PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The Carbonic Acid, Organic Matter, and Micro-Organisms in Air, More Especially of Dwellings and Schools

Thos. Carnelley, J. S. Haldane and A. M. Anderson

Phil. Trans. R. Soc. Lond. B 1887 **178**, 61-111
doi: 10.1098/rstb.1887.0004

IV. *The Carbonic Acid, Organic Matter, and Micro-organisms in Air, more especially of Dwellings and Schools.*

By Professor THOS. CARNELLEY, *D.Sc., and* J. S. HALDANE, *M.A., M.B., University College; and* A. M. ANDERSON, *M.D., Medical Officer of Health, Dundee.*

Communicated by Sir HENRY E. ROSCOE, *F.R.S.*

Received June 10,—Read June 10, 1886.

[PLATE 6.]

IT has been fully proved that the habitual breathing of air vitiated by the presence of human beings has a most important effect on the death-rate. We nevertheless possess as yet scarcely any accurate data as to the connection between the death-rate and the quantities of such impurities as it is at present possible to measure. Nor, so far as we are aware, have any systematic observations been made as to the relative amounts of these impurities in different samples of vitiated air.

The quantity of carbonic acid (or of carbonic acid and oxygen in more refined investigations) is usually taken as a measure of the total impurity. It is, however, highly improbable that an increase in the carbonic acid and a slight diminution in oxygen materially affect the death-rate (cf. HIRT, 'Die Krankheiten der Arbeiter,' 1873).

The organic matter and micro-organisms in the air are in all probability far more important factors.

The original object of the present investigation was to examine systematically the air of various classes of houses with the view of comparing the amounts of carbonic acid, organic matter, and micro-organisms with one another, and with the death-rates in the same classes of houses. During the progress of our work, however, several additional questions presented themselves, and the actual scope of the research has therefore been as follows :—

1. An investigation of the outside air so far as was necessary for purposes of comparison with the determinations made inside buildings.

2. A comparison of the quantities of the above-mentioned constituents of the air in one-roomed, two-roomed, and the better class of houses with one another, and with the death-rates and relative frequencies of various diseases in the several classes of dwellings.

3. An examination of the air in schools, with special reference to the cubic space

and to different methods of ventilation, and other circumstances affecting the quality of the air.

4. An examination of the air in some other classes of buildings.

5. An investigation into the sources of the organic matter and micro-organisms of air inside buildings, and the circumstances affecting the number of micro-organisms; also of the relative number of bacteria and moulds in both outside and inside air.

METHODS.

1. *Carbonic Acid.*—PETTENKOFER's well-known method was employed.

2. *Organic Matter.* — The process described by Professor CARNELLEY and Mr. MACKIE was made use of ('Roy. Soc. Proc.,' vol. 41, p. 238).

It must not be forgotten that the term "organic matter" is a very indefinite one, and that by it is really meant the bleaching action of the air on a dilute solution of potassium permanganate acidified with sulphuric acid. It therefore includes not only organic matter properly so called, but those substances which air sometimes contains, such as sulphuretted hydrogen, sulphurous acid, &c., which also bleach a permanganate solution. Even the organic matter itself may be of very different kinds and vary considerably as regards its influence upon health, some doubtless being quite harmless, whilst some may exert a very deadly effect. In so far, therefore, as the method does not distinguish between these various constituents of air, but brings them all into the same category, it is a very imperfect method. But, as no better process has yet been devised, it is the only one which has been at our disposal.

3. *Micro-Organisms.*—In determining the number of micro-organisms, HESSE's method ('Mittheilungen aus dem Kaiserlichen Gesundheitsamte,' vol. 2, p. 182) was employed.*

A piece of wide glass tubing, about 70 cm. long and 3·5 cm. wide, is closed at one end by means of a perforated india-rubber cork, through which passes a small piece of glass tubing about 10 cm. long and 1 cm. wide, and containing a plug of cotton wool at each end. The other end of the large tube is closed by two india-rubber caps fitting one over the top of the other, the inner one being perforated by a round opening of about 1 cm. in diameter. The whole being thoroughly cleansed, about 50 c. c. of KOCH's jelly (containing the juice of 1 lb. of meat, 10 grammes of peptone, 5 grammes of common salt, and 50–100 grammes of French leaf gelatine to 1 litre of water, and, after heating, very slightly over-neutralised with sodium carbonate) is introduced into the tube. The tube, with its contents, after replacement of the cork, is exposed to a temperature of 100 C., in an atmosphere of steam, for at least an hour, and then allowed to cool. When the jelly assumes a syrupy consistency the tube is

* As HESSE's method is not generally known, especially among chemists, and as the literature referring to it is not easily accessible, it has been thought advisable to describe it in greater detail than would otherwise be necessary.

placed in a horizontal position and turned round until the jelly is just beginning to set; the whole of the inner surface of the tube is by this means coated with jelly, and a flat surface is formed at the bottom, where most of the jelly collects before setting. When the tube is to be used it is set horizontally on a tripod, or other convenient stand, with the flat surface of jelly on the lower side of the tube. The outer cap is then removed, and a measured quantity of air drawn slowly through the aperture in the inner cap and along the tube by means of an aspirator, the india-rubber tube of which is connected with the end of the small tube passing through the cork of the large tube. For aspirating, two graduated bottles are used, one being hung to the upper part of the tripod, and the other standing on the ground. The rate of flow is regulated by the size of the glass nozzle through which the water flows into the lower bottle, or by means of a small screw clip.

The whole of the micro-organisms in the aspirated air always settle on the lower half of the tube; and when a proper rate of flow is chosen the resulting colonies (which develop in the course of a few days) appear closest near the cap, gradually becoming more and more sparse as the farther end of the tube is approached, so that the last part of the tube is entirely free from colonies (see Plate 6, figs. 2–5). For further information we must refer to HESSE's paper; but it is desirable to mention more specially some details of the method as it was employed by us. As regards length and width of tubes, we did not consider it necessary in our experiments to adhere strictly to one size. It is exceedingly difficult and expensive to procure tubing of the same width and in such lengths as will cut up without great waste into pieces of say 70 cm. long; and for our purpose the advantages would have been scarcely appreciable.

HESSE recommends that the tubes should have edges turned out at one end, in order that the caps may fit more tightly. This, however, increases the risk of cracking during sterilisation, and makes it difficult to remove or replace the cap without a good deal of inconvenient manipulation, which increases the danger of artificial infection of the air. We found it better to employ square pieces of india-rubber sheeting, which were fastened by means of stout umbrella rings. The inner cap is first fixed on, the part of the cap next the end of the tube being freed from creases by slightly stretching the cap. It is then easy to fix the outer cap by means of a ring applied quite close to the end of the tube. If any creases are left under the ring the tube is sure to leak. An additional ring applied higher up keeps the edges of the square in proper position. When the tube is used the last-mentioned two rings are removed, and the outer cap can then be taken off without any manipulation likely to infect the air. During the experiment the cap is placed in a solution of corrosive sublimate and replaced still moist, the superfluous drops having, however, been first carefully shaken off.

The apparatus used for sterilisation was essentially the same as that employed by HESSE, and consisted of a sufficiently large cylinder of iron plate, about 3½ feet long, fitted on the top of an ordinary potato-steamer and provided with a perforated lid.

The whole was covered externally with felt. A temperature of 100° was easily maintained inside the cylinder.

The tubes were at first sterilised by being kept for half an hour at 100° on two successive days. Latterly they were simply kept for an hour at 100°. Any failure in sterilisation would be easily detected by the appearance of colonies inside the jelly, and by their distribution round the tube. But this was never obtained in the case of tubes sterilised by the above method (cf. KOCH, GAFFKY, and LŒFFLER, 'Mitth. a. d. K. Gesundheitsamte,' vol. 1, p. 332 *et seq.*), nor did any colonies ever appear inside sterilised tubes kept unused for long periods.

The rate of air-flow employed was, as a rule, about one litre in three minutes. The most suitable rate in any given case depends on the number of micro-organisms in the air and the rapidity with which they settle. When there are many in the air to be examined it is best, as a rule, to make the rate of flow more rapid. The error arising from the crowding together of colonies near the entrance is far greater than any likely to occur from the passage of micro-organisms into the cotton wool. Not only do the colonies coalesce if crowded together near the entrance, but substances appear to become diffused through the jelly, which entirely prevent the growth of some of them. Again, when the particles to which bacteria are attached are heavy, as occurs, for instance, in outside air on a dry windy day in towns, a rapid current is also necessary on account of the heavy particles coming down very rapidly on entering the tube. On the other hand, a slower current is desirable when there are no heavy particles in the air, as in the case of a room which has been standing quiet, or outside air in damp weather. It is, of course, quite easy to tell from the distribution of the colonies in the tube whether a proper rate of flow has been chosen.

The quantity of air taken was usually half a litre in bad atmospheres, one or two litres in better ventilated rooms, and from one to ten litres in outside air, according to circumstances. The latter quantity would frequently be insufficient in making systematic observations on outside air, as in many cases no colonies develop from ten litres. The quantities taken were, however, sufficient as regards the purposes we had in view in examining outside air. The tubes after the samples had been collected were exposed horizontally on racks in a room the temperature of which was kept tolerably constant during the day all winter by means of a warm-air ventilating apparatus. They were left until no more colonies made their appearance—a period of, practically speaking, from three to four weeks. In a good many cases the colonies had begun to run together before this time had elapsed. In such cases we made an allowance for probable increase, based on the percentage increase observed in other tubes.

Probably a better arrangement would have been to have kept them in a large incubator at about 20°, but, having begun by exposing them in the laboratory, we thought it best to continue doing so all through our experiments.

The tripod employed was about three feet high, so that the samples were always collected at that height from the floor.

As some adverse criticisms of HESSE's method, contained in an article by PAWLOWSKY ('Berliner Klinische Wochenschrift,' 1885, No. 21), appear to have attained some notice, it may be well to state that these criticisms, as will easily be seen on reading the article, depend on a complete misunderstanding of the method of sterilisation employed by HESSE. The new method suggested by PAWLOWSKY is not only no improvement, but would give absolutely nugatory results.

We have preferred HESSE's method on account of its great simplicity and other important advantages. We consider it to be a most convenient and elegant process. MIQUEL's method ('Organismes Vivants de l'Atmosphère,' p. 175) could not well have been applied by us under the conditions to which our work was subject. MIQUEL (p. 151) used as a standard nutrient medium a *bouillon* of LIEBIG's extract, of 1·024 specific gravity, and incubated it at 30° to 35°. How such a nutrient medium compares with KOCH's meat jelly, used under the conditions of our experiments, has not, so far as we know, as yet been determined. We cannot, therefore, compare at present the numerical results of our observations with those of MIQUEL in his valuable series of observations on the micro-organisms of outside air.

In stating our results, the carbonic acid is represented in all cases by the number of the volumes of the gas contained in 10,000 volumes of air.

The organic matter is represented by the volumes of oxygen required to oxidise the oxidisable organic matter in 1,000,000 volumes of air.

The micro-organisms are represented by the number per litre of air. It must also be distinctly understood that this number includes only those which grow on KOCH's nutrient jelly of the composition previously stated, and kept in a room under ordinary conditions. If the jelly, for instance, were acid, the numbers and the ratio of bacteria to moulds would be different.

OUTSIDE AIR.

In order to draw conclusions from an examination of air inside buildings, it is of course necessary to know the state of the outside air. As regards each of the constituents estimated, considerable variations were found at different times and places.

The following Table gives the results of determinations made on different days and in all kinds of weather during the winter and spring of 1885–86, and in various parts of the towns of Dundee and Perth. The observations were made at intervals over the same period as that during which the air of schools, houses, &c., was examined.

	Dundee (town, quiet places.)				Dundee (suburbs).				Perth (outskirts).			
	No. of determinations.	Lowest.	Highest.	Mean.	No. of determinations.	Lowest.	Highest.	Mean.	No. of determinations.	Lowest.	Highest.	Mean.
Carbonic acid	32	2·2	5·6	3·9	5	1·8	3·5	2·8	3	2·9	3·5	3·1
Organic matter	46	1·7	16·8	8·9	10	0	5·6	2·8	5	1·7	4·5	3·1
Total micro-organisms:—*	15	0	2·2	0·8	1	..	..	0·1	..	..	..	..
Bacteria	14	0	1·9	0·6	1	..	..	0	..	..	..	..
Moulds	14	0	1·3	0·2	1	..	..	0·1	..	..	..	..

The above Table shows:—(1) That the average carbonic acid and organic matter were much lower in suburban than in town air. Presumably they would be still less in country air. No conclusion can be drawn as regards the relative proportion of micro-organisms in town and suburban air, as only one determination was made in the latter case. (2) That this difference is relatively much greater in the case of the organic matter than in that of the carbonic acid. (3) That the quantity of organic matter, at least in town air, varies within much greater limits than that of the carbonic acid. (4) That the average number of micro-organisms in town air was rather less than one per litre for town air in Dundee in winter. (5) That the number of bacteria in the air of quiet places in winter in Dundee was about three times as great as the number of moulds. In the open streets during dry and windy weather the proportion of bacteria is much greater (see pages 99 (Table) and 101).

The numbers of which the above are the means exhibited variations of every degree within the limits shown in the Table. Some of the causes of these variations will appear from the following Tables.

Influence of Day and Night, and of Open and Closed Places.

This is clearly shown in the Tables given below. The day has been supposed to extend from 5 A.M. to 7 P.M., as these are about the hours at which work begins and ends at the mills and factories in Dundee. Although the ordinary work begins at 6 A.M., the boiler fires, &c., begin to smoke about 5 A.M. By "open places" we mean ordinary streets, large yards, squares, &c.; whilst by "close places" are meant narrow lanes, entries, back-yards, and other places closely surrounded by houses, and more especially by crowded low-class houses. No determinations were made in close places during the day.

* A larger number of micro-organisms (11 per litre on an average) were found at places in or close to open streets on which there was much traffic (see page 99, Table). These observations were made in April and May, 1886, and subsequently to those detailed above.

All the observations included in the above Table were made with ten litres of air.

	Open places. Day.				Open places. Night.				Close places. Night.			
	No. of determinations.	Lowest.	Highest.	Mean.	No. of determinations.	Lowest.	Highest.	Mean.	No. of determinations.	Lowest.	Highest.	Mean.
Carbonic acid	20	2·2	5·3	3·8	9	3·0	5·6	4·1	7	3·2	5·4	4·2
Organic matter	34	1·1	16·8	9·5	9	2·2	6·7	3·9	7	5·6	11·8	8·4
Total micro-organisms:—	6	0·3	2·2	1·2	2	0·1	0·2	0·15	6	0	1·3	0·54
Bacteria	6	0	1·9	0·7	2	0·1	0·2	0·15	5	0	1·3	0·49
Moulds	6	0·2	1·3	0·5	2	0	0	0	5	0	0·1	0·01

The above Table shows: (1) That, with the exception of the carbonic acid, all the determinations made in open places gave much lower results during the night than during the day. The organic matter was reduced to less than one-half, and the micro-organisms to nearly one-tenth, of what they were during the day. The carbonic acid, though represented as being slightly less during the day, was practically the same; for, according to the method of treating the data, the night would show a slightly higher or a slightly lower result than the day. (2) That in all cases the determinations made during the night gave higher results for close than for open places. With the exception of the carbonic acid, this difference is very considerable. Though the figures for carbonic acid are near, yet the average for close is distinctly higher than for open places. The average for open places is possibly a little too high, as any other method of treating the data would give a somewhat lower result. (3) That, with the exception of the carbonic acid, even close places at night give a lower average than open places by day, thus proving distinctly that both organic matter and micro-organisms are considerably less during the night than during the day. The moulds more particularly showed a large reduction.

The influence of day and night, and the effect of town and suburban conditions, is shown in a conclusive manner by the next Table. This Table records a series of hourly observations made simultaneously at two different places for a period of twenty-four hours. One of the places at which the samples were collected was the large open playground of the Dundee High School in the centre of the town, and the other a somewhat elevated position on the western outskirts overlooking the Tay. The prevalent direction of the wind was about south-west, *i.e.*, across and down the valley of the Tay from the Ochil Hills. The standard solution employed in both cases was the same; and the analyses, apart from the collection of the samples, were carried out by the same person. The results of the full Table (p. 68) may be summarised as follows:—

April 2nd and 3rd, 1886.		Town.				West suburbs.			
		No. of Determinations.	Lowest	Highest.	Mean.	No. of Determinations.	Lowest.	Highest.	Mean.
Day, 5 A.M. to 7 P.M.	Carbonic acid	13	2·6	4·1	3·25	13	1·7	2·8	2·3
	Organic matter	12	2·8	9·6	6·2	13	1·7	8·1	5·3
Night, 7 P.M. to 5 A.M.	Carbonic acid	7	3·0	4·1	3·45	10	1·7	2·4	1·75
	Organic matter	6	2·5	6·8	4·6	10	Too small to estimate.	4·5	1·86

As before, the day is taken as extending from 5 A.M. to 7 P.M.

