneva, has its counterpart in the atmosphere. It is curious to see a large body of water like the Rhone plunge down toward the bottom of the lake, leaving only floating substances on the surface.

The present author believes that since particles of water in the air a little smaller than those of fine blue haze would be quite invisible, owing to their inability to reflect light, like a soap film a millionth of an inch thick, which is quite invisible, there must be a quantity of water in moist, transparent air which is competent to arrest heat waves by absorption, and is not in the state of vapor. He believes that a theoretical and experimental investigation of the various conditions of vapor and water in the air would lead to interesting and important results. The effect of a thin veil of cirrus, and of a slight, equally distributed haze upon the intensity of solar radiation has been recently investigated at Catania and Casa del Bosco (4,725 feet above the sea). The cirrus was found capable of intercepting 30 per cent of the radiant solar energy. The haze intercepted 23 per cent when the sun was 10 degrees above the horizon, and only 4 per cent when the sun was at an altitude of 50 degrees. When the sky was light blue and cloudless the absorption was greater than when it was deep blue.[1] Of course, these experiments refer to the whole thermal solar energy, and there is at present no record of the varying amounts of absorption of dark heat only, or of the varying loss by radiation from an object on the surface of the earth in different conditions of the unclouded sky.

SOUND IN AIR.

Experiment has still to determine the rate of propagation of sound in air at different temperatures in average atmospheric conditions at those temperatures in different countries; the rate of propagation for intense compared with feeble sounds; the rate for notes of widely different pitch, and what sounds may be most effective at long distances to the ear and to recording instruments. It is conceivable that instruments may be constructed which would enable messages to be sent by the voice or otherwise through long distances of air. Converging lenses of gas have been constructed for focusing sounds, and similar ones might perhaps be utilized if made on a large scale.

The homogeneity and discrepancy or heterogeneity of the atmosphere have been ascertained to be very important in the transmission and arrest of sound waves; it seems frequently to be impossible, with our present knowledge, to distinguish a good from a bad hearing day. The air is often divided, apparently, into laminæ or divisions of different density, humidity, etc., which stops waves of sound and may even reflect them loudly, though transparent. All these points deserve further elucidation, and are of consequence for maritime and military and naval purposes. They may also serve, with other prognostics, for the forecast of weather. The echoing power of clouds of different kinds is not well made out. The practicability of production of sounds in a dense medium, such as air under pressure or in carbonic acid gas, in order to increase its intensity, is worth investigation.

POSITION OF THE PLANETS, SUN SPOTS, AURORÆ, WEATHER, AND CROPS.

Investigation of the reality of connection between the position of the planets, the number and extent of solar spots and prominences, terrestrial magnetic disturbances and auroræ, cycles of weather, and agricultural crops.

AEROLITES.

The number of aerolites, or shooting stars, which enter the atmosphere daily; their size, weight, and any effect they may have on the upper atmosphere. The possibility of any general sky illumination by the passage of small particles, compared to fine dust.

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[1] Rendiconti del Reale Instituto, Lombardo, 1894.

LIMITS OF THE ATMOSPHERE.

The theoretical limits of the atmosphere; whether any portions are being continually lost into space, and gained from space.

ABSORPTION OF THE SPECTRUM.

The absorption and reflection of various portions of the spectrum of the atmosphere, by air and by vapors, at different heights. The connection of radiation and absorption with states of weather and approaching changes; diathermancy and translucency in connection with forecasting. Absorption of several portions of the visible and invisible spectrum in different states of the air.

COMBINED FORECASTING.

An inquiry into and formulation of a plan for a combined system of weather forecasting. In addition to the present schemes and practice of weather forecast as used in Europe and America, it would seem desirable to employ observation of local instruments and phenomena. Trained observers are often able to make a more correct forecast for their district from the appearance of the sky, etc., than they receive from a central office. The training of observers is a necessary preliminary to a much more extended system of observation. The present writer has proved that a great deal of use may be made of a number of different signs taken in combination. Thus the character of a haze, the superposition of currents, the exact character and appearance of clouds and their edges, the length of trail of steam from a locomotive, the color of the sky and sun, and of morning and evening clouds, the radiation from an exposed thermometer, and the size and manner of fall of raindrops, often give a fair prediction of coming weather. These should be used in combination with the reports of barometric and other instrumental readings from the various stations, and in aid of the established system of data used for weather forecasts. Locally observed phenomena, many of them not at present recognized as significant, might, after a certain number of years' observation, have a definite percentage value assigned to each as a prognostic, and the observer, provided with a table of values, might then add up the percentages of all the signs observed on each occasion, and from the total obtain a very fair estimate of probability of coming weather over a district of moderate area. The following table is intended to furnish an example of such a system of local combined forecast, with imaginary figures:

Station: Haslemere, Surrey, England. Time, 9 a. m.

[Probability of rain in thirty-six hours.]

	Per cent.
Upper clouds, cirrus, cirro-cumulus, from west-northwest. Lower clouds, cumulus, from southwest	16
Edges of cirro-cumulus, hard	27
Edges of cumulus, rounded and hard	31

	Per cent.
Motion of cirrus, fast	23
Motion of cumulus, very slow	8
Vertical height of cumulus compared with breadth, great	73
A few waves or close ripples of well defined hard cirrus strata nearly overhead.	84
Length of steam trail, moderate (estimated 90 yards)	52
Color of clouds at dawn, pale yellow	58
Regular or irregular distribution of clouds	(?)
Regularity or variability of temperature and humidity in adjacent strata, etc.	(?)
[Probability of rain in twenty-four hours.]	
Visibility, great	70
Audibility, great	61
Humidity, difference of bulbs, 4 degrees	46
Humidity (increasing or diminishing), diminishing	29
High clouds, increasing	68
Cirrus (straight or tangled), tangled	81
Stars last night, much twinkling	71
Smoke, tending downward	69
Total	877

Probability, rain.

The number of items in the forecast might be much increased with increasing knowledge, and the value of each sign would also increase with continuous exact observation. Moreover, each sign should be studied not as a single item, but as occurring with others, and when considered in relation to others would gain much in value. Thus, visibility is not infrequent in fine dry weather, and also occurs in moist weather, before rain. If observed day after day in fine weather, its value in forecasting is evidently much less than when occurring in somewhat unsettled weather. In fact, each sign has properly a particular value in particular kinds of weather, and the special value has to be ascertained. The length of time during which a certain type of weather has continued is in some proportion to the probability of the ensuing days being of a similar type.

When the total of the various percentages exceeds a certain fixed amount, the probability of bad weather rises to something approaching certainty, and perhaps the probability of fine weather when the amount is minus goes a little further still. When, in addition, the probability announced by the central office from wide data is in the same direction, it becomes justifiable to place reliance on the forecasts for agricultural purposes and general district warnings. It will also eventually be of great use to farmers to have telegraphic information forwarded to districts toward which bad weather is moving, if there is reason to regard the change as more than local when first noticed.

ON SOME POSSIBLE MODIFICATIONS OF CLIMATE BY HUMAN AGENCY.[1]

There can be no doubt that some effect upon climate, shown more by physiological influences upon mankind than by instrumental records,

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[1] This section is derived from MS. written in 1891, but not in any way published.

has been produced by extensive afforesting or disafforesting, substitution of pasture for arable land, drainage of wet land, and irrigation; but certain means still remain untried which, if undertaken on a large scale, would probably bring about more important changes than any hitherto accomplished, with the exception, perhaps, of the drainage of wide marshy areas like the fens of East Anglia, irrigation works in India, and changes in the irrigated area of the basin of the Nile.

The drainage works of the eastern counties put an end to the once prevailing ague of the low levels, and the cessation of irrigation in parts of the Nile Valley seems to have deprived the plague, which was once a dreaded affliction, of its former power. The substitution of pasture for arable land tends to increase the cold of the lowest atmospheric stratum, and ground fogs are favored by the active radiation of grassy surfaces.

The influence of mountain ranges, even of small elevated tracts, upon surrounding districts in a climate such as that of England has long been recognized, and no traveler can be surprised to find fewer fine days and more rain in the hilly country than on the plain, but some of the less striking geographical conditions which tend to increase or diminish the rainfall or cloudiness of neighboring localities have been little noted and appear to deserve investigation. During a visit in September, 1889, to the coast of Donegal adjoining Slieve League, a mountainous cliff about 1,600 feet high, the summit of the cliff was observed by the author to be much more densely clouded than the vicinity; this characteristic is common to high, somewhat isolated mountains on our western coast. Moreover, the beginning of the cloud formation took place at a distance of fully a quarter of a mile or half a mile to windward of Slieve League, so that the modification of the wind blowing from the sea took place long before the strong upward trend caused on actually reaching the cliff. The air was raised and expanded, and its moisture partially condensed by the pressure in advance, due to the opposing mass, and not, as commonly stated in text-books, by the cold tops causing condensation. Now, a similar effect is produced by ranges much lower than the Donegal coast mountains, and when the wind is sufficiently charged with vapor rain would begin to fall on many occasions at a considerable distance to windward, and would always be greater in annual amount near the hills than in the more distant low country. Such instances occur in the west highlands of Scotland, the west of England, and Wales. The excess of rainfall begins at a little distance to windward of the hills, reaches a maximum a little to windward of the highest altitudes, and declines again toward the low country on the other side. The western coasts of Britain, Norway, Ireland, and Spain and Portugal all have a large rainfall, and, on the whole, the number of days on which rain falls decreases continually from west to east, except where mountain ranges or hills demand a fresh tribute of moisture. Thus, in the west of Great Britain, among mountains, the average yearly rainfall is from 45 to 150 inches, and in the west, away from the hills, from 30 to 45 inches, while in the eastern counties it is only from 20 to 28 inches. This very large effect is produced by mountains of moderate extent and of average elevation of 2,000 to 3,000 feet. At Bergen, in Norway, the fall is 89 inches; at Coimbra, in the Spanish Peninsula, 118 inches; at Nantes, 51 inches, and at Bayonne 49 inches. In parts of Sweden and Russia it is as low as 15 inches; in France the average is 30 inches; in the plains of Germany and Russia 20 inches.

But the most striking instance of the rain-compelling power of mountains is afforded by the Khasia Hills, situated about 200 miles north of the head of the Bay of Bengal, and only about one-third of the height of the Himalayas. Here the annual rainfall is said to be 600 inches, of which 500 fall in seven months. At 20 miles farther inland, beyond the hills, the annual amount is reduced to 200 inches; at 30 miles to 100 inches; and at Gowahatty, in Assam, to 80 inches. In the more westerly Himalayas, where the southwest monsoon has already been drained of part of its vapor by passing over a tract of dry land and hilly country, the rainfall is only 120 to 140 inches. Similar instances occur in India, e. g., Bombay, on low ground, 75 inches; among the Western Ghauts, at Uttra Mullay, 263 inches; at Poonah, more inland, 24 inches.

In Mauritius, at Cluny, in the vicinity of mountains and exposed to the southeast trade wind blowing from the sea, the rainfall in almost any month is from four to six times greater than at Gros Cailloux, on the northwest coast, only 16 miles distant.

In England the difference between hilly and level districts is well observed in the winter, when the clouds are low, and when precipitation is less due to ascensional currents than to vapor-laden winds. The clouds on rainy days in winter are very frequently between 500 and 1,000 feet above the sea level. The effect of low hills is consequently most marked at this season. Dartmoor, Exmoor, the Chiltern, Cotswold, Derbyshire, Surrey, and Hampshire hills severally raise the observable rainfall above that of the surrounding country. At the head of the valley of Longdendale, near Manchester, nearly 1,000 feet above the sea level, the rainfall in 1859 was 53⅓ inches; on the west side, and just over the summit on the east side, 58½ inches. At Penistone, a few miles farther east, it was 39 inches, and at Sheffield, still farther east, 25 inches. The height of the hills producing this effect is about 1,400 feet. Similarly, the fall varied from 39.1 inches at Rochdale to 67 inches at Blackstone Edge (1,200 feet), 32.25 at the easterly foot of the ridge, and 20 inches at York in 1848. In 1859 a gauge on the westerly side of Loch Ard gave 92 inches, while another near Glenfinlas, farther east, gave only 48 inches. The instances of Slieve League, of Hoy, and of the South Downs show that it is not only mountainous masses, but also mere barriers against the wind from the rainy qaurter which cause precipitation. The air will be equally lifted to windward whether the obstacle consist of a mountain or of a galvanized iron screen.

SYMONS'S BRITISH RAINFALL.

An examination of the means for fifteen years at a number of stations in England shows that such cases are not isolated. At Saltash, on the southwest side of Dartmoor, the rainfall was 53.87, at Lee Moor (860 feet), on Dartmoor, 68.96, and at Bovey Tracey, east of Dartmoor, on low ground, 46.08. At Clyst Hydon, the mean was only 34.21; at Exeter, 36.61; and at Exmouth, 34.74. Similarly, at Tavistock (316 feet), near the western edge of Dartmoor, the fall was 54.18; while at Tiverton (450 feet), at some distance northeast of Dartmoor, it was 44.35. At Kingsbridge, to the south, where the influence of Dartmoor was not conspicuous, owing to its position with regard to the prevailing winds, only 37.15 was registered. Taunton, protected apparently by the precipitating influence of both Dartmoor and Exmoor, as well as by the nearer Blackdown Hills to the southwest, recorded only 29.75, against Tavistock's 54.18 and Barnstaple's 41.95.

In Sussex we find that the South Downs, mostly 600 to 700 feet high, and the ranges of hills on the southwest border of Surrey, have an appreciable effect, though they do not exceed 800 feet, except at a very few points. Thus, Arundel registered 34.29; the rising ground north of Chichester, 34.90; Petworth, 36.19; Midhurst, 39.65; Fernhurst, 32.19, against 28.41 at Dunsfold, near Godalming, some miles to the northeast of the hills; 26.55 at Weybridge, still farther east, and 26.13 at Greenwich. At Alton, on high ground (496 feet), the fall was 35.58, against 26.73 at Reading. At St. Lawrence, Isle of Wight, and Osborne, the record gave only 31.20 and 29.91, respectively, and the seacoast from the Isle of Wight to Dover has an average of less than 30 inches. On the low ground of the eastern counties, where the air would no longer be forced upward in crossing the land, the amounts diminish to 24.22 at Royston, 23.78 at Peterboro, 22.81 at Cambridge, 22.63 at Ely, and 21.85 at Shoeburyness. But the low hills of Norfolk and Lincoln raise the amount to 28 and 29 inches.

In the Midlands and northern counties the distribution of rain is similar. Thus, while at Sedbergh, Penistone, and Dunford Bridge, the amounts were 55.26, 56.76, and 55.75, stations at a moderate distance eastward of the hills registered as follows: York, 26.93; Doncaster, 27.33; Leeds, 27.70; Sheffield, 35.02; Stockwith, 23.66; Lincoln, 23.83. The rainfall of Carlisle is remarkable, only 30.07, owing to its position to the northeast of the mountains in the same county, where the amounts reach 80 and 100 inches. In the neighborhood of Sheffield the fall varies from 43.26 at 1,100 feet at Redmires to 33.03 at Broomhall, not many miles distant. Buxton, at 989 feet, has 57.14 inches, and Chatsworth, about 20 miles distant, 36.66. Tunstall, a little eastward of the mountains of the North Riding of Yorkshire, has only 28 inches against 55.26 at Sedbergh on their western side.

In Scotland the rainfall of the northern part of Elgin and Nairn, protected by the mountains intervening between it and the west coast, is less than half that of western Sutherland, Inverness-shire, and Skye. Portree, in Skye, has 81.75 against 25.87 at Inverness. The east coast of Scotland, generally, is very much drier than the west, although the large precipitation during east winds tends to counteract the effect which the mountains westward have in reducing its rainfall during the prevalence of the equatorial currents. Great differences in rainfall may exist within a small area; for instance, the rainfall at Perth is only 32.10 and at Ochtertyre 44.17 against 50 at Lochearnhead, and the rainfall at Bothwell Castle is only 29.98 against 115.46 at Ardlui. At Braemar, at the height of 1,114 feet, the rainfall is only 36.50, owing to the great mass of high mountains toward the south and west.

In Ireland the greatest amounts are registered on the southwest and west coasts, and the fall diminishes inland eastward of the mountains, until in the northeast corner the average is only about 30 inches against 60 to 80 in the west.

Among the above instances the most instructive, perhaps, for the present purpose are the records of Midhurst, Petworth, and Arundel, compared with those a little south and north of these stations. It is plain that the action of the long, wall like ridge of the South Downs, not exceeding 600 feet in average height, is sufficient to cause from 5 to 10 inches excess of rain in its immediate neighborhood, the rainfall 20 miles westward and 8 miles southward, being only about five sixths of that which occurs in close proximity to this ridge. Part of the deficiency on the coast must be attributed to the frequent exemption from heavy showers which form over the land, but not over the sea, in summer. The present author has observed this, especially on days with a light westerly or southerly breeze, and has also noted the preference of thunderstorms for the low ground between the hills and the downs. The greatest fall takes place at Midhurst, which lies about 5 miles north of the South Downs, and at the foot of the southern slope of a second ridge, Henley Hill, about 600 feet high, which stretches from east to west. Compared with Dunsfold, about 17 miles to the northeast, the amount is in the proportion of 4 to 3. Dunsfold is probably deprived of a good deal of rain by the mass of Blackdown (900 feet) 8 miles to the south. Fernhurst, near a cleft or dale in some high hills on its northern side and 2 miles north of Henley Hill, has, roughly, 7½ inches less than Midhurst. That even lower hills (400 feet) in a flat country may raise the rainfall of their climate by 5 or 6 inches is shown by the records of the high ground of Norfolk and Lincolnshire.

Now, the practical inference from these statistics is that it may be possible where desirable to imitate natural barriers on a small scale and to increase rainfall in their proximity in order to diminish it elsewhere. Thus, if between Chichester and Arundel the natural height of the Downs were to be raised by 300 feet, the rainfall would be increased a mile or so southward and perhaps a few miles northward, but would be diminished over the northern half of Sussex, and probably in Surrey, to an appreciable degree.

Similarly, a wall of 400 feet in height between Yes Tor and Hartland Point, in Devonshire, would increase precipitation along a band parallel with the wall, but would give a drier climate to the more easterly portions of the county, and probably also to Somersetshire. In England, not only does the greatest quantity of rain reach us from the southwesterly quarter, but the clouds are lowest in the rains from that quarter, so that the greatest effect of a barrier is produced on rains coming from south and southwest.

The method of construction is a question for engineers. Would it be possible to construct a screen several hundred feet high, of iron, as used in the large gasometers which we see in the neighborhood of our large towns? Or is masonry necessary in order to withstand the extreme possible pressure of strong winds?

The desirability of forming any such artificial barrier would, of course, depend on the calculated probable benefit to be conferred on any county or district, and it would very likely be only in rare cases that the increased geniality of climate would repay the outlay. Possibly it is only worth considering in the case of very wet climates, or of places where little rain falls and more is needed. In England, supposing for a moment that its erection is desirable, the line to be taken for a wall must be such that there would be very little disturbance of natural features of interest or beauty; in fact, it should either be across barren moors or wastes, or else parallel to the cliffs on a desolate coast. The line above suggested from Yes Tor, near Okehampton, toward Hartland Point, appears in all respects a favorable one for the purpose, as the country to be crossed is dreary and almost uninhabited. The wall would have an additional advantage of permitting trees to be planted on its northeast side in a broad belt, so as to make the beginning of a forest, where the winds are now too severe for vegetation. Another favorable stretch of country lies along the ridge of the South Downs between Swanage and Bridport. A high barrier here would give to a large part of Dorsetshire and southeast Wiltshire a climate not unlike that of Bournemouth, which owes its dryness to the hilly promontory of the Isle of Purbeck.

Portsdown Hill, which runs east and west for nearly 7 miles, and is over 400 feet high, would be another highly favorable ridge for an experimental wall, say 400 feet in height. The practicability of works of this kind can hardly be questioned when we hear of structures like the reservoir embankment at Bombay, a stone barrier 118 feet thick, over 100 feet high, and 2 miles long. A less amount of material would have gone toward a wind wall 30 feet thick at the base, 300 feet high, and 3 or 4 miles long.

A wall 300 or 400 feet in height and 5 or 6 miles in length, extending from near the Thames a few miles east of London in a northwest direction, would probably have the effect of stopping a considerable amount of fog, which often moves from the Essex marshes toward the metropolis. It would somewhat increase the annual rainfall on its westerly side. A wall stretching from northwest to southeast across some of the heaths in the neighborhood of Woking would reduce the rainfall of northeast Surrey and of London.

The effect of a wall, like that of a perpendicular cliff, would be to drive the impinging air vertically upward, so that the increased rainfall would take place near the wall and a little to leeward.

Experimental barriers might be first erected across the mouths of valleys open toward the west or southwest, for in many such situations a wall 1 or 2 miles long and 500 or 600 feet high would cause increased precipitation near the ocean, and a considerably drier climate in nearly the whole of the remainder of the valley. For example, a wall across the valley, a little to the north of the town of Neath, would reduce the rainfall of the Vale of Neath for a long distance, and many of the Welsh valleys opening westward to Cardigan Bay might be equally protected from excessive winter rains.

With regard to other countries, there are localities where a structure a few miles long based on rocks or ridges already some hundred feet above the sea would prove very beneficial in reducing rainfall farther inland. In other exceptional cases, where precipitation is deficient, it might be promoted on the windward side by similar means.

In parts of Australia, local rainfall might be appreciably increased by raising the height of ridges. Wherever water is scarce and valuable and the climatic conditions favorable, experimental barriers would give interesting results.

Some American cities are very liable to be attacked and partially destroyed by violent tornadoes or whirlwinds. These storms usually proceed from about the same direction, and it might possibly be an experiment worth making to set up a wall, say 300 feet high and 2 miles long, on the dangerous quarter, with the object of breaking their force. The clearing of forests seems to favor the development and progress of American tornadoes by allowing the surface of the earth to become more highly heated and by reducing friction, for they are caused chiefly by the breaking of unstable equilibrium when the lowest strata are highly heated and a cold current prevails within a few miles of the earth's surface.

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SMITHSONIAN MISCELLANEOUS COLLECTIONS.

— 1073 —

HODGKINS FUND.

THE AIR OF TOWNS.

BY

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Of Yorkshire College, Leeds, England.

[WITH TWENTY-ONE PLATES.]

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THE AIR OF TOWNS.

By Dr. J. B. Cohen.

[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:

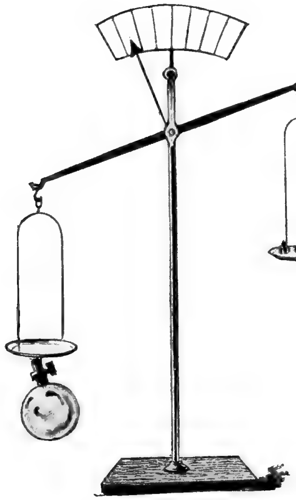
Composition of the atmosphere.

Oxygen	20. 61
Nitrogen	77. 95
Carbonic acid	0. 03
Aqueous vapor	1. 40
Nitric acid	Traces.
Ammonia	
Ozone	

Composition of the atmosphere in tons.

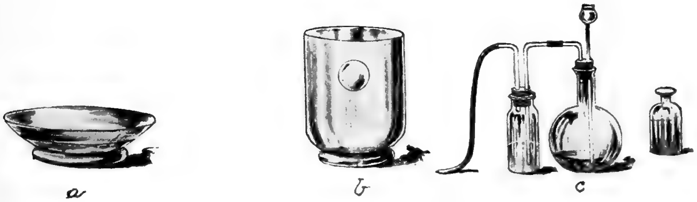
	Millions of tons.
Oxygen	1, 233, 010, 000
Nitrogen	3, 994, 593, 000
Carbonic acid	5, 287, 000
Aqueous vapor	54, 460, 000

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.

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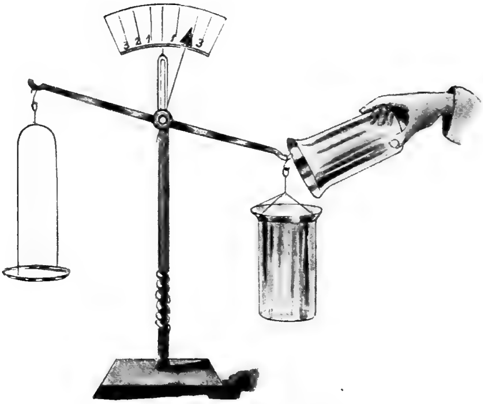
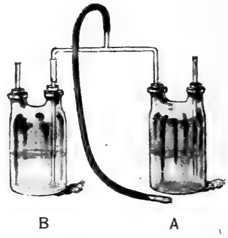
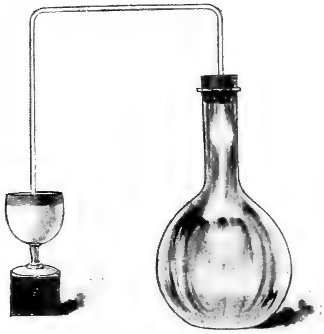


4.—Weight of carbonic acid.

5.—Demonstration of carbonic acid in breath.



6.—Demonstration of carbonic acid in the lungs.



7.—Production of carbonic acid.

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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

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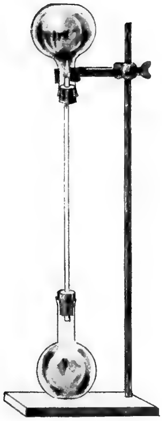
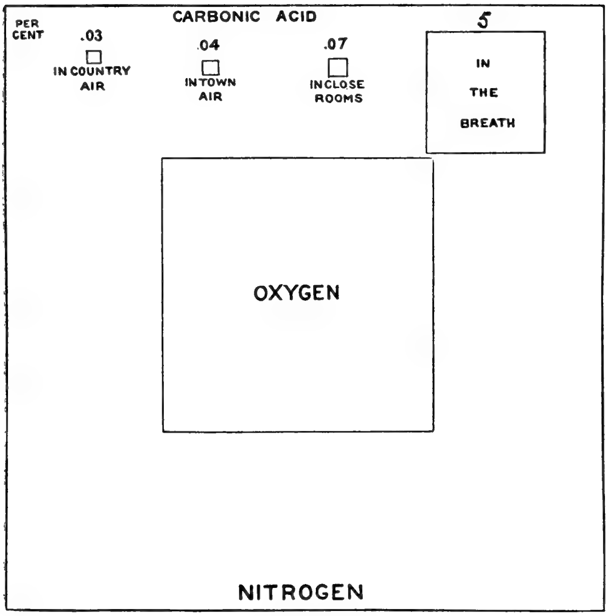
[1] Angus Smith.



8.—Diffusion of carbonic acid.



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

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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?

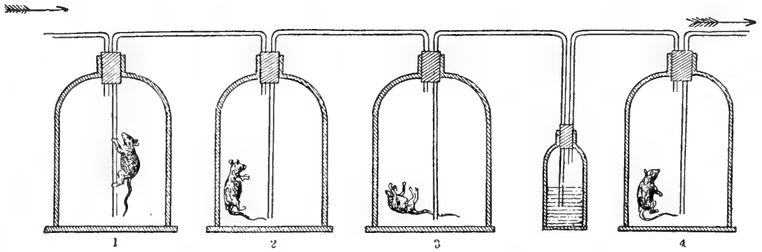
I desire to refer to a very ingenious experiment which has been carried out by the French physiologist Brown-Séquard.

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.

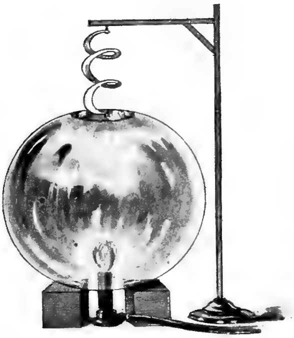
Whatever may be the exact nature of this poison, of which little more than its mere existence is known, there can be little doubt that the amount in town air, indicated by 0.001 per cent, produces a cumulative effect upon our vitality, which makes us long for fresh country air, and which no doubt enhances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

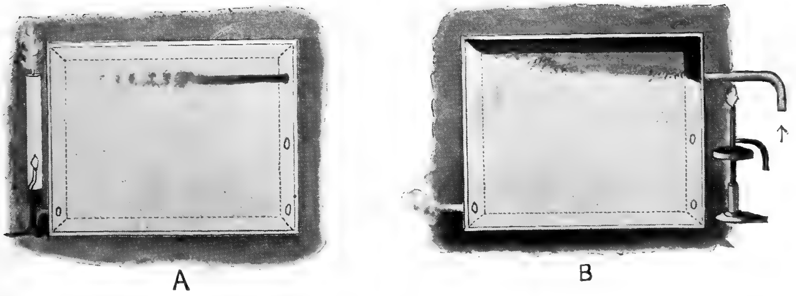
Let us consider the case of a person sitting in a room and consuming



10.—Brown-Séquard experiment with expired air.



11.—Ascent of warm air.



12.—Principles of ventilation and heating.

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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.

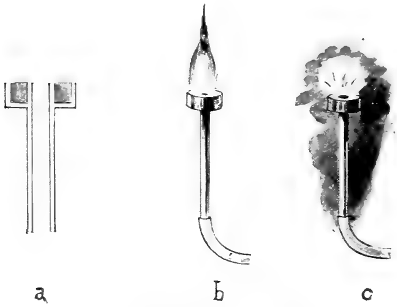
A more economical method is to warm the air of rooms by means of steam or hot-water pipes; but in this case there is no natural ventilation, no fresh air is introduced as with the open fireplace, and special means must be provided to supply the defect.

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:

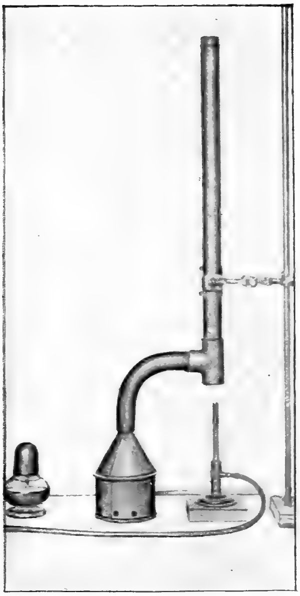
The illustration (fig. 12) represents a shallow, air-tight box with a glass front. Three small circular holes are bored along one side equidistant and one at the bottom of the opposite side. In *A* this hole is fitted with a glass T piece, the top vertical end of which passes through a cork of a lamp 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 T 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.

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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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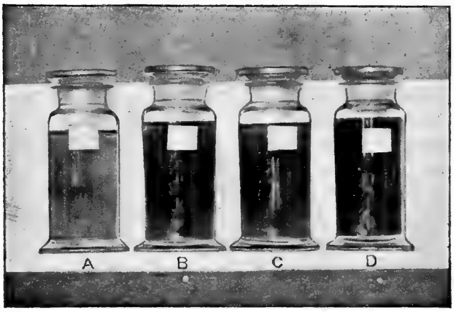
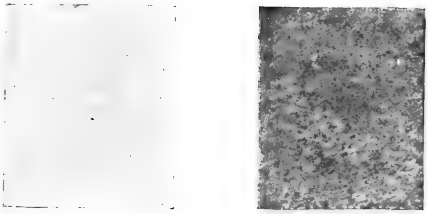
[1] I should recommend the following pamphlets: The report of "The National Association for Testing Smoke-Preventing Appliances," the address of whose secretary is Mr. Fred Scott, 44 John Dalton street, Manchester. "On the abolition of smoke from steam boilers," by T. Patterson, M. D. Publishers, Chronicle 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.

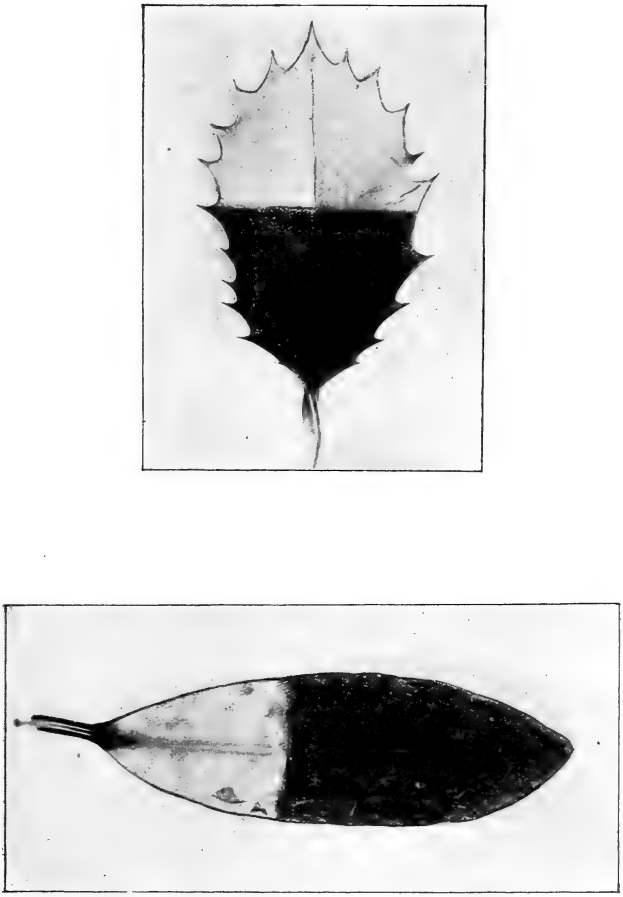
Before we can understand the effects of smoke we must learn its composition. I have analyzed two samples, one of which was deposited on the orchid houses at Chelsea during fog, and the other was obtained from my chimney sweep. They contained respectively 14 and 15 per cent of a nasty, sticky oil. Were 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.

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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

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[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:

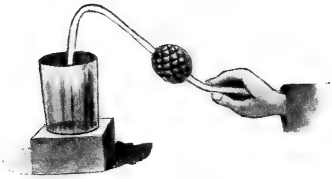
> "There are difficulties in making any change. Masters will not take the trouble to alter their furnaces, nor will the men alter their method of stoking the fires unless they are compelled. The numberless alterations made in the construction and conduct of chemical works during the last twenty years 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.

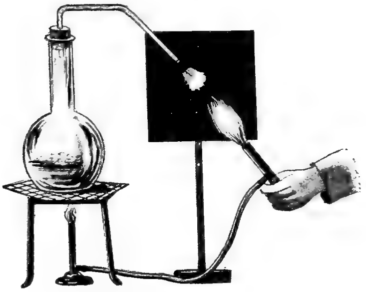
I believe that if the employer were obliged to put in an efficient smoke-preventing appliance, of which there are several in the market, he would reap advantages in two ways. He would probably economize in fuel and the health of his workmen would be improved. But, as the alkali inspector says, the manufacturer 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,

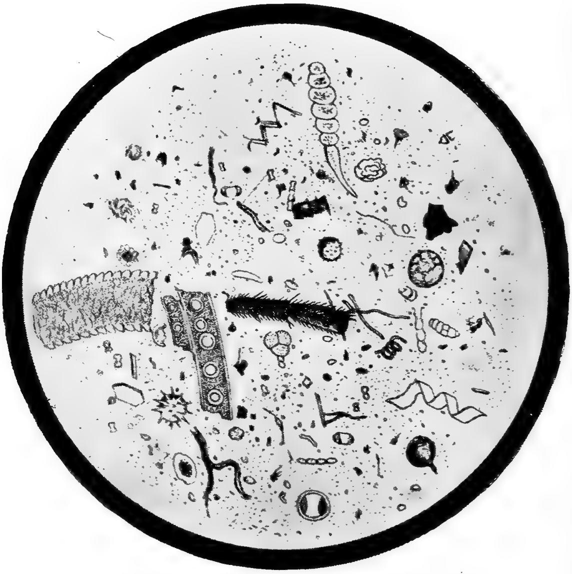
"This city now doth like a garment wear
The beauty of the morning; silent, bare
Ships, towers, domes, theaters, and temples lie
Open unto the fields and to the sky
All bright and glittering in the smokeless air."



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.

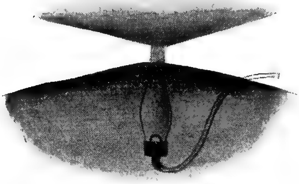
We can learn something more from this experiment. The dust is mainly organic; that is, the product, living or dead, of animal and plant life, living germs or dead spores or animal and vegetable refuse matter; for if I now bring a red-hot poker or a Bunsen flame beneath the beam, black smoke appears to 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

23



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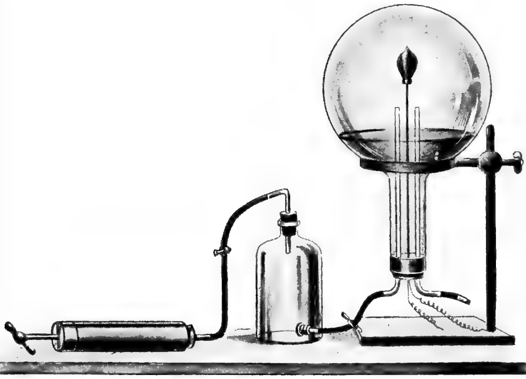
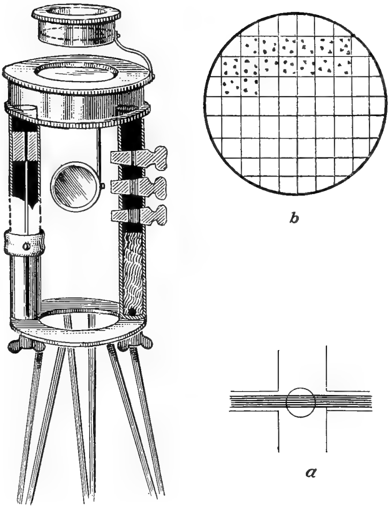
23, 24.—Beams of light through dustless air.



25.—Nature of fog.

THE AIR OF TOWNS.



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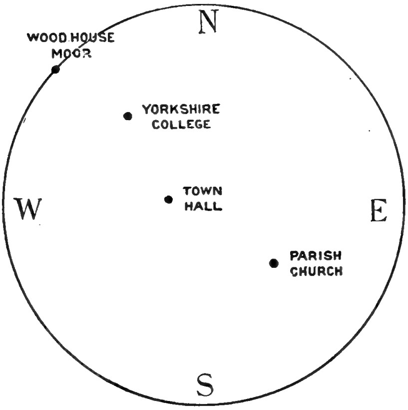

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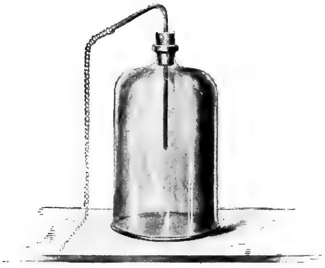

28

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

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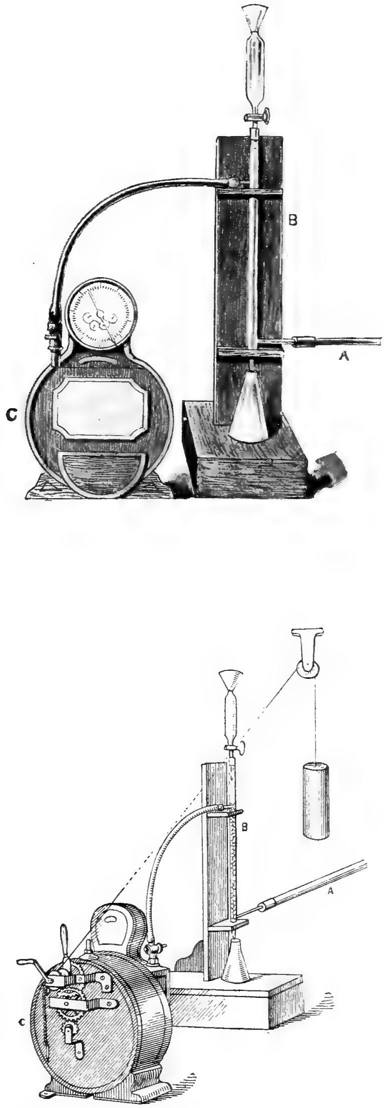
[1] Dr. Russell.



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_3 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_3 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 $1\frac{1}{4}$ 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.

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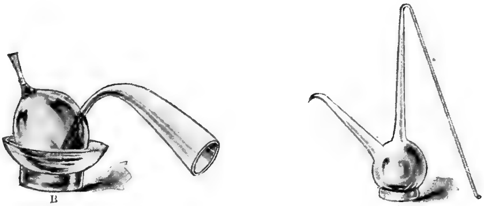
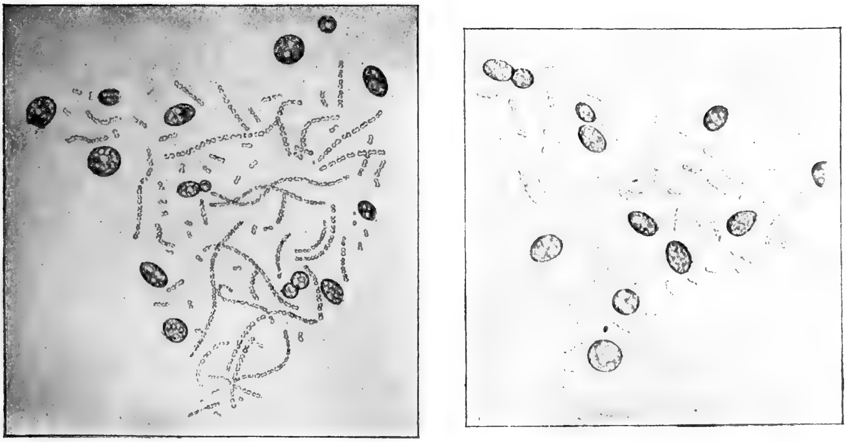
[1] Professor Tyndall.

30.—Yeast plant.

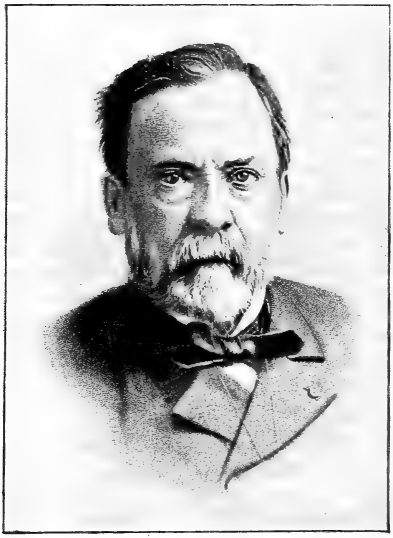


31.—Cause of vinous fermentation.



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

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[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

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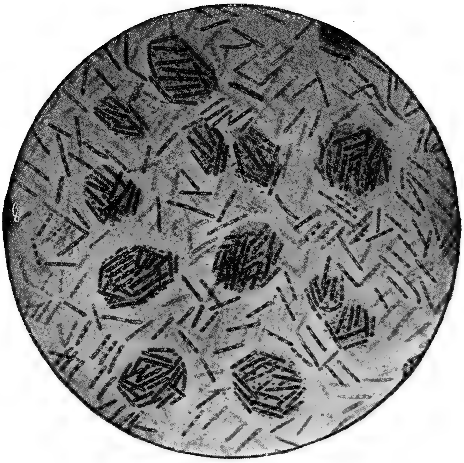
[1] Miquel.

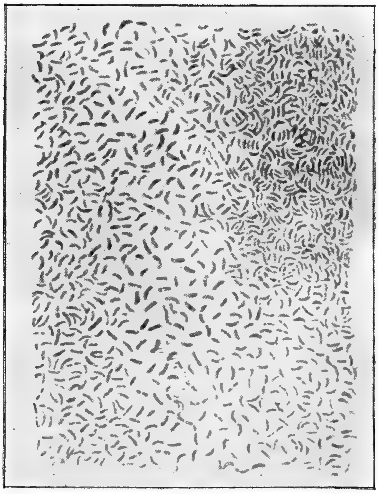
33*a*.—Bacillus of tuberculosis. ×1500. (Crookshank.)



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

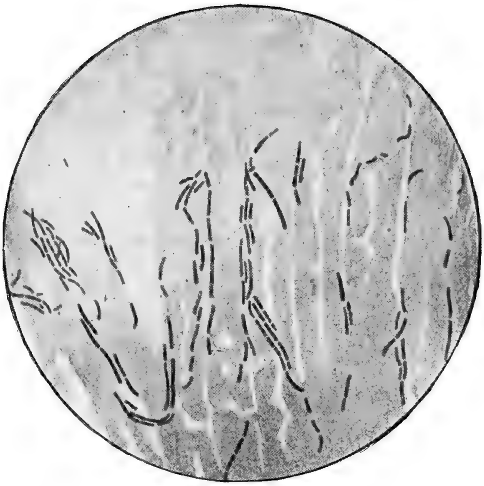
THE AIR OF TOWNS.

33c.—Typhus bacillus. (Schenk.)

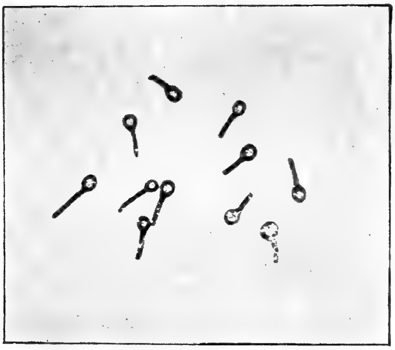


3 d.—Cholera bacillus. (Schenk.)

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.

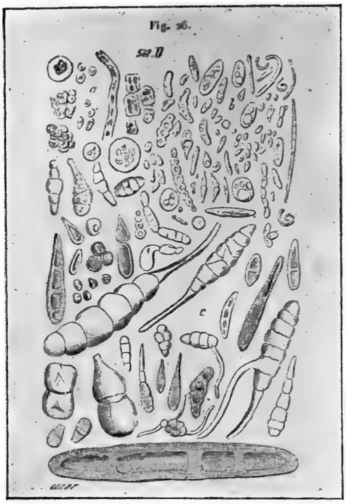
The number does not appear to vary proportionately with change of temperature: but if we compare the rainfall with the number of microbes we see at once a rapid diminution. The rain evidently carries them down to the earth. But they are far from being destroyed. The moisture seems to assist reproduction, 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.

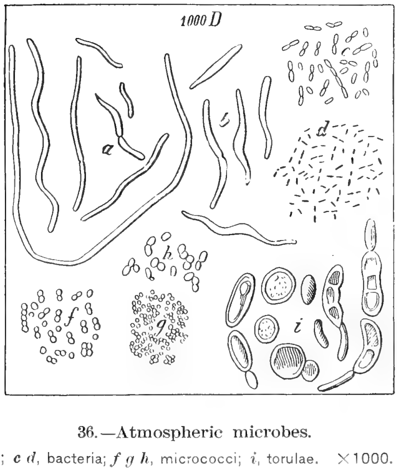
The number, 21 to 22, for the streets of Paris is a rough average. In dry, dusty weather, following rain, the number may rise to 150. Directly after wind and rain it may fall to an average of 6 per cubic foot.

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



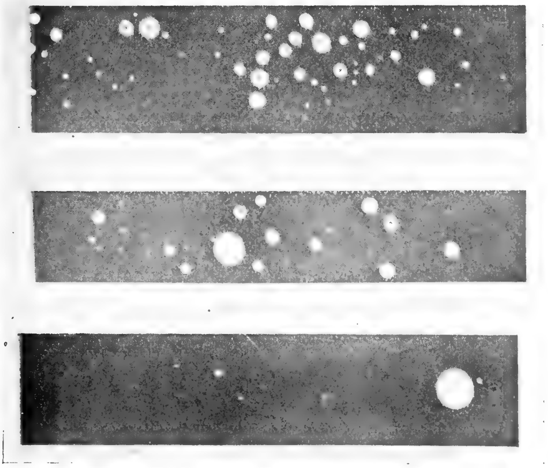
35.—Atmospheric microbes.
a, algae; *b*, cells of cryptogams; *c*, spores of cryptogams. ×500. (Miquel.)



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

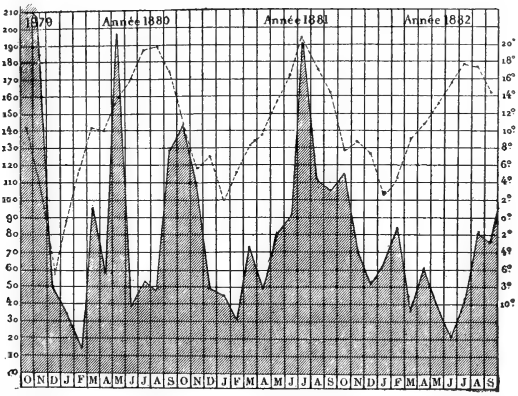
THE AIR OF TOWNS.

37.—Apparatus for counting microbes in the air.

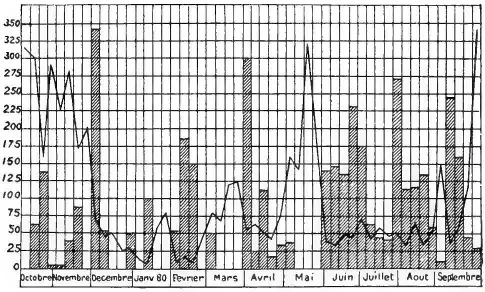


38.—Microbes in air of schoolroom.

THE AIR OF TOWNS.

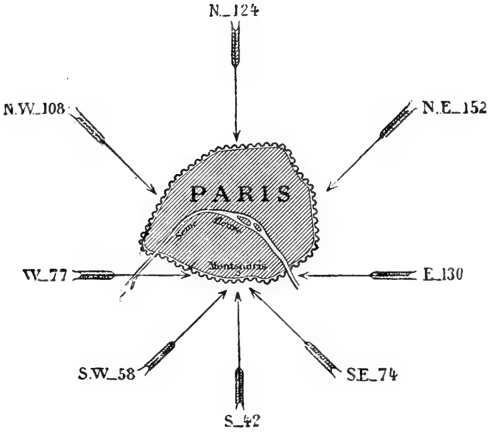


39.—The variation of the number of bacteria with the temperature. 1880–1882. (Miquel.)



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.

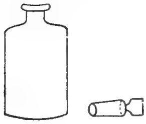


FIG. 1.

(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.

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.

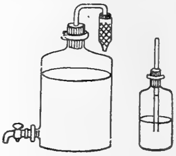


FIG. 2.

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
3¼	.07716
4¼	.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.

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* 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.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

— 1077 —

Hodgkins Fund

EQUIPMENT AND WORK OF AN AERO-PHYSICAL OBSERVATORY

BY

ALEXANDER McADIE

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1897

EQUIPMENT AND WORK OF AN AERO-PHYSICAL OBSERVATORY.

BY

ALEXANDER McADIE.

[Memoir submitted by Mr. McAdie in the Hodgkins Fund Prize Competition of the Smithsonian Institution in 1894, and awarded honorable mention, with a bronze medal.]

SUBJECT.

A. The known properties of atmospheric air considered in their relationships to research in every department of natural science, and the importance of a study of the atmosphere considered in view of these relationships.

B. The proper direction of future research in connection with the imperfections of our knowledge of atmospheric air, and the conditions of that knowledge with other sciences.

Two years ago the trustees of a New England university received plans and specifications for a laboratory. It was not to be a chemical laboratory nor a physical one, nor yet geological nor biological, but one to be devoted to investigation and research in aero-physics. During the present year one of the universities on the Pacific slope has established, or contemplates doing so, a chair of meteorology. At the time of the presentation of the plans and specifications referred to above, it was pointed out that, with the possible exception of the department of mathematics, every department of science then represented at that university would be directly served and greatly benefited by the work of this high-class aero-physical laboratory. The chemist, the physiologist, the biologist, botanist, and physicist must have authoritative knowledge of the conditions of external air pressure, temperature, humidity, and atmidometry (if the word may be used) at the time of their experimentation if true results are to be obtained.

And back of research and investigation always there looms up the application of knowledge to the needs and wants of the community. In aero-physics there exists without doubt a demand for standard records and exact determinations. Even as these lines are written the demand for standard rainfall, temperature, wind, pressure, sunshine, and cloudiness records is greater than the skill and industry of the meteorologist, as he is now equipped, can meet. That the " nature and properties of atmospheric air in connection with the welfare of man " is a topic crying aloud for recognition let the vexed questions arising in our daily intercourse answer. The courts call constantly for information, and authenticated records are admitted as evidence. Intelligent inquiry for data not available confronts the meteorologist daily. The engineer, be he civil, mining, electrical, or sanitary, knocks with increasing frequency at the door of the aero-physicist. The physician's inquiries are manifold. Averages, extremes, and rates of change affect our well-being; and yet when he receives all the data now available he receives but a meager portion. With reference to the origin and spread of disease and in all questions of pathogenesis and metabolism, we are but poorly off in knowledge of the relation to these of either the chemical or physical properties of atmospheric air. Rayleigh and Ramsay have just shown in their work on nitrogen how little we know of that very gas which by volume in 100 parts of our atmosphere would be 79.19. With the discovery of argon our conception of the part played by nitrogen in organic life must undergo change. This discovery, in the words of a great chemist, Sir Henry Roscoe, is one " of the greatest possible interest and importance, and of special significance as being one brought about by the application of exact quantitative experiment to the elucidation of the problem of the chemical constitution of our planet."

Pass now to a description of this proposed aero-physical laboratory and it is perhaps but proper to say that at least two observatory-laboratories somewhat approximate the equipment here set forth.

BAROMETRY.

Standard barometers—Wild-Fuess, Fortin, or Kew.
Multiplying barographs—Richard, Marvin, or Draper.
Aneroid, Redier or improved Hicks.
Statoscope for minute fluctuations of pressure;—of especial value during thunder-storms and gusts.
Sundell normal barometer.
Telebarometers, distant from each other not less than 1,000 feet in a horizontal direction and 500 feet in a vertical direction. This implies that the laboratory must be situated on the summit of a hill or mountain, with base stations. Buchan, in his résumé of the work done at Ben Nevis, intimates that some very important relations are thus discoverable.

THERMOMETRY AND HYGROMETRY.

Standard types of thermometers—exposed, wet-bulb, maximum and minimum, water and soil.

Thermographs and self-registering psychrometers.

Assmann aspiration psychrometer.

Telethermographs and telehygrographs.

INSOLATION.

Actinometer (Schwolsen).

Langley's bolometer, with appropriate galvanometers for the exploration and mapping of the solar spectrum, particularly the infra-red portion.

Photographic records of the more prominent absorption lines due to aqueous vapor in the atmosphere, and comparison, after proper scale determination, with the intensity of standard solar lines, with the ultimate aim of ascertaining this distribution of vapor in the atmosphere at various altitudes and variations therefrom.

Spectroheliograph. A good 12 or 14 inch photographic objective for investigating the relations of solar spots, faculæ and prominences.

NEPHOSCOPY AND PLUVIOMETRY.

Sunshine recorders of various types.

Nephoscopes and Pole star recorders.

Rain gauges and evaporometers.

ATMIDOMETRY.

Barus's device for showing colors of cloudy condensation.

Aitken's dust-counter or coniscope.

The determination of the amount of haze or smoke present in the atmosphere is now quite neglected in meteorology, although a matter of very considerable importance to health. We should have daily records of the relative purity of the atmosphere.

ANEMOMETRY.

Anemoscopes.

Anemo-cinemograph—an instrument showing the varying force exerted by the wind, superior to the old form of anemograph; and yet some further improvement looking to a fuller recognition of what has been termed "the internal work of the wind" is desirable.

Helicoid anemometer.

Clino-anemometer, or instrument for registering currents not horizontal.

Wind pressure gauge and suction anemometer.

THERMODYNAMICS AND CHEMISTRY.

Apparatus might be devised which would give graphically the thermodynamic conditions of the atmosphere. The volume, pressure, temperature, and density of the air being known, we ought to be able to follow the isotherms and adiabatics through the varying conditions in cyclone and anti-cyclone at all levels. Thus Hertz (Graphische Methode zur Bestimmung der Adiabatischen Zustandänderungen feuchter Luft, Meteor. Zeits., 1884) has given the adiabatics for the dry, rain, and hail stadia, and it is practicable to follow a given air mass through the varying thermodynamic conditions.

ELECTROMETRY.

Proper apparatus for measurements in atmospheric electricity.

Mascart-Kelvin electrometers for the determination of the potential of the air. The type of voltmeter known as the multiple quadrant electrometer, or substantially Lord Kelvin's air leyden, should be installed with an automatic register for continuous records of the electrification of the air.

Elster and Geitel's apparatus, modified, for records of the air "leakage" of electrical charge under the influence of ultra-violet light.

Brontometer, for use in the study of the strains and stresses in air between highly electrified clouds or cloud and earth. The name brontometer is used, but some more appropriate type of instrument than the present is desired. It now gives the time of each lightning flash, the duration of thunder, the changes in direction and force of the wind, in temperature, humidity, and barometric pressure during a thunder-storm ; but there is wanting the photographic auxiliaries to delineate the character of each discharge. The true direction in space and the dimensions of the discharge are determinable by such means. The potential fluctuations added to such data will enable us to study the strains and ruptures in the atmosphere after the thunder-storm as completely as a plate of fractured armor can be studied after a test.

PHYSIOLOGY AND BIOLOGY.

The known properties of atmospheric air are clearly of great importance in all physiological and biological research. In the latter, atmospheric environment must be an effective factor in the variation of species, and in the former, at the very outset, do we not meet an intimate relation between the irritability of nerve and muscle with atmospheric conditions?

How important to know the atmospheric conditions as influencing exhilaration and fatigue. The so-called "sensible" temperature, for example, enables one to live in the temperatures of the Southwest in summer and renders temperatures lower by twenty degrees elsewhere unbearable.

In such a laboratory, then, trained intellects studying the properties of atmospheric air, would, we firmly believe, influence research in every department of applied science. In agriculture the value is apparent; in economics, history, hygiene, botany, geology, and biology, questions now unanswered would be disposed of. In that much-dreamed-of consummation, the conquest of the air, when transportation shall be by air-ships and communication by air-runners or disturbances of the electrified air, the contributions to knowledge from such a laboratory would be incessant and without price. Aye, in directions now unthought of, the aero-physicist would push onward in the great region now unexplored. When the Berlin Academy, in 1879, offered a prize for the experimental determination of a relation between electromagnetic forces and the dielectric polarization of insulators, perhaps no one—certainly neither Helmholtz nor his assistant, whose attention he directed to the matter—foresaw more than certain experimental determinations. Hertz took his problem as he received it. We have his own words that he started out to prove that changes of dielectric polarization in non-conductors produced the same electromagnetic forces as do currents which are equivalent to them, and that electromagnetic as well as electrostatic forces are able to produce dielectric polarizations; and yet, further, that in all these respects air and empty space behave like all other dielectrics. "I saw no way," he says (see "Electric Waves"), "of testing the first and second for air, but both would be proved simultaneously if one could succeed in demonstrating for air a finite rate of propagation and waves." Let us exult in Hertz as the first aero-physicist and join Lord Kelvin in his triumphant declaration, when referring to waves of electric force, that "the processes in air represent on a million fold larger scale the same processes which go on in the neighborhood of a Fresnel mirror or between the glass plates used for exhibiting Newton's rings."

The direction in which the demand for immediate application of our knowledge of aero-physics is greatest is in connection with the tides and fluxes of the aerial ocean in which we live, the storms and currents of the atmosphere. There is a popular impression that forecasting weather conditions is in a high degree a matter of scientific procedure. Much that is scientific in character has been done, it is true; but, without disparaging such work, it remains none the less true (and we but echo the sentiments of those professionally engaged in forecasting) that the present condition of our knowledge is quite unsatisfactory. Newton's boy playing upon the seashore and picking up here and there a pebble while the broad ocean of truth lay all unexplored before him may be not unfairly compared with the forecaster of to-day. One of the proper directions of future research in connection with our knowledge of atmospheric air, then, is the prevision of the weather. To foregauge the changes in the atmosphere is not the least promising direction for future research in connection with the imperfections of our knowledge of atmospheric air. We speak not of "controlling" the weather. The making of rain, of warm and cold waves, the maintenance of equable temperatures are, despite the present apparent extravagance of such aspirations, serious and legitimate fields for the application of science; but the nearer problem, that of accurately forecasting weather changes, has already been carried to a certain degree of success, and we may well therefore confine our study to methods available for the improvement of weather prediction.

This, then, is the problem before us, viz., the successful scientific forecasting of atmospheric conditions. In no other direction would the work of the aero-physical laboratory, to which reference has been made, be so pronounced; and carried from the present short period to periods of weeks or months, what branch of applied science will be found to exert so great an influence upon the welfare of man?

We shall present first a careful analysis of methods in use—*i. e.*, a study in detail of the synoptic weather map, discussing the sources of its unquestioned strength and its elements of weakness, and then consider methods as yet untried, but which have scientific indorsement and seem to be applicable to the question before us.

The principle underlying the synoptic weather map of every weather service is simultaneity of observation. A forecaster has before him a bird's-eye view, as it were, of the conditions existing at a given moment. After an experience of nearly twenty-five years, when the question is asked, "Has the synoptic map realized the expectations of meteorologists and justified the expense of its existence?" the answer is, "Yes." But if the further question is asked, "Is the forecaster of to-day as far in advance of the forecaster of 1870 as might reasonably be inferred from the lapse of time?" the response is halting and uncertain. The experience of the past ten years would seem to indicate that we are close to exhausting the capabilities of the weather map in its present form. The introduction of modern inventions may help some, for we recall that it was the telegraph which made the map possible, and the telautograph, for example, may enable us to get continuous records in place of the fragmentary ones now in use; but not until we are able to reach out from the earth surface and study *in situ* air stratification and record simultaneous changes at all levels will the great advance in forecasting be accomplished. The exploration of the upper air by "aerodromoi" means the determination of abnormal temperature and rainfall relations at various heights.

Cloudy Condensation.—Perhaps even more than temperature, rain is the element of least certainty in forecasting. How, then, can we improve the methods in use for foretelling the likelihood and determining the causes of rain? Of the physical processes of condensation we know much and at the same time little. Studies of condensation from fusion, vaporization, and solution, and particularly on the passage from vapor to liquid in the free air and the control of the conditions determining such passage, should be undertaken. With our present rather crude outfits some work might be done in the nature of preliminary surveys of cloud land. At present cloud maps are of such indefiniteness that but limited use is made of them in forecasting. Granted that cloud types and motions have little of the significance that some enthusiastic nephoscopists claim for them, the fact nevertheless remains that clouds from their very office are significant exponents of air-strata conditions. Hildebrandsson long ago showed that the upper currents move along somewhat parallel to the lower currents up to a certain height, and then change their motion. and we are all familiar with Clement Ley's law, "upper clouds have a distinct centrifugal tendency over areas of low pressure, and a centripetal over those of high." If we knew more about cloud motion and stratification, forecasting would be more certain.

To illustrate in a rough way the importance of cloud motion, let us take the date August 27, 1893, a time when telegraphic reports from Florida and the southeastern seaboard were interrupted. It is evident that if no reports can be obtained by telegraph, the synoptic map as at present used must fail. Such was the case during the memorable storm of March 11–13, 1888—the so-called "blizzard." But in the storm of 1893 it so happened that the most destructive storm of the year was heading in towards the Florida coast. No reports were to be had from Florida, high wind having blown down the poles. What, then, was the forecaster to do? The motions of the upper clouds at Lynchburg, Chattanooga, Knoxville, and Norfolk plainly indicated the position of the "low." If, with such crude and undeveloped observations, there was so much of value in cloud-work, with how much more definiteness could this storm have been located had the motions of the upper clouds at various points been instrumental determinations. One much-needed advance in forecast work is the use of nephoscopes, and it is passing strange that our weather services have not long ago discarded their methods of eye observation. Color, form, and relative motion appeal so strongly to the imagination that even a practiced observer will misinterpret the cloud.

Observations with high-order nephoscopes would be valuable in throwing light on that which is so essential—a knowledge of the true motion of the air. The convectional theory of cyclonic formation, of which Ferrel was the great advocate, has in its favor all that we at present know of cloud motion. But we know so little. The so-called descensional theory finds, on the other hand, in the general upper circulation the initiative impulse for storm formation. From this point of view, cyclones and anti-cyclones are but great double vortex knots in the general air stream. The upper current works down through the anti-cyclone and in a reversed twist out through the cyclone; and it is evident that cloud motion, had we but the means of observing it properly, would give weighty evidence? Similarly the condensation conditions in free air must be studied. We may get an inkling of the size of the water globules by the colors of cloudy condensation. The Newtonian interference colors might be made use of in some modified form of Michelson's "interferential refractometer" to get the dimensions of the condensing particles. The increase and decrease of size might be determined and variations interpreted as favoring or not favoring condensations. Every line of research tending to give knowledge of the extent and intensity of conditions favoring condensation should be encouraged by weather services. At present the forecaster lacks information worthy of acceptance concerning the amount of vapor overhead at different levels; nor has he any clew whatever as to impending motions of the same, ascensional or descensional. Perhaps the question of the production of artificial rain will force meteorologists to develop our knowledge in this direction. Storm motion is to be regarded in the light of a key unlocking an appropriately unstable condition of atmosphere. "Dry" storm areas prove beyond doubt that something beside storm mechanism is necessary for precipitation. The energy of a storm and its rate of motion would mean vastly more to the forecaster if he had at his command the seasonal vapor conditions for all elevations. Theoretically the claim of the rain-maker has this much truth to it, that in some districts, at certain times, not only the smoke of a small brush fire, but the unfolding of an umbrella, might suffice to initiate an air motion which would result in more or less precipitation. Furthermore, the forecaster must always clearly distinguish between conditions favoring storm progression and the likelihood of storm formation. Some of the factors operative in storm formation and which the forecaster should be cognizant of are: extent of in-draught of warm moist air and counter-draft of cold dry air; relative instability of the air; topography as affecting air drainage, and the vapor values at different elevations. It is very important that the values of the absorption lines due to aqueous vapor be determined. Becker, in the "Trans. Roy. Soc. Edin.," XXXVI, has mapped 928 lines of this character. He divides the aqueous lines into three groups somewhat as follows:

Wave-lengths, 6,020 to 5,666, comprising about 678 lines.
" 5,530 " 5,386, " " 106 "
" 5,111 " 4,981, " " 116 "

But this list can undoubtedly be extended, and particularly in the infra-red portion of the spectrum, where we naturally would expect to find the most marked atmospheric effects. We suggest, then, as one of the most fruitful directions for research the exploration of the solar spectrum with the view of determining the vapor present at different levels under varying conditions and the application of the knowledge so obtained to forecasting weather changes. A hint from Buchan, in his résumé of the work done at Ben Nevis, a high-level meteorological observatory, should not be overlooked. Although discussing temperatures, his remarks will apply with equal force to vapor values: "The departures from the normals, especially inversions and extraordinary rapid rates of diminution with height, are intimately connected with cyclones . . . and form data as valuable as they are unique in forecasting storms." We would urge, too, the mathematical discussion of each storm, particularly with respect to storm energy and motion. The storm of August 26, 27, 28, 1893, sometimes known as the Sea Islands storm, from the great damage done along the Carolina coast is one that will always draw the attention of the meteorologist. The story of the origin of this storm, its path, the terrors of the accompanying rise of the waters, whereby nearly twelve hundred lives were lost, has been graphically given in the popular magazines of the day. We propose to test with it some equations given by Maxwell Hall (Jamaica Meteor. Obs., vol. I) for determining storm approach when observations are available for one side of the storm only.

Other things being equal, we may assume that the storm will be retarded by—

1. Opposing conditions such as obstructive "high"—that is, a slow-moving, inert anti-cyclone.
2. Decrease of storm energy or weakening in the formative factors.
3. When the slope of the diurnal and seasonal curves of pressure (and the reverse for temperature) is opposed in direction to the gradient caused by the storm.

Conversely, we may look for an increase of storm energy with persistence of conditions favoring storm development.

If p = pressure reduced and corrected for diurnal variation,

C = twelve-hour change,

v = velocity of wind in miles per hour,

r = distance from the centre of cyclone,

$\frac{dp}{dt}$ = rate of fall of pressure per hour,

$\frac{dp}{dr}$ = gradient or fall per mile toward the centre,

$$\frac{\frac{dp}{dt}}{\frac{dp}{dr}} = \frac{\text{rate of fall}}{\text{gradient}} = \frac{dr}{dt} = \text{rate of approach,}$$

as a first approximation for the time of arrival, divide the distance by the rate of approach. These values are given in column "A," in the table below.

$$A = \frac{r}{\frac{dr}{dt}} \text{ or } \frac{r\,dt}{dr}. \qquad f = 1 \div (dr \div dt).$$

It must be pointed out that in a calculation of this kind we are restricted to the use of such data as are available for the forecaster at a particular time. We think that the following, which could have been obtained at the times indicated, would have been serviceable in forecasting this storm, and particularly the values which are underscored as indicating the probable path and duration of the storm:

Approach of Storm of August 25, 26, 27, 28, 1893.

Date.	Station.	Pressure.	C	v	r	$\frac{dp}{dt}$	$\frac{dp}{dr}$	A	f
Aug. 26, 1893, 8 a. m.	Titusville. . .	29.90	—.06	22	250	.004	.001	30	.20
	Jupiter.......	29.80	—.10	24	160	.008	.014	$\underline{24}$	.15
Aug. 27, 1893, 8 a. m.	Savannah.....	29.78	—.16	20	200	.012	.002	30	.15
	Charleston....	29.84	—.12	24	230	.01	.002	50	.20
	Jacksonville..	29.62	—.24	20	120	.02	.003	$\underline{20}$	.17
	Titusville.....	29.34	—.38	40	—80	.036	.003	$\underline{-8}$	.30
Aug. 28, 1893, 8 a. m.	Lynchburg....	29.84	—.12	8	230	.01	.002	70	.25
	Raleigh.	29.64	—.26	22	220	.03	.002	25	.12
	Charlotte.....	29.30	—.54	24	100	.014	.003	6	.8
	Augusta......	28.96	—.72	26	—20	.06	.01	$\underline{-4}$	....

A line drawn through the underscored values for the dates in question will be found to almost coincide with the path of the storm. Minus values indicate the retrogression of the disturbance.

Suppose further, however, that, starting with the fundamental equation $pv = RT$, we were able to follow any given air wave as it is propagated in a manner similar to that in which an ordinary sound wave is followed. Lord Rayleigh ("On the Vibrations of an Atmosphere," Phil. Mag., Feb., 1890) has given a numerical example of the high degree of rarefaction necessary before there is a change of sign for a period of one hour. In C. G. S. measure, $n = \frac{2\pi}{3600}$ and "a" (the velocity of sound) $= 33 \times 10^4$, $g = 981$; then the ratio of the density at a given height to the density at the ground comes out 1/290. This, of course, is for an upward wave; but for the case of "a swaying of the atmosphere from one side of the earth to the other" Rayleigh deduces a period of 23.8 hours. He remarks, however, that the suitability of the value of "a" is very doubtful, and, further, that the suppositions of his paper are inconsistent with the use of Laplace's correction to Newton's theory of sound propagation. Moreover, can the heat and cold present in atmospheric vibrations be supposed to remain constant? But the near approach of this period to 24 hours he considers to be of more than passing interest and possibly connected with the diurnal and semi-diurnal variations of the barometer.

Now, the forecaster has to deal with a succession of atmospheric waves, and it is just the gain or loss of heat accompanying the propagation of the slower waves that he attempts to forecast. Therefore we think it to be of prime importance to introduce into our forecast work as far as possible numerical values for atmospheric vibrations.

ATMOSPHERIC ELECTRICITY.

We have thus far discussed the known properties of atmospheric air chiefly in connection with aqueous vapor. There remains another equally important line of research intimately related to the vapor conditions and likewise of great importance in weather prevision, viz., atmospheric electricity.

At the outset we advocate the introduction of that unstable and seemingly lawless element, the electrical potential of the atmosphere, on the synoptic weather chart. To the graphic representation of air pressure, temperature, and in a crude way, air motion, let us add, although it does seem unpromising, the electrical potential, corrected for temperature, elevation, quantity of vapor present (see further on Exner's experiments and the very recent paper of Kelvin on the Subtraction of Vapor from Air and the Electrification). The potential charted for any given moment upon the synoptic map will give, in the general electrification of the lower air strata, significant equipotential lines and areas. The time is ripe for such a preliminary survey, or, as Sir William Thomson once called it, "electro-geodesy"—in brief, an extended synchronous survey of the potential of the lower air.

We may begin our plea for such work by a reference to the work of Professor Franz Exner, of Vienna. With praiseworthy persistency he has determined the potential values in all localities accessible to him, and with some approximation the potential gradients at various elevations. The work of Elster and Geitel, especially their later work, constituting what may be termed researches in electrical actinometry, is a natural outcome of and supplement to Exner's work. As we shall see, Exner's determinations were all made with portable electroscopes or electrometers, and while the instruments used by him differ in design from those (in our opinion preferable) used in the United States, Great Britain, and France, the scope and method of work have been practically similar. The differences in results are mainly of degree, Exner having carried his work further. The aim throughout has been the exploration of the electrostatic field of the earth. In the experiments of Elster and Geitel at Wolfenbuttel (see "Sitz. Akad. Wien.," June, 1892, and subsequently; also "Nature," March, 1893), the direction of research has been that of the relation of the potential values to the intensity of ultra-violet radiation. This we see at a glance opens up a new field of investigation in the discovery that ultra-violet light accelerates the dissipation of an electrical charge, and there is no telling what further developments may come in both electrometry and actinometry.

S. V. Arrhenius ("Meteor. Zeits.," vol. v, p. 297, and "Phil. Mag.," July, 1889) touches upon the influence of solar radiation on the electrical phenomena of the earth's atmosphere, and shows that when the air was irradiated by ultra-violet light it conducted like an electrolyte. We recall that Hertz found in his experiments that the receiver required continual readjustment, either because of the shaking or the slight burning of the points, and that ultra-violet light falling on the "vibrator" prevented its proper action, the sparking in the "resonator" ceasing or becoming feeble. This discharging action seemed to be particularly noticeable when the violet light fell upon negatively electrified points. Elster and Geitel have shown ("Sitz. d. K. Akad. der Wissen. Wien.," 99 Band, x heft, s. 1011) that a body with a negative charge is discharged under the influence of the above-described radiation more rapidly than a body charged positively. For example:

	Rate of loss when positively electrified.	Rate of loss when negatively electrified.
Rusty iron	16	24
Polished iron	16	31
Charcoal	11	25
Mica	12	26

The above results show clearly a more rapid loss of the negative charge.

Professor Oliver Lodge, in a lecture upon the work of Hertz, delivered at the Royal Institution June 1, 1894, used the following language:

"While Hertz was observing sparks such as these, the primary or exciting spark and the secondary or excited one, he observed as a bye-issue that the secondary spark occurred more easily if the light from the primary fell on its knobs. He examined this new influence of light in many ways, and showed that although spark light and electric brush light were peculiarly effective, any source of light that gave very ultra-violet rays produced the same result. Wiedemann and Ebert and a number of experimenters have repeated and extended this discovery, proving that it is the cathode knob on which illumination takes effect; and Hallwachs made the important observation, which Righi, Stoletow, Braly, and others have extended, that a freshly polished zinc or other oxidizable surface, if charged negatively, is gradually discharged by ultra-violet light."

Lodge hints in his lecture of the possible great value of these relations in atmospheric electricity.

Collecting the observations of the potential fall in the case of negatively electrified bodies exposed to sunlight, Elster and Geitel have tabulated the values of the mean daily potential, the temperature, and the vapor pressure. These are given on the following page. Would it not be a very happy and profitable research to undertake in the United States a similar series of experiments confirming and extending the results now at hand? Particularly at Pike's Peak and at Mount Washington could such determinations be effectively undertaken. At the former station the range of vapor pressure is so large that the curves now known could be extended. A physical law expressing the relation of the potential and the intensity of the more refrangible rays would perhaps be the outcome.

Elster and Geitels Potential-vapor Values.

Mean.	$\frac{dv}{dn}$	v	Mean vapor pressure in mm.	Mean temperature in C°.
6 observations	502	54	1.4	—11.8
6 “	430	59	1.7	—10.1
14 “	400	141	2.3	— 6.4
15 “	318	150	3.5	— 0.8
23 “	252	257	4.4	4.7
8 “	137	91	5.5	10.0
11 “	184	120	6.4	9.9
16 “	148	169	7.5	12.6
13 “	112	158	8.4	15.1
14 “	115	135	9.4	16.8
7 “	118	76	10.7	19.4
5 “	121	54	13.8	21.8

We can get at the relation of the potential values and the quantity of vapor present in the following way:

The weight of aqueous vapor in a cubic metre of saturated air is the product of the weight of a cubic metre of dry air at $0°$ C, pressure 760 mm. and the density of the aqueous vapor, and the pressure of aqueous vapor in saturated air, all divided by 1 plus the temperature correction.

$W = \frac{ad}{1 + \alpha t} \frac{F}{760}$, where $a = 1.29278$ kg, $d = 0.6221$, and $\alpha = 0.003667$

the weight of vapor then is $0.622 \frac{1.29278}{1 + .003667\, t}$.

	Observed v.	Estimated v.
1.6	502	469
1.9	430	442
2.5	400	364
3.7	318	268
4.6	252	224
5.6	137	189
6.5	184	166
7.6	148	145
8.4	112	133
9.4	115	119
10.6	118	107
13.5	121	85

And thus, as the authors point out, with the exception of the vapor group 5.5 mm., the potential curve runs inversely with the vapor pressure, and the observed values and the estimated values agree fairly well up to a certain point. When the number of grammes of moisture in a cubic metre of air at the earth's surface exceeds 8, however, the agreement no longer holds. (See diagram, page 18.)

The aim of all this, as we shall see in discussing Exner's observations, is the determination of a relation between the potential gradient and the humidity and the construction of apparatus in the nature of an electro-hygroscope. One advantage this new method might possess over spectroscopic methods is at times of cloud formation. Cloudy condensation we know limits rain-band investigation, but the electro-hygroscope would in all probability be serviceable with visible as well as invisible vapor. Indeed, it is not certain but that the potential values would be more strongly marked at such times.

We must give now as briefly as possible the results of the observations of Elster and Geitel on the Hoher Sonnblick, some 10,168 feet above sea level, and at its low-level station, Kolm-Saigurn. As we said above, such observations, repeated at Pike's Peak and other high-level stations in the United States, would certainly widen the horizon in aero-physical work. Harvard College Observatory has published in its "Annals" the meteorological observations made at Pike's Peak for a given number of years. If one will turn to pages 459, 460, and on, he will find such observations as the following:

" . . . faint auroral streamers and beneath them the usual sheet lightning flashed incessantly. . . . "

" . . . at night the summit capped by a cloud so small that the observer at the base could hardly see it, and was frequently lit up by flashes of lightning. . . . "

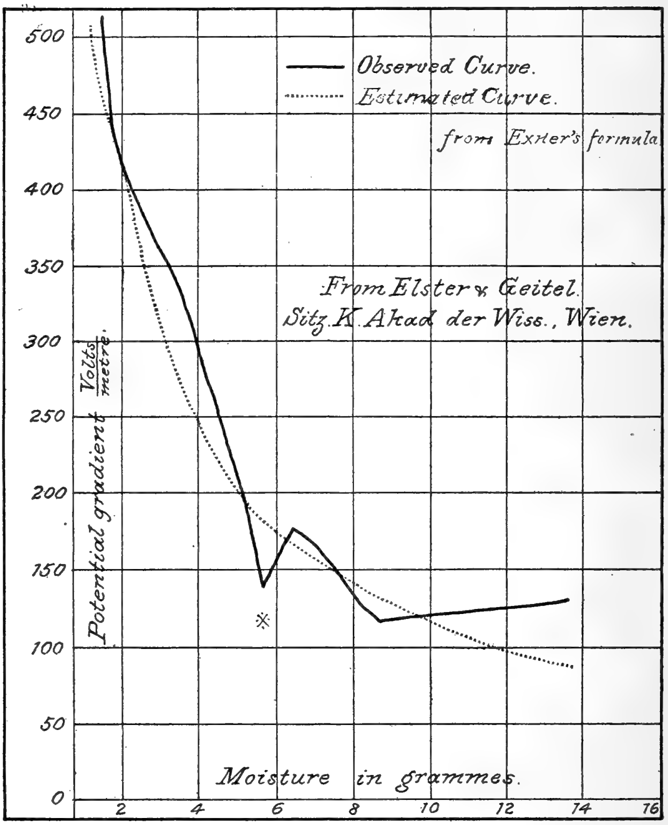
" . . . heavy snow, with thunder and lightning. . . . "

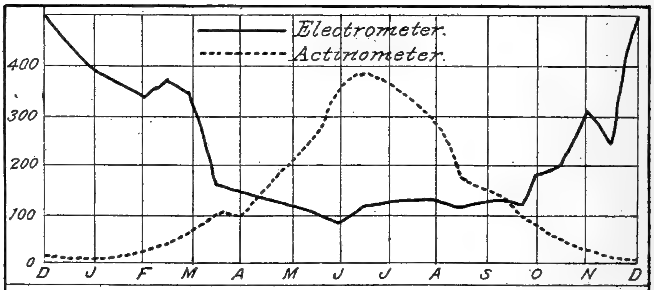
" . . . electricity increased and decreased with the fall of hail—a fact noticed in all hail-storms at the station. . . . "

In few ways, therefore, do we think that investigation under the conditions of the Hodgkins bequest could be more effectively undertaken than in investigation of the electrical condition of the atmosphere at some such station as Pike's Peak.

The Sonnblick observers found—

1. " The intensity of the most refrangible rays of the solar spectrum, as measured by the discharging action on negatively electrified surfaces of amalgamated zinc, increases with the height above ground in such a manner that at a height of 3,100 metres it is twice as great as on ordinary level ground."





Simultaneous Actinometer and Electrometer yearly Curves

Elster & Geitel.

2. " Notwithstanding this increase in the power of discharge of light, we [Elster and Geitel] did not succeed in establishing with certainty any new actinometrically active surface. Even perfectly freshly fallen snow as well as dry rock were not appreciably discharged by light."

3. " Waterfalls can produce negative falls of potential in a valley and even to considerable heights (1,600 feet), and it may be assumed that this remarkable phenomenon is not produced by friction, but by the influence of the normal positive fall of potential on the finer pulverulent water which detaches itself from the large masses of water; and it may perhaps be assumed that in a rain-cloud the process of self-induction increases to high values the originally feeble negative charges of a layer of air dust at the foot of a fall."

4. " In July, 1890, on three days, which were almost cloudless until 1 p. m., the normal positive fall of potential on the top of the Sonnblick was apparently constant. The morning maximum, which in the Plain and Alpine valleys occurs with great regularity between 7 a. m. and 9 p. m., was not observed at a height of 10,168 feet."

5. " Before the outburst of the storms which we observed on the 16th, 18th, and 20th of July, the positive fall of potential within the cloud, which sent only a small quantity of rain, went slowly down to the value zero and remained there for a long time."

6. " In storm clouds the atmospheric electricity usually changes its sign after a discharge of lightning, as with storms on the plain."

7. " Saint Elmo's fire was found to be a constant accompaniment of storms. It was not found that negative Saint Elmo's fire was more infrequent than positive."

8. " The observation that negative Saint Elmo's fire follows bluish lightning and positive follows reddish lightning was frequently confirmed by us. The direction, then, of the electrical current which traverses the atmosphere in the form of lightning appears to have an influence on the color of the lightning."

All of the above results may be found in the " Phil. Mag.," May, 1891, and " Wien. Berichte," November, 1890. We shall now proceed to comment upon them.

It is of some interest to know whether our mountain peaks, taking as they must a negative electrification from the earth, are discharged more rapidly when illuminated by the more refrangible rays. Since the above experiments were made the entire question of the capacity of the air and the disposition of a charge has been brought forward for discussion by Kelvin's paper on the subtraction of vapor from air and the consequent change in electrification. J. J. Thomson has shown in his recent paper on the " Electricity of Drops " that a small amount of impure matter in water is enough to produce a marked change in the electrification, and that therefore no study of atmospheric electricity will be complete which does not take into account the degree of purity. Kelvin from laboratory experiments (see paper read before British Association at Oxford; also "Nature," July 19, 1894) concludes that the air does not retain a negative electrification so long as it retains a positive. Kelvin says, "the equilibrium of electrified air within a space enclosed by a fixed bounding surface of conducting material presents an interesting illustration of elementary hydrostatic principles. The condition to be fulfilled is simply that surfaces of equal electric 'volume density' are surfaces of equal potential, if we assume that the material density of the air at given temperature and pressure is not altered by electrification. This assumption we temporarily make for want of knowledge; but it is quite possible that experiment will prove that it is not accurately true." "On the supposition of electric density uniform throughout the spherical enclosure, each cubic centimetre of air experiences an electrostatic force toward the boundary in simple proportion to the distance from the centre and amounting at the boundary to nearly 10 per cent. of the force of gravity upon it; . . . . " "Under natural conditions with great density there must be an important ponderomotive force quite comparable in magnitude with that due to difference of temperature." . . . "Negatively electrified air over negatively electrified ground with non-electrified air above it in an absolute calm would be in unstable equilibrium."

Lord Kelvin gives an estimate of the density and force in a given enclosure.

Let V equal the potential indicated by the water-dropper; a equals the radius of the spherical hollow (in which the air was); ρ equals electrical density of air at distance r from center; then from—

$$V = 4\pi\int_{o}^{a}\left(\frac{r^2}{r} - \frac{r^2}{a}\right)dr$$

if ρ is constant,

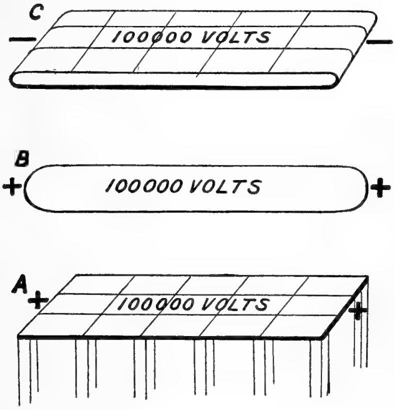
$$V = {}^2/_3\, \pi\rho a^2$$

$$\rho = 3V/2\, \pi a^2.$$

Suppose V equals 38 volts or 0.127 electrostatic units *C. G. S.;* a equals 50 cm. and $\rho = 2.4\times10^{-5}$, the electrostatic force at a distance r being ${}^4/_3\, \pi\rho r = 10^{-4}r$.

Hence a small body electrified with a quantity of electricity equal to that possessed by a cubic centimetre of air and placed midway ($r = 25$) between the surface and centre of the inclosure experiences a force equal to $2.4 \times 10^{-9} \times 25$ or 6×10^{-8}, or approximately 6.10^{-5} grammes, which is 4.8 per cent. of the force of gravity on a cubic centimetre of air of density 1/800. "During a thunder storm," says Kelvin, "the electrification of air, or of air and the watery spherules constituting cloud, need not be enormously stronger than that found in our experiments." (In the experiments referred to below higher values were obtained.) "This we see by considering that if a uniformly electrified globe of a metre diameter produces a difference of potential of 38 volts between its surface and centre, a globe of a kilometre diameter, electrified to the same electric density, reckoned according to the total electricity in any small volume (electricity of air and of spherules of water if there are any in it), would produce a difference of potential of 38,000,000 volts between its surface and centre. In a thunder-storm, flashes of lightning show us differences of potentials of millions of volts, but not perhaps of many times 38,000,000 volts, between places in the atmosphere distant from one another by half a kilometre."

One may go farther and say that in this electrification of air may lie the possibility of principles valuable in aerial navigation, for as in the ordinary Thomson electrometer the aluminum needle between the quadrants moves always from the region of high (positive) to the region of low (negative) potential, so if the potentials are sufficiently high a charged body free to move in the air will move from the place of high to the place of low potential. Thus in the accompanying diagram if *A* represents a highly charged (and by this we mean voltages in the hundred thousands) insulated conductor, *B* a mobile conductor charged equally high and same sign as *A*, then *C* an oppositely charged mass, B will move from *A* to *C*.



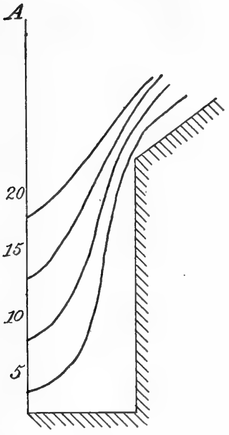
J. J. Thomson (see "Nature," July 26, 1894) holds that a molecule of gas cannot be electrified, but that the atoms may be. The question as it presents itself to his mind is, "Is the electricity in the charged gas carried by molecules or atoms?" "A square centimetre of surface immersed in air at standard temperature and pressure is struck by about 10^{15} molecules per second, yet such a surface will retain for hours without sensible loss a charge of electricity which, as we know from the electrolytic properties of liquids and gases, could be carried by a few thousand million of particles if these were to receive such a charge as the atoms of the air are able to carry."

We see, then, how much remains to be determined and how valuable in connection with the proposed electrometric survey the aero-physical laboratory would be.

Returning now to the results of Elster and Geitel, under their fourth deduction it is said that the morning maximum in the potential curve was not observed at a height of 10,168 feet. This, we think, is a most interesting result, and the result should be confirmed or disproved without delay. If need be, observations of the potential at great heights could be made by the aid of kites. With regard to the fifth result, the positive fall of potential within a cloud which gave but a small quantity of rain, we can only say that the whole subject of the relation of potential to rainfall calls for investigation. Much has been surmised and but little done. Our experimental evidence is scanty, being limited to a stray observation here and there. One interesting observation made on August 9, 1892, may be referred to. A kite connected by wire with a quadrant electrometer was raised and kept at some elevation above the summit of Blue hill, Massachusetts. At 7.40 p. m. a thunderstorm, which for some twenty minutes had been approaching from the west, was near enough to cause an incessant stream of sparks from the kite string. When the string was connected over a Mascart insulator to the electrometer—*i. e.*, the needle, one set of quadrants being charged highly positive and the other highly negative—a sizzling discharge occurred. Stinging shocks could be felt on touching the kite wire, and if a ground wire near by was held within a fraction of an inch a discharge of sparks ensued. Rain began about 8.10 p. m. and ended in a few minutes, the amount being about one-hundredth of an inch; lightning was frequent and vivid to the north and northeast, and, as we learned the next day, did much damage to barns in that locality. Although the electrical phenomena were to be seen thus plainly from ten to fifteen miles away, we were not able after the rain to obtain sparks from the kite wire. This seems therefore to confirm the Sonnblick observation.

With regard to Saint Elmo's fire, it is of interest to quote in conjunction with the Sonnblick experiments the Ben Nevis observations. Buchan states that from 1883 to 1888 fifteen cases of Saint Elmo's fire had been observed. All occurred during the night-time, indicating that there is no electrometer at the observatory and no means of determination other than visibility, from September to February. On one occasion it was heard during the daytime. All cases were noticed during the prevalence of well-marked lows, generally about six hours after the center had passed.

Observations of the Potential.—The first source of error in determining the true potential of a point in air is to be found in the bending of the equipotential lines by the walls of buildings, the sides of mountains, hills, etc. In a rectangular court fifteen metres wide, with walls twenty-five metres high and forty metres long, it was found by Exner; (see "Repertorium der Physik," xxii, heft 7) using a collector suspended by a silken cord and connected with a quadrant electrometer in such a way as to be readily moved up or down and from one side to another, that the value of the potential varied. The contour of the potential surfaces was approximately that shown in the accompanying diagram. With the collector two metres from the wall, at heights of 5, 10, 15, and 20 metres, the potentials were 2, 7, 17, and 48 volts respectively. With the collector in the centre of the court, at the same heights, the values of the potential were 5, 11, 32, and 68 volts. The determination is open to criticism, however, in this: that, the potential being at times exceedingly variable, no method in which but one collector is employed can give conclusive results. The experiment should be tried with two similar collectors. The experiments made in Washington a few years ago by the Signal Service (see Mendenhall, Memoirs of the National Academy) are therefore preferable, inasmuch as two electrometers calibrated to



give like deflections for like voltages were employed. The collectors were frequently interchanged and other checks applied. The following mean values were obtained:

Height.	Potential at beginning.	After five minutes.
6.1 m.	20 volts.	30 volts.
7.7	38	51
9.1	48	. .
12.0	60	72
16.8	121	141

Notice that a time element comes into the discussion, for it appears that the collector requires some little time to come to the potential of the air. Again, it appeared that by varying the rate of flow the values would be somewhat altered, and it would therefore be necessary in any extended survey to use not only similar instruments but similar times. Pellat (see "Comptes Rendus," March, 1885, p. 375) found while studying the means employed to get the potential of the air that with a flow of eight litres in twelve hours about six minutes were required for the electrometer to attain the proper value, while with a flow of twelve litres only five minutes were needed. Water-droppers are the collectors most generally used, but there are other forms, and in some ways preferable. The paper match (blotting paper soaked in nitrate of lead) is slower than the water-dropper and gives somewhat lower values.

Assuming that a proper collector can be designed and the error due to bending corrected, we have as the first problem the determination of the potential gradient at any height. Exner (see "Ursache und Gesetze der Atmos. Elec.") experimented with balloons carrying insulated water-droppers. Three sets of observations were made at 400, 550, and 660 metres, with the hope of getting an approximate value for 500 metres. A constant value of 193 volts was obtained, but the constancy is perhaps due to the fact that the balloon traversed the distance in a few minutes. From measurements made with small balloons he obtained for the potential in free air—

Metres.	Volts.	Metres.	Volts.
17	100	25	160
18	110	27	170
20	120-140	30	195–210
21	130	34	250
22	160	40	280
25	160		

and from these $\frac{d^2v}{dn} = 6.8$ volts per metre.

These values were obtained, however, with a burning match-collector, and we propose to apply a correction to them for that reason. Sir William Thomson, in a paper read before the meeting of the British Association in 1889, gives observations made by McLean and Goto for that year, showing "that an enclosed mass of air is electrified negatively by the burning of a paraffin lamp, of coal gas, of sulphur, magnesium, and several other substances, while, on the other hand, the burning of charcoal electrified a room positively." In some experiments made by us in 1890 it was found that the flame in the dark room where the electrometer was installed electrified the air of the room and materially affected the readings. The electrification amounted to as much as 19 or 20 volts negative, while an average value for the air outside (the nozzle of the collector was about a metre from the wall and 12 metres from the ground) was 50 volts positive. Ventilating the room thoroughly, we found, caused a disappearance of this negative electrification. We would reduce the value 6.8 volts found by Exner to something like 34 volts, following Pellat's relative weights of 1, 5, and 10 for match, water, and flame.

Another set of observations made upon an exposed mountain side gave Exner the following values:

Metres.	Volts.	Metres.	Volts.
3	110	18	520-550
5	140-150	19	550
6	210	20	660
7	230-250	25	820
12	280-405	30	970
14	480		

which would make the linear potential gradient of much higher value. Valuable observations were made by the United States Signal Service under the supervision of Dr. Mendenhall. A résumé of the observations can be found in Third Memoir, vol. v, National Academy of Sciences. The influence of varying temperature and humidity were in part elimnated by a long series of observations. The instruments used were modified Mascart electrometers and large similar water-droppers. The methods and adjunct apparatus were alike at all stations.

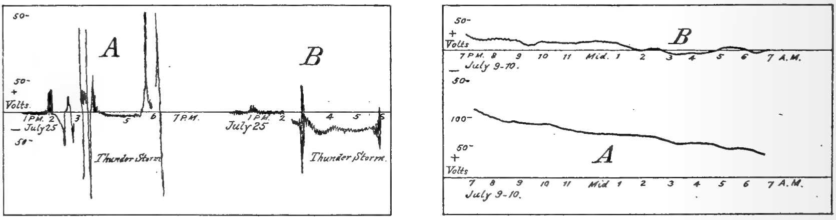
For the particular question which we are discussing—the potential gradient—we are obliged to refer to a table not found in the published report, although it was one of the most important. This table gives the most extensive and comparable values yet obtained for determining the potential gradient in the lower layers of the air. The values are somewhat smaller than might be anticipated, but this may be explained by the proximity of buildings.

Date.	Number of observations.	Mean value of potential.		Difference for 138 metres.
		High.	Low.	
June 26	399	289	134	155
July 17	60	1,129	93	1,036
July 20	107	389	70	319
Sept. 21	40	212	107	105
Oct. 4	94	586	192	394
Oct. 5	82	300	108	192
Oct. 7	97	435	112	323
Oct. 14	87	140	24 (*a*)	116 (*a*)
Nov. 1	4 (*b*)	1,137	265	872
Nov. 3	98	943	248	695
Nov. 12	15	—849 (*c*)	—254 (*c*)	—604 (*c*)
Nov. 12	65	458	36	422
Dec. 15	13	487	4 (*d*)	483 (*d*)
Jan. 29	26	413	141	272
Feb. 9	54	1,825	89	1,736

(*a*) Denotes values at lower station below zero.
(*b*) Observations not simultaneous; differing few minutes.
(*c*) During rain; negative values at both stations.

We have, therefore, a mean value for the potential of the air, at an elevation of 500 feet, of 637 volts. If we omit negative values and consider only positive we obtain 543 volts, or, roughly, 4 volts per metre elevation. We have no right, however, to omit the negative values, and the true value for free air would be doubtless higher than the figure here given. For the lower station we find the mean value of the potential to be about one-fifth of that at the upper, while the elevation is about one-eleventh.

Thunder-storms.—As might be anticipated, there are some remarkable variations in the potential during thunder-storms. We are able to record the time of lightning by well-marked variation in the potential. The accompanying diagrams show the potential variations during a thunder-storm at both an upper and a lower station. For purposes of comparison, some characteristic fair-weather curves are given. Thunder-storms cannot be studied to the best advantage until the electrometer comes into

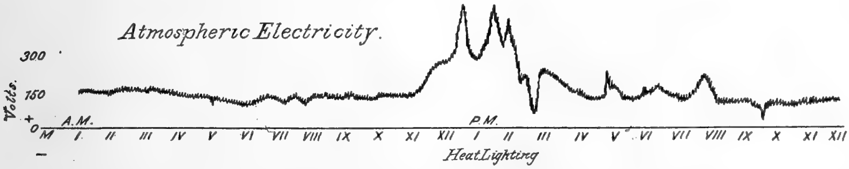


Electrical Potential of the Air Photographically registered at two Stations.
A.- 194 m. above Sea-level and B - 74 m. above Sea-level.

general use. Disruptive discharges occur when the stress in the atmosphere between the cloud and ground exceeds a certain value, determined, of course, by conditions of pressure, humidity, and dustiness. As the heavily charged cloud approaches the locality where the electrometer is placed, the needle indicates a steadily increasing strain. When this tension exceeds the dielectric strength of the air the lightning occurs. The dielectric strength of the air, according to Sir William Thomson. under ordinary conditions of temperature and pressure, is about 9,600 grains weight per square foot, or about 1.37 pounds. This is equivalent to 656 dynes per square centimetre. The pull, then, which the air ordinarily can withstand is not over .67 of a gramme per square centimetre.

In the daytime many flashes of lightning may pass unnoticed, and even in the night-time some may be unobserved; but, aside from these, there exists a myriad of minor discharges which are all unknown to the eye. Hence the electrometer method, which enables us to take cognizance of minor discharges, constitutes a decided advance. Another way of accomplishing the same end would be the employment of properly tuned Hertzian resonators. It is *quite possible to time lightning flashes without seeing them*, and this we accomplished a few years ago in the tower of the Smithsonian Institution. An observer, with watch in hand, was asked to time all flashes which he saw. Meanwhile, in a darkened room, we studied the movements of the needle. The times of lightning were found to correspond with certain disturbances in the potential. The agreement is very close, except that there will always be found to be more disturbances than recorded flashes, indicating, perhaps, that there are discharges which the eye does not see.

Thunder-storms are not the only atmospheric disturbance in which the electrification of the air varies in a noteworthy manner. We have found most remarkable perturbations of the potential occurring during snowstorms. We give the following record at great length because we think it is the most accurate record as yet available. It shows that *a snowstorm is closely akin to a thunder-storm.*



We have, too, the potential variations during heat lightning, and still more, the relations to auroral displays, all awaiting systematic investigation. Is it too much to say that in no other way can research be so profitably pursued as in connection with the electrification of the air?

Potential Fluctuations During Snowstorm, March 5 and 6, 1890.

Time.	Potential in volts.		Time.	Potential in volts.	
	Positive.	Negative.		Positive.	Negative.
5:30 p. m	70		10:35 a. m		60
40	70		36		65
6:00	70		37		250
05	45		38		85
10	37		39		157
9:00 a. m		25	40		157
30		312	50		275
40		250	51		200
42	75		52		300
43		125	53		150
44		250	54	75	
45		125	55	110	
47	200		56	250	
48	150		57	500	
49	250		57:30		
50	100		45		50
51	250		58	7	
52	275		59	500	
53	325		11:00 a. m	250	
54	350		01	162	
55	212–275		02	182	
57	250		03	10	
58	150		04	75	
59	275		05	Over 575 off	scale and
10:00 a. m	200			continued	so until—
01	225		10	100	
02	275		10:15	115	
03	312		11		Off scale neg.
04	287		20		Off scale neg.
05	200		21		300
06	250		22		450
07	210		23		475
08	162		24		275
09	170		25		275
10	100		26		
13:30	25		to		Off scale neg.
14	105		33		
16:30	300		34		225
17	187–250		35		150
18	45		36	200	
18:15		75	37	175	
19		8	38		75
19:30	188		39		15
20	125		40		65
21	115		41		56
22:30	50		42		60
23	90		43		80
24	95		44		65
25	50		45		80
26	50		50		190
27			12:05 a. m		137
27:30	160		15		170
28	175		25		207
29		250	30		185
30		100	45		237
31		80	55		195
31:30	20		2:30 p. m	140	
32		20	35	175	
33	100		40	157	
34	150				

We have referred above to the possibility of studying electrical discharges in the atmosphere from an entirely new standpoint. The method would consist in the use of a resonator or resonators, with proper vibration periods, capable of responding to the ether oscillations. The rapidity of vibration in any electrical system being directly proportional to the linear dimensions, we may assume for a flash of lightning one thousand meters long the existence of vibrations at a rate of, say, three hundred thousand per second.

Dr. Lodge (see "Phil. Mag.," August, 1888), has worked out at some length the values for an ordinary flash of lightning.

Now V, the velocity of propagation, is equal to $\frac{1}{(\sqrt{\mu K})}$ and the wave-length $\lambda = VT = 2\pi\sqrt{\frac{L}{\mu} \cdot \frac{S}{K}}$ where $\frac{L}{\mu}$ is the electromagnetic measure of induction and $\frac{S}{K}$ is the electrostatic measure of capacity.

$$\lambda = \frac{2\pi V}{p} = 2\pi\sqrt{\frac{LS}{\mu K}}. \qquad p = \frac{1}{\sqrt{LS}}.$$

We may expect the longest sparks when the periods of the cloud-earth system and the proposed resonator are the same. The length of each conductor, then, should be half a wave-length or some multiple of half a wave-length.

Such resonators may occur naturally, and perhaps herein is an explanation of sympathetic distant flashes which are sometimes seen, the second flash being the response of a natural resonator.

CONCLUSION.

An aero-physical laboratory would afford opportunity for important research and investigation. A most promising field, we have attempted to show, lies in the increase of knowledge of conditions controlling the weather. We urge investigations in all lines bearing upon forecasting or foretelling weather. As examples of proper and profitable lines of study in this direction, let us mention: v. Helmholtz on "Studies of viscosity effects in the general circulation of the atmosphere;" "Studies of the mutual influence of whirls." Practical application of knowledge of this character being the great desideratum of modern meteorology. For example, Helmholtz gives as a practical deduction in one of his papers the statement that extremely violent winds are prevented in the general circulation by whirl action—*i. e.*, by the mixing which a whirl with its relatively large surface can accomplish. Again, his study of wave-action at the common boundary of two fluids or of a fluid and a gas has a practical application in the measurement of air billows. We may some day correlate the wave frequency and character with the force and direction of the wind. Oberbeck's papers on the "Motions of the atmosphere," Hertz's "Graphic method of showing the adiabatic changes in moist air," and v. Bezold's "Thermodynamics of the atmosphere" are all excellent illustrations of valuable research work along the lines we advocate. The two last named are of particular value to the forecaster, and v. Bezold's work gives an insight into the physical processes brought into action as a given mixture of air and vapor passes through various levels and environments. He treats of just such conditions as the forecaster is likely to meet. We want to be able to forecast with certainty the formation and dissolution of fog and cloud, and we must therefore know the air mixture, the quantity of heat, the cycles of cooling by contact and radiation, and the adiabatic expansions and compressions for various levels. When such data are accessible, the forecasting of weather will move from its present resting place of empiricism. We have further tried to point out the value of determinations of the total moisture in any given stratum of atmosphere. Although the problem is far from being an easy one and far more involved than appears at first glance, we believe that it is within our power from systematic study of the absorption lines due to water vapor to ascertain the vapor distribution. The infra-red portion of the spectrum, being rich in these lines, should be explored with this end in view.

In another direction, that of atmospheric electricity, we urge experimentation, for we believe that therein may lie possibilities of great extension of our knowledge of atmospheric phenomena. We know almost nothing of the electrification of the atmosphere; how the air acquires its charge we do not know, and of the distribution of the potential and the significance of its variations we have only fragmentary and scant knowledge. In 1752 an experiment, simple enough in its details, demonstrated the nature of the lightning flash. In 1895 the aurora, the origin of the electricity of thunder-clouds, and similar questions are as the nature of the lightning was one hundred and forty-three years ago. In what direction have we a more promising field for the increase and diffusion of "knowledge of the nature and properties of atmospheric air in connection with the welfare of man?"

SMITHSONIAN MISCELLANEOUS COLLECTIONS

— 1125 —

Hodgkins Fund

AN INVESTIGATION ON THE INFLUENCE UPON THE VITAL RESISTANCE OF ANIMALS TO THE MICRO-ORGANISMS OF DISEASE BROUGHT ABOUT BY PROLONGED SOJOURN IN AN IMPURE ATMOSPHERE

BY

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AN INVESTIGATION ON THE INFLUENCE UPON THE VITAL RESISTANCE OF ANIMALS TO THE MICRO-ORGANISMS OF DISEASE BROUGHT ABOUT BY PROLONGED SOJOURN IN AN IMPURE ATMOSPHERE.

By D. H. BERGEY, M. D.

This is a report of an investigation outlined by, and conducted under the supervision of Drs. John S. Billings and S. Weir Mitchell, in which an attempt has been made to determine whether impure atmosphere produces detrimental influence upon the animal organism as shown in greater susceptibility to certain diseases.

OUTLINE OF THE INVESTIGATION PROPOSED BY DR. BILLINGS.

"The impurities to be tested are carbonic acid in the proportions of 0.5 to 2.0 per cent. by volume; ammonia and carbonate of ammonia in the proportion of 0.1 to 1.0 per cent.; the products of respiration of a series of animals arranged as in the Brown-Séquard experiments; and the gases from offensive putrefying material.

Afterward it may be desirable to test the effects of sulphuretted hydrogen, and of the vapors of certain volatile organic compounds having offensive odors (skatol, indol, mercaptan).

The micro-organisms to be tested are those of anthrax, streptococcus, diphtheria, tuberculosis, and of croupous pneumonia.

The animals to be used are mice, rabbits, guinea-pigs, and later monkeys.

It is desirable that in each set of experiments the effects of high temperatures (80°-95° F.) be compared with those of lower temperatures (50°-60° F.).

The animals to breathe these mixtures are to be placed in glass jars, or bell-jars, and the inhalation of each mixture should continue for at least one week before inoculations are made, and should continue for a week after the inoculations."

The expenses of this investigation were defrayed out of a grant obtained from the Hodgkins Fund in the hands of the Smithsonian Institution.

Unexpected difficulties were encountered all along in conducting the investigation. The problem of maintaining an atmosphere of fairly constant composition, with the relative proportions of the impurities ranging within the prescribed limits, was a difficult one to solve, and in fact could not be attained with the apparatus employed. It was deemed advisable to expose the animals to the impure atmosphere for at least a month before inoculating them, consequently it was found impossible to maintain the atmosphere at the desired point of impurity during the entire experiment. At times the impurities fell below the prescribed limit, and, in turn, the air supply fell, especially during the night, to a point below that at which it would support life, and some or all of the animals were smothered, and the experiment had to be started over again.

In consequence of these difficulties only six experiments have been brought to a conclusion. A number of others were commenced, but failed through the loss of several or all of the animals; these accidents occurring frequently after the animals had been under experiment for several weeks and were nearly ready for the inoculations. Much time was lost in this manner.

Because of the difficulties encountered, and the indefinite character of the results obtained, only two forms of atmospheric impurities were tested—that of the respiratory impurities with animals in bell-jars arranged in series as in the Brown-Séquard experiments, and the effects of ordinary atmospheric air containing 0.5 to 2.0 per cent. by volume of pure carbonic acid gas. Each form of experiment was repeated successfully three times, using different micro-organisms for the inoculations with each of the three sets of experiments.

A. Inoculations with staphylococcus pyogenes aureus.

Experiment I.

Respiratory impurities.—Six rabbits were placed under bell-jars of 37 litres capacity, arranged in series as in the Brown-Séquard experiment. A current of air was maintained through the series of bell-jars by means of a water pump. The experiment was commenced May 19, 1896, and terminated June 29, 1896. The animals were inoculated on June 23 with 1 cc. of a 24-hour old bouillon culture of staphylococcus pyogenes aureus. The details of the experiment are shown in Table I.

TABLE I.

Date, 1896.	Hour.	No. 1, 2200 g.	No. 2, 2085 g.	No. 3, 1890 g.	No. 4, 1350 g.	No. 5. 1820 g.	No. 6, 2010 g.	C. ft. air per h.	% of CO_2.	Remarks.
May 19....	10.00 a. m.									No. 1 is nearest the pump.
" 22....	4.45 p. m.				+ 1805 g.	+	+	5.0		No. 4, 5 and 6 smothered. Continued with four animals.
" 23....	5.00 "							5.25	3.65	
" 26....	4.00 "							3.78	3.75	
June 1....	8.30 a. m.							9.5	3.55	New pump.
" 4....	2.30 p. m.							9.7	2.60	
" 8....	9.15 a. m.							9.7	3.33	
" 13....	2.00 p. m.							9.36	2.42	
" 16....	3.00 p. m.							9.83		
" 23....	10.45 a. m.									Animals inoculated with staphy. pyog. aur.
" 24....	8.45 a. m.			+						No. 3 is dead.
" 29....	11.30 "							9.41	2.16	
" 29....	5.15 p. m.									Experiment stopped. Nos. 1, 2, and 4 living.
		1850 g.	1802 g.		1410 g.					Present weight.

The staphylococcus pyogenes aureus was recovered from the site of inoculation, peritoneal fluid, pleural cavity, and spleen of No. 3.

EXPERIMENTS WITH CARBONIC ACID GAS.

The CO_2 experiments were conducted in the following manner: The animals were all placed under a bell-jar of 37 litres capacity, through which a current of air was maintained by means of a blower operated by the force of the laboratory water supply. The pure carbonic acid gas was derived from a large cylinder of compressed gas, and entered the air supply of the bell-jar through a Y-tube connection. The rate of flow of the carbonic acid gas was regulated by means of the stopcock on the supply tank. By this means a fairly constant supply could be obtained if carefully watched and regulated.

EXPERIMENT II.

Carbonic acid gas.—Four guinea-pigs were placed under a 37 litre bell-jar. The experiment was commenced May 19, 1896, and terminated June 29, 1896. The details of the experiment are shown in Table II.

TABLE II.

Date, 1896.	Hour.	No 1, 405 g.	No. 2. 315 g.	No. 3, 335 g.	No. 4, 330 g.	% of CO_2.	Remarks.
May 19....	1.00 p. m.						
" 19....	4.00 p. m.					2.21	Air analysis—on air as it enters the bell-jar.
" 20....	9.15 a. m.					8.13	Air analysis—on air as it enters the bell-jar.
" 23....	9.30 "					0.66	Air of bell-jar.
" 26....	4.00 p. m.					0.66	" " " "
June 1....	8.30 a. m.					0.66	" " " "
" 4....	2.30 p. m.					1.80	" " " "
" 8....	9.15 a. m.					0.20	" " " "
" 13....	2.00 p. m.					1.98	" " " "
" 19....	9.00 a. m.			+			No. 3 dead.
" 23....	10.45 "	275 g.	272 g.		265 g.		Present weight.
" 23....							Inoculated with staphy. pyog. aur.
" 24....	8.45 "				+		No. 4 dead.
" 24....	7.30 p. m.		+				No. 2 dead.
" 29....	11.30 a. m.					3.44	Exp. terminated. No. 1 seems all right, weight 247 g.

Staphylococcus pyogenes aureus recovered from the site of inoculation, blood, liver, spleen and the peritoneal fluid of Nos. 2 and 4.

Control animals inoculated with staphylococcus pyogenes aureus at the time of inoculating the animals of experiments I and II.

June 23, 1896.

Control rabbit No. 1, weight 1820 g.
" " " 2, " 1410 g.
" " " 3, " 1460 g.
" " " 4, " 1385 g.

Each of these animals was inoculated with 2 cc. of a 24-hour old bouillon culture of staphylococcus pyogenes aureus.

June 23, 1896.

Control guinea-pig No. 1, weight 300 g.
" " " 2, " 420 g.
" " " 3, " 340 g.
" " " 4, " 310 g.

Each of these animals was inoculated with 2 cc. of a 24-hour old bouillon culture of staphylococcus pyogenes aureus.

6/24/96. Exp. I. Rabbit No. 3 died.
6/25/96. Control " " 1 "
6/25/96. " " " 4 "
7/7/96. " guinea-pig " 1 "

All the other animals under experiment and those used as controls are alive 6/29/96.

B. Inoculations with bacillus diphtheriae.

EXPERIMENT III.

Brown-Séquard experiment.—Five guinea-pigs were placed in bell-jars of 14 litres capacity arranged in series. Experiment commenced November 7, 1896, and terminated December 19, 1896, when each of the animals was inoculated with 1 mg. of a 24-hour old blood serum culture of bacillus diphtheriae (attenuated). For the details of the experiment see Table III.

TABLE III.

ate, 1896.	Hour.	No. 1, 640 g.	No. 2, 480 g.	No. 3, 620 g.	No. 4. 590 g.	No. 5, 650 g.	C.ft. air p'rh	% of CO_2.	Remarks.
ov. 7....	5.00 p. m.							1st bell jar.	No. 1 is nearest the pump.
" 8....	11.30 a. m.						11.0		
" 27....	5.00 p. m.			+	+			4.06	
" 29....	12.00 "			570 g.	595 g.				Nos. 3 and 4 dead. Replaced by fresh pigs.
ec. 1.....	3.00 "	+						4.74	
" 9....	9.00 a. m.	730 g.							No. 1 dead. Replaced by fresh pig.
" 19....	4.15 p. m.							1.78	Experiment stopped.
" 19....	4.15 "								Inoculated with B. diphtheriae.
		635 g.	430 g.	535 g.	530 g.	525 g.			Present weight.

No. 1 was found dead after 48 hours.
" 2 " " " " 39 "
" 3 " " " " 40 "
" 4 " " " " 39 "
" 5 " " " " 47 "

EXPERIMENT IV.

Carbonic acid gas.—Four guinea-pigs were placed under a 37 litre bell-jar, November 17, 1896, and the experiment terminated December 19, 1896, when they were each inoculated with 1 mg. of a 24-hour old blood serum culture of bacillus diphtheriae. The details of the experiment are shown in Table IV.

TABLE IV.

Date, 1896.	Hour.	No. 1, 515 g.	No. 2, 500 g.	No. 3, 525 g.	No. 4, 470 g.	% of CO_2.	Remarks.
Nov. 17 ...	10.30 a. m.						
“ 27 ...	9.00 “					2.49	Air entering bell-jar.
Dec. 1....	3.00 p. m.					0.519	“ “ “ “
“ 19....	4.00 “					0.67	“ “ “ “
“ 19....	4.30 “						Experiment stopped.
“ 19....							Inoculated with B. diphtheriae.
		435 g.	400 g.	420 g.	370 g.		Present weight.

No. 1 was found dead after 39 hours.
“ 2 “ “ “ “ 39 “
“ 3 “ “ “ “ 39 “
“ 4 “ “ “ “ 68 “

Control animals inoculated with bacillus diphtheriae.

12/14/96. Control guinea-pig No. 1. Inoculated with 2 mg. of bacillus diphtheriae; died in 4 days.

12/17/96. Control guinea-pig No. 2. Inoculated with 5 mg. of bacillus diphtheriae; died in 2 days.

The animals of experiment III died as follows:

No. 1 was found dead after 48 hours.
“ 2 “ “ “ “ 39 “
“ 3 “ “ “ “ 40 “
“ 4 “ “ “ “ 39 “
“ 5 “ “ “ “ 47 “

The animals of experiment IV died as follows:

No. 1 was found dead at 39 hours.
“ 2 “ “ “ “ 39 “
“ 3 “ “ “ “ 39 “
“ 4 “ “ “ “ 68 “

The post mortem lesions in all these animals were typical, and the bacillus diphtheriae was recovered from the site of inoculation in each instance.

C. Inoculations with anthrax vaccine, followed by bacillus tuberculosis.

EXPERIMENT V.

Brown-Séquard experiment.—Five guinea-pigs were placed in bell-jars of 14 litres capacity arranged in series. The experiment was commenced February 4, 1897, and terminated February 24, 1897, when the animals were inoculated with Prof. Chester's First Anthrax Vaccine. The details of the experiment are shown in Table V. As none of the animals were affected by the anthrax vaccine they were inoculated with bacillus tuberculosis, March 4, 1897.

TABLE V.

Date, 1897.	Hour.	No. 1, 322 g.	No. 2, 338 g.	No. 3, 293 g.	No. 4, 318 g.	No. 5, 360 g.	% of CO_2.	Remarks.
eb. 4....	10.30 a. m.							No. 1 is nearest the pump.
" 9....	3.00 p. m.					1.47		Air of bell-jar No. 1.
" 13....	5.00 "					1.46		" " "
" 23....	3.30 "					1.20		" " "
" 24....	4.00 "							Experiment stopped.
" 24....								Inoculated with anthr. vac.
" 24....		298 g.	297 g.	256 g.	286 g.	317 g.		Present weight.
ar. 4								Inoculated with B. tuberculosis.
" 30					+			No. 4 dead. T. bacilli found.
pril 4....				+				" 3 " " "
" 9....						+		" 5 " " "
" 11....		+						" 1 " " "
" 12....			+					" 2 " " "

Tubercle bacilli were demonstrated in the spleen, lymphatic glands and the lungs of all the animals.

EXPERIMENT VI.

Carbonic acid gas.—Four guinea-pigs were placed under a 37 litre bell-jar, December 28, 1896, and the experiment was terminated February 24, 1897, when they were inoculated with the anthrax vaccine. On March 4, 1897, they were each inoculated with bacillus tuberculosis. For details of the experiment see Table VI.

Tubercle bacilli were demonstrated in the lymphatic glands, lungs and spleen of all the animals.

Control animals of anthrax vaccine and tuberculosis inoculations.

2/24/97. Control guinea-pig No. 1, weight 650 g.
2/24/97. " " " 2, " 750 g.

Inoculated with anthrax vaccine, but failed to die, and were again inoculated with bacillus tuberculosis 3/4/97.

No. 2 died 3/27. Found tubercle bacilli in the spleen and at the site of inoculation.

No. 1 died 4/27. Glands tubercular, also lungs, liver and spleen.

3/4/97. Control guinea-pig No. 3, weight 700 g.
3/4/97. " " " 4, " 700 g.

Inoculated with bacillus tuberculosis.

5/17/97 No. 3 dead. Lungs and glands show masses of tubercules. Liver and spleen smaller numbers.

5/28/97 No. 4 killed. Lungs and glands show masses of tubercles. Liver and spleen smaller numbers, but are very much congested.

TABLE VI.

Date, 1896.	Hour.	No. 1, 200 g.	No. 2, 230 g.	No. 3, 217 g.	No. 4, 195 g.	% of CO_2.	Remarks.
Dec. 28....	3.30 p. m.						
1897. Jan. 15....	9.00 a. m.				+		No. 4 dead.
" 18....	3.30 p. m.	+	+			3.47	Air entering bell-jar.
" 25....	10.00 a. m.	272 g.	277 g.		360 g.		Nos. 1 and 2 dead. Replaced by fresh pigs.
" 29....	1.30 p. m.					14.9	Air entering bell-jar.
Feb. 4.....	2.30 "					0.4	" " " ".
" 9.....	3.00 "					0.32	" " " "
" 23.....	3.30 "					7.01	" " " "
" 24.....	3.00 "						Experiment stopped.
" 24.....							Inoculated with anthrax vac.
" 24.....		252 g.	236 g.	248 g.	285 g.		Present weight.
" 25.....			+				No. 2 dead. Examination post mortem negative.
Mar. 4.....							Inoculated with B. tuberculosis.
" 19.....					+		No. 4 dead, bacilli found.
" 30.....				+			" 3 " " "
April 10...		+					" 1 " " "

SUMMARY OF RESULTS.

In the staphylococcus and diphtheria inoculations the cultures used appear to have been insufficiently attenuated to show any difference in the effects produced upon the animals under experiment and the control animals. It is, however, very doubtful whether cultures of these organisms could be attenuated to such a degree as to still kill a weakened animal and not kill a control, healthy animal.

The anthrax vaccines used do not kill a healthy guinea-pig, but it was expected that the animals might present sufficient lowering of the vitality to become affected by the vaccines. This, however, was not the case. The animals having failed to die from the effects of the anthrax vaccines, they were then inoculated with an attenuated culture of tuberculosis. All the animals under experiment died much earlier than the control animals. These results indicate a lowered vitality. Whether this lowered vitality was brought about by the atmospheric conditions under which they had lived, or whether it was brought about solely through changes in their diet while under experiment, or whether both these causes were active in producing the result, it is impossible to say. The animals lost flesh and decreased in weight while under experiment. It is not improbable that the loss in weight and the decrease in vitality are both traceable to the same causes.

SMITHSONIAN MISCELLANEOUS COLLECTIONS.

1170

A SELECT
BIBLIOGRAPHY
OF
CHEMISTRY

1492-1897.

BY

HENRY CARRINGTON BOLTON.

◆

FIRST SUPPLEMENT.

CITY OF WASHINGTON:
PUBLISHED BY THE SMITHSONIAN INSTITUTION.
1899.

The Knickerbocker Press, New York

CONTENTS.

PREFACE.

The Select Bibliography of Chemistry, 1492–1892, was published in 1893; this First Supplement includes works omitted in that volume and brings the literature of chemistry down to the close of the year 1897. In the following pages the lines of the original work have been followed, the term chemistry being taken in its fullest significance; the range of topics will be seen in the Subject-Index and their distribution in the Table on page vii. This Supplement does not embrace Academic Dissertations, a catalogue of which is nearly ready for the press.

As in the first volume, the titles are grouped in Sections with a view to facilitating reference: I. Bibliography; II. Dictionaries; III. History; IV. Biography; V. Chemistry, Pure and Applied; VII. Periodicals. Section VI., Alchemy, has been dropped. The scope of each Section is explained in the first volume, and it need only be here pointed out that in each (excepting those of Biography and Periodicals) the titles are arranged alphabetically by authors, translations of each work following the original in the alphabetical order of the English names of the languages. The order is the same as in the Table on page vii. In the Section of Biography the titles are placed under the names of the persons described, with cross-references from the authors.

In the preparation of this Supplement I have been fortunate in securing, through the agency of the Smithsonian Institution, the co-operation of eminent men of science and letters in several parts of the world. In response to requests addressed to the gentlemen named below, they contributed more than two thousand titles, as shown in the statement:

TITLES CONTRIBUTED.*

13 Arabic, by Dr. Y. Sarrûf, of Cairo, Egypt.
20 Finnish, by Professor Ed. Hjelt, of Helsingfors.

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* The number of titles here given does not agree in each case with those in the Table on page vii, because many were duplicates, and some were Dissertations.

49 Japanese, by Professor Percy Wilkinson, of Melbourne, and Professor J. Sakurai, of Tōkyo.
93 Bohemian, by Professor Bohuslav Brauner, of Prague.
125 Dutch, by Professor J. H. van 't Hoff, of Rotterdam.
141 Portuguese, by Professor Charles Le Pierre, of Lisbon.
205 Swedish, by Professor P. T. Cleve, of Upsala.
644 Danish, Norwegian, Swedish, by Mr. Axel Moth, of Copenhagen and New York.
760 Russian, by Professor A. Krupsky, of St. Petersburg.

To these gentlemen sincere thanks are due for their valuable and efficient co-operation. It is to be regretted that promises made by others were not fufilled.

I am under obligations to several persons for assistance in proof-reading. Dr. Immanuel M. Casanowicz, of the Smithsonian Institution, read the Russian; Mr. Louis Solyom, of the Library of Congress, read the Polish, Bohemian, and Slavonic languages; Miss Aletta S. S. Nickelsen, of the Smithsonian Institution, read the Swedish, Danish, Norwegian, and Finnish; and Mrs. Henry Carrington Bolton read the Italian and assisted in reading the proof of the entire volume.

In the preparation of this Supplement I visited the following Institutions and wish to express sincere thanks for personal attentions shown me by their Directors, Librarians, and Assistant Librarians: Biblioteca Nazionale, Naples; Biblioteca Nazionale Centrale Vittorio Emanuele, Rome; Istituto Chemico, Rome; Biblioteca Marucelliana, Florence; Biblioteca Nazionale, Florence; Biblioteca Brera, Milan; Bibliothèque Royale, Brussels; Bibliothèque Nationale, Paris; British Museum, London; Harvard University, Cambridge; Public Library, Boston; Massachusetts Institute of Technology, Boston; Public Library, New York; Columbia University, New York; as well as the following in Washington, D. C.: United States Department of Agriculture, United States Geological Survey, Library of Congress, United States Patent Office, Smithsonian Institution, and the Surgeon-General's Office of the United States Army.

HENRY CARRINGTON BOLTON.

WASHINGTON, D. C.

NUMBER OF TITLES IN THE SEVERAL LANGUAGES.

	I. Bibliography.	II. Dictionaries.	III. History.	IV. Biography.	V. Pure and Applied.	VII. Periodicals.	TOTALS.
Arabic					13		13
Armenian					3		3
Bohemian			1		97		98
Danish	1			1	146	3	151
Dutch		1	6	1	180	3	191
English	34	14	40	75	772	37	972
Finnish			1		19		20
French	9	17	49	40	943	27	1085
German	28	29	66	36	1195	107	1461
Greek					3		3
Hungarian					4		4
Icelandic					4		4
Italian		3	21	2	400	8	434
Japanese					49		49
Latin			4	1	73		78
Norwegian					16		16
Polish					6		6
Portuguese	2	3	2		116		123
Rumanian					1	1	2
Russian	21	13	33	16	496	2	581
Spanish		1	3		56	1	61
Swedish		2		9	185		196
Tamil					1		1
Turkish					1		1
Volapük		1					1
TOTALS	95	84	226	181	4779	189	5554

The number of titles in the SELECT BIBLIOGRAPHY is 12,031, making a grand total in the two volumes of 17,585.

EXPLANATION OF ABBREVIATIONS AND SIGNS.

The abbreviations of titles of periodicals used in Sections III. and IV. will be found on pages 1159–1164 of the BIBLIOGRAPHY.

* prefixed to a title indicates a work in the private library of the editor.

† following a date signifies current at that date.

‖ following a date signifies publication discontinued.

Ill., illustrated.

Pl., plates.

Fol., 4to, 8vo, etc. The sizes given are only approximate, having been taken largely from catalogues using different standards.

Bibl., Select Bibliography of Chemistry, 1893.

Pagination is given only of those works examined by the editor or by a collaborator.

Cross-references in a given Section refer to works in the same Section unless otherwise stated.

A SELECT BIBLIOGRAPHY OF CHEMISTRY

1492-1897.

FIRST SUPPLEMENT.

SECTION I.

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SUBJECT-INDEX.

This index is limited to special topics and does not include works of an encyclopedic character. Section IV being self-indexed is not included.

Entries are made under specific words so far as possible. Roman numbers refer to Sections; Arabic to pages. In a few instances dates have been inserted for obvious reasons.