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THE ATMOSPHERE OF THE UNDERGROUND ELECTRIC RAILWAYS OF LONDON.

A STUDY OF ITS BACTERIAL CONTENT IN 1920.

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(With 1 Text-figure and 6 Charts.)

CONTENTS.

I. INTRODUCTION.

FOR the purpose of ascertaining, so far as possible, the bacterial content prevailing in the air of the London Electric Tube railways, investigations were undertaken during the first half of 1920. The general object aimed at was to obtain information as to the degree of bacterial air contamination to which passengers were exposed in the course of daily travel and to learn how far the means provided for ventilation of the carriages and underground railways were effective from this point of view.

With the recent severe influenzal epidemics of 1918 and 1919 still fresh in the mind, there was also coupled the view that overcrowding and insufficient carriage ventilation were contributory factors in the spread of infection in the past and likely to be so again in the event of a recurrent epidemic, which then threatened but did not materialise.

Among previous publications on atmospheric pollution available for reference and guidance, particular mention must be made of the work of F. W. Andrewes on the Atmosphere of the Central London Railway in 1902, contained in his Bacteriological Report to the Parliamentary Committee of

the London County Council(1). So appropriate to the work in hand, this investigation proved invaluable, as will appear evident from frequent comparison and quotations made in subsequent pages of the present report. Use has also been made of the Reports by Carnelly, Haldane and Anderson on the Air of Dwellings and Schools (1887)(2) and by Graham-Smith on the Micro-organisms in the Air of the House of Commons in 1902, reprinted in the *Journal of Hygiene*, 1903(3). At a later date (1906) was published Mervyn Gordon's Bacteriological Report(4) in Section IV of the *Investigation of the Ventilation of the Debating Chamber of the House of Commons* (Cd. 3068) to which further reference will be made. More recently, in 1908, there appeared in book form a comprehensive study of the *Air and Ventilation of Subways*, by G. A. Soper, Ph.D.(5), which includes a review of the air conditions of the various European subways used for railway passenger traffic and gives an account of the particular investigations carried on in the New York subways in 1904—the basis of the publication.

The comparisons of the conditions reported, notably in the Central London Railway (Andrewes, 1902), the Metropolitan Railway of Paris (1901) and the New York Subways (1904), do not, in Dr Soper's opinion(5*a*), afford criteria for fixing a definite standard of purity for the air of subways, which, he says, "should be kept as pure as necessary to meet the sanitary requirements of the particular place in question—in other words each subway should be considered on its own merits." He observes also that, such subways as the Metropolitan of London and Rapid Transit of New York more nearly resembling streets than buildings, the standards regarded as suitable for the latter are not sufficiently exacting for superficial subways, whereas for the deep tubes of London, far below the streets, it is desirable to raise a high standard of purity.

II. PROCEDURE ADOPTED FOR EXAMINATION OF AIR OF LONDON TUBE RAILWAYS.

The following six Electric Railways were made the subject of investigation:

1. Central London.
2. City and South London.
3. Bakerloo.
4. Piccadilly and Brompton.
5. Hampstead and Highgate.
6. The Inner Circle of the Metropolitan District.

It was considered advisable that efforts should be directed to obtaining samples of air at times when the carriages and platforms were most likely to be crowded, *i.e.* during the rush hours and preferably between 5 and 7 p.m. In order that atmospheric conditions governing the time of year might not prejudice the results, journeys were made alternately on the various railways, rather than consecutively on each railway in turn. On the days corresponding with the tests carried out on the railways, samples for purposes of comparison

were also taken of the open air at points more or less in the neighbourhood of the railway concerned, but not invariably so.

Certain preparatory and trial samples for bacteriological examination were taken during the month of February but the investigations proper, the results of which are contained in this report, were not begun until March 3rd and were concluded on May 31st, 1920.

Through the courtesy of the authorities of the London Electric Railway Company, by the grant of special free passes and letters of introduction, every facility was afforded to the work of collecting the samples of air on the trains and platforms.

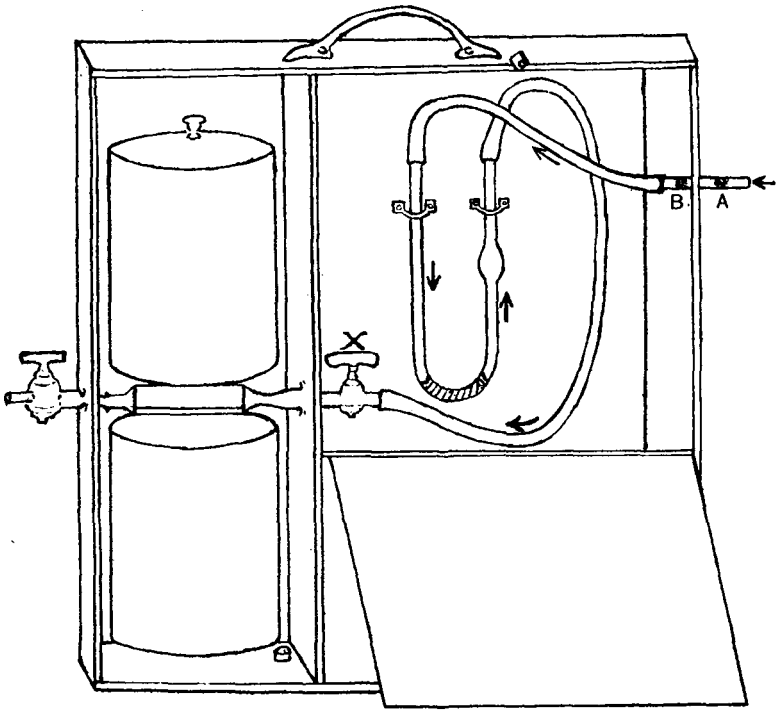
The majority of samples were taken while the trains were in transit and during the most crowded hours of the evening, *i.e.* between 5 and 7 p.m. A total of 60 samples of the air in the carriages was collected, *i.e.* ten from each railway, and alternate samples were examined by plate culture for organisms growing at 37° C. (mesophil group) and for those growing at 20° C. (psychrophil group). Therefore from each railway in all five samples were examined at 37° C. and five samples at 20° C. A total of 22 samples was also collected on the platforms of the most crowded underground stations of the various railways, excepting the District Railway, during the rush hour. Forty samples were taken of the outside air in the following localities: Charing Cross Gardens, Temple Gardens, steps of 2 Savoy Hill, the roof of Savoy Hill Buildings, the top of Duke of York's steps, Pall Mall, in Hyde Park, near Marble Arch Entrance, near the Serpentine and near Hyde Park Corner Entrance, also on Hampstead Heath and on Clapham Common.

	No. of samples
Railway carriages	60
Station platforms	22
Station passages	2
Outside air	40
Total	124

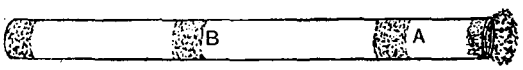
Of this total, nine samples, seven from carriage air and two from platform air, were rejected owing to unreliable cultural results due to confluence of colonies or liquefaction of culture media; thus leaving a net total of 115 samples (75 of Underground Railway Air and 40 of Open Air) on which the whole investigation is based.

Method of Collection of Samples of Air for Bacteriological Analysis. For the purpose of collecting the organisms contained in a known volume of air, an aspirator constructed on the hydrostatic principle was made use of attached to a special glass sampling tube. The method adopted was in principle that introduced by Frankland (6), subsequently used by Haldane and Laws and more recently by Andrewes and Graham-Smith, namely, the aspiration of a known volume of air through a plug of glass wool which retains all micro-organisms and can subsequently be distributed through a suitable cultivating medium in a glass capsule. The volume of air which had been

found most convenient and suitable for investigation was 5 litres, a larger quantity being liable to yield a number of organisms too great for accurate counting. The sampling tube (*AB*) consisted of a glass tube, 5 inches in length and one-third inch in diameter, containing two plugs of pounded glass wool placed at about one-and-a-half inches from either end of the tube, the one (*A*) firmly compressed to a quarter of an inch in thickness, the other (*B*) less compact. The ends of the tube were also plugged with cotton wool to prevent



Hydrostatic Aspirator



Sampling Tube (Half Actual Size)

Fig. 1.

the introduction of accidental contaminations in handling and connecting up with the rubber tubing. Before use the plugged sampling tube was carefully sterilised by heating in the dry oven to 160° C. for an hour, and kept in a plugged sterile test tube until required.

The aspirator employed was of familiar pattern, consisting of two connected brass cylinders each of 1 litre capacity, one being filled with water, and the two rotating on a hollow axis, which communicated by means of a stop-cock (*X*) and rubber tube with a glass U tube; the latter was connected

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by rubber tubing to the glass sampling tube containing its two plugs of powdered glass wool—*A* and *B*. The whole was enclosed in a wood framework measuring $15 \times 16 \times 4\frac{3}{4}$ ins., weight 15 lbs., and being quite portable was convenient for use in the railway carriages. Aspiration was effected by rotating the double cylinder, thus allowing the flow of water from the upper to the lower half and with it the suction of air through the plugs in the sampling tube to the emptying cylinder.

Count was kept of each rotation corresponding with the aspiration of 1 litre of air, and the sampling tube remained in place till the required 5 litres had been aspirated. The tube was then carefully detached, the ends replugged with sterile wool, and transferred to the sterile test tube for return to the laboratory.

The cultivation of organisms caught in the glass wool plugs from the air aspirated through the sampling tubes was effected in the following manner:

Each of the two plugs was projected into separate sterile glass capsules by means of a sterile glass rod driven down the lumen of the tube. The plug was then thoroughly broken up with sterile wire loops under cover of the capsule-lid. Melted agar-agar or gelatin, according to whether cultivation at 37° C. or 20° C. was to be applied, was poured quickly over the lower half of the capsule, and the teased glass wool and melted culture medium were thoroughly mixed by inclining the capsule slightly from side to side. When the medium had completely set, the agar plates were incubated at 37° C. and the gelatin at 20° C. Incubation was allowed to go on for six days, careful inspection being made each day to watch for development of colonies, which were "ringed" as they became visible, and finally counted. The aggregate of colonies thus obtained in each total count of two capsules represented the number of organisms derived from 5 litres of air. As was to be expected it was found that the capsule inoculated with the plug nearest the free end of the sampling tube yielded by far the greater bulk of colonies, it being exceptional to find more than a very few colonies in the capsule containing the second or inner plug. The counts of colonies having been tabulated, subcultures were then made from a certain proportion. With the application of further cultural tests and by the morphological and staining characters of the resulting growths, as described under Section VII, an attempt was made to classify the various organisms isolated.

III. SUMMARIES OF THE RESULTS OBTAINED ON THE SIX UNDERGROUND RAILWAYS.

1. THE CENTRAL LONDON RAILWAY.

The atmosphere of the Central London Railway having been bacteriologically examined in 1902 by F. W. Andrewes, the results obtained in 1920 were of particular interest after the lapse of 18 years during which the conditions above ground had changed considerably owing chiefly to the replacement of horse traffic by motor traffic.

Summary of bacteriological counts of colonies from 5 litre samples of air from the Central London Railway.

	No. of colonies growing in agar-agar at body temperature	Colonies growing in gelatin at room temperature
Railway carriages	7	—
	9	—
	17	37
	16	—
	13	17
	—	57
Average	12·4	37
Platforms	28	40
	13	40
Average	20·5	40
Total averages of carriage and platform air	14·7 at 37° C.	38·2 at 20° C.
Averages of open air controls on corresponding dates ...	11·7	20·6 per 5 litres

These results for the Central London Railway may be compared with those obtained by Andrewes in his examination of 12 samples of the air in the railway carriages, platforms, passages, lifts and tunnels of the same railway during March to June, 1902.

Total Averages (1902).

(1) Colonies at 37° C. per 5 litres of air 6·9.

(2) Colonies at 20° C. per 5 litres of air 44·1.

It should be noted that crowded conditions were selected for the observations of the present survey, and that the culture media were given a period of six days, which will partly account for the higher counts obtained of colonies developing at body temperature, whereas in the conditions during Andrewes' observations there was no excessive crowding of passengers, and his plates were not incubated for longer than four days.

2. City and South London Railway.

Summary of bacteriological counts of colonies from 5 litre samples of air from the City and South London Railway.

	No. of colonies growing in agar-agar at body temperature	Colonies growing in gelatin at room temperature
Railway carriages	24	—
	5	—
	21	49
	32	71
	6	29
Average	17·6	49·6 per 5 litres
Platforms	10	—
	8	47
	21	37
Average	13	42 per 5 litres
Total averages of carriage and platform air	16	46·6
Averages of open air controls on corresponding dates ...	8·5	36

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3. BAKERLOO RAILWAY.

Summary of bacteriological counts of colonies from 5 litre samples of air on the Bakerloo Railway.

	No. of colonies developing on agar-agar plates at body temperature	No. of colonies developing on gelatin at room temperature
Railway carriages	14	—
	7	48
	11	36
	40	52
	13	24
Average	17	40
Platforms	17	71
	26	36
Average	21·5	53·5
Total averages of carriage and platform air	18·3	44·5
Averages of open air controls on corresponding dates ...	8·2	36

4. PICCADILLY AND BROMPTON RAILWAY.

Summary of bacteriological counts of air samples on the Piccadilly and Brompton Railway.

	No. of colonies developing at body temperature 37° C.	No. of colonies developing at room temperature 20° C.
Railway carriages	31	42
	18	52
	18	30
	23	40
	20	—
Average	22	41
Platforms	21	56
	37	—
Average	29	—
Total averages of carriage and platform air	24	44
Averages of open air controls on corresponding dates ...	13·6	41·6

5. HAMPSTEAD AND HIGHGATE RAILWAY.

Summary of bacteriological counts of colonies obtained from the air of the Hampstead and Highgate Railway.

	No. of colonies developing at body temperature 37° C.	No. of colonies developing at room temperature 20° C.
Railway carriages	47	33
	11	49
	20	45
	18	37
	29	—
Average	25	41
Platforms	35	60
	15	23
Average	25	41·5
Total averages of carriage and platform air	25	41·2
Averages of open air controls on corresponding dates ...	8	32

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6. Metropolitan District. (Inner Circle.)

Summary of bacteriological counts of colonies obtained from 5 litre samples of air on the Inner Circle of the Metropolitan District Railway.

	No. of colonies developing at body temperature 37° C.	No. of colonies developing at room temperature 20° C.
Railway carriages	10	32
	10	—
	13	—
	22	30
	53	70
	40	53
Average	24·6	46·2
Averages of open air controls on corresponding dates ...	16	23·5

IV. GENERAL CONSIDERATION OF THE BACTERIOLOGICAL RESULTS.

From the foregoing summaries of the different observations made on the various railways it may be noted that taking the total averages of the bacteriological counts the following results are obtained:

(1) For railway carriages.

No. of samples: 53			No of organisms growing at 37° C. (mesophil)*			No. of organisms growing at 20° C. (psychrophil)*		
at 37° C.	at 20° C.		Averages†	Highest	Lowest	Averages†	Highest	Lowest
5	3	Central London	12·4	17	7	37	57	17
5	4	Bakerloo	17	40	7	40	52	24
5	3	City and South London	17·6	32	5	49·6	71	29
5	4	Piccadilly and Brompton	22	31	18	41	52	30
5	4	Hampstead and Highgate	25	47	11	41	49	30
6	4	Metropolitan District (Inner Circle)	24·6	53	10	46·2	70	30

(2) For platforms.

No. of samples: 20								
3	2	City and South London	13	21	8	42	47	37
2	2	Central London	20·5	28	13	40	40	40
2	2	Hampstead	25	35	15	41·5	60	23
2	2	Bakerloo	21·5	26	17	53·5	71	36
2	1	Piccadilly and Brompton	29	37	21	56	56	56
		Metropolitan District	No tests made			No tests made		

(3) Total averages for railway carriages and platforms.

Central London	14·7	38·2
City and South London	16	46·6
Hampstead and Highgate	25	41·2
Bakerloo	18·3	44·5
Piccadilly and Brompton	24	44
Total average	23·2	45·3

* The differentiation of the mesophil (37° C.) and psychrophil (20° C.) organisms into separate groups does not constitute a hard and fast distinction between the two, for the mesophil group, enumerated as such, may include a proportion also of the psychrophil organisms. But the majority of pathogenic organisms proper will be strictly mesophil, only growing at body temperature.

† per 5 litres of air.

The result of the samples taken at the foot of the escalator at Oxford Circus Station serving both the Central London and Bakerloo Railways is not included in the above total average (45·3). This observation yielded the highest

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count obtained anywhere, viz. 51 colonies at body temperature (37° C.) and 110 colonies at room temperature (20° C.). It was taken under conditions of passenger density and air movement likely to yield a high rate of bacterial contamination.

Open air controls. Observations made on dates corresponding with those on the various railways yielded the following averages:

Railways Dates corresponding with observations on the	Organisms at 37° C. (per 5 litres)	Organisms at 20° C. (per 5 litres)
Central London	11·7	20·6
Bakerloo	8·2	36
City and South London	8·5	36
Piccadilly and Brompton	13·6	41·6
Hampstead and Highgate	8·0	32
Metropolitan District	16·0	23·5
Averages of all open air controls	11·0	31·6

At 37° C. Highest 31 (Hyde Park)
Lowest 2 (Hampstead Heath)
At 20° C. Highest 85 (Hampstead Heath)
Lowest 6 (Roof of Savoy Hill Buildings)

The combined averages of results obtained from all railways yielded:

	Organisms at 37° C. (per 5 litres)	Organisms at 20° C. (per 5 litres)
For carriage air	19·8	42·8
For platform air (including the result of sample taken at Oxford Circus escalator between the Bakerloo and Central London Stations) ...	26·6	52
For carriage and platform air	23·2	45·3

As a large proportion of the organisms present in the air do not grow at the body temperature (37° C.), the estimate of total number must be drawn from a consideration of the counts obtained at room temperature (20° C.).

It will be seen from the figures given above that the Central London Railway yields the lowest total average of organisms for railway carriage air (37 per 5 litres); the Bakerloo comes next with 40, followed by the Hampstead and Piccadilly Railways with 41 each, and then the Metropolitan District with 46·2, and lastly the City and South London with 49·6. In the platform samples, too few perhaps to provide reliable data, the counts varied from an average of 40·0 for the Central London to 56 per 5 litres of air for the Piccadilly Railway. The higher range of the bacterial content is to be attributed to the greater draught and dust disturbance prevailing on the platforms.

Grouping together both carriage and platform results the total averages place the Central London first with 38·2, then the Hampstead Railway with 41·2, the Piccadilly follows next with 44, and the Bakerloo with 44·5; lastly the City and South London Railway with 46·6. Owing to the Metropolitan District Stations all being directly open to the outside air no platform samples were taken on the Inner Circle.

The average counts of total organisms in the open air obtained on corresponding dates from open air controls are found to vary from 20·6 to 41·6

per 5 litres, *i.e.* a degree of microbic air pollution not greatly behind that found in railway air and in one group actually slightly above the corresponding railway averages; the total means appear as 31·6 for open air and 45·3 for railway air.

The comparison is, however, less close when the figures of average results for organisms growing at body temperature are considered. That the disparity between railway and open air counts should be more marked in the body temperature or mesophil group is not surprising, in view of the usually crowded conditions under which railway samples were taken, favouring a greater proportion of organisms growing at the higher temperature. Taking the average of all results the differences between open air and railway air appear more evident but are still not as great as might perhaps have been expected.

Open air and railway air compared.

	Open air		Railway air	
No. of organisms obtained at body temperature	11		23·2	per 5 litres
Ratio	1	to	2	
No. of organisms obtained at room temperature	31·6		45·3	per 5 litres
Ratio	10	to	14·5	

Comparison of the results of the recent observations with those of other workers. Comparison may here be drawn between the figures above quoted and the results obtained by other observers, notably Andrewes in 1902. Between the figures derived from the latter's report and those of this paper there is found to be extraordinarily close agreement for the total averages of the number of organisms growing at room temperature particularly in the case of railway air. For the number of organisms growing at body temperature in the two series of observations the *ratio* between open air and railway air is also very much the same, viz. as 1 to 2, but in the case of the recent observations the actual total at body temperature is some three or four times higher for both open and railway air. This increase, at any rate for railway air, may, as already suggested, be accounted for in part by the crowded conditions existing at the time the samples were taken. Such a hypothesis can scarcely be put forward, however, to explain the increase in the number of organisms growing at body temperature in the open air. It would be a daring suggestion to throw out that the increase in the latter may be due to the vast development in human and motor traffic, compared with what existed 18 years ago, and consequently greater microbic air pollution, despite a diminution in horse traffic.

The total averages of the respective observations are as follows:

	Open air		Average of six Tube Railways	Central London Railway air
	1902 (F.W.A.)	1920 (J.G.F.)	1920 (J.G.F.)	1902 (F.W.A.)
No. of organisms growing at body temperature (37° C.)	3·4	11·0	23·2	6·9 per 5 litres
No. of organisms growing at room temperature (20° C.)	33·9	31·6	45·3	44·1 „

If the results of the two series of observations obtained in the Central London Railway are alone compared there is, however, not quite so close

an agreement between the number of organisms growing at the two temperatures.

Average of carriage and platform samples on the Central London Railway obtained in the recent observations

Organisms growing at body temperature	14·7 per 5 litres
Organisms growing at room temperature	38·2 „

A comparison may also be made with the results of Graham-Smith's(3) experiments on the air of the House of Commons during July, 1902.

Place	No. of organisms per litre at 20° C. varying between
In chamber during debate on July 21st	10·6 and 4·4
Ventilating shaft to chamber	2·6 and 0·8
Committee, Dining and Smoking Rooms of the House of Commons	44·2 and 20·9
Outside air, July 18th	6·0 and 1·5 (according to altitude)

The air of the open space surrounding the Houses of Parliament contained 4·2 organisms per litre which he regarded as a comparatively small number. The mean of his experiments, numbering 11 in the Debating Chamber, was 5·8 per litre. This, from the bacteriological point of view, he described as remarkably pure; the mean of six experiments in the Committee, Dining and Smoking Rooms was considerably higher (32·3 per litre).

The mean of Andrewes' results at 20° C. reduced to the same proportion per litre yielded for

(1) Central London Railway air ...	8·82 per litre
(2) Outside air	6·78 „

The mean of the 1920 observations reduced to the same proportion per litre yielded for

(1) Railway air of all the six railways ...	9·00 per litre
(2) Outside air	6·32 „

The results of these later observations, when viewed in comparison with the findings of Andrewes and Graham-Smith, may be regarded on the whole as satisfactory evidence of no really gross microbic air pollution in the various railways concerned.

The results of observations at an earlier date may be quoted from the work of Carnelly, Haldane and Anderson(7) in Dundee dwelling-houses and schools, published in the *Philosophical Transactions*, 1887, and by Carnelly (1893–4)(8). They reported on the influence of locality, age of the buildings, cleanliness and ventilation. In 28 naturally ventilated schools described as very dirty a mean of 152·1 organisms per litre was obtained, but in 18 schools in which mechanical ventilation was in use the average number of organisms amounted only to 16·58 per litre. Where, however, better conditions of cleanliness existed such as in private schools, though naturally ventilated, the degree of microbic pollution was found to be very considerably lower, viz. nine organisms per litre. A still lower figure prevailed in good class and mechanically ventilated institutions where cubic space was much greater, such as 2·8 and 3·6 per litre in the Dundee University College and High School respectively.

The influence of cubic space, general cleanliness and number of occupants in the bacterial air content was also shown by the results of observations made in various dwelling-houses.

The air of one-roomed houses yielded an average of 60 organisms per litre, of two-roomed houses 46, and of four or more roomed houses nine only per litre. The results of their observations of outside air varied between 0·8 per litre for quiet places and 17·5 per litre in busy streets. A standard of air purity was suggested for dwelling-houses and schools and it was considered that a limit of 20 organisms per litre should not be exceeded.

In the samples taken of railway air it will be noted that the results are well within this limit and only once exceeded it, in the case of the air examined at the foot of the Oxford Circus escalator, when 22 organisms per litre were obtained.

It should be pointed out, however, that the standard of purity advocated of 20 organisms per litre is based on results derived from observations taken under conditions of atmospheric pollution which were unhesitatingly condemned. Moreover, this standard a quarter of a century ago was probably regarded as presenting an improvement within the then bounds of possible attainment.

There are grounds for the belief that such a limit at the present day cannot be considered satisfactory or sufficient.

The observers qualified their standard as applicable only to the method then employed in the use of Hesse's Tube (measuring 70 cm. by 3·5 cm.) coated with Koch's jelly, over which air was aspirated at the rate of 1 litre in three minutes. Their readings of the number of resulting colonies also extended over a period of three to four weeks at room temperature for each examination made. An improved and somewhat more accurate and practicable method was introduced by Frankland(6) who conducted a number of experiments on the air outside the Science Schools, South Kensington. He aspirated measured quantities of air through a narrow glass tube containing sterile glass-wool plugs, such as was used by Andrewes in 1902, and has been adopted in the present investigations as likely to give the most reliable results. Frankland's control experiments with both the Hesse Tube and the narrow tube plugged with glass wool showed on the whole remarkable agreement between the results of the two methods, when conducted in the still atmosphere prevailing in a closed room; howbeit, the Hesse method was regarded as yielding results generally slightly too high—on the other hand, under conditions of disturbed air and free currents in active movement such as obtained outside, Frankland estimated the Hesse Tube to yield considerably too high a figure, which required correction by deduction of one-third of the number of organisms per litre—19 of Frankland's original experiments on the outside air yielded an average of seven organisms per litre. With further tests by a later method applied to some 40 observations he obtained an average of between 4 and 2·5 per litre for the air outside the Science School Laboratories and in examinations

made outside St Paul's Cathedral his results averaged 1 per litre at the top of the Dome, 3·8 per litre at the base of the Dome and 4·7 per litre in St Paul's Churchyard.

The average of Graham-Smith's figures for the air outside the Houses of Parliament varied between 1·5 and 6 per litre, according to altitude.

Andrewes' average for London air in 1902 was 6·78, and the mean of the recent open air tests in various parts of the Metropolis was 6·32 per litre.

In the bacteriological investigations of the air of New York subways in 1903, about 3000 samples were examined. They included numerous exposures of plate culture media for periods of 15 minutes or less, and estimations derived from the filtration of measured quantities of air through sand filters, taken in the subways (but not in the cars), and in the open air of the streets outside. They yielded numerical results the exact opposite of those found both in 1902 and 1920 in the London investigations, *i.e.* an average ratio of two organisms in the street air to one in the subway air; plate exposure providing an average of 1150 organisms, growing at body temperature, in street samples and 500 in subway air; and the filtration method giving 6500 organisms per cubic metre in the streets and 3200 per cubic metre in the subways(5 *b*). The very different conditions, atmospheric and constructional, pertaining to the London and New York tube systems and streets, do not, perhaps, afford a fair basis for comparison of the respective ratios of the bacterial contents of the street and tunnel atmospheres of the two Capitals, and, as already quoted, "each subway should be considered on its own merits." The New York report includes studies of the possible action on bacteria of lubricating oils (in use on the running machinery) and of the deodorants and disinfectants, employed on platforms and in conveniences, but found to be of negative bactericidal value. Also, many analyses of dusts and numerical determinations of the bacteria, present in the dust of subways, were made and compared with dust samples from theatres, hotels and elsewhere. Detailed examinations of this character were, however, quite outside the range of the present investigation.

Dr Soper in his conclusions(5 *c*) was of opinion that according to usual standards based on chemical and bacteriological analyses the general air of the New York subways (not of the cars) was always and everywhere satisfactory; the exchange of air was abundant except in closed and crowded carriages and where dense crowding on platforms occurred.

The high temperature of the subways was the most evidently objectionable feature, especially in the morning and evening rush hours, the heated air not escaping with sufficient rapidity for comfort, although renewed often enough for health.

He regarded the bacteriological condition of subway air as satisfactory in that only half as many bacteria were found as in the air of the streets, although too much reliance was not to be placed upon this comparison as a guide to the condition of the subway air.

V. RELATIONSHIP OF THE NUMBER OF ORGANISMS IN THE AIR OF RAILWAY CARRIAGES TO PASSENGER DENSITY.

At the time of collection of air samples in the carriages approximate estimations of the number of travelling passengers were made and grouped under the head of passenger density (*vide* Charts I and II) as "packed," "half standing," "standing," "full," "$\frac{3}{4}$ full," "$\frac{1}{2}$ full," "$\frac{1}{4}$ full," and "empty," numerically represented for purpose of comparative charting by the figures 100, 74, 64, 54, 40, 27, 14 and zero, 54 being the average of the total seat accommodation in a single compartment.

The observations were made with a view to tracing relationship between passenger density, particularly overcrowding, and the bacterial content of the air prevailing at the time in the moving trains. In discussing any such possible correlation it is necessary to bear in mind that a high bacterial content is associated with dust disturbance due to fluctuating air currents, in the absence of which floating microbic particles will tend to subside with a gradual lowering of the bacterial air content. The process of settling, however, is extremely slow since the weight of a bacterium is less than a billionth of a gram and it may be held in suspension for considerable periods (9).

In the air of a compartment which has been emptied, provided the air remains still, the degree of microbic pollution will steadily diminish—the more quiescent the state of air the greater will be the subsidence of dust and the reduction in the number of micro-organisms in suspension in the air.

A condition of absolute stillness of the air can, however, never be found in a moving train and would only be possible when stationary and with windows and ventilators closed.

By charting the mean of all observations made consecutively and under corresponding conditions of passenger density for the respective groups of mesophil and psychrophil organisms, an attempt has been made (Chart I) to

Tabulated results of the total averages showing comparison of passenger density and number of organisms per 5 litres in corresponding observations on the air of railway carriages on the six railways concerned.

	Central London		Bakerloo		City and South London	
Passenger density in compartment	40·0	46·0	60·0	60·0	88·0	64·0
No. of organisms in 5 litres	27·0 (at 20° C.)	15·0 (at 37° C.)	37·0 (at 20° C.)	21·0 (at 37° C.)	49·6 (at 20° C.)	20·0 (at 37° C.)

	Piccadilly and Brompton		Hampstead and Highgate		Metropolitan District		Total railway carriages	
Passenger density in compartment	46·0	51·0	55·0	52·0	87·0	87·0	62·0	58·0
No. of organisms in 5 litres	41·0 (at 20° C.)	27·0 (at 37° C.)	41·0 (at 20° C.)	24·0 (at 37° C.)	31·0 (at 20° C.)	46·0 (at 37° C.)	40·0 (at 20° C.)	23·0 (at 37° C.)

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demonstrate the relationship of passenger density and the bacterial content of the carriage air on each of the six railways.

In the case of the mesophil group there appears to be a general tendency for the bacterial and passenger curves to run parallel, except on the Piccadilly Railway, the number of organisms per 5 litres of air rising and falling with the increase and decrease of passenger density. This parallelism becomes more evident on the psychrophil side, especially on the Metropolitan District and South London Railways, but again in the case of the Piccadilly Railway and

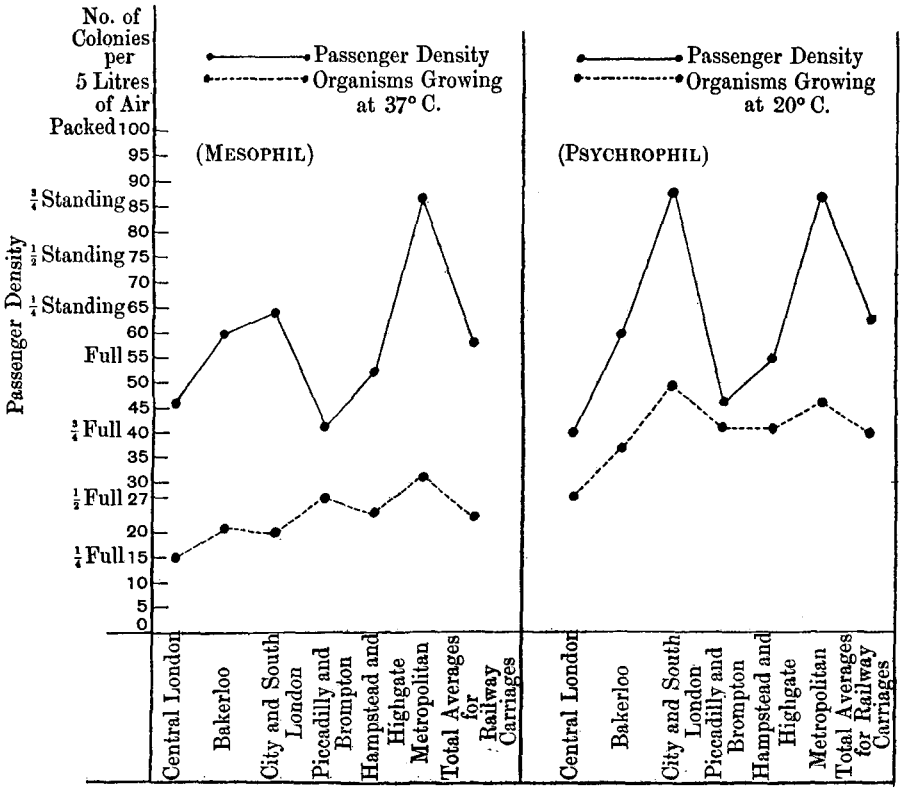

Chart I. Relationship of passenger density and bacterial air content—as shown by the mean of total observations made on corresponding dates.

to a less degree the Hampstead Railway, the lower mean of the passenger rates is associated with a relatively high average bacterial content.

The results of the individual observations taken consecutively under approximately the same conditions of passenger density for the two bacterial groups, show on Chart II a fairly close parallel agreement, though at different levels, between the mesophil curves of four of the railways, viz. Metropolitan District, Central London, and most marked for the South London and Hampstead and Highgate Railways, where the bacterial content of carriage air falls with the fall in passenger rate for each line.

In the case of the Piccadilly and Bakerloo Railways, however, there is not

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the same conformity, the bacterial content showing a sustained rise for the one and an irregular rise and subsequent fall for the other railway, in spite of a mutual progressive decline of the passenger rate of both lines.

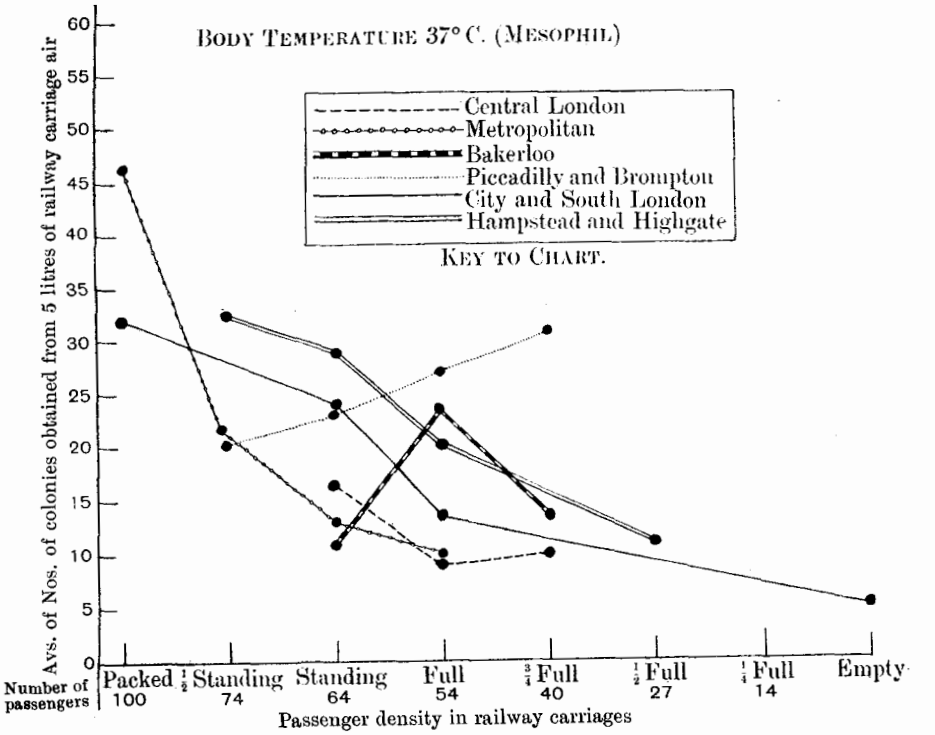
Similarly, on the psychrophil side of Chart II the fall in bacterial content and passenger density run parallel except on the Piccadilly and Hampstead Railways, both of which show a rising bacterial content with a falling passenger rate.

Though difficult to explain satisfactorily, discrepancies of the two temperature groups, especially in the case of the exceptions mentioned, notably the Piccadilly Railway, are to be partly accounted for by changes in passenger density occurring while the samples for the respective temperature groups of organisms were being taken on the lines concerned.

The mesophil group of organisms may be taken generally to include those derived from a human or animal source and does not embrace the large proportion of moulds which develop at the lower temperature. Broadly speaking, whilst the number of mesophil bacteria would seem to vary as the passenger density, this parallelism is apparently more marked in the case of the psychrophil group.

The comparisons of the various observations concerned, however, cannot be too closely driven on account of the differing phases of ventilation and movements both of train and passengers during the course of taking a single sample of 5 litres, a process occupying about eight minutes. In this time there occurred stoppages at stations, opening and closing of carriage doors, exit and entrance of passengers creating considerable changes in the currents of air circulating through the compartment and likely to affect the numbers of floating organisms. In addition to these temporary alterations, factors common to each particular line have to be borne in mind as influencing air movement, such as the position of the doors and the number and position of windows which may be open or closed. In the case of the Metropolitan District Railway carriages, where doors open at the sides of the carriages either in the middle or at the end, there is less encouragement for a clear passage of air through the compartment than in the case of the other lines, where many of the carriages have end-doors permitting of free current, and frequently it may happen that one end is left open throughout the journey.

A further factor, affecting the results of observations on the Metropolitan District Railway, is the type of ventilating window in use, particularly in the older carriages running on the Inner Circle. Of two types still used, one drops open on release of spring catches placed centrally or at each side, the other has to be raised, and kept open by supporting hooks. In either case the simultaneous use of both hands is required to open the window. This action few people are able or will trouble to carry out, consequently the window remains shut. The central double spring catch is more easily worked but is often out of order or the window frame refuses to drop. In all the other railways the ventilating frame is readily opened by depressing a ring



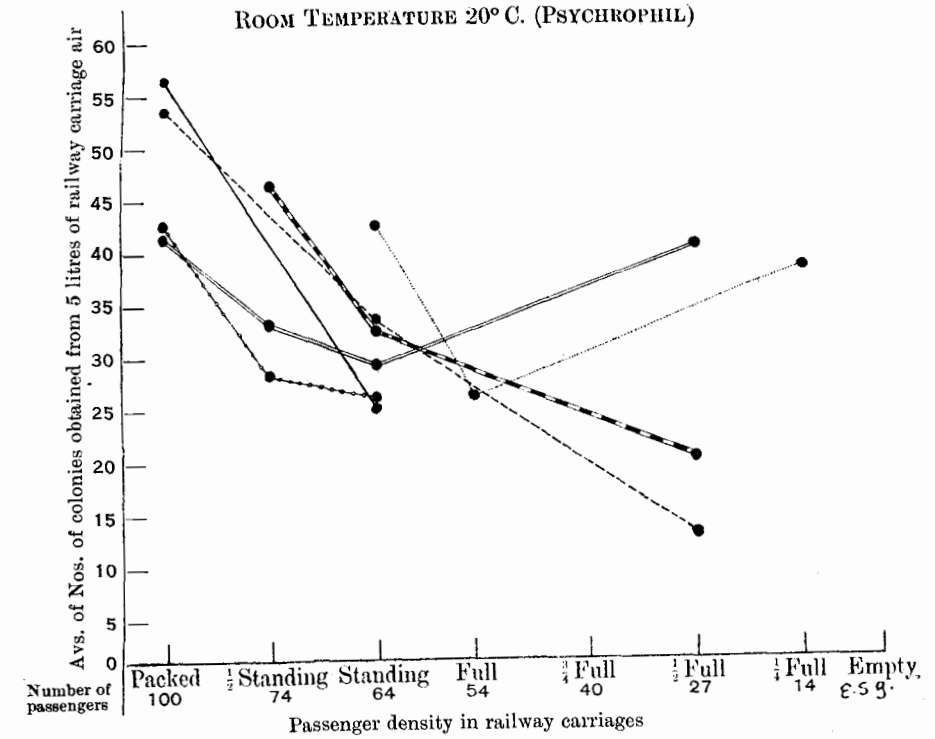


Chart II. Charts of individual observations taken consecutively and under approximately corresponding conditions of passenger density for each of the temperature groups and showing relations between passenger density in moving trains and number of organisms growing at body temperature and room temperature.

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attached to the central catch and the window falls forward at once. From the greater simplicity of this type of window it follows that there is better prospect of ventilation than can be obtained on the Inner Circle, on which there would seem to be a tendency for the carriages to carry on the vitiated air from station to station.

There are, therefore, infinite possibilities of constant change of atmospheric conditions arising from fluctuating currents and passenger movement which may influence bacteriological results of individual observations, but by taking the averages of a number of results it would appear, from the charts and figures given, that a certain degree of uniformity and correlation between a series of observations bearing on bacterial content and passenger density can be secured.

With reference to the systems of ventilation employed and the means relied upon for renovating the air in the different Tube Railways, it may be stated here that the method in vogue on the Central London Railway, of the introduction of air by pumping engines combined with dependence on piston action of the trains in motion and an extracting fan at Liverpool Street Station, is probably more efficacious than the methods of ventilation used on the other railways. The Bakerloo, Piccadilly and Brompton, and Hampstead and Highgate depend largely on extraction fans and use only pumping engines at some of the change stations. The piston action of trains plays a part on these lines, and on the City and South London Railway it would appear to be the sole means of effecting change of air. In the case of the Metropolitan District Railway, whose stations are all open to the outside air, the piston action would for this reason be inhibited to a considerable extent. This fact and the absence of any pumping or extraction means, together with overcrowding, and on the Inner Circle the unsatisfactory type of window frame already mentioned, may possibly account for the high figures of observations obtained on the Inner Circle of the Metropolitan Railway and City and South London Railway.

In the report on the New York subways great importance is attached to the piston action of trains (5 *g*) moving through tunnels, especially non-stop express, in creating ventilation currents and change of air, to the extent of superseding the need of blow holes to the surface and rendering unnecessary the operation of mechanical devices such as fans. The superiority of train movement over fan power for the ventilation of underground railways is also emphasised in a report (1910) on the Hudson River Tubes (10), which states: "The velocity and directions of the air is governed almost entirely by train movements and not by the fans.... It is therefore evident that the function of the fans is only to take the air pushed to them by the trains or to deliver fresh air where the trains can push or draw it through the stations or tunnels, and this fact should mainly govern the locations for other fans and air ducts."

VI. AN "INDEX OF BACTERIAL POLLUTION" OF RAILWAY CARRIAGE AIR.

For the purpose of estimating a suggested "index of pollution," observations derived from samples taken consecutively and under as nearly identical conditions of passenger density as possible for each of the two temperature groups have only been utilised. This involves the omission of certain individual observations figuring in the total results given on p. 130 and with which there was no corresponding sample in one or the other temperature group. By using the figure for the bacterial content as the divisor and that of the corresponding passenger density as the quotient, the ratio of the one to the other is obtained, giving the "index of bacterial air pollution" in possibly truer proportion for each railway than by consideration of bacterial content alone, irrespective of passenger density.

A comparison of the ratios of the one to the other shows that the index of pollution for each of the six railways varies in the mesophil and psychrophil groups and in the relative positions occupied by some of the railways in the two groups.

Moreover, the degrees of pollution of carriage air, viewed from the standard of bacterial content alone, undergo considerable rearrangement in the order of precedence (*vide* p. 130), when passenger density is taken into account and the ratios of the two are estimated as the "index of pollution." This rearrangement most affects the positions of the Metropolitan District and City and South London Railways in the psychrophil group, where they become respectively 1st and 2nd instead of 5th and 6th in order of purity. Conversely the Central London drops from 1st to 4th place whilst the positions of the other

MESOPHIL GROUP.

Railway		Average of number of organisms in 5 litres of carriage air growing at 37° C.	Average of corresponding passenger density	Ratio of bacterial content to passenger density
1. City and South London	(3rd)*	20	64	1 to 3·2
2. Central London	(1st)	15	46	1 „ 3
3. Bakerloo	(2nd)	21	60	1 „ 2·9
4. Metropolitan District	(6th)	31	87	1 „ 2·8
5. Hampstead and Highgate	(5th)	24	52	1 „ 2·2
6. Piccadilly and Brompton	(4th)	27	51	1 „ 1·9
Average for all railways		23	60	1 „ 2·6

PSYCHROPHIL GROUP.

		Do. at 20° C.		
1. Metropolitan District	(5th)	46	87	1 to 1·9
2. City and South London	(6th)	49·6	88	1 „ 1·76
3. Bakerloo	(2nd)	37	60	1 „ 1·6
4. Central London	(1st)	27	40	1 „ 1·5
5. Hampstead and Highgate	(4th)	41	55	1 „ 1·4
6. Piccadilly and Brompton	(4th)	41	46	1 „ 1·1
Average for all railways		40	62·6	1 „ 1·5

* Bracketed figures denote positions in order of air purity based on the averages of all observations on bacterial content alone; *v.* p. 8.

three railways are less affected, the Bakerloo falling from 2nd to 3rd, the Hampstead and Piccadilly Railways each dropping from 4th to 5th and 6th on the list.

In the mesophil group the changes in order are less marked; the Metropolitan District and South London Railways each gain two places, the latter displacing the Central London from the 1st place, the Piccadilly falling from 4th to 6th, changing places with the Metropolitan, whilst the Bakerloo and Hampstead Railways remain in their respective positions of 3rd and 5th.

From the evidence provided by the ratio of bacterial content to passenger density, reckoned as the "index of pollution," it would appear that the increase of the two does not occur in strict linear relationship—whereas with a rising passenger rate and overcrowding, the total bacterial content is undoubtedly increased, the increase in bacterial pollution of carriage air is not in direct proportion to the high passenger rate, but is relatively less per passenger than with a lower passenger density.

The observations on which the above ratios are based are however too few and their numerical relationships too close to afford sufficiently reliable data for drawing any but the most tentative conclusions.

Moreover, any such possible conclusions call for further reservation from the presence of additional factors already alluded to, which necessarily influence the bacterial content of subway carriage air and cannot be estimated, namely, dust disturbance created by air currents and passenger movements, and the unknown amount of residual bacterial impurity retained by and possibly peculiar to the compartment itself.

VII. SPECIES OF ORGANISMS FOUND IN THE AIR OF THE TUBE RAILWAYS.

(With reference in particular to the group of Moulds.)

Species of organisms found in Tube Railway air. The attempt at identification of the many varieties of organisms obtained in plate culture from samples of railway and platform air proved an extremely difficult and laborious task, the results of which can only be regarded in a large proportion as approximate.

The main object of the search has been, if possible, to find evidence of organisms pathogenic to man; for this reason, and in order to restrict the dimensions of the work, no detailed examination has been made of the cultural growth of colonies obtained in the control tests of the outside air. Such a comparison would without doubt have been of considerable interest and importance but appeared to be impracticable and outside the scope of the general purpose of the investigation.

As no facilities were available for animal experiments, any attempt at establishing the pathogenicity of a particular species was out of the question. Generally speaking, except in a few instances, the evidence provided by subculture tests failed to show the presence of organisms known to be pathogenic.

Such failure, which is indeed to be expected, attended the results of both Andrewes' and Graham-Smith's investigations. Attention was particularly paid to the possible presence of so common an organism as *Bacillus coli communis*, contained, of course, in horse dung and therefore likely to be conveyed everywhere by particles of dust. In no case, however, could it be identified.

There are many pathogenic organisms which will not long survive outside the contact of the human body, being unable to withstand the effect of desiccation and changes of temperature. Again, for successful cultivation under the most favourable circumstances, such delicate organisms require special media, *e.g.* blood serum or blood agar, for their growth, and even if these were employed the chances of their discovery among the numerous and more hardy varieties of air-borne organisms is infinitesimal.

[As pointed out to me by Mr J. H. Coste, F.I.C., the influence, too, of electrical discharge, whether by direct local action, radiation, or electrophoresis on the survival of organisms in the Underground Railways is quite unknown. Indeed the field of research offered by such consideration might lead to some explanation of the comparatively low degree of microbic pollution apparently prevailing in the air of the carriages and platforms.

The results of the examination of sewer air by Andrewes (11) and Horrocks (12) have shown a remarkable degree of freedom from microbic pollution, possibly to be accounted for by the adherence of organisms to the moist surfaces and by the fluid stream flowing in a confined channel acting as a germ trap. With the substitution of electrical for fluid attraction, it is conceivable, on expert authority [1], that the deposition of germ-laden dust particles in railway air may be favoured by electrostatic force, such as is associated with the high potential conductor rails along the course of the Tube Railways, leading to a sedimentation and trapping of matter in suspension.]

Among the species approximately identified are certain organisms which have been located as existing saprophytically and, so far as is known, harmlessly in the mouth and nasal passages and about the skin of the body. The proportion of these organisms in railway air is roughly estimated at about 20 per cent.

Carnelly, Haldane and Anderson (13) have demonstrated that bacteria are not given off in the *ordinary* respiration of healthy persons, and that the micro-organisms derived from the skin and clothes of persons actually present in a room are few in comparison with those attached to particles of dust, for which a room acts in the nature of a trap. The now well-known fact was also proved by Hesse (14) that when a room is left quiet, micro-organisms settle out in a few hours leaving the air comparatively free. But with the disturbance of dust, as by stamping or shuffling the feet, the bacterial content of the air is enormously increased, although ordinary movements of many persons in a room, as the three observers above-mentioned have shown, are not sufficient to produce any marked change in the numbers of organisms.

[1] Prof. A. O. Rankine, D.Sc.

It is perhaps not too much to assume that, when harmless saprophytes are present in and recoverable from the air of Tube Railways, under existing crowded conditions of travel, there is every possibility that the pathogenic and more sensitive varieties of organisms may be conveyed from one passenger to another in the minute droplets expelled in the process of coughing, sneezing, laughing and loud talking. Experiments undertaken by Trillat and Mailein (15) have shown the important influence of moisture on the growth of organisms and have proved that whilst dryness of the air on the one hand is detrimental to their survival, with increasing atmospheric humidity on the other, conditions become favourable to the maintenance and development of bacteria and probably more particularly of those whose optimum temperature is that of the body. Hence in the railway carriage, a confined and often crowded space, the greater the humidity, the higher is the bacterial content of the air likely to be, and consequently the better the chance of the conveyance and survival of pathogenic organisms from passenger to passenger.

The correlation of the bacterial content with passenger density, which has already been mentioned and displayed on Charts I and II, has particular bearing in the case of the Metropolitan District Railway (Inner Circle) and City and South London Railway.

For the differentiation of the various species of organisms derived from the samples of railway air, subcultures were planted on agar-agar, gelatin and potato, in broth and litmus milk; occasional use was also made of certain sugar fermentation tests. Approximate recognition of the species depended on the response to these tests, the colour and character of growth, also on staining reactions of film preparations, and appearances in hanging drop as regards shape, arrangement and motility.

No attempt was made to obtain quantitative results for the different species by examining every colony on each plate; such a task would have been well-nigh impossible. Therefore a selection only was relied upon to yield approximate information as to what organisms were present. In all, over 250 original colonies from the gelatin and agar-agar plates of railway air samples were submitted to subculture tests. In addition six samples of 10 litres of railway air were specially examined, three for *B. coli communis*, and three for anaerobic organisms, without revealing evidence of either.

It has not been thought necessary to group the species according to the individual railways, but it is sufficient rather to summarise the various species for all the Tube Railways generally.

The main object of identification being to discover the presence of pathogenic organisms, *i.e.* those whose optimum temperature is that of the human body, the mesophilic group, attention has not been paid to the classification of the psychrophilic group or those particular organisms which prefer room temperature. Such an omission may be regarded as unscientific and one to be deprecated, but it was realised *ab initio* that so comprehensive and detailed an investigation was beyond the real scope of this survey.

In the New York investigations Soper frankly states that the determination of the various species of organism in subway air was regarded as impracticable and likely to yield no result of value, and the demonstration of pathogenic bacteria was held beyond the possibility of bacteriological technique (5 *d*).

Interesting observations (5 *e*) were however made on the viability of the pneumococcus by exposure of pneumonic sputum to the air of the New York subways. It was found that the organism still retained its virulence in dried sputum after 23 days' exposure, whereas in sunlight, as other observers had shown, it was killed in four hours.

M. H. Gordon (4), in his report on the air of the House of Commons in 1906, states: "The majority of bacteria found in air are harmless and their individual significance, even if a name can be attached to them, conjectural, or at most botanical," and again, "The kinds of bacteria of most significance in air are primarily those capable of causing disease in man, and especially those capable of producing this effect when inhaled. Such micro-organisms, however, even when present in air are difficult to detect. Although of the greatest significance when found, the detection of specific pathogenic micro-organisms in air is so uncertain in the present stage of bacteriology that failure to find them by the methods at present available, even after careful search, does not necessarily imply their absence."

Nevertheless, the results of the detailed efforts to determine the identity of the various organisms present in the Tube air of the Central London Railway recorded by Andrewes (1) in his Bacteriological Report of 1902 afforded a study worthy of emulation, despite his failure to detect any true pathogenic organisms other than saprophytes of the human body.

On reference to bacteriological literature but little help was provided by the ordinary text-book, which deals almost entirely with disease-bearing organisms. But by recourse to such compilations as Sternberg's *Manual of Bacteriology* (16) and Chester's *Manual of Determinative Bacteriology* (17) it has been possible to obtain an approach to approximate classification and identification, but in a certain number it proved impossible to name the organism from records available.

Classification of micro-organisms obtained from the air of London Tube Railways

(1) Group of Coccus.	No. of times found	Source from which it was originally described
Micrococcus albus liquefaciens	10	Normal nasal mucus
„ flavus	9	Air and water
„ candicans	7	Air, water, milk, urine, etc.
„ candidus	6	Water
„ lactericeus	4	From the human mouth
„ salivarius	4	Saliva of man
„ nivalis	4	Air
Staphylococcus pyogenes albus	3	Surface of body and deeper parts of skin
Micrococcus citreus	3	Water
„ simplex	3	Water
„ albus	3	Water and beer
„ cumulatus	3	Nasal mucus in man

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	No. of times found	Source from which it was originally described
Micrococcus versicolor	3	Air
,, cereus	2	Human abscess
,, aurantiacus	2	Air and water
,, subflavus	6	Nasal mucus
,, aureus	2	Air
,, aquatilis	2	Water
,, magnus	2	Air
,, roseus	2	Air
,, cinnabareus	1	Air and water
,, conglomeratus	1	Air and dust
,, coronatus	1	Air
,, luteus	1	Air and water
,, aerius	1	Milk
,, albicans tardissimus	3	Human secretion

(2) Group of Bacillus and Bacterium.

(*a*) Motile.

Bacillus mesentericus vulgatus	9	Widely distributed—dust, etc.
,, ,, fuscus	6	Widely distributed—dust, etc.
,, plicatus	3	Milk
,, subtilis	4	Dust, etc.
,, stellatus	1	Milk
,, fluoresceus crassus	1	Air and water
,, aurantiacus	1	Water
,, tenuis	1	Milk
,, solitarius	1	Soil
,, striatus flavus	1	Water and surface of body

(*b*) Non-motile.

Bacterium refractans	3	Water
,, nubilum	2	Water
,, acidum	2	Milk
,, vermiculosum	1	Water
,, rubidum	1	Air
,, xerosis	1	Conjunctiva
,, salivae	1	Mouth
,, aerophilum	1	Air and water
,, filiforme	1	Water
,, coccoideum	1	Milk
,, ovale	1	Water
,, crassum	1	Human sputum
,, punctatum	1	Milk

(3) Group of Sarcina.

Sarcina lutea	7	Air and mouth
,, alba	4	Air
,, subflava	4	Soil
,, aurantiaca	1	Air

(4) Group of Streptothrix.

In all 27 colonies in this group were sub-cultivated and placed provisionally among three varieties:

Streptothrix albido	Air
,, chromogena	Air, water and stomach contents
,, foersteri	Air and water

On account of the speciality of this group, sub-cultures were sent to the well-known mycologist, Prof. D. Pinoy, of the Pasteur Institute, Paris, for identification and classification. He very kindly examined the specimens, and his report states that the majority belong to the *Nocardia dissonviller*, which is a saprophyte, and appears only to have played a pathogenic rôle in

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a case of ocular conjunctivitis reported by Landrien. Two varieties belong to another species not yet determined, but not pathogenic.

(5) Group of Moulds.

The proportion of moulds to bacterial colonies found:—

(1) in the open air control tests, out of a total of 222 colonies with 30 moulds, was as 1 to 7·5, or 13·5 per cent. of moulds. The highest proportion obtained (26·6 per cent.) was from a sample taken at the foot of the Duke of York's Column on a dull day with a moderate steady N.W. wind—the lowest (10·2 per cent.) was obtained in Charing Cross Gardens on a calm day with light southerly airs. The percentage obtained by Andrewes in his observations on the open air was 24·8, the highest (76·4 per cent.) being in a sample from Hyde Park.

(2) in the samples of air from all the railways, out of 1094 colonies with 136 moulds, the proportion was as 1 to 8·4, or 12·5 per cent. of moulds, the highest percentage figure obtained was 26 on the Metropolitan Railway (Inner Circle); the lowest 2·7 per cent. on the Central London Railway. On the various railways the proportion appears as follows:

	Proportion of moulds to bacterial colonies	Percentage of moulds
Metropolitan District	1 to 5·7	17·6
City and South London	1 ,, 6·4	15·6
Piccadilly	1 ,, 8·3	12·0
Hampstead	1 ,, 8·5	11·7
Bakerloo	1 ,, 8·8	11·2
Central London	1 ,, 10·7	9·3

Andrewes, working on the Central London Railway only, obtained 93 moulds out of a total of 574 colonies or 16·2 per cent., the highest proportion in one sample being 44·4 per cent. and the lowest 1·8 per cent. [In the New York subway air the ratio of moulds to bacteria was 1 to 40, and usually the moulds were less numerous in the air of the subways than in the street air (5*f*).]

In the results obtained by Carnelly, Haldane and Anderson (18) in Dundee in 1886, the ratio of bacteria to moulds stood in far higher proportion. The figures they give appear as follows:

	Proportion of moulds to bacteria
Outside air. Quiet places	1 to 2·5
,, Busy streets	1 ,, 14·9
Naturally ventilated schools:	
Board schools	1 ,, 131·8
Private schools	1 ,, 30
Mechanically ventilated schools:	
General average	1 ,, 28·5
Harris academy (Board school)	1 ,, 31
Half-time school	1 ,, 27
University College	1 ,, 15·6
High School (cubic space much greater)	1 ,, 4
Dwelling-houses:	
One-roomed	1 ,, 49
Two-roomed	1 ,, 20
Four- and more roomed	1 ,, 21

They found that with increasing vitiation of the air the proportion of bacteria to moulds increased largely, and that this increase could be attributed to dust disturbances; of the two, bacteria settled out more speedily than the moulds as the air became quiet. It was recommended that in setting a standard of purity the ratio of bacteria to moulds should not exceed 30.

The conditions of atmospheric bacterial pollution prevailing in Underground Railways would seem to be in no way comparable to those obtaining in schools and dwelling-houses. The differences implied are largely due to the conflicting phases of ventilation and the constant changes, produced by rapid movement of passengers and trains, inseparable from railway travel, and may serve to explain the lack of agreement to be found in the two series of observations which cannot fairly be placed side by side, as they do not afford equivalent grounds of comparison for the purpose of supplying a common standard of purity.

Classification of moulds. As in the case of identification of bacterial colonies so with the moulds, no attempt was made to subcultivate every mould appearing on the gelatin plates, but a selection was made and sent to Mr J. Ramsbottom, M.A., F.L.S., mycologist to the British Museum, South Kensington, who very courteously undertook their examination and has identified the following species[1]:

(1) *Group—Phytomycetes. Mucor Mucedo* L., one of the commonest saprophytic fungi—principally on mouldy bread.

(2) *Group—Ascomycetes.*

(*a*) *Aspergillus* (*Sterigmatocystis*) *nidulans* (Eidam) Winter. Found on four occasions. Both stages of this fungus were obtained—the early conidial or *Aspergillus* stage and the later ascocarp (*Eurotium*) stage with budlike tufts. This fungus which was originally found on old bees'-nests has not previously been definitely recorded in this country.

(*b*) *Aspergillus* (*Sterigmatocystis*) *ochraceus* Wilhelm. What is probably this species was found in two cultures—sclerotia (hardening of the hyphal bed of the fungus) occurred which unlike the similar looking ascocarps of *A. nidulans* did not contain asci and spores. The fungus was first found on black bread—it also occurs on moist plants.

(*c*) *Aspergillus* (*Sterigmatocystis*) *niger* van Tieghem. Found on decaying plants, mouldy bread, etc.; also responsible for the pathological condition known as Aspergillosis—an infection by the mould attacking the ear passages occasionally, and more rarely the lungs; obtained twice in subculture.

(*d*) *Eurotium repens* (perfect stage of *Aspergillus repens*) (de Bary). Both conidial and ascospore stages—a common saprophyte—obtained once in subculture.

[1] Specimen cultures were subsequently sent to the National Collection of Type Cultures, Lister Institute.

(3) *Group—Hyphomycetes.*

*(*a*) *Aspergillus fumigatus* Fresen.—occurs on decaying plants, mouldy bread, etc. Causes local inflammatory lesions in human beings especially in the ear (v. Siebenmann, *Die Schimmelmykosen*, 1889), also responsible for pulmonary aspergillosis in Man, and found in the lungs, bronchial passages and ears of birds—obtained once in subculture.

(*b*) *Penicillium glaucum* Link. One of the commonest moulds. Recent work has shown that this is a composite species containing probably 80 to 100 micro-species—obtained nine times in subculture.

(*c*) *Citromyces.* A genus intermediate between *Penicillium* and *Aspergillus*; is a citric acid ferment and commonly found on fallen fruit—obtained twice in subculture.

(*d*) *Acrostalagmus cinnabarinus* Corda. A common saprophyte found on rotting potatoes, dung, etc.—obtained once in subculture.

(*e*) *Cladosporium herbarum* Link. Common saprophytic fungus.

(4) *Group of Yeasts* (5). The following were identified: *Monilia variabilis*, *Torula torulospora* (2). Two torulae were unnamed.

It may be pointed out that in the foregoing classifications, whilst it has been found impossible to place certain species of micro-organisms, for the reason that the works consulted give no clue to their identity and that there may be among them hitherto unnamed varieties of organisms, there is evidence of a proportion, amounting roughly to about 20 per cent. of the coccus, bacillus and sarcina groups, which although probably mere saprophytes and not recognised as pathogenic, were originally described as having been found in the mouth and nasal passages of human beings. Without laying too great stress on such sources of air contamination, the evidence is at any rate suggestive and significant of the possibility, in times of epidemic and in the crowded conditions of underground railway travel, of the conveyance of pathogenic organisms such as those of influenza, pneumonia and diphtheria from person to person.

Carnelly, Haldane and Anderson state(20):

"As regards the influence of the micro-organisms of air it seems probable that for persons in perfect health the great majority of organisms are harmless. The ciliated epithelium of the respiratory passages probably sweep 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.

"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...."

* Castellani (19) in his Milroy Lectures (1920) on the Higher Fungi in relation to Human Pathology, states: "Aspergillomycosis of the ear is comparatively frequent." He mentions cases apparently due to *A. fumigatus*, *A. niger*, *A. repens* and *A. nidulans*, all of which were identified in culture from Tube air.

A natural consequence of such catarrhal state, particularly under the influence of overcrowding during epidemics, is the liability to attack by influenza, acute bronchitis and broncho-pneumonia which, as the authors go on to emphasise, are largely responsible for the high mortality rates in measles and whooping-cough.

In summarising the chief points of this section it is incumbent to observe that our knowledge of the bacteriology of the air is still very incomplete and based perhaps on somewhat crude and unsatisfactory methods of investigation. Research on improved lines especially for the discovery of pathogenic organisms is still needed, including the examination of larger amounts of air and a greater number of samples than the work of this survey comprises. Much time, which it has been impossible to give, and additional assistance, which has not been available, would be required for carrying out particularly the more elaborate details of identification of the many species of organisms present in the air of the Electric Tube Railways.

SUMMARY AND CONCLUSIONS.

1. The bacterial content of the air of the Underground Railways, when the average of all results of the bacteriological investigations is taken, does not numerically compare unfavourably with the outside air of London.

2. The ratio of the number of organisms growing at room temperature appears to be about 14 for railway air to 10 outside air. For those growing at body temperature the ratio is considerably higher, namely 2 to 1 respectively. The mean per litre, for room temperature organisms, is about 9 in railway air, 6·3 in the outside air; for body temperature organisms 4·6 for railway air, 2·2 for outside air.

3. The bacterial content of platform air, except on the City and South London Railway, would appear to be higher than that of carriage air; the total mean for platform air being 52 and for carriage air 42·8 organisms per 5 litres, or a ratio of 16·4 and 13·5 respectively to 10 of the open air. The higher proportion in platform air is generally speaking to be accounted for by the greater amount of draught and dust disturbance.

4. The ratios of the total bacterial content of railway carriage air and carriage and platform air on the six lines to open air are estimated in the following proportions:

	Open air: 10.	
	Carriage air	Carriage and platform air
Central London	11·7	12
Bakerloo	12·6	14
Hampstead and Highgate	13	12·8
Piccadilly and Brompton	13	13·8
Metropolitan District (Inner Circle)	14·6	—
City and South London	15·7	15

5. Increase or decrease in passenger density is generally, but not invariably, associated with a rise or fall in the bacterial content of railway air

affecting both the room temperature group and body temperature group of organisms. The correlation is more evident on the Inner Circle of the Metropolitan District and the City and South London Railways.

6. With increasing passenger density and overcrowding the consequent rise in bacterial content of railway carriage air does not appear to follow in direct numerical proportion and may be relatively higher per passenger in a less crowded compartment, due possibly to the freer play of ventilation currents on dust particles offered by the clearer space.

7. The ratio of bacterial content to passenger density, though necessarily influenced by fluctuating air currents and movements of passengers in leaving and entering a compartment, is suggested as providing an "index of pollution" for carriage air and possibly affording a truer estimate of atmospheric bacterial pollution than if measured by bacterial content alone.

8. In comparison with the results obtained on the Central London Railway by Andrewes in 1902 the atmosphere on that railway in 1920 would appear to show a satisfactory state of bacterial purity, with a lower bacterial content than on other underground railways, notably the Metropolitan District and City and South London Railways, where the higher content may be attributable to overcrowding and unevenly controlled carriage ventilation.

9. In view of the rise in bacterial content of railway air consequent on dust disturbance by air and train movements, measures to bring about the deposition and removal of dust from carriages, platforms and running track are likely to prove beneficial by reducing the amount of floating bacterial impurity.

10. In no instance were pathogenic organisms specifically proved to be present other than certain of the moulds, *e.g. Aspergillus niger* and *fumigatus*. The apparently high proportion of micro-organisms suggested as emanating from the mouth and nasal passages of human beings indicates the possibility that crowding of passengers, with the existing ventilating arrangements for certain of the carriages and tubes