It will be seen that the quantity of carbonic acid in the air during the day on which the experiments were made was extremely low, even falling to 1·7 volumes on the west of the town during the night. The frequent lowness of the carbonic acid in Dundee during last winter is very remarkable, and difficult to account for. It is true that the results were obtained during winter, and many of them in the middle of the

April 2nd and 3rd, 1886.	Temperature.		Carbonic acid.		Organic matter.		Remarks.
	Town.	West suburbs.	Town.	West suburbs.	Town.	West suburbs.	
	° Fahr.	° Fahr.					
7.15 A.M.	..	..	..	..	5·3	8·1	Somewhat overclouded, otherwise bright sunshine. Breezy, S.S.E. Chimneys smoking strongly. Smell of smoke. Smoke also blown across to west of town from bridge works.
8.15	..	..	2·7	1·9	8·1	4·1	Sunny, S.S.E.
9.15	50	48	2·6	2·4	4·5	6·3	Overcast; strong wind, S.
10.15	..	49	2·9	2·6	..	6·3	Ditto, S.S.W.
11.15	52	49	3·3	2·6	6·5	4·8	Ditto.
12.15 P.M.	..	49	3·2	2·8	3·2	1·7	Ditto. Wind rather more from West.
1.15	53	51	4·1	2·6	..	4·8	Ditto. Wind S.W.
2.15	54	49	3·3	2·2	7·1	7·0	Ditto.
3.15	..	48	2·9	2·4	9·6	5·6	Ditto.
4.15	49	46	3·2	2·2	2·9	5·3	Rain. Wind fallen.
5.15	48	44	2·7	2·2	6·2	5·1	Ditto.
6.15	47	42	3·2	2·6	3·9	..	Ditto. No wind.
7.15	..	41	3·2	1·9	..	4·4	Ditto.
8.15	..	40	3·0	1·7	3·3	2·9	Ditto.
9.15	43	40	3·8	2·4	2·5	4·1	Ditto.
10.15	43	39	3·3	1·7	..	1·9	Rain stopped. Wind rising.
11.15	..	40	3·2	1·7	3·9	2·2	Ditto. Wind higher.
12.15 A.M.	42	39	..	1·7	6·8	too small	Drizzling rain. Wind less.
1.15	..	39	..	1·7	..	,,	Fine, overcast, little wind.
2.15	41	38	3·6	1·7	5·0	,,	Fine, and nearly clear. Wind slight. W.
3.15	..	38	4·1	1·7	6·4	,,	Ditto.
4.15	..	37	..	1·7	..	3·1	Ditto.
5.15	38	36½	4·1	1·7	6·3	4·4	Ditto. Mill fires lighting up in the town, and a good deal of smoke about.
6.15	37	36	4·1	1·7	8·1	6·6	Ditto.

night, when the carbonic acid is generally said to be lowest. Dundee is also close to the open sea, and without any large town near it. FODOR ('Hygienische Untersuchungen,' 1881), from a large number of observations, gives the limits as 2 to 6 volumes, outside which cases very seldom occur. He states that carbonic acid is lowest in winter and on the seashore. LEVY ('Annuaire de Montsouris,' 1882) gives the mean carbonic acid at the observatory of Montsouris (suburbs of Paris) as 3·0 volumes. The mean carbonic acid in air appears to be distinctly lower than the quantity (4 volumes) maintained by the older authorities.

MIQUEL finds that the number of micro-organisms is also much greater in the centre of a town than in the suburbs. This is doubtless due to the stir in the town raising dust, &c. (see below). Our own observation that the number of organisms is greater during the day in a town is what might be expected for the same reasons. In this connexion it will be of interest to give the results of four observations made on two different nights in one of the central courts of the Houses of Parliament in April and May of the present year.

Time.		Carbonic Acid.	Organic matter.	Total micro-organisms.	Bacteria.	Moulds.
April 19–20th	8.30 P.M.	4·1	3·1	9·2	9·2	0
	1.0 A.M.	. .	. .	4·0	3·6	0·4
May 18–19th	6.0 P.M.	4·1	2·5	18·0	14·0	4·0
	12.30 A.M.	4·4	too small	3·0	1·5	1·5

At the time of the first observation in each pair the streets were very busy.

These results, so far as they go, are in perfect accord with the conclusions deduced from the results in Dundee.

THE AIR OF DWELLING-HOUSES.

Mode and Time of taking Samples of Air.—The samples were taken during the night, between 12.30 A.M. and 4.30 A.M. This appeared to be the most favourable time for avoiding disturbing conditions, and at the same time obtaining fair specimens of the air breathed during the night. The one-roomed houses were mostly those of the very poor. Sometimes as many as six, or even eight, persons occupied the one bed. In other cases there was no bed at all. The occupants of the two-roomed houses were as a rule much better off, belonging mostly to the artisan class.

Mr. KINNEAR, the head of the Sanitary Department of Dundee, was good enough to place at our disposal a horse and covered van, by which means we were enabled to make the analyses in the street outside the houses selected for examination. Two of the inspectors belonging to the same department assisted us in our work in the case of the poorer class of houses. Those houses were visited without warning of any kind to the inhabitants, so as to avoid the risk of having the rooms specially ventilated in preparation for our visit. In every case but one we were most civilly received, and willingly allowed to collect the necessary samples of air, measure the room, and obtain such information as was required. We were, in fact, agreeably surprised to find that so little objection was made to our untimely visit. The precaution was, of course, taken of having the door open for as short a time as possible, and of avoiding unnecessary movements such as were likely to stir up dust and contaminate the air. In the case of one-roomed houses the samples were taken about the centre of the room. In two-roomed houses we found that the door was always kept open between the two rooms, and that usually there were people sleeping in both rooms. We therefore in those cases took the samples by the door communicating between the two rooms. About ten minutes in each room were, as a rule, required in order to take the specimens, measure the room, &c., and about twenty minutes subsequently for determining the carbonic acid and organic matter in the van. Half-an-hour in all was, therefore, required for each house. We could thus visit five or six houses each night, besides taking and analysing samples of outside air in the courts or lanes in which the houses were situated.

In the case of houses of four rooms and upwards, houses of various sizes and in different parts of the town were selected, and were usually those of acquaintances. With one exception, we always found the windows and doors closed in the houses we visited. The rooms were examined in their usual conditions in every respect.

	One-roomed houses.				Two-roomed houses.				Houses of four rooms and upwards.			
	No. of cases.	Lowest.	Highest.	Average.	No. of cases.	Lowest.	Highest.	Average.	No. of cases.	Lowest.	Highest.	Average.
Persons per house (per room in last class)	29	2	10	6·6	13	4	10	6·8	18	1	3	1·3
Space per person	29	104	528	212	13	148	395	249	18	391	4206	1833
Temperature (° F.)	21	43	61	55	9	50	59	53·5	13	42	63	54·5
Carbonic acid. .	29	6·3	32·1	11·2	12	7·1	13·2	9·9	18	4·5	11·7	7·7
Organic matter .	29	7·8	38·1	15·7	11	5·0	30·2	10·1	18	1·1	12·0	4·5
Total micro-organisms :—	28	6·0	240·0	60·0	13	8·0	128·0	46·0	18	0·5	22·0	9·0
Bacteria . .	19	6·0	120·0	58·0	11	6·0	118·0	43·0	16	0·5	16·0	8·5
Moulds . . .	19	0	5·0	1·2	11	0	10·0	2·2	16	0	1·0	0·4

The results shown in the above Table come out even more strikingly if, instead of giving the average total quantity of carbonic acid and organic matter, we give the quantities present in excess of the outside air at the time. This is done in the following Table. As the number of micro-organisms in the outside air was so small, they may be neglected, and therefore no change as regards micro-organisms is needed.

Above outside air.	One-roomed houses.				Two-roomed houses.				Houses of four rooms and upwards.			
	No. of cases.	Lowest.	Highest.	Average.	No. of cases.	Lowest.	Highest.	Average.	No. of cases.	Lowest.	Highest.	Average.
Temperature (°F.)	21	9	30	19	9	16	23	18	13	5	19	14
Carbonic acid ..	25	1·7	16·5	6·6	11	2·8	9·0	5·5	10	1·7	6·1	3·3
Organic matter ..	25	0	26·3	6·2	10	0	3·9	2·2	16	0	3·2	1·4
Total micro-organisms :— ..	28	6	240	60	13	8	128	46	18	0·5	22	9·0
Bacteria ..	19	6	120	58	11	0	118	43	16	0·5	16	8·5
Moulds ..	19	0	5	1·2	11	0	10	2·2	16	0	1	0·4

Or, taking the average quantity (in excess of outside air) of carbonic acid, organic matter, and micro-organisms respectively in houses of four and more rooms as unity, then in one- and two-roomed houses we have as follows :—

	Houses of four rooms and upwards.	Two-roomed houses.	One-roomed houses.
Cubic space per person	1	0·13	0·11
Carbonic acid	1	1·5	2·0
Organic matter	1	1·6	4·4
Micro-organisms (total)	1	5·1	6·7
Bacteria	1	5·1	6·9
Moulds	1	5·5	3·0

The influence of cubic space per person in sleeping-rooms is indicated in the following Table, which includes all classes of houses. These are divided into seven groups, according to the cubic sleeping-space per person.

Cubic space per person.	No. of houses.	Temperature.	Carbonic Acid.	Organic matter.	Total micro-organisms.	Bacteria.	Moulds.
Cubic feet.							
100– 180	14	55	11·5	15·1	80	78	1·8
180– 260	18	54	10·7	15·1	49	47	1·5
260– 340	6	53	10·3	11·8	32	31	0·7
340– 500	4	57	9·2	8·4	42	40	2·1
500–1000	6	54	8·6	5·6	6	6	0
1000–2500	8	53	6·7	3·9	9·1	8·5	0·7
2500–4000	4	57	7·9	5·0	13·1	12·8	0·4

It will be seen from the above that the carbonic acid, organic matter, and micro-organisms* all diminish in quantity as the cubic space per person increases from 100 to about 1,000 cubic feet. When, however, the cubic space increases beyond 1,000 cubic feet, the carbonic acid, organic matter, and micro-organisms show a slight, but

* See p. 95.

distinct, increase. This, unless it be a mere coincidence, appears to be an anomalous result; but it may perhaps have the following simple explanation:—A large bed-room of, say, 3,000 cubic feet has usually about the same means of ventilation as one of only 1,000 cubic feet. Consequently the air will be changed less frequently in the larger than in the smaller room, so that in the former portions, at least, of the air will be comparatively stagnant. Air vitiated by respiration will, therefore, in these portions at any rate, be removed more slowly than in a smaller room. If this be true, the results in the above Table would seem to indicate that about 1,000 cubic feet is the most appropriate sleeping-space per person in an ordinary bed-room without special means of ventilation.

In the above Table the absolute quantities of carbonic acid and organic matter are given, but similar results are obtained if we make allowance for the carbonic acid and organic matter in the outside air at the time. This has been done in the following Table:—

Above outside air.	No. of houses.	Temperature.	Carbonic Acid.	Organic matter.	Total micro-organisms.	Bacteria.	Moulds.
Cubic feet.							
100– 180	14	19	6·1	5·6	80	78	1·8
180– 260	18	19	6·9	6·5	49	47	1·5
260– 340	6	19	5·8	1·9	32	31	0·7
340– 500	4	18	5·2	1·9	42	40	2·1
500–1000	6	13	4·2	2·9	6	6	0
1000–2500	8	13	2·6	1·5	9·1	8·5	0·6
2500–4000	4	16	2·8	3·3	13·1	12·8	0·4

Comparison of Mortality Statistics with the Composition of the Air of Dwelling-Houses.

One of us, being the Medical Officer for Dundee, made arrangements for the year 1884 with the various Registrars of Deaths in the town, whereby, in addition to the information which is usually given on the registration of death, full particulars were also obtained of the number of rooms and persons in the house in which the death occurred, as well as of other similar data. This has enabled us to make a detailed comparison of the death-rates with the composition of the air in various classes of dwelling-houses.

This, we believe, is the first time such a comparison has been made, and is, in fact, the first time it has been possible, owing to the lack of necessary data. The following Table represents the results we have thus obtained. In constructing this Table, there has been a difficulty as regards the deaths occurring in the Infirmary and Poor-houses. These deaths, in the case of some diseases, materially affect the results, and, as they are almost always those of people belonging to one- and two-roomed houses, we have added a final column to the Table, in which the data for the Infirmary and Poor-houses are added to those for the one- and two-roomed houses together. The numbers in this column for those diseases which are not materially affected by the Infirmary and Poor-houses are placed in square brackets.

The Table is divided into five sections, of which the first gives the chemical and physical data referring to the different classes of houses; the second, the statistics of the death-rate; the third, statistics as to the mean age at death; and the fourth and fifth, the death-rates caused by different diseases. Those given in Section 5 are placed separately, because the number of deaths to which they refer is too small to allow of a general conclusion being drawn as to any possible connexion with the different classes of houses. The figures are, however, of sufficient interest in themselves to deserve a place in the Table.

Again, the diseases in the fourth section, and which cause more than 50 deaths, are divided into three classes, of which (A) contains those which show a complete parallelism with the number of rooms in the house; and (B) those which show a complete parallelism only when the Infirmary and Poor-house deaths are taken into account; while (C) includes those which do not exhibit any *evident* connexion with the class of house. The cubic spaces per person given in the first section are the means of our own observations, though it is probable that they are somewhat lower than they would be for the whole town. Unfortunately we have no statistics as regards the condition of the air in 3-roomed houses.

A consideration of the Table shows:—

(1.) That, as we pass from 4-roomed and upwards to 3-, 2-, and 1-roomed houses, not only does the air become more and more impure, as indicated by the increase in the carbonic acid and organic matter, and more especially of the micro-organisms, but that there is a corresponding and similar increase in the death-rate, together with a marked lowering of the mean age at death.

(2.) That the rapid increase in the death-rate as we pass from 4- to 1-roomed houses is by far the most marked in children under five; that the death-rate among these young children in 1-roomed houses is nearly four times as great as in 4-roomed houses, whereas the general death-rate is not quite twice as great; further, that although there is still a marked increase in the death-rate for all above five years of age in the smaller houses, yet this increase is comparatively small, and is not evident unless the deaths in the Infirmary and Poor-houses be included in the 1- and 2-roomed houses. The death-rates of persons above 70 and also above 80 years of age in the different classes of houses is likewise interesting and instructive. In each of these cases the death-rate rapidly increases from 1- to 4-roomed houses; showing, not that persons above these ages are more likely to die in 4-roomed than in 1-roomed houses, but that there are more persons of advanced age living in the better class than in the 1-roomed houses.

(3.) The mean age at death in the better-class houses is almost twice as great as in 1-roomed houses. Persons living in 1-roomed houses have, therefore, the chance at

TABLE of the Chemical, Physical, and Death-Rate Statistics referring to Different Classes of Houses.

		No. of cases.	Whole population.	Houses. 4-roomed and upwards.	3-roomed.	2-roomed.	1-roomed.	1- and 2-roomed, including Infirmary and Poor-houses.
Chemical and physical statistics.	Total estimated population	..	150,329	23,007	22,087	79,825	25,410	..
	Average number of persons per room	60	..	1·3	..	3·4	6·6	..
	Space per person (in cubic feet)	60	..	1833	..	249	212	..
	Average temperature (° Fahr.)	43	..	54½	..	53½	55	..
	Carbonic acid (vols. per 10,000)	59	..	7·7	..	9·9	11·2	..
	Oxidisable organic matter (O required per 1,000,000 vols. of air)	58	..	4·5	..	10·1	15·7	..
	Total micro-organisms	59	..	9·0	..	46·0	60·0	..
	Bacteria	46	..	8·5	..	43·0	58·0	..
	Moulds	46	..	0·4	..	2·2	1·2	..
			Per 1000.					
Death-rate.	*General death-rate	3119	20·7	12·3	17·2	18·8	21·4	23·3
	Death-rate of children under 5 years of age	1347	9·0	3·3	5·8	9·8	12·3	10·8
	Ditto of all above 5 years of age	1772	11·7	9·0	11·4	9·0	9·1	12·5
	Ditto of all above 20 „ „	1419	9·4	8·2	8·9	7·3	8·5	9·8
	Ditto of all above 70 „ „	293	1·9	2·4	2·1	1·4	1·3	1·4
	Ditto of all above 80 „ „	75	0·5	0·65	0·77	0·39	0·20	0·41
Mean age at death.	Of all who died	3119	24·5†	40·0	30·6	21·3	20·9	23·9
	Of all who died above 70 years	293	76·3	76·9	77·2	76·9	74·6	76·0
	Of all who died above 20 „	1419	53·6	57·7	54·4	51·6	54·8	52·1
	Of all who died below 20 „	1619	2·5	4·5	4·4	2·2	1·8	2·3
	‡Of all who died above 5 „	1732	45·2	51·7	45·5	43·0	48·2	44·1
	Of all who died below 5 „	1306	1·1	1·4	1·2	1·1	0·9	1·0
	Of all who died between 5 and 20 years	313	9·2	11·7	12·2	8·3	7·0	8·3
			Per 10,000 living.					
Diseases causing more than 50 deaths.	Deaths from under-mentioned causes:—							
A	§Diarrhœa	253	16·9	6·1	11·3	17·4	26·4	[20·2]
A	§‖Measles	94	6·3	1·3	3·6	7·0	9·1	[7·9]
A	§Convulsions	78	5·2	1·7	2·3	6·5	6·7	[6·6]
A	Accidents (including overlaying)	93	6·2	1·7	1·8	3·4	14·6	8·3
A	Premature birth and debility during first days of life	177	11·8	3·0	6·3	13·4	17·0	[14·8]
A	§Acute bronchitis and broncho-pneumonia	224	14·9	7·8	9·5	13·4	26·7	[17·6]
B	Chronic bronchitis	159	10·6	6·3	9·5	8·1	16·5	11·8
B	Croupous pneumonia	155	10·3	3·5	6·6	12·7	9·5	12·5
B	§Meningitis	122	8·1	5·7	6·8	8·9	6·7	8·9
B	§‖Hooping-cough	99	6·5	0·9	6·8	8·3	6·3	[7·8]
B	Tumours	73	4·2	2·2	3·6	4·1	3·1	5·7
B	Heart (valvular) disease	159	10·6	9·1	9·5	8·4	9·4	11·1
C	Phthisis	369	24·6	13·0	27·6	24·4	14·6	26·4
C	Apoplexy, thrombosis and embolism of vessels of brain	160	10·7	17·4	5·9	6·9	7·9	10·2
C	§Diphtheria and croup	93	6·2	7·0	4·1	6·9	3·1	6·5
C	"Old age"	150	10·0	8·7	12·7	5·5	7·5	9·7
Diseases causing less than 50 deaths. D	Suicide	7	0·5	0·4	0·4	0·4	0·4	0·5
D	Septicæmia (including puerperal)	14	0·9	0·4	0·4	0·5	0·4	1·1
D	Scarlet fever	10	0·7	1·3	0·9	0·25	0·8	0·5
D	Erysipelas	11	0·7	1·3	0·9	0·4	0·8	0·6
D	Typhus fever	2	0·1	0	0	0·1	0·4	0·2
D	Typhoid fever	13	0·9	0·4	1·8	0·9	0	0·8
D	Intestinal obstruction	16	1·1	0	0·9	0·6	2·4	1·3
D	Peritonitis	21	1·4	0·4	5·0	0·6	0·4	0·9
D	Acute and chronic Bright's disease	41	2·7	0·9	4·1	2·8	0·8	2·8
D	Chronic bone and joint disease	29	1·9	1·8	1·4	1·6	0·8	2·1
Miscellaneous. E	Rare diseases	130	8·6	5·6	7·7	8·2	5·9	9·5
E	Unsatisfactory certificates	245	16·3	14·7	19·9	17·5	14·6	..
E	Deaths which could not be classified	122	8·1	..	..	..	..	..

* Death-rates for 1884:—Edinburgh, 19·7; London, 20·3; Birmingham, 21·4; Leeds, 24·2; Liverpool, 25·2; Manchester, 26·4; Glasgow, 26·9. Death-rates for 1883:—London, 22·7; English Towns, 19·6–26·7; Copenhagen, 21·4; Paris, 25·3; Berlin, 26·9; Vienna, 29·5.

† Mean age at death for all England is about 40·4 (PARKES, p. 522).

‡ Mean age at death of all who died above 5 was (from 1875–81) in London, 49·3; Paris, 47·2; Vienna, 44·1; and Berlin, 43·6.

§ Chiefly children.

‖ The majority of deaths by measles and hooping-cough are due to secondary broncho-pneumonia.

birth of living only one-half as long as those in better-class houses, or they die nearly 20 years sooner, on the average, than those of the better class. This is an enormous difference. If we take the mean age of those who died above 20, we find that a similar lowering of the mean age at death likewise occurs in the worse class of houses, though not nearly to such a marked degree. It is, in fact, only the strong ones who have survived in the 1- and 2-roomed houses, the weaker ones having been mostly cut off before they reach the age of 5 years. The higher mean age at death of those who died above 20 years of age in 1-roomed houses, though possibly due partly to the fact that a larger proportion of the people living in 1-roomed houses are employed in outside labour during the day than is the case with the other classes, is, doubtless, chiefly due to a process of natural selection, whereby the weaker ones have been taken off earlier in life, so that those who are left are much more able to combat circumstances unfavourable to life than are those in 2- and 3-roomed houses, and who have not undergone this natural selection to nearly such a great extent.* The Table also shows that in better-class houses persons above 70 are likely to live about a year longer than those above 70 years of age in 1- and 2-roomed houses, although the latter are to a much greater extent a "survival of the fittest."

(4.) As regards deaths from particular causes, those from phthisis require special notice.

As is well known, and as other statistics† have conclusively proved, the prevalence of phthisis is very largely affected by the state of purity of the air. It might have been expected, therefore, that the death-rate from phthisis especially would show a marked parallelism with differences in the condition of the air, and, consequently, in the

* KÖRÖSI (see 'Annales d'Hygiène Publique,' vol. 14, 1885, p. 571) finds that for the years 1874-1881 in Buda-Pesth the mean age at death was :—

	Of all who died: Below 5 years of age.	Of all who died: Above 5 years of age.
Among the rich	1·3 years	52·0 years
" middle class	1·2 "	46·1 "
" poor	1·0 "	41·6 "

Or, arranged according to the class of houses, as follows :—

	Of all who died above 5 years of age.
Best class of houses	44·2 years
Middle " "	42·2 "
Worst " " (cellars)	39·9 "

† See PARKES' 'Hygiene,' 6th edition, page 133 *et seq.*, also page 105, in which a large number of facts are adduced, of which the following may serve as examples :—

Two Austrian prisons, in which the diet and mode of life were, it is believed, essentially the same, offer the following contrast :—In the prison of Leopoldstadt, at Vienna, which was very badly ventilated, the death-rate in 1834–1847 was 86 per 1,000, and of these no less than 51·4 died from phthisis.

In the well-ventilated House of Correction in the same city, the death-rate (1850–1854) was only 14 per 1,000, and of these 7·9 died of phthisis.

class of house. This, however, is not so according to the Table, for the death-rate from phthisis is much the highest in 3-roomed houses, and then diminishes to 1-roomed houses, in which it becomes almost as low as in better-class houses. When the deaths from phthisis in the Poor-houses and Infirmary are set down against those living in 1- and 2-roomed houses, this class has still a lower death-rate from phthisis than those living in 3-roomed houses. On consideration, the explanation of this appears to be quite simple. Deaths from phthisis do not usually occur much under 20 years of age, tubercular disease under that age usually taking other forms. Now those living in 1-roomed houses, and who would be most liable to be attacked by phthisis, have been already killed off at a much earlier age by diarrhœa, acute bronchitis, broncho-pneumonia, tubercular meningitis, etc.; hence the smaller death-rate from phthisis in 1- and 2-roomed houses. In fact, the diseases just mentioned may be almost considered as the complement of phthisis, so that as the one increases the total of the others diminishes, but less rapidly: their sum, therefore, still shows a marked increase from 4- to 1-roomed houses.

	Number of rooms.			
	4 and upwards.	3	2	1
Death-rate per 10,000 from:—				
Diarrhœa, acute bronchitis, broncho-pneumonia, and meningitis	19·6	27·6	39·7	59·8
Phthisis	13·0	27·6	24·4	14·6
Total from all the above causes	32·6	55·2	64·1	74·4

Were only the cases of diarrhœa occurring during childhood included in the first category, the above figures would become still more striking.

(5.) The considerable increase in acute bronchitis, broncho-pneumonia, etc., as we pass from 4- to 1-roomed houses, fully confirms, though in a different way, previous observations as to the effect of impure air in promoting pulmonary diseases. A very conclusive example of this is given in the report by Deputy Surg.-General SIMPSON (and quoted in PARKES' 'Hygiene,' 6th edit., p. 135) on the health of the South Afghanistan field-force during the time they wintered at Candahar in 1880–81.

(6.) Of those diseases which are usually considered infectious, measles, hooping-cough, and diphtheria (including croup) are the only ones for which there are sufficient deaths to allow a conclusion to be drawn. Of these, the mortality from measles and hooping-cough, but especially the former, shows a very distinct connexion with the class of house. Contrary to expectation, the mortality from diphtheria and croup does not show any connexion with the class of house.*

(7.) It is seen that deaths certified as being due to "old age" do not run parallel with the different classes of houses, though one would have expected that they would have done so, and that the numbers would have diminished from 4- to 1-roomed houses. "Old age" is a somewhat indefinite term as a cause of death, and would be materially affected by the mode in which the doctors filled in the certificates; so that it does not form a safe indication of the number of people of advanced age living in the various classes of houses. A reliable indication of this, however, is furnished by the death-rate of persons who die above 70 or above 80 years in the different classes of houses; and, as already remarked above, this shows a complete parallelism, and proves conclusively that there is a much larger proportion of old people living in the better than in the worse class of houses.

The effects of impurity in air on the death-rates from different diseases are more particularly discussed below (page 105).

The Air of Schools.†

In the course of our investigations we have examined the following schools and other educational institutions in Dundee :—

(a.) *Sixteen ordinary Board schools* (all the schools under the Dundee Board).— Two rooms were examined in each school. Some of the schools were heated by fires and others by hot pipes. They were all ventilated by the ordinary means usually adopted in such buildings, viz., fires, ventilators in the roof, and open windows. The great majority of the latter opened by means of hinged panes, opening obliquely so as to direct the entering current upwards.

(b.) *The Harris Academy.*—This school is also under the Board, but is of a higher grade than the ordinary Board schools, and the children are of a higher class. Fifteen rooms were examined in this school on various occasions and under different conditions. Of those examined, twelve rooms were mechanically and three naturally ventilated.

(c.) *A half-time school* belonging to one of the large mills in the town.—The two rooms (one for girls and the other for boys) were frequently examined under different conditions. The children in this school are employed half the day in the mill, and are at school the other half. This school was ventilated mechanically.

(d.) *Two denominational schools.*—Two rooms in each; these were naturally ventilated and heated by fires.

* Körösi (*loc. cit.*) has shown that the mortality from infectious diseases generally increases with the density of the population, and that this is most marked in the case of hooping-cough and measles, but is not evident with scarlet fever and diphtheria. (Cf. below, p. 107.)

† See also Supplementary Note, p. 111.

(e.) *One private school (girls).*—Three rooms examined. Heated by fires and ventilated naturally.

(f.) *The Dundee High School.*—Six rooms examined. Ventilated mechanically.

(g.) *The two Lecture-rooms and large general laboratory of the Chemical Department, University College.*—These were frequently examined under various conditions. Ventilated mechanically.

We have thus examined no less than sixty-eight different schools and college class-rooms, and some of these many times, under different conditions as regards ventilation.

Of these forty-two were ventilated in the ordinary way by fireplaces, windows, &c. (natural ventilation), twenty-six were ventilated by fans which blew air into the rooms (mechanical ventilation).

The comparatively large number of schools in Dundee which are ventilated mechanically make it a very good field for testing the relative efficiency of natural and mechanical ventilation. The large number of data we have thus been able to obtain in schools ventilated on the two systems will, we think, be of considerable interest, not only to educationalists, but to all who have to do with the ventilation of public buildings.

The method adopted in all those rooms which are mechanically ventilated* is to blow air by fans over hot pipes, and thence into the several rooms by broad, shallow, upright shafts, opening at a height of five feet from the floor. The vitiated air is taken off by shafts which open two feet from the floor and carry the air up into a chamber in the roof. Thence it is discharged through louvre-boarded ventilators, fitted inside with valves, which prevent any possibility of back draughts. As a rule there is an outlet shaft at each end of the room, and one or more inlet shafts on each side. The air on entering the room thus passes wholly or partially towards the ceiling, and must thence pass downwards to find an exit by the upcast shafts, which open near the floor. The current is intended to sweep the whole room in this way, while the broad and shallow inlet shafts, through which a large volume of air enters at a low velocity, ensure a good distribution of air with as little draught as possible.

All the schools were examined during the winter months, between December 16, 1885, and April 28, 1886. They were visited without previous warning, except in one or two cases where special experiments were to be made, such as having the ventilating fans stopped, &c. We observed the state of the windows before entering; and the masters were always good enough to keep them in the same condition during our observations as that in which we found them. Hence, if any windows were open on our arrival they remained so, or if shut they remained shut, our object being to have everything under the usual conditions so far as possible. The samples were collected as near the centre of the room as possible. The results are stated in the following Table :—

* For all these Mr. WM. CUNNINGHAM, of Dundee, was the engineer.

	Schools.							
	Naturally ventilated.				Mechanically ventilated.			
	No. of cases.	Lowest.	Highest.	Average.	Average.	Lowest.	Highest.	No. of cases.
Per cent. of windows open	..	..	..	22	3	..	..	..
No. present, including staff	39	27	191	92	64	20	170	20
Space per person	39	56	427	168	164	119	228	20
Temperature (° Fahr.)	35	44	65	55·6	62	58	69	18
Carbonic acid	39	7·9	37·8	18·6	12·3	7·0	19·6	20
Organic matter	38	5·0	40·3	16·2	10·1	3·4	19·0	20
Total micro-organisms :—	35	8	600	152*	16·58*	0	58	18
Bacteria	28	8	600	151	16·0	0	56	18
Moulds	28	0	4	1·1	0·58	0	2	18
Or above outside air :—								
Temperature (° Fahr.)	25	3	34	16·8	24	22	26	3
Carbonic acid	39	4·4	34·3	15·1	8·9	3·5	16·1	20
Organic matter	38	0	31·4	7·8	1·1	0	5·3	20

Or, if we take as units the average cubic space, the average excess over outside air of temperature, of carbonic acid, and of organic matter, and the average micro-organisms, in mechanically ventilated schools, the comparative results for naturally ventilated schools may be expressed as in the following Table :—

	Mechanically ventilated.	Naturally ventilated.
Cubic space per person	1	1·0
Temperature in excess of outside air	1	0·66
Carbonic acid ,, ,,	1	1·7
Organic matter ,, ,,	1	7·0
Micro-organisms ,, ,,	1	9·2
Bacteria ,, ,,	1	9·4
Moulds ,, ,,	1	2·0

The above Table shows that with mechanical ventilation, the space per person being the same :—(1) The carbonic acid was three-fifths, the organic matter one-seventh, and the micro-organisms (see pp. 96, 97–98) less than one-ninth of what they were in schools ventilated by ordinary methods. (2) That, notwithstanding this very great improvement in the purity of the air, the temperature is very considerably higher in the mechanically ventilated schools.

To produce such improvement in purity by the ordinary methods of opening windows, &c., would have reduced the temperature to a very uncomfortable and dangerous degree. The improvement is also obtained with comparatively little

* The marked difference between these two classes of schools is shown still more distinctly by the fact that of the mechanically ventilated schools only two contained more than 26 micro-organisms per litre, whereas of the naturally ventilated schools only three contained less than 26 per litre.

perceptible draught. When a draught is perceptible it is a warm, and not a cold draught, as is the case with ventilation by an open window.

Mechanical ventilation does not merely reduce the number of micro-organisms during the time it is in action, but has, as will be shown below (p. 97), a marked effect after it has been stopped and replaced by natural ventilation, this effect extending over a period of many days at least.

Further, mechanical ventilation, as shown by Professors BRAZIER and NIVEN, of Aberdeen University (see below), keeps the composition of the air more or less constant at different points in a room, whereas with natural ventilation it is liable to be much more impure at one part than another.

We have not included in the above Table the Dundee High School nor the only private school we have examined, as in these two cases the cubic space per person was about three times as great as in the other schools. The results for these two schools were as follows. It will be seen that practically they confirm the conclusions drawn from the results in other schools, though the effects of mechanical ventilation are not nearly so marked. The reasons for this will appear subsequently (page 98).

	Private school. (Girls.) Naturally ventilated.				Dundee High School. (Boys and girls.) Mechanically ventilated.			
	No. of rooms examined.	Lowest.	Highest.	Average.	Average.	Lowest.	Highest.	No. of rooms examined.
Number present	3	6	11	9	36	13	64	6
Space per person	3	320	528	457	538	320	1102	6
Temperature (° Fahr.)	3	56	57	57	57	51·5	60·5	6
Carbonic acid	3	10·7	13·3	11·9	13·0	8·5	16·4	6
Organic matter	3	6·2	11·8	8·9	3·9*	1·7	5·6	6
Total micro-organisms	3	4	15	9·3	3·6	1	11	7
Bacteria	3	4	15	9·0	2·9	1	10	7
Moulds	3	0	1	0·3	0·7	0	3	7

Last year Professors BRAZIER and NIVEN made a report to the Aberdeen School Board on the ventilation of schools in that town. From this report it appears that they examined (the carbonic acid only being determined) four different schools ventilated in the ordinary manner, and two schools ventilated mechanically by fans. From their detailed results we have calculated that the average temperature and carbonic acid in excess of the outside air were as follows:—

*A determination of the organic matter in the outside air was not made when the High School was examined; but, as the outside organic matter on the day we visited the private school amounted to only 1·6, the private school must have been considerably in excess of the High School, even allowing nothing for the outside air when the latter school was examined.

	Temperature. (° Fahr.)	Carbonic acid.		Ratio.	
				Temperature.	Carbonic acid.
Mechanically ventilated . .	16	11·0	Or	1·0	1·0
Naturally ventilated . . .	14·6	17·0		0·9	1·6

It will be seen that, though the average excess of carbonic acid found by them was somewhat higher than what we have found from the examination of a much larger number of schools, yet the ratio is practically the same (1 to 1·6 instead of 1 to 1·7). Like us, they found the excess of temperature over outside air greater in the mechanically than in the naturally ventilated schools, though the difference is not so marked in their observations as in ours. They conclude that mechanically ventilated schools "compare very favourably with those on the other system." We, however, would speak much more strongly than this in favour of mechanical ventilation, since it not only considerably reduces the carbonic acid, but effects a very much greater reduction of those impurities which are undoubtedly far more injurious to health than the usual excess of carbonic acid. It does this also without producing the very objectionable fall in temperature necessarily associated with effective natural ventilation. We entirely agree with Professors Brazier and Niven in believing that the system of ventilating by open windows is, for winter, at least, very objectionable. The severe draughts thus produced are possibly a worse evil than defective ventilation.

It is true that mechanical ventilation is apparently more costly; but it remains to be proved that it really is so. As our results show, the cubic space per child would not require to be nearly so great, in order to maintain a given standard of purity, on the mechanical as on the "natural" system. Hence the cost of building would be less. The cost of heating would also be reduced, on account of the smaller space to be heated. The reduction in space could most advantageously be made in the height of the rooms.

The chief difficulty in connexion with mechanical ventilation is to maintain a proper distribution of the air, and consequently of the heat, in several rooms within the same building. With proper care, however, there is no reason why this should not be accomplished.

The all-important argument for mechanical ventilation is that it maintains a certain standard of purity, and, unless some simpler method which will maintain a similar standard can be devised, its adoption in crowded schools seems to be very much required.

When we come to consider that the children who attend average Board schools for six hours a day are during that time subjected to an atmosphere containing on an average nearly 19 volumes of carbonic acid per 10,000, and a very large proportion of organic matter, and no less than 155 micro-organisms at least per litre, we need not be surprised at the unhealthy appearance of very many of these children. It must also be borne in mind that many of them are exposed for nine hours more to an atmosphere which, as we have shown above, is about five times as impure as that of an ordinary bed-room in a middle-class house. They are thus breathing for at least fifteen hours out of the twenty-four a highly impure atmosphere. The effects of this are often intensified, as is well known, by insufficient food and clothing, both of which must render them less capable of resisting the impure air. The fact that these schools become, as will be shown below, after a time habitually infected by bacteria renders it probable that they also become permanent foci of infection for various diseases, and particularly perhaps for tubercular disease in its various forms. From the considerations advanced later on (page 106), it will be seen how an ordinary simple cold, brought on say by a draught, may become a source of great danger to a child attending such a school.

The *cubic space per person in schools*, unlike that in houses, shows no definite connexion (as will be seen below) with the purity of the air, except as regards the number of micro-organisms. In mechanically ventilated schools these diminish in a marked manner with increase of cubic space. In naturally ventilated schools, on the other hand, the number of micro-organisms was found to increase as the cubic space increases from 50 to 250 cubic feet, after which it diminished (cf. pp. 93, 94, 95).

Cubic space per person.	Naturally ventilated.				Mechanically ventilated.			
	No. of cases.	Carbonic Acid.	Organic matter.	Total micro-organisms.	No. of cases.	Carbonic Acid.	Organic matter.	Total micro-organisms.
Cubic feet.								
50–100	6	21·5	16·2	119	..	..	..	..
100–150	14	15·5	19·6	128	7	14·0	7·8	23
150–200	5	18·9	12·3	150	8	11·4	9·6	14
200–250	9	21·1	16·8	188	5	11·8	12·3	10
250–300	4	17·1	9·5	187	..	..	..	..
300 and upwards	4	15·1	11·8	12	6	13·0	3·7	2

Boys' and Girls' School-rooms.—The difference between boys' and girls' rooms is most marked. Out of fifteen pairs of rooms, one room of each pair being occupied by boys and the other by girls, and under circumstances* as nearly as possible the same, no less than fourteen gave a *much lower* result in favour of the girls as regards micro-organisms, whilst the only exception against the girls was a room in one of the denominational schools. This room was lighted only by two skylights, though in

* Such as class of children, mode of ventilating, cubic space, time of experiment, &c., and, with but one exception, in the same building; in this exception the two schools were in connexion with one another.

other respects similar to the boys' room, which was lighted by windows (open) and had only half as much space per person as the girls' room.

In ten pairs which could be compared for carbonic acid eight were *very largely* in favour of the girls, whilst in one of the two exceptions the girls were only *very slightly* in excess of the boys. As regards the oxidisable organic matter, there were, out of nine pairs which could be compared, six *largely* in favour of the girls, whilst of the three exceptions two were only slightly in excess of the boys. With two exceptions, out of ten pairs of rooms compared, the temperature with the girls was always lower than with the boys.

The average results are given in the following Table :—

	Space per person.	Tempera-ture. (° Fahr.)	Carbonic Acid.	Organic matter.	Micro-organisms.		
					Total.	Bacteria.	Moulds.
No. of rooms compared .	30	20	20	16	30	30	30
Boys	275	60	15·0	7·9	92	90	2
Girls	382*	58	12·3	6·7	65	64	1

It is thus seen that boys tend to make the air of a room more impure than girls do, and that consequently they require a more efficient ventilation in order to maintain a given standard of purity in the air of their rooms. The reasons for this are not far to seek, and may be stated as follows :—(1) The boys are more restless, and so raise more dust, which necessarily contains micro-organisms (see below). For the same reason they evolve more carbonic acid, and probably organic matter. (2) The girls are, as a rule, cleaner, and this has a marked effect (as will be shown below) in diminishing the number of micro-organisms. (3) Boys usually come to school after more violent exercise than girls, which results in the production of more carbonic acid, and probably of organic matter (see below). (4) From differences in constitution, more or less apart from the above reasons, boys evolve more carbonic acid, and perhaps of organic matter (see PARKES' 'Hygiene,' 6th edn., p. 114). Or, to sum up some of the above reasons, and put them from a slightly different point of view, boys eat more than girls.

THE AIR OF MILLS AND FACTORIES.

We have only examined four of these, samples having been taken from two rooms in each. As the results obtained differ very widely in the several cases, we are not

* This cubic space in favour of the girls is caused by the space per person in one of the rooms being very much larger than in any other.

able to draw any very definite conclusions in respect to them. Such results, however, as we have obtained are expressed in the following Table. All the works examined were engaged in the manufacture of jute and tow, this being the staple trade of Dundee. The visits were all made without previous intimation as to the time of our visit.

	No. of rooms examined.	Lowest.	Highest.	Average.
No. of persons present	8	6	500	157
Space per person	8	593	5485	1773
Temperature (° Fahr.)	6	45	58	53
Carbonic acid	8	4·8	23·2	13·3
Organic matter	8	5·3	36·1	17·4
Total micro-organisms	6	4	600	160
Bacteria	6	4	586	114
Moulds	6	0	600	125

A room in one of the mills gave a total of (at least) 260 micro-organisms per litre, of which 12 were bacteria and 248 were moulds. The moulds in this case grew very rapidly, and finally filled and choked up the tube. They had a very beautiful and delicate appearance, like frosted glass, and with a woolly texture. Being much struck with the character of this growth, and not having obtained anything similar in any other case, we made a second examination of the room five weeks after the first visit. The result was the same as before, except that the moulds grew even more rapidly and luxuriantly. This time they amounted to at least 586 per litre. The predominating species of mould appeared to be exactly the same as in the first case, and it rapidly overgrew any other moulds or bacteria which appeared in the tube. One of the tubes containing these moulds is represented in Plate 6 (fig. 1).

What the cause was of the prevalence of this mould in the room we could not discover at the time. We subsequently learned, however, that about eight months previous to our visit the owners of the mill had purchased, and subsequently manufactured, a considerable quantity of loose re-dried jute which had been saved from a stranded vessel. This may possibly have been the original source of the moulds which had come to prevail in the mill.

Dundee Royal Infirmary.

We also made an examination of four different wards in the Infirmary. One series of observations was made in the afternoon between 4.30 P.M. and 5.5 P.M., and the other in the early morning of the following day between 2.40 A.M. and 5.30 A.M. Previous intimation had, of course, to be given in this case. The wards are heated by hot pipes and fires, and ventilated on the natural system. All the windows (about ten) in each of the wards were open about one inch at the time of our visit. The Infirmary is situated in a large open space on a hill at the back and on the north side of the town. The results were as follows:—

March 26th and 27th, 1886.	Time.	Gas jets burning.	Temperature.	No. of persons, including nurses.	Space per person.	Carbonic acid.	Organic matter.	Total micro-organisms.	Bacteria.	Moulds.	Remarks.
	p.m.		° Fahr.								
Accident Ward	4.30	0	58	18	1388	5·8	8·9	2·5	2	0·5	Felt very fresh.
Children's Ward	4.40	0	59	29	1034	6·1	6·2	2	2	0	Not close, but a distinct odour very perceptible.
Medical Ward No. 12	5.0	0	61	24	1458	4·9	7·5	5	1	4	Somewhat faint close smell.
,, ,, No. 10	5.5	0	62	11	3182	4·3	6·5	0	0	0	Felt fresh; scarcely any smell.
Outside air in front of Infirmary	6.20	...	48	...	...	3·2	3·5	...	...	...	Wet rainy day. Windy. S.E.
	a.m.										
Children's Ward	2.40	2	59	28	1071	6·9	1·9	6	2	4	Scarcely any smell; much fresher than in day.
Medical Ward No. 12	3.35	2	60	23	1522	5·5	2·0	4	1	3	Scarcely any smell.
Outside air as before	5.0	...	43	...	...	3·5	3·8*	...	...	...	Fine, but somewhat overcast. Mill chimneys, tops of which were on level with Infirmary, were turning out black smoke in large quantity.
Accident Ward	5.10	1	53	18	1388	7·8	5·1	28	26	2	Fresh; scarcely any smell.
Medical Ward No. 10	5.25	1	60	11	3182	4·1	5·7	0	0	0	No smell; fresh.

If the ventilation was in its normal condition, the above results indicate a very satisfactory state of things as regards the air of the Infirmary wards.

Having now described the results obtained in the various classes of buildings, the air of which was examined, we must now turn to certain special points of general interest.

Relation of Quantity of Carbonic Acid to Quantity of Organic Matter and Number of Micro-organisms.

No constant relation between the quantities of carbonic acid, organic matter, and micro-organisms can be detected in individual cases (see PARKES, p. 147; also DE CHAUMONT, 'Roy. Soc. Proc.,' vol. 23, p. 188). Sometimes we find a high organic matter accompanied by a low carbonic acid, whilst under other circumstances the reverse may be the case. A determination of carbonic acid alone is therefore never a sufficient indication of the purity or otherwise of a given sample of air. Nevertheless, by taking the average of a considerable number of observations, we find that there is a *general* relationship, so that a high carbonic acid is, as a rule, accompanied by a high organic matter, and *vice versâ*, though this is by no means always the case. There appears, however, to be no definite connexion between the number of micro-organisms and the amount of carbonic acid (see page 93).

* The sudden increase in oxidisable organic matter at this time was due to the firing up of the boilers at the mills, the tops of the chimneys of which were on a level with the Infirmary, and large quantities of thick black smoke were being turned into the air.

These conclusions will be seen to follow from the accompanying Tables :—

	Carbonic acid.	Organic matter.	Total micro-organisms.	No. of cases.
	Mean.	Mean.	Mean.	
With 2– 4 volumes Carbonic acid*	2·7	5·6	1·9	56
,, 4– 6 ,, ,,	4·9	6·1	3·5	27
,, 6– 8 ,, ,,	7·3	10·4	29·7	25
,, 8–10 ,, ,,	8·9	9·5	33·5	26
,, 10–12 ,, ,,	11·1	11·4	79·6	29
,, 12–15 ,, ,,	13·3	11·8	36·3	27
,, 15–20 ,, ,,	17·0	13·0	137·0	31
,, 20–30 ,, ,,	22·9	13·6	82·0	12
,, 30 and above ,,	37·1	19·8	53·0	9
With 0– 2·8 volumes of Oxygen required for organic matter	4·3	1·6	5·3	21
,, 2·8– 5·6 ,, ,, ,, ,,	6·8	4·2	10·1	52
,, 5·6– 8·4 ,, ,, ,, ,,	9·7	7·2	34·1	58
,, 8·4–11·2 ,, ,, ,, ,,	10·7	9·7	29·2	24
,, 11·2–14·0 ,, ,, ,, ,,	11·9	12·6	88·3	31
,, 14·0–16·8 ,, ,, ,, ,,	16·0	15·4	57·1	17
,, 16·8–22·4 ,, ,, ,, ,,	18·5	19·3	145·0	17
,, 22·4 and above ,, ,, ,,	18·8	29·7	87·0	15

In the first, the other constituents are compared with the carbonic acid as standard; in the second, with the organic matter as standard.

Circumstances affecting the Organic Matter in Air.

The most important circumstances which suggest themselves as likely to affect the amount of oxidisable organic matter in air are the following:—(1) Combustion of coal, (2) ditto of coal gas and of oil, (3) respiration, (4) dust, (5) physical exercise, (6) cleanliness.

1. *Combustion of Coal.*—A close connexion is traced between the amount of organic matter present in air and the combustion of coal. This point has been investigated by one of us in conjunction with Mr. Wm. Mackie ('Roy. Soc. Proc.,' vol. 41, p. 238), and as a result of that investigation it was found that in town the organic matter was lowest during the night, rather higher in the morning (5 A.M. to 10 A.M.), considerably higher in the middle of the day (10 A.M. to 3 P.M.), and higher still towards evening (3 P.M. to 8 P.M.), after which it decreased. It is generally rather high in the early morning (5 A.M. to 7 A.M.), when fires are being lit, and the black smoke of incomplete combustion discharged from the chimneys (compare pp. 65–69; also Parkes, p. 117).

In examining the air of a room for organic matter, it is therefore necessary also to determine the condition of the outside air at the same time.

2. *The Combustion of Coal Gas* does not appreciably increase the quantity of organic

* Compare Parkes, 6th edit., p. 116.

matter in air, whereas a burning oil lamp has a very marked effect in this respect (see Carnelley and Mackie, *loc. cit.*).

3. *Respiration.*—Carnelley and Mackie (*loc. cit.*) have also shown that the quantity of organic matter in the air of a room becomes greater as the period of vitiation by respiration increases. In this connexion we have made a set of experiments with the object of determining the amount of organic matter in undiluted expired breath. For this purpose the observer inspired the air of the room through his nose, and expired through the mouth into a closed bottle of about $3\frac{1}{2}$ litres capacity, and provided with a small outlet tube for the escape of the excess of expired air. This bottle was maintained at a temperature of about 45° C. by immersion in warm water, in order to prevent condensation of moisture from the breath. When the bottle was full of expired air, for which 50 expirations were considered sufficient, the temperature of the enclosed air was observed, the inlet and outlet tubes closed, and the bottle removed from the bath and allowed to cool down to the temperature of the room, when the inlet tube was opened and air allowed to enter to fill the partial vacuum. The temperature of the enclosed air was again observed, and the amount of organic matter determined in the usual way. A determination of the organic matter in the air of the room was likewise made at the same time. The proportion of expired and unrespired air of the room in the bottle could be found by calculation. Then, by deducting from the total organic matter that present in the known proportion of unrespired air, the difference gave the amount of organic matter in undiluted breath. Care was taken to breathe as nearly as possible in a natural manner. The results obtained were as follows :—

Observer A.			Observer B.		
Total in expired air.	In air of room.	Excess in expired air.	Total in expired air.	In air of room.	Excess in expired air.
3·3	1·6	1·7	6·5	3·0	3·5
12·4	3·2	9·2	12·2	1·6	10·6
5·8	1·6	4·2	13·3	4·7	8·6
11·8	2·2	9·6	13·1	1·9	11·2
15·6	2·0	13·6	10·1	2·3	7·8
Average per litre		7·6	Average per litre		8·3

The above determinations were mostly made on different days. According to these experiments the amount of oxidisable organic matter in breath is by no means constant, but varies from time to time, nor is the quantity so great as one might have expected. It is possible, however, that the organic matter in freshly expired breath is not in a condition to readily reduce permanganate, but after exposure for some time in the air it may undergo such a change as will render it more readily oxidisable.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

4. *Effect of Dust and of the Stagnation of the Air.*—An atmosphere which has been entirely at rest for some time contains less organic matter than it did previously. This, however, is not necessarily due altogether to the settling down of solid organic dust (though dust materially affects the determinations), but is probably owing in part to oxidation. The effect of stagnation, and thence of settling, and possibly of partial oxidation, was shown by the following results :—

	Organic matter.	Second experiment.
Air of dark cellar which had been kept closed for some time	9·4	
Outside air at same time	13·2	
Air-tight room after being well ventilated with outside air and then closed for three days	4·9	
Outside air on third day	9·5	
Same room after ventilation with outside air	3·2	1·7
Ditto, after being closed for two days	Too small to estimate	Too small to estimate.
Ditto, after ventilation with outside air	1·7	Ditto
Same room after five persons had been in the room for $\frac{3}{4}$-hour with the door closed	3·2	
Ditto, after the room had been closed for two days	1·7	
Organic matter in outside air at end of period	1·7	

A similar effect is also shown in the case of the large sewer under the Houses of Parliament. This sewer forms a cul-de-sac at the end by the Victoria Tower, whence it runs the whole length of the building to the Clock Tower, where it joins the Metropolitan sewer. Before the recent alterations, this sewer was ventilated by suction, caused by a furnace at the bottom of the Clock Tower. Practically, therefore, this suction was pulling against what tended to become a vacuum ; the effect being that, though there was a good draught by the Clock Tower, the strength of the air-current gradually diminished as the blind end of the sewer was approached, so that near the Victoria Tower end no draught was perceptible. Here the air remained stagnant. Suspended organic matter would thus settle down, and in consequence of this and of oxidation there would be an increase in carbonic acid, accompanied by a diminution in the organic matter, as we pass from the Clock Tower end to the Victoria Tower end of the sewer. This is shown as follows :—

	First determination.		Second determination.	
	Carbonic acid.	Organic matter.	Carbonic acid.	Organic matter.
In the sewer by the Clock Tower end . .	7·3	12·9	5·2	11·8
Ditto, midway between the Clock and Victoria Towers	8·2	13·0	7·0	9·5
Ditto, by the Victoria Tower	8·5	9·4	8·5	9·4

The first determinations were made between the hours of 5 P.M. and 7.30 P.M., and the second between 10.30 P.M. and 12 midnight.

5. *Effect of Physical Exercise.*—As is well known, physical exercise causes a marked increase in the amount of carbonic acid exhaled in the breath.* A similar effect appears to be likewise produced in the quantity of organic matter. We were led to this conclusion from the results obtained in the case of a mechanically ventilated "half-time school," attached to one of the mills in Dundee. The children in this mill are divided into two lots, one of which works the first part of the day, and attends school the second part, the second lot alternating with the first. On two different days we made an examination of the school just before the second school began, the room having been first well ventilated for twenty minutes and the carbonic acid and organic matter determined. The children were then admitted direct from their work in the mill, and the carbonic acid and organic matter again determined at the end of thirty minutes, and again at the end of an hour. The results were as follows:—

	First day.		Second day.†	
	Carbonic acid.	Organic matter.	Carbonic acid.	Organic matter.
Girls' School.—Beginning of hour	3·0	3·8	5·0	3·9
Middle ,, ...	9·6	10·7	12·3	6·2
End ,, ...	7·1	6·4	11·4	3·9
Boys' School.—Beginning of hour	4·0	5·1	3·9	2·9
Middle ,, ...	11·5	6·3	17·1	4·5
End ,, ...	11·2	7·3	15·1	2·9

6. *Cleanliness* has little or no apparent influence on the quantity of organic matter in air. (See Table, p. 96.)

* Cf. PARKES' 'Hygiene,' p. 148, where PETTENKOFER'S statement is quoted to the effect that in hard work a man evolves twice as much carbonic acid as in gentle exertion, and three times as much as during repose.

† This was the day of the great snow-storm last winter, when the quantity of organic matter in the outside air was much below the average.

Sources of and Circumstances affecting the Number of the Micro-organisms in Vitiated Air.

It has been shown by HESSE (*loc. cit.*) that when a room is left quiet the micro-organisms settle out in a few hours, so that the air becomes comparatively free (cf. TYNDALL'S experiments on sterilisation of air by subsidence). Hence it is clear that a certain amount of physical disturbance in a room is a condition necessary to the presence of micro-organisms in the air. It might naturally be supposed that the effects of physical disturbance would tend to obscure all other factors affecting the number of micro-organisms present in air. It is, therefore, necessary to consider first what, other things being equal, are the limits of the influence of ordinary physical disturbances on the number of micro-organisms.

The first observation bearing on this point was made at the High School. A determination was first made with the class in the room under ordinary conditions. The boys were then told to stamp with their feet on the floor for a short time. This they did with particular vigour and gusto, raising a cloud of dust which diffused itself through the room. A second determination was then made. The first determination gave 11 per litre, and the second about 150. It will be noticed that, although the increase is very great, the number found barely reaches the average in the naturally ventilated Board schools.

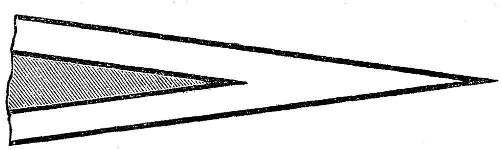
Such violent disturbances as that just described are, however, altogether exceptional. What is of more importance is the effect of slighter disturbances, such as occur frequently. In the same school, on another day, the boys were allowed to go out during a determination. The number found per litre was 5, as compared with an average of 1·8 in five other rooms in which the classes were sitting. The difference due to the disturbance was small as compared with the differences caused by other factors (see below). Again, in the small Chemical Lecture-room the number was actually less (1·5 per litre) at the end of a lecture than at the beginning (3 per litre). The room had only been slightly disturbed before the lecture. Again, in the Large Lecture-room the average found on three separate occasions, after an hour of a crowded popular lecture, was only 4·7 per litre. All these determinations were made before the audience left.

In the case of houses of four rooms and upwards, the rooms were classified according as the occupant rose from bed before the determination or not. The average for the former class was 12 per litre, for the latter 7 per litre. Again, in a set of observations on a block of 2-roomed houses, we started later than usual, and found that in three of the rooms visited the people were already stirring. The average in these rooms was 76 per litre, while in the other two the average was 90. The difference was due mostly to one of the former houses, which was cleaner than the rest, giving a lower number (34).

From the above results, taken in connexion with what follows, wey ma conclude that the effects of minor differences as regards physical disturbance, such as cannot well be avoided in making observations in a number of rooms, are not in themselves sufficient to obscure the influence of other important factors. Nevertheless we always endeavoured to examine each class of rooms under conditions as nearly as possible the same as regards physical disturbance. In examining dwelling-rooms, it was, of course, impossible to avoid the disturbances due to our own presence in the room. But these disturbances must have been tolerably uniform, and we knew (see below) that our own persons did not act to any appreciable extent as a source of contamination.

In the cases hitherto referred to, the effects have been studied of an increase of physical disturbance apart from the simultaneous introduction of any other factor not previously in operation. A new factor, previously latent, may, however, be brought into operation by physical disturbances, as for instance when some object specially likely to give off bacteria is disturbed. For example, one of the observations at the Infirmary in the early morning was made immediately after the making of a number of beds in the ward. The number of micro-organisms found was 28 per litre, as compared with an average of 2·8 per litre in the other wards.* It was, of course, to

* We may refer here to an interesting phenomenon observed in connexion with the jelly in the tubes. It had been found that in some of the tubes crystals tended to make their appearance on the surface of the jelly after the tube had been used, and that these crystals were much more numerous and much smaller near the perforation in the cap, becoming fewer and larger towards the other end (see Plate 6, fig. 4). They thus resembled in their distribution the colonies of bacteria. We might represent diagrammatically their number and distribution as compared with the colonies of bacteria by a diagram



such as the accompanying. The inner shaded triangle represents, as regards number and distribution, the bacteria; the large triangle the crystals. These crystals only appeared in tubes made of inferior glass, apt to dissolve and crack on the surface. We have not as yet determined their composition. Probably they were composed of phosphate of lime, and were due to the lime dissolved from the glass combining with the phosphoric acid contained in the meat juice.

Of the tubes used at the Infirmary, four showed these crystals. The crystals were counted, and the corresponding numbers of crystals and colonies per litre were as follows :—

	Crystals.	Colonies.
Ward 10 (5 P.M.)	14	0
„ 10 (5·30 A.M.)	44	0
„ 12 (3·30 A.M.)	115	4
Accident Ward (5 A.M., after some of the beds had been made)	1600	28

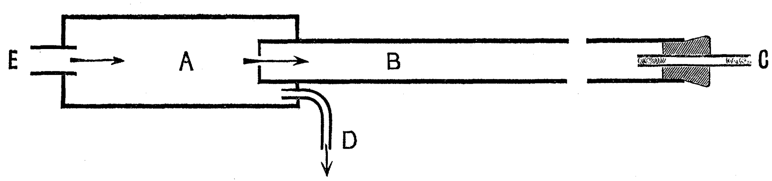
In the two tubes first in the list, all the crystals were very large, like those near the cork in the last tube. Taking the numbers in the first three tubes together, the ratio of colonies to crystals is 1 : 43, while the ratio in the last tube is 1 : 57. The ratio of crystals to colonies thus appeared to correspond roughly.

The formation of the crystals was evidently determined by solid particles falling on the jelly, just as be expected that a large number of bacteria would be given off from bed clothes when shaken.*

In connexion with this subject some of our observations in jute mills are of interest. In each of three large rooms examined in different mills the air was loaded with jute fibres, the amount of physical disturbance being very great in each. In the air of the first, 4 bacteria per litre were found; in that of the second about 586 bacteria per litre were found, and 14 moulds; in that of the third about 12 bacteria and 248 moulds (see pp. 83–84). The latter observation was repeated with a similar result five weeks later. These observations show how small the influence of physical disturbance may be unless combined with other factors.

It is evident that the micro-organisms present in the air of an inhabited room may conceivably come (1) from the air-passages of the persons present, or (2) from their clothes and skin, or (3) may have been previously present in the room. We shall consider in succession these possible sources.

1. The air-passages might possibly give off micro-organisms in the breath. As regards this point we made the following direct experiments. A piece of very wide glass tubing, A (see diagram), of about 20 centims. length, was fitted at each end with a cap of india-rubber sheeting similar to the cap of the tube of HESSE's apparatus. Through a hole in one of the caps the end of an ordinary HESSE's tube, B, was passed, so that the part of the latter covered by its cap was completely inside the piece of wide tubing. Through another hole at the same end of the wide tube A there passed a piece of narrow glass tubing D. The cap at the other end of the wide tube was also perforated by a very short piece of glass tubing of medium width, E. The tube A having been washed thoroughly with 1 per cent. corrosive sublimate solution and allowed



to dry, the cap of the tube B was cautiously removed, and the apparatus arranged in the position described. The observer expired through the tube E, inspiring through his nose, while immediately afterwards the aspirator attached to C was set in motion. The object of D was to allow of the free escape of the breath not sucked into B. In order

crystallisation of a supersaturated solution of a salt is set up by dust particles dropping into the solution. The fact that the crystals were larger when there were few present doubtless depended on their having more jelly from which to draw during their formation. The whole phenomenon suggests a possible method for determining the number and relative rate of settling of the dust particles in given volumes of air. As the data given above tend to show, there is probably a rough correspondence, under similar conditions, between the number of solid particles suspended in air and the number of micro-organisms.

* This observation gives one a vivid idea of the manner in which an infectious disease may spread through a ward.

to prevent condensation, A was surrounded by a cloth wrung out of hot water. As the heat would have melted ordinary jelly if used for B, Agar jelly was employed instead. Another similar apparatus was prepared and placed with its tube, E, close to the face of the first observer. A second observer inspired through the tube D of the second apparatus, expiring through his nose. Unrespired air was thus drawn into the tube B under conditions as nearly as possible the same as with the expired air of the first apparatus.

Two pairs of experiments were first made when the laboratory was quiet. Each pair was carried out simultaneously, equal quantities of air being taken. The results were as follows :—

No. 1	Respired air	0
	Unrespired air	1 mould
No. 2	Respired air	0
	Unrespired air	1 mould.

2 litres of air were aspirated in each case, the rate of aspiration being the same within a few seconds.

It thus appears that micro-organisms are not given off in the ordinary respiration of healthy persons—or at least not to any appreciable extent. On the contrary, those present in the air appear to stick to the mucous membrane of the nose, larynx, trachea, &c., so that the air passages practically act as filters. In order to test this more thoroughly, we made another pair of observations, the laboratory being this time full of dust stirred up by vigorous sweeping, &c. Unfortunately, however, as will be seen from the results of this experiment, the dust of this laboratory appears to contain very few micro-organisms. One litre of air was aspirated. The results were as follows :—

Respired air	0
Unrespired air	3 bacteria.

These results harmonise with Professor TYNDALL'S demonstration of the optical purity of the last part of the air of each expiration. They are also in accordance with the whole of our experiments on vitiated air. Thus, by reference back to the Table (p. 86), it will be seen that, while the increase of carbonic acid runs parallel, on the whole, with the increase of organic matter, the micro-organisms first increase, and then diminish with the increase of carbonic acid. The latter diminution is also noticed if we take the rooms in the naturally ventilated Board schools, and divide them into three classes, according to the amount of carbonic acid.

	No. of cases.	Micro-organisms.
Class 1. (Carbonic Acid 7·88–15·77).	12	131
,, 2. (Carbonic Acid 15·97–20·78).	12	235
,, 3. (Carbonic Acid 21·14–37·84).	11	84

The lower number of micro-organisms with a higher amount of carbonic acid may probably be due to the filtration of the air through the air-passages of the scholars —not a very desirable process of purification.

A similar Table for 1- and 2-roomed houses does not show this diminution, but could not have been expected to do so, considering the small amount of carbonic acid as compared with schools. The rooms, when divided into equal classes, according as the carbonic acid was above or below a middle point, give the following results :—

		Micro-organisms.
One-roomed	Carbonic acid above .	76
	Carbonic acid below .	57
Two-roomed	Carbonic acid above .	38·5
	Carbonic acid below .	38·1

Some experiments in the Chemical Lecture-rooms will be of interest in this connexion. At a popular lecture, during which the Large Lecture-room was crowded, and the ventilating apparatus was not in action, the carbonic acid and organic matter were, after an hour, 37·61 and 15·8 respectively (average of two determinations each). The micro-organisms, at the same time, were only 6 per litre. Again, in the Small Lecture-room (ventilation closed), just before the entry of the students (carbonic acid 5·18, organic matter 4·8), 2·5 micro-organisms per litre were found, while at the end of the lecture (carbonic acid 19·57, organic matter 11·2) 1·5 per litre were found. In another experiment in the same room (ventilation open) 3 micro-organisms per litre were found at the beginning (carbonic acid 3·46, organic matter 9·2), while 1·5 were found at the end (carbonic acid 13·21, organic matter 13·1).

2. The skin and clothes of the persons present in a room at the time of an observation also occur naturally as a probable source of infection of air. That this source, however, is of much less importance than might be supposed may, we think, be shown from our observations.

In order to obtain data on this point, it is necessary to eliminate as far as possible disturbing influences arising from the condition of the room itself, particularly, as will be seen from the sequel, *habitual* bad ventilation and want of cleanliness. The Chemical Lecture-rooms are habitually ventilated mechanically, and frequently scrubbed ; hence the experiments made in them are of special value in this reference. The observations in the large room were made during a course of evening popular lectures on political economy, the audience being drawn from various classes of society. There was occasional applause, which must, of course, have tended to stir up micro-organisms. The following were the results :—

		Micro-organisms per litre.	
		Before lecture.	After lecture.
Large Lecture-room	1. Ventilation on . .	..	4
	2. ,, off* . .	..	6
	3. ,, on . .	..	3
Small Lecture-room	1. ,, off* . .	2·5	1·5
	2. ,, on . .	3	1·5

The observations at the end of the lectures were made after the audience had been in for an hour, and before they left. The fact that the numbers found were so small after the lecture shows that the influence of the bodies and clothing of persons of average cleanliness present in a room upon the number of organisms in the air is at least small as compared with the influence of other conditions.

As no micro-organisms come from the breath, those which come from persons present in a room must arise from their clothes and skin. Hence, if we take the carbonic acid as a rough measure of the total impurities arising from the persons of those present in a room, it should be a rough measure of the micro-organisms from the clothes and skin. The increase of carbonic acid does not, however, as we have seen, run parallel with increase of micro-organisms, and this supports our previous conclusion that the number of micro-organisms given off by the skin and clothes of persons actually present in a room is small as compared with those coming from other sources.

3. As the micro-organisms in the air of a room do not come to any large extent from the persons present at the time, they must come from the room itself. The circumstances in connexion with the room which are of most importance in influencing their number may be now considered.

A. *Cubic space.*—The influence of cubic space in the naturally ventilated schools which may fairly be compared with one another is traced in the Table (p. 82). It will be seen that the organisms increase with increase of cubic space up to 250 cubic feet per child, when there is no further increase. The marked diminution above 300 cubic feet, shown in the Table, depends on the observations made in a private school which was scrupulously clean. The results are therefore not comparable with those obtained in Board schools. The diminution with cubic space below 200 cubic feet will recall the similar diminution with increase of carbonic acid above a certain point. Possibly filtration through the air-passages may be again the explanation here. This is a point which we intend to investigate further.

In the case of dwelling-rooms, pp. 71–72, the micro-organisms decrease as the cubic space increases, but this must be largely due to the fact that other sanitary conditions improve as the cubic space increases. Above a thousand cubic feet there is a slight

* Only off during the lecture.

increase, not very easy to explain. In mechanically ventilated schools the micro-organisms decrease with increase of cubic space (p. 82), which is nevertheless quite in accordance with the filtration hypothesis.

B. *Cleanliness of rooms and persons* habitually *present in them.*—In order to show the influence of differences as regards cleanliness, we have classified the houses and schools as shown in the following Table. This Table requires no comment. It shows most conclusively the enormous influence of differences as regards cleanliness on the number of micro-organisms.

		No. of cases.	Average space per person.	Average carbonic acid.	Average organic matter.	Average micro-organisms.
One-roomed houses	Clean	1	295	8·0	13·1	18
	Dirty	7	200	9·9	18·1	41
	Dirtier	13	221	10·7	13·5	49
	Very dirty	6	220	11·0	15·1	93
Two-roomed houses	Very clean	2	273	12·2	10·8	10
	Clean	4	264	9·3	7·7	22
	Dirty	7	233	9·4	11·2	69
Naturally ventilated Board schools	Cleaner	12	167	19·7	18·1	91
	Average cleanliness	12	166	14·2	16·2	125
	Dirtier	12	191	22·5	15·2	198
Mechanically ventilated schools and college	Cleanest	7	194	12·5	12·7	3
	Clean	11	155	12·8	8·3	16
	Less clean	4	152	10·8	9·8	30

The houses were classified from notes made at our visits. The naturally ventilated schools were classified by the sanitary inspectors at our request.

C. *Ventilation.*—It is most important, as we shall see, to consider separately the ventilation at the time of the observation and the habitual ventilation.

a. Ventilation at the time.—In order to obtain data as regards its influence, we made a number of experiments on rooms provided with mechanical ventilation, examining them with it off, and again with it on, other conditions being equal as far as possible. The results are given below. The ventilation was kept off for an hour (during which the class was in the room) before the observations were made.

	Ventilation off.		Ventilation on.	
	Carbonic Acid.	Micro-organisms.	Carbonic Acid.	Micro-organisms.
Harris Academy, Room 1	14·0	21	13·5	24
Harris Academy, " 2	18·8	38	13·3	14
Harris Academy, " 3	16·4	16	15·6	16
Harris Academy, " 4*	16·0	20	. .	22
Small Chemical Lecture-room	19·6	1·5	13·2	1·5
Large " " "	37·6	6	10·8	3
Ventilated half-time school, Boys	15·1	14	11·6†	47†
Ventilated half-time school, Girls	11·4	12	10·0†	9†
Averages	18·6	16	12·6	17

It thus appears that ventilation by mechanical means at the time of the experiment had no appreciable effect on the number of organisms in the air of rooms, in spite of its great influence on the carbonic acid and organic matter. (See also p. 79.)

β. The influence of the habitual state as regards ventilation cannot be determined quite so satisfactorily, as it is necessary to compare results in different rooms. In order, however, to determine the effect of a few days of natural ventilation on the micro-organisms in the air of a school habitually ventilated mechanically, the artificial ventilation was stopped for a week in the half-time school previously referred to. The results were as follows :—

	Boys.	Girls.	
Previous average	47	18	
Ventilation off, Monday	56	36	Average for the week. Boys. 63, Girls. 19
Ventilation off, Tuesday	102	12	
Ventilation off, Wednesday	34	22	
Ventilation off, Thursday	74	20	
Ventilation off, Friday	52	6	
Ventilation on since Monday morning, Tuesday	60	8	

The observations were made at the same time each day. Unfortunately the boys were always standing and moving about at this time, hence the number of micro-organisms is made abnormally high as compared with previous results in the same room. The data obtained, however, show that the effect of having the ventilation off for a week was not appreciable in raising the number of organisms in the air. The numbers found were, in both the boys' and the girls' room, actually less in the second than in the first half of the week. These results harmonise with our observation as regards the influence of age. (See below.)

* Compared, not against the same room, but one with as nearly as possible the same space per person.

† Average of two determinations.

Although the condition as regards ventilation during short periods of time may be of slight influence on the organisms in air, yet the habitual condition seems to exercise a marked influence.

In the mechanically ventilated half-time school, just referred to, the average of all the observations made during occupation (including those with the ventilation off) was 34 per litre. The school is a very old one, and the scholars come straight from the mill to the school in their work clothes. The air in the spinning flat of the mill itself had been found to contain about 600 micro-organisms per litre. All the conditions except the habitual ventilation are thus in favour of a very high number of micro-organisms. Nevertheless, the number found is less than a fourth of the average number found in naturally ventilated Board schools (155), a sixth of that in the dirtier naturally ventilated schools, and a ninth of that in the older naturally ventilated schools.

Unfortunately, the rooms in the Harris Academy provided with mechanical ventilation are very much newer than those without it, so that the two sets of rooms are not strictly comparable. But, from the exceedingly low results in the High School (an old school), it is probable that age makes very little difference with mechanical ventilation. The average in the mechanically ventilated rooms of the Harris Academy was 16 per litre, whilst in the naturally ventilated rooms of the same school it was 117. Even if we make a large allowance for difference in age, the contrast is still very striking. The number is more than thrice as great as in the mechanically ventilated half-time school referred to above, in spite of the age of the latter, and of the scholars being much less clean.

Lastly, we may compare the naturally ventilated private school referred to previously against the High School. The cubic space and age were about the same. The private school was exceedingly clean and quiet, and there were no boys in it. Every condition was in its favour, except that the ventilation was by natural means. The average in the private school was 9·3; that in the High School 3·6. Both numbers are, of course, low.

D. In order to show the influence, if any, of age (probably as conditioned by cleanliness), we have classified the naturally ventilated Board schools as follows:—

	No. of cases.	Micro-organisms per litre.
Opened before 1866	7	311
„ 1875–1880	20	150
„ 1884–1885	5	38

Unfortunately, in the case of the oldest division of schools, in all but one case the children were exceptionally dirty, so that nothing can fairly be deduced from the number for this class.

We do not as yet possess sufficient data to enable us to account completely for the accumulation of micro-organisms in a room. It is possible that a room acts as a sort of trap for the particles to which bacteria or their spores are attached. This seems on the whole more likely than an actual multiplication of bacteria in the air or about the floor or furniture of a room.

Relation of Bacteria to Moulds in various Kinds of Air.

Up to this point we have generally considered the micro-organisms as a whole, and have said but little as to the bacteria and moulds separately. It is now necessary to refer to these groups more particularly.

In this connexion the most important point is the relative proportion of bacteria to moulds in various kinds of air. This is specially interesting, because it may furnish, taken in connexion with other considerations, a valuable indication of the vitiation of air by animal and other impurities. It must be distinctly understood that the relation is that observed with jelly of the composition stated previously, and rendered faintly alkaline after heating.

In 167 out of 179 cases in which we observed the relation, the number of moulds is less than that of the bacteria. Of the exceptions, two were in the very abnormal case of the mill referred to above (p. 84). The rest were either in outside air or in very pure atmospheres (*e.g.*, four in the Infirmary). The purer the air becomes, the more nearly, as a general rule, do the bacteria and moulds become equal. Thus, in outside air in Dundee, taken in quiet open places, where there was but little traffic, there were only 2½ bacteria on an average to each mould, whereas in the open streets in the centre of the town, during dry dusty weather, the ratio was 15 to 1. In buildings a much higher proportion usually prevails.

The following Table shows the connexion of this ratio with the general state of purity of the air in various classes of buildings :—

	Carbonic Acid.	Organic matter.	Total micro-organisms.	Bacteria / Moulds	Remarks.
Outside air (quiet places)	3·9	8·9	0·8	2·5	Winter.
„ (streets)	3·1	2·8	17·5	14·9	April and May.
Naturally ventilated schools:—					
Board schools	18·6	16·2	152·	131·8	
Private school	11·9	8·9	9·	30·0	
Mechanically ventilated schools:—					
General average	12·3	10·1	16·58	28·5	* This number is probably too high, for many of the determinations were made during ordinary experimental lectures on chemistry, when reducing gases were possibly present.
Harris Academy (Board school)	12·8	8·4	16·0	31·	
Half-time School	10·8	9·5	28·0	27·	
University College	12·5	12·9*	2·8	15·6	
High School†	13·0	3·9	3·6	4·	
Houses:—					
One-roomed	11·2	15·7	60·	49	† The cubic space per person in this school is about three times as much as in any of the foregoing.
Two-roomed	9·9	10·1	46·	20	
Four and more rooms	7·7	4·5	9·	21	

The explanation of the ratio $\frac{\text{Bacteria}}{\text{Moulds}}$ increasing with the vitiation of the air is that moulds come mostly from the outside air. When the air in a room becomes vitiated the bacteria increase largely, while the number of moulds is affected to a relatively much less extent, if at all.

This is well illustrated by some observations made in the half-time school already referred to. The unoccupied room was first well ventilated by means of the fans, and the carbonic acid, micro-organisms, and organic matter determined. The children were then admitted, and the determination made at the end of half an hour, and again at the end of an hour. The results were as follows :—

		Carbonic Acid.	Organic matter.	Bacteria.	Moulds.
Boys' School, First day	Beginning of hour . . .	4·0	5·1	4	2
	Middle " . . .	11·4	6·4	Not determined	
	End " . . .	11·1	7·3	56	2
Second day .	Beginning of hour . . .	3·9	2·8	0	3
	Middle " . . .	17·1	4·4	Not determined	
	End " . . .	15·1	2·8	14	0
Girls' School	Beginning of hour . . .	5·0	4·0	0	3
	Middle " . . .	12·3	6·2	Not determined	
	End " . . .	11·4	3·9	8	4

Thus in three experiments the number of bacteria was much greater at the end of the hour than at the beginning, whereas the number of moulds had remained practically constant.

The effect of stirring up dust is to increase the ratio. The bacteria are increased, while the moulds are little affected. Thus, in the High School the micro-organisms were determined just before and just after the boys had raised a cloud of dust by stamping on the floor. Before stamping, 10 bacteria and 1 mould were found ; after stamping, 150 bacteria and 0 moulds. Again, in one of the wards in the Infirmary, where the beds had just been made, the ratio was $\frac{14}{1}$, while the next highest ratio observed in any of the other wards was $\frac{3}{2}$. No dust had been raised in any of the latter wards, except what was due to ordinary movements about the wards.

Relative lightness of moulds and bacteria.—The ratio of bacteria to moulds is considerably affected if the air remains quiet for any length of time, as the bacteria (or rather the particles to which they are attached), as a rule, settle out much more rapidly than moulds. In fact, the moulds settle out so slowly that we have never noticed the effects of their subsidence in the course of our observations.

The relative lightness of moulds as compared with the particles to which bacteria are attached has already been observed by HESSE ('Mitth. a. d. K. Gesundheitsamte,' vol. 2, p. 186), who found that moulds, as a rule, penetrate much further into the tubes before settling down on the jelly than bacteria do. He gives many measurements of their actual distance. Our own observations are in accordance with his on this point. He has also made a number of very interesting observations in this connexion on the relative ease with which moulds and bacteria penetrate fine pores.

In consequence of the relative lightness of moulds, the ratio of bacteria to moulds tends to diminish when the air of a room remains at rest. We had a room kept closed for two days, after ventilation with outside air; the ratio was then found to be $\frac{\cdot 4}{\cdot 4}=\frac{1}{1}$, whereas in outside air the ratio about that time was $\frac{2\cdot 5}{1}$.

The same thing is exhibited by the ratio of bacteria to moulds on still and windy days respectively, as proved by the following ratios, which are the mean results of all our available data.

Still, damp days	$\frac{\text{Bacteria}}{\text{Moulds}}$	$= \frac{\cdot 36}{\cdot 37}$	$= 1$
Windy, damp days	„	$= \frac{\cdot 63}{\cdot 5}$	$= 1\cdot 3$
Still, dry days	„	$= \frac{\cdot 7}{\cdot 27}$	$= 2\cdot 6$
Windy, dry days	„	$= \frac{10\cdot 6}{\cdot 75}$	$= 14\cdot 1$

These results are all from observations in Dundee only. They show not only the effect of wind, but also that of dryness and dampness of weather. Other things being equal, there are thus fewer bacteria in the air on damp or still days than on dry or windy days. The moulds do not seem to be affected by wind or dryness to anything like the same extent.

The relative lightness of moulds and bacteria is also shown by some observations made at the top and at the foot of the Clock Tower at Westminster. The results were as follows :—

	First observation.	Second observation.
Top: $\frac{\text{Bacteria}}{\text{Moulds}}=$	$\frac{2}{19}=\cdot 10$	$\frac{2}{13}=\cdot 15$
Bottom: $\frac{\text{Bacteria}}{\text{Moulds}}=$	$\frac{7}{18}=\cdot 40$	$\frac{18}{22}=\cdot 81$

At the time this experiment was made the number of moulds in the air was exceptionally large.

Standards of Purity.

It will be convenient, and, we trust, serviceable, to give at this place what we would propose as standards of purity.

The air of a dwelling-house or school must be considered bad if the following limits be exceeded :—*

		Total.	Excess over outside air.
Carbonic acid	For dwelling-houses	10 vols. per 10,000	6 vols. per 10,000
	For schools	13 ,, ,,	9 ,, ,,
Organic matter		..	2·0 vols. oxygen per 1,000,000
Total micro-organisms		..	20 per litre

The ratio $\frac{\text{Bacteria}}{\text{Moulds}}$ should not exceed 30.

* The above standards are based on the following data :—

CARBONIC ACID—

Of the 29 one-roomed houses examined, 14 contained above and 15 below 10 vols. (total), or 9 above and 16 below 6 vols. (excess).

Of the 13 two-roomed houses examined, 5 contained above and 7 below 10 vols. (total), or 8 above and 3 below 6 vols. (excess).

Of the 18 four (and more) -roomed houses examined, 1 contained above and 17 below 10 vols. (total), or 1 above and 17 below 6 vols. (excess).

Of the 42 naturally ventilated school-rooms examined, 38 contained above and 4 below 10 vols. (total), or 41 above and 1 below 6 vols. (excess).

Of the 26 mechanically ventilated school-rooms examined, 21 contained above and 5 below 10 vols. (total), or 18 above and 8 below 6 vols. (excess).

Of the 42 naturally ventilated school-rooms examined, 31 contained above and 11 below 13 vols. (total), or 31 above and 11 below 9 vols. (excess).

Of the 26 mechanically ventilated school-rooms examined, 9 contained above and 17 below 13 vols. (total), or 8 above and 18 below 9 vols. (excess).

Of the 42 naturally ventilated school-rooms examined, 29 contained above and 13 below 14 vols. (total).

Of the 26 mechanically ventilated school-rooms examined, 4 contained above and 22 below 14 vols. (total).

ORGANIC MATTER (excess over outside air)—

Of 29 one-roomed houses, 25 required more and 4 less than 2 vols. oxygen per million.

Of 11 two-roomed houses, 7 required more and 4 less than 2 vols. oxygen per million.

Of 13 four (and more) -roomed houses, 2 required more and 11 less than 2 vols. oxygen per million.

Of 41 naturally ventilated school-rooms, 35 required more and 6 less than 2 vols. oxygen per million.

Of 26 mechanically ventilated school-rooms, 5 required more and 21 less than 2 vols. oxygen per million.

MICRO-ORGANISMS (excess over outside air)—

Of 28 one-roomed houses, 22 contained more and 6 less than 20 micro-organisms per litre.

Of 13 two-roomed houses, 9 contained more and 4 less than 20 micro-organisms per litre.

Of 18 four (and more) -roomed houses, 1 contained more and 17 less than 20 micro-organisms per litre.

Of 38 naturally ventilated school-rooms, 32 contained more and 6 less than 20 micro-organisms per litre.

Of 25 naturally ventilated school-rooms, 6 contained more and 19 less than 20 micro-organisms per litre.

In reference to the above standards the following remarks are necessary :—

(1.) The above limits for houses apply more particularly to sleeping-rooms.

(2.) It has been considered necessary to allow a somewhat higher limit for carbonic acid in schools than in dwelling-houses. The reasons for this are :—(*a*) The quantity of carbonic acid produced by respiration during waking hours is greater than when asleep, and it is therefore more difficult to maintain so low a standard in the former case.* (*b*) The average cubic space per person is at present considerably less in schools than in even one-roomed houses. (*c*) The examination of 68 different school-rooms, 30 of which were considered to be sufficiently well ventilated, shows that, even when ventilated mechanically by fans, an upper limit of 13 vols. per 10,000 (or 9 vols. in excess of outside air) is as low a one as we could reasonably expect not to be exceeded. We are fully of opinion, however, that the limit should not be fixed higher. The data on which the above opinions are based will be seen from the foot-note on page 102.

(3.) The upper limit of 10 vols. per 10,000 for dwelling-houses (especially in sleeping-rooms) is the one which is usually adopted by most authorities, and this we can fully confirm. WILSON ('Handbook of Hygiene,' and quoted in PARKES, p. 115) states that in cells (in Portsmouth Convict Prison) of 614 cubic feet, always occupied, he found 7·2 vols. of carbonic acid, and that the prisoners inhabiting these cells were healthy and had a good colour. In cells of 210 cubic feet, occupied only at night by prisoners employed outside during the day, he found 10·4 vols. of carbonic acid. The occupants were all pale and anæmic.

DE CHAUMONT ('Roy. Soc. Proc.,' vol. 23, p. 187) gives 6 vols. (or 2 vols. in excess of the outside air) as the maximum amount of carbonic acid admissible in a properly ventilated space. He believes that an atmosphere ceases to be *good* when the carbonic acid reaches 8 vols. (or 4 vols. in excess); that it becomes *decidedly bad* when the carbonic acid reaches 10 vols. (or 6 vols. in excess); and that it becomes *very bad* when 12 vols. (or 8 vols. in excess) is reached. Though it would be very desirable, could this lower limit be maintained, yet from our own investigations it seems to be practically impossible, in schools at least, without involving too great a cost or using an extensive "open window" ventilation. The latter would be very objectionable, and quite inadmissible in winter. The standards proposed above are practical, and may be attained without draught, so that we may reasonably expect and demand that the air of dwellings and schools should be maintained within the limits of purity assigned above.

The lower limit for carbonic acid, proposed by DE CHAUMONT, is based as follows ('Roy. Soc. Proc.,' vol. 23, p. 187) :—(1) That the air of a room should be maintained in such a state of purity that a person coming directly from the external air should

* PETTENKOFER found that in repose a man of 28 years evolved at night, when asleep, ·56 cubic foot of carbonic acid, and ·78 in the day-time, with very moderate exertion

perceive no trace of difference in odour between the room and outside air in point of freshness. (2) That the presence of organic matter is, on an average, perceptible to the sense of smell when the coincident carbonic acid, due to respiratory impurity, reaches 2 vols. per 10,000, or a total of about 6 vols.

In almost all the houses and schools visited we took a note of the odour perceived on entering the room; and, although as a general rule the odour was some indication of the condition of the air in the room, yet this was by no means invariably so. In some cases an extremely close and almost overpowering odour was detected when the carbonic acid amounted to only 7 or 8 volumes per 10,000, while in other cases the smell was only slight with as much as 17 volumes, and in one case as much as 20 volumes. In these latter instances the organic matter was only slightly above the limit we have allowed.

The smell is, in fact, greatly influenced by the temperature, and also by the humidity of the air, as De Chaumont himself points out. The state of cleanliness of the persons in the room, and of the room itself, has a most important influence on the smell, quite independently of the amount of carbonic acid. There may also be other strongly smelling substances in a room which do not appreciably affect the chemical composition of the air. Our observations in the Infirmary wards (page 84) were very instructive in this respect. Thus, in one ward, where the excess carbonic acid was 2·9 volumes, there was a very perceptible odour. A few hours later the excess in the same ward was 3·4 volumes, but the ward felt much fresher, and the odour was barely perceptible.

For similar reasons the feeling of closeness is not a safe guide as to the amount of organic matter in a room. The combustion of gas in a room will produce a high carbonic acid and a feeling of closeness, but, as shown above, it will have little effect on the organic matter. It should be stated that De Chaumont's results apply to rooms at night in which lights were not burning, whereas, in almost all the one- and two-roomed houses we visited, an oil lamp was kept burning.

The standards of purity adopted above are practical limits, which should easily be maintained by proper methods, and at not too great a cost. They are not fixed so low as might be desirable, but they are as low as practicable with the present methods of ventilation, unless, indeed, expense is no object.

As our experiments were all made between the end of November and the end of April, the standards deduced from them apply strictly only to the winter months. They might, therefore, be lowered to 8 volumes (4 volumes in excess) of carbonic acid in the case of houses, and 10 volumes in the case of schools, during warmer weather, when the injurious effects of draughts would be in great part eliminated.

(4.) The excess carbonic acid is due to respiration and combustion. The organic matter is due to respiration and the combustion of coal, oil, and possibly (to a slight extent) gas; also to dust. The carbonic acid and organic matter may, therefore, be taken as a measure of the influences contaminating the room about the time of the observation, whereas the number of micro-organisms is largely dependent on its previous history, as shown above.

(5.) In proposing the above standards, we wish it to be distinctly understood that they should be taken in conjunction, and not singly. The carbonic acid, more especially, is not a safe guide when taken alone.

(6.) The standard for micro-organisms is for KOCH'S jelly, of the composition previously stated.

So far as we are aware, a standard of purity has not previously been proposed for organic matter and micro-organisms.

THE NATURE OF THE MICRO-ORGANISMS PRESENT IN "VITIATED AIR."

On this point we purpose to say but little at present. The great majority of the colonies which appear on the jelly consist of micrococci of very various kinds and with various naked-eye appearances (see Plate 6, figs. 2 and 3). Bacilli are not nearly so common; the moulds are also of very various kinds. As was to be expected, these colonies are not always pure cultivations. In conjunction with Dr. HARE, of the Surgical Laboratory, Edinburgh University, one of us has cultivated and described some of the more characteristic and commonly occurring species. A series of inoculation and inhalation experiments with pure cultivations was also begun under Dr. HARE'S direction in the same laboratory. The results of these experiments were negative in the case of the few species tried as yet.

PROBABLE INFLUENCE ON HEALTH OF THE DIFFERENT ABNORMAL CONSTITUENTS OF VITIATED AIR.

We have placed (p. 74) the results of our analyses alongside of statistics as to the death-rates in the classes of houses the air of which we examined; but it is no very easy task to determine how far differences in the death-rate are due to differences in the air breathed, and how far to other causes, such as improper or insufficient food. There is, however, abundant evidence from other sources as to the enormous influence on the death-rate of the air habitually breathed, apart from other causes (cf. PARKES' 'Hygiene,' 6th edn., p. 133). Hence we may take it as quite certain that the above differences in the death-rates in Dundee are largely due to the differences in the quality of the air habitually breathed.

As regards the influence of the separate constituents by which the air was contaminated, it is even more difficult to come to positive conclusions.* But a short discussion as to what seems probable may serve at least to give a more definite direction to one's ideas in considering the matter.

As regards carbonic acid, it seems almost certain that its presence in houses in the proportions we found could not have a sensibly deleterious effect. A slight increase

* We hope to throw further light on this point by a series of direct experiments on animals with air containing vitiating constituents separately, and not in such proportions as to cause acute poisoning.

of carbonic acid and diminution of oxygen can easily be made up for by a slight increase in the rapidity of the respirations or flow of blood through the lungs, or in the depth of the former. We know also that there are many conditions, such as adherent pleuræ or slight heart disease, which must have a very great influence on the function of respiration, and which yet do not appear seriously to affect the general health.

The case of the oxidisable organic substances in air would appear to be totally different from that of the carbonic acid. These substances, unlike carbonic acid, appear to accumulate in stagnant air until they are present in quantities as large as, or even larger than, in pure expired air. Thus the average excess of the bleaching from expired air over that of the laboratory was found to be about 7·9 in the series of observations detailed at p. 87, and the average excess in the air of naturally ventilated schools was almost exactly the same. Although, as previously remarked, there are probably other factors to be taken into account here, the figures given are sufficiently striking. They make it appear probable that increased frequency of respiration may be of no avail whatever in making up for the impurity of the air.

The facts just alluded to appear all the more striking when we consider that expired air contains about 438 volumes per 10,000 of carbonic acid, whereas the highest carbonic acid found in schools was only 37·8 volumes. It is probable that poisoning by organic substances given off by the breath and skin has a very great effect in lowering the general health and predisposing to other diseases. The deaths from "debility" and "convulsions" in infants are perhaps in considerable proportions due to sub-acute poisoning by these substances.

As regards the influence of the micro-organisms of air, it seems probable that for persons in perfect health the great majority of them are harmless. The ciliated epithelium of the respiratory passages probably sweeps them out as fast as they become entangled in the mucus with which it is bathed. Even those which have penetrated as far as the trachea and bronchial tubes are thus probably ultimately swallowed. It seems scarcely possible that any can ever reach the air-cells.

The conditions are different, however, when there is even a slight catarrh of the respiratory passages. The bacteria in air are then probably a source of considerable danger. The bacteria doubtless propagate themselves in the secretions, which are only imperfectly expelled on account of the disorganization of the epithelium, and are therefore apt to be sucked or driven into the air-cells. A condition is thus produced comparable in many respects to that in the deep part of a punctured wound. Broncho-pneumonia and further destructive changes seem a very natural consequence. It may be that few species of bacteria in addition to the bacillus of tubercle are capable of thus causing serious injury (see THAON, 'Rev. de Médecine,' December, 1885), but that bacteria in air do act in this way seems at least very probable.

This hypothesis is quite in agreement with the death-rates given above. The enormous increase in the death-rate from acute bronchitis and broncho-pneumonia is due for the most part to a simple bronchitis (caused perhaps by exposure) becoming complicated with broncho-pneumonia, which latter runs an acute and rapidly fatal course.

The very high death-rates for measles and hooping-cough in one- and two-roomed houses is due, not, to any considerable extent, to the increased frequency of these diseases, but for the greater part, especially with measles, to secondary broncho-pneumonia. They are diseases which the majority of children of all classes have some time or other. During even a mild attack the respiratory passages are in a condition which, as explained above, makes them specially liable to be attacked by micro-organisms. Hence it is natural that broncho-pneumonia should appear in proportion to the contamination of the air breathed by the patient. In a ward in a children's hospital, where the ventilation was bad, THAON (*loc. cit.*) has observed that the mortality is three times as great as in another with good ventilation.

In scarlet fever there is no bronchial catarrh, hence the micro-organisms of air are probably not a special source of danger. We have inserted the death-rates from scarlet fever in the Table, although the number of deaths is too small for any definite conclusions to be drawn from them. The death-rate for the year was twice as great in the houses of three rooms and upwards as in the one- and two-roomed houses. If, however, we take the mean of this and the previous year, for which we also possess data as regards scarlet fever, the death-rate (31 deaths in all) is about a third greater in one- and two-roomed houses. This increase is not in proportion to the increase (two-thirds) in the general death-rate in the lower class of houses, and does not compare with the increase from measles, and, to a less marked extent, hooping-cough.

It will be of interest to reproduce here a valuable Table prepared by Professor MAX GRUBER ('Wiener Med. Wochenschrift,' December 26th, 1885) from KÖRÖSI'S statistics of the town of Buda-Pesth for the years 1879–82. KÖRÖSI had compared the death-rates in the lowest class of rooms ("cellars") with the death-rates in the rest of the town for various diseases, and the Table shows the percentage increase or decrease in the death-rates.

	Percentage increase or decrease in death-rate.
Measles	+159
Hooping-cough	+100
Scarlet fever	− 8
Croup and diphtheria	+ 11
General death-rate	+ 35

The death-rate from scarlet fever here shows an actual decrease in the lowest class of dwelling. It seems just possible that this low death-rate may to some extent be accounted for by the same reasons as those for which artificially inoculated small-pox is less fatal. We cannot doubt that scarlatina is more common in the lower class of houses, and that, *ceteris paribus*, it is more fatal.

With diphtheria and croup, broncho-pneumonia is of exceedingly frequent occurrence, it is true (found in 90 per cent. of the fatal cases of diphtheria, according to Thaon, *loc. cit.*) But here the chances of broncho-pneumonia are about equal, whatever the number of micro-organisms in the air, because in these diseases the broncho-pneumonia is due to the specific poison of the disease, and caused by the spread downwards of infection from the throat. In diphtheria the patches of broncho-pneumonia are, according to Thaon, full of the same organisms as are present in the false membrane, and which produce artificial diphtheria in animals (Loeffler, 'Mittheilungen a. d. K. Gesundheitsamte,' vol. 2, p. 421). The death-rates both in Dundee and Buda-Pesth are in consistence with this hypothesis.

The curious relation in the death-rate from phthisis appears to depend on the mutual interaction of constitutional predisposition and bad hygienic conditions. The mere fact that, the worse the hygienic conditions, the more do children who are weakly die off in childhood, does not altogether account for the differences in the death-rate from phthisis. For, in spite of this survival of the fittest, the general death-rate above 20 increases steadily from the better to the worse houses (including Infirmary and Poor-houses), although the increase is nothing like so great as it is for children. Were phthisis due merely to the influence of bad hygienic conditions, we should, therefore, still expect the death-rate to increase up to the two- and one-roomed houses. As a matter of fact, although those under good hygienic conditions suffer by far the least from phthisis, yet it tells most heavily on those under only moderately bad hygienic conditions, and this is the case even when all the deaths in the Infirmary and Poor-houses are set down against those under the worst hygienic conditions, *i.e.*, those in the one- and two-roomed houses. This would seem to indicate a predisposition to tubercular disease in a certain proportion of the individuals, quite apart from general constitutional weakness. Under good hygienic conditions the great majority of these will escape altogether. Under medium conditions a large proportion will survive the tubercular diseases of childhood, but only to fall victims to phthisis later on in life. Under the worst conditions most will die of tubercular disease during childhood. So few will survive that, although a larger proportion of them will die than of the survivors under medium conditions, yet the death-rate from phthisis on the whole population in the worst houses will be less.

The fact that the mortality from croupous pneumonia increases so markedly from four- to two-roomed houses, and out of all proportion to the death-rate above childhood, is an important confirmation of the theory of its being caused by micro-organisms. The fact that it is rather less fatal in one- than in two-roomed houses is due probably to the fact that it is to a very large extent treated in the Infirmary, where very many recover who would certainly die at home.

Remedies.

It is not within the scope of this paper to discuss at length the methods which should be employed for maintaining a reasonably pure atmosphere in schools and in dwellings; but the following suggestions, as the result of experience, may not be without some value.

(1.) As our results show, the state of the air in the Board schools in Dundee is extremely bad, and urgently needs improvement. Doubtless the schools in other towns are in a similar condition. The symptoms ascribed to overpressure, which has been complained of so extensively of late, are probably largely due to the defective ventilation of the schools. Defective ventilation weakens and depresses the energies so that a child certainly cannot gain the full advantage of its education under a bad system of ventilation. It therefore behoves School Boards to pay much more attention than hitherto to the ventilation of their schools.

A sufficiently pure air in schools appears to be attainable only by mechanical ventilation. It is true, the necessary conditions of purity may also be got by the use of open-window ventilation; but then, in winter at least, the ill-effects of draughts are probably greater than those due to insufficient ventilation.

Of the systems of mechanical ventilation, it is better to blow air into the room, and allow it to find its own way out (preferably up special shafts), than to ventilate by extraction. Draughts are more easily avoided by the former method. But the great objection to the suction method is that a partial vacuum tends to be produced, which would greatly accelerate the entry of sewer-gas into the room from any defective drains, whereas the "blow-in" method has the positive advantage of producing the opposite effect. By blowing warm air into a room a much more uniform and higher temperature may be attained during winter; and this method is also independent of the state of the weather. All parts of the room are more thoroughly heated and ventilated than under the natural system. The air should be blown in under a low velocity through sufficiently large upright shafts, in order to avoid draughts.

(2.) In regard to houses, mechanical ventilation is, of course, out of the question, but very satisfactory results may be obtained in the case of a large block of buildings let out on flats in single- or double-roomed houses, as is largely the case in Scotch towns, by having a large open-air space or landing on each flat, and provided with open wire-grated windows without glass, so that a good current of fresh air may be maintained along the passages and staircases, whereby a pure, instead of an already vitiated, air enters and supplies the various rooms.

This was shown in a very marked manner in a large block of such one-roomed houses in Dundee. This block was eight stories high, covered an area of 555 square yards, and contained 136 separate one-roomed and four two-roomed dwelling-houses, Owing to bad trade, only the four lower flats are now occupied, but a few years ago all the houses were tenanted, and then had a population of about 700, or about three quarters of a square yard of ground to each person. It is, in fact, the largest and closest-packed block in Dundee. Formerly the ventilation was very bad, but by order of the sanitary authorities one room on each flat was thrown open as an air space, and the glass removed from the windows and replaced by open wire grating. The average temperature in this block was 54°, or only 1° below the average of all the one-roomed houses we examined, although the outside air at the time was 5° lower on the average than on the nights when the other one-roomed houses were examined. The analytical results obtained were as follows :—

	General average of 1-roomed houses.	Block of buildings referred to.			
		House on 4th flat.	House on 3rd flat.	House on 3rd flat.	House on 2nd flat.
Space per person	212 cubic feet	193	169	193	225
Temperature	55° Fahr.	..	52	53	56
Carbonic acid	11·2	8·6	7·9	8·8	10·0
Organic matter (excess)	6·7	4·0	3·8	3·0	3·3
Total micro-organisms	60	21	95	45	53

From this it will be seen that the open-air spaces have a marked effect in improving the condition of the air in such houses as those referred to. Since this alteration has been made a very marked improvement has taken place in the health of the inhabitants of this block of buildings.

(3.) The practice adopted in almost all small houses of keeping a lamp burning during the night is one to be deprecated, as it must add very considerably to the contamination of the air, especially in one-roomed houses, in which the cubic space per person is so small.

(4.) Cleanliness, both of the person, and more particularly of the dwelling or school, is of the very utmost importance in maintaining the purity of the air as regards micro-organisms, and one which from this point of view has not been previously advocated.

(5.) Though far from depreciating the beneficial effect of abundant air space, yet we think that the frequency with which the air in a room is changed is a far more important point to be attended to in providing a pure atmosphere.

(6.) Ventilation by mere diffusion should never be depended on alone, for, though it may remove a considerable portion of the carbonic acid, it has, probably, but little effect in reducing the organic matter and micro-organisms.

(7.) It is most important that the windows in houses and schools should be made to open widely, so that at intervals a good current of air may be sent through the room. This would be very effective in removing the organic matter and micro-organisms.

In conclusion, we have to express our best thanks to Miss Etta Johnstone, of

University College, for her paintings; to Mr. KINNEAR, Chief of the Sanitary Department, for his kindness in constantly furthering our work; to the Head Masters of the various schools we examined, and particularly to the Rectors of the High School and Harris Academy. Many other gentlemen have also given us valuable assistance, for which we are indebted. The photograph we owe to the kindness of Professor STEGGALL.

SUPPLEMENTARY NOTE.

(Added December, 1886.)

On dividing the naturally ventilated schools we examined into two classes, according as they were heated and ventilated by fires or by hot pipes respectively, we obtained the following results. The data for mechanically ventilated schools are added for comparison.

Description of School.	No. of rooms examined.	Carbonic acid.	Organic matter.	Total micro-organisms.
Ventilated mechanically, and heated by hot air blown into the rooms	20	12·3	10·1	16·5
Heated by fires, and ventilated in the ordinary way	18	16·9	15·7	169·
Heated by hot pipes in the room itself, and ventilated by windows, ventilators in the room, and in some cases by a few TOBIN'S tubes	21	20·0	16·5	92·

The above Table shows that with fires the carbonic acid was considerably and the organic matter slightly less than with hot pipes, while the number of micro-organisms was very much larger.

The above average for micro-organisms in schools with fires does not include the four denominational school-rooms. If we include them, the average is 241. The number 169 for micro-organisms includes all the Board schools; but those with fires have an average age of about fourteen years, whereas those with hot pipes average only about seven years. If, however, we take only the schools built between 1875 and 1880, the averages are as follows, and give practically the same results as regards the large excess of micro-organisms in schools with fires.

	No. of rooms examined.	Average age.	Total micro-organisms.
		years.	
Schools with fires, built 1875–80 .	7	2·9	171·
,, hot pipes, ,, .	13	3·5	108·

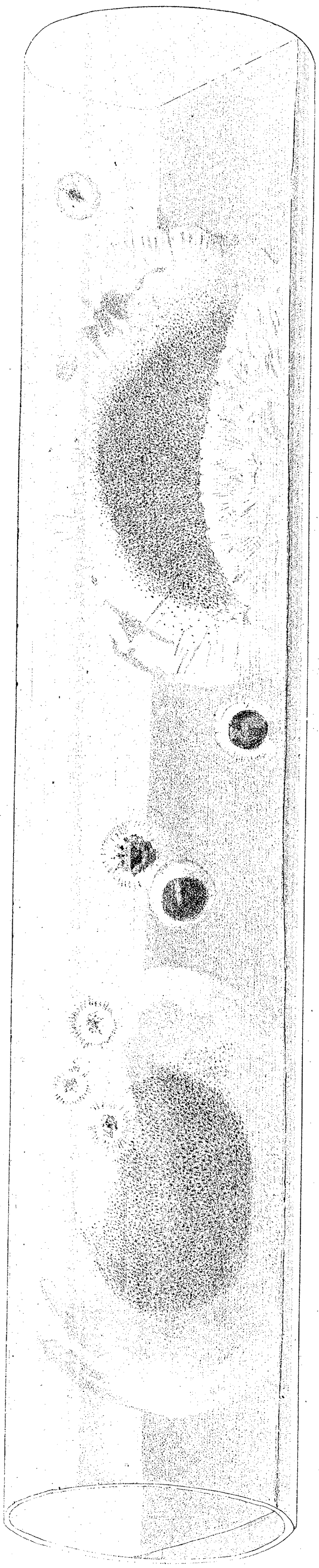


Fig. 1

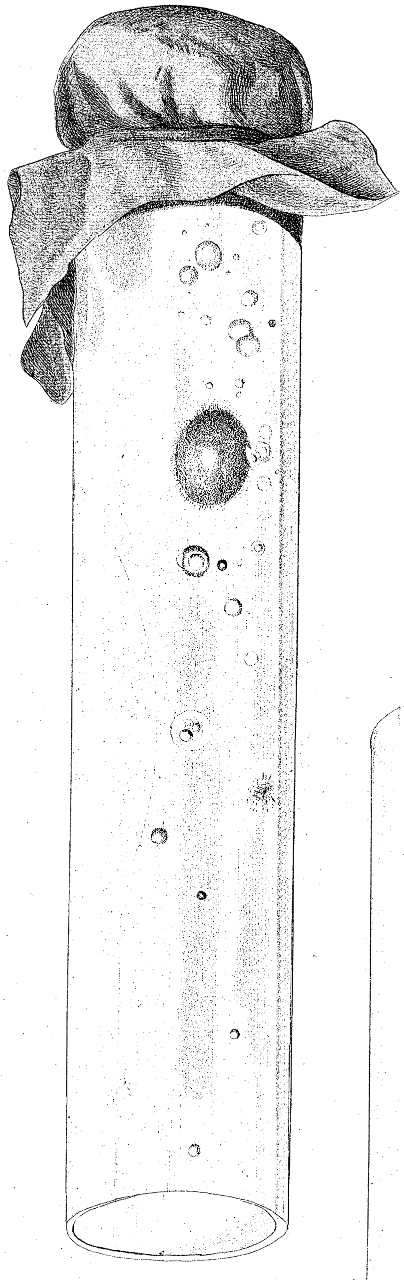


Fig. 2

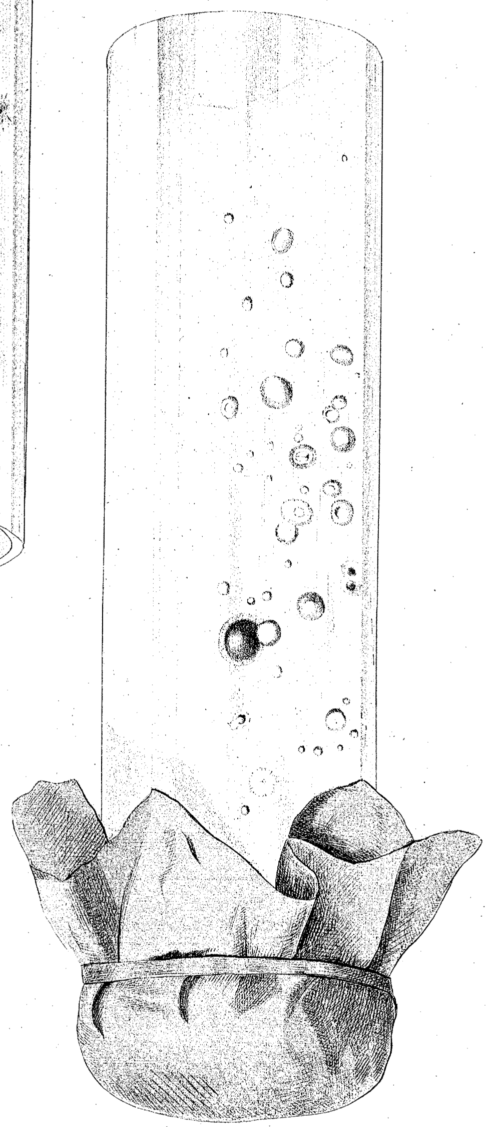


Fig. 3

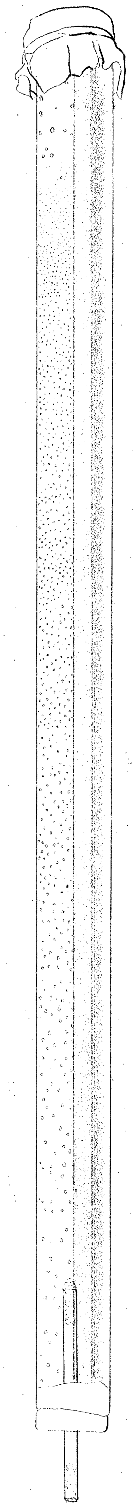


Fig. 4

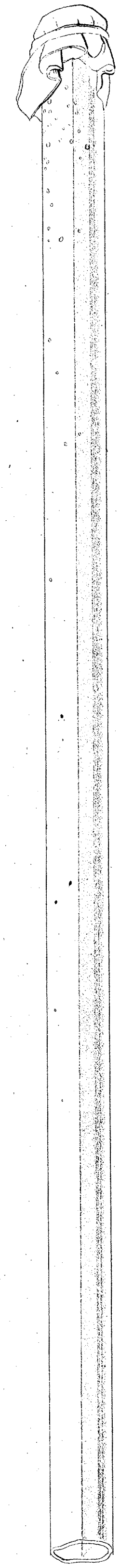


Fig. 5

THE CAMBRIDGE SCIENTIFIC INSTRUMENT COMPANY.

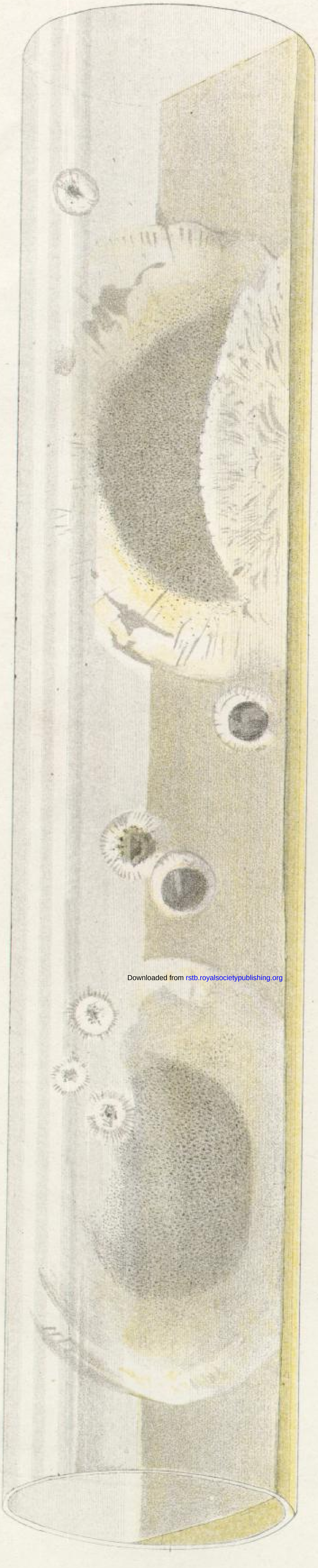


Fig. 1

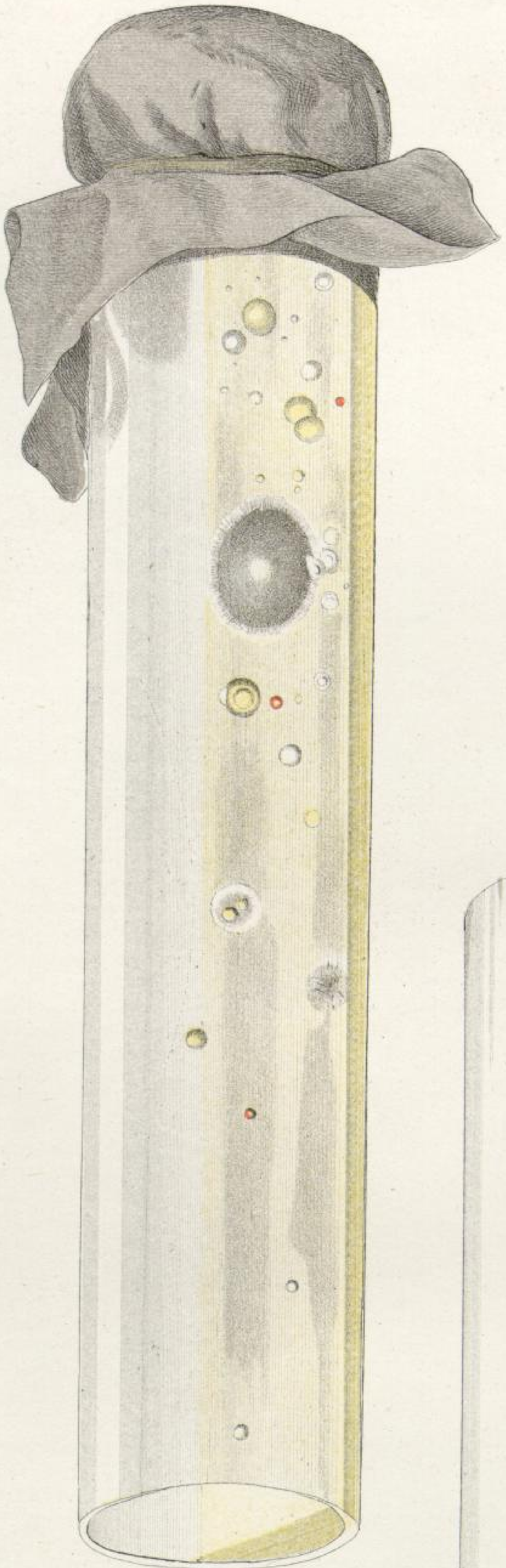


Fig. 2

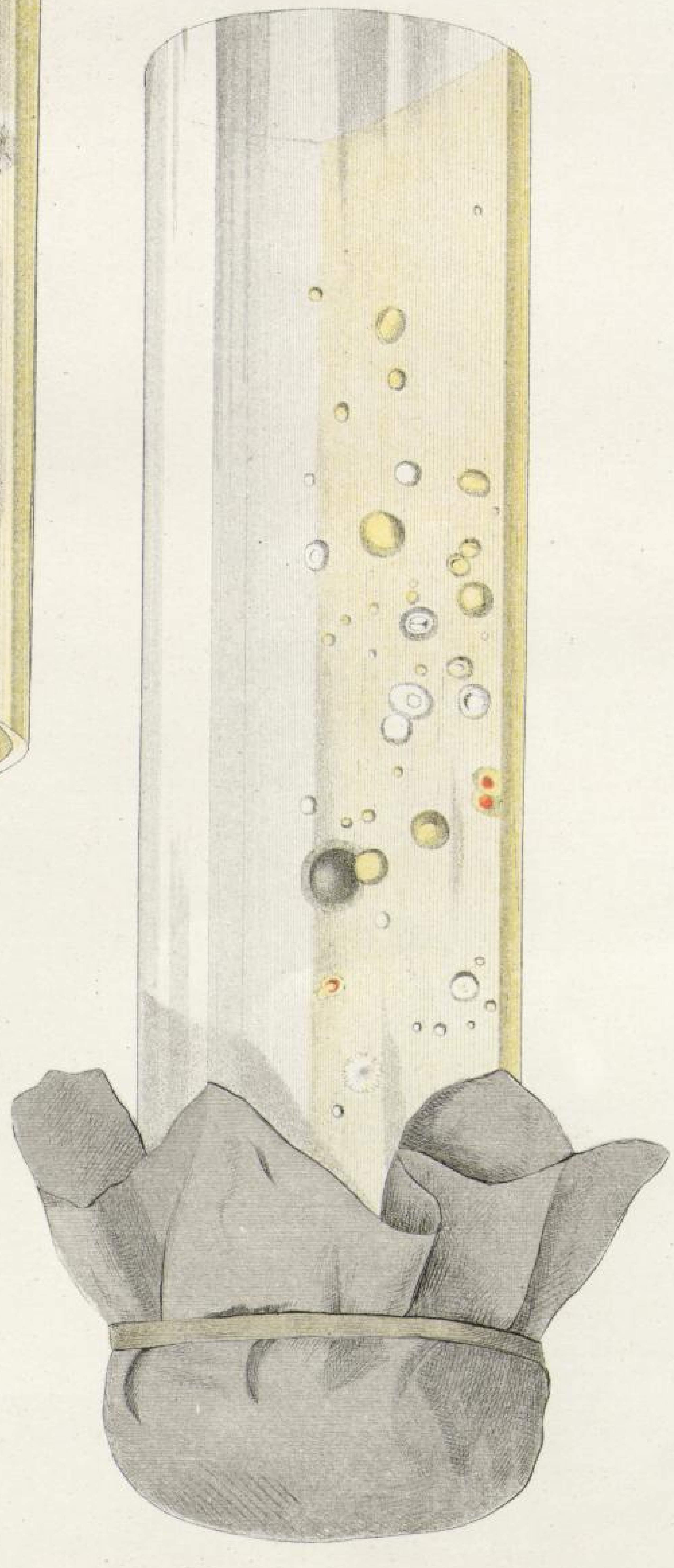


Fig. 3

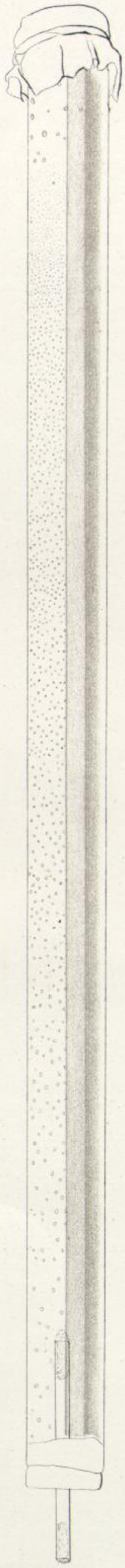


Fig. 4

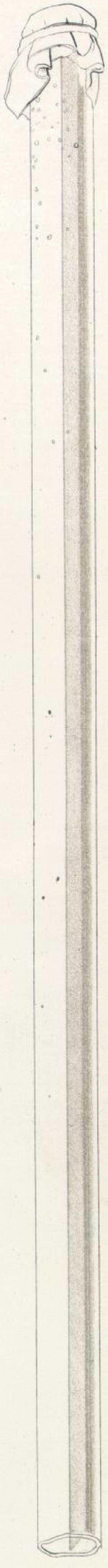


Fig. 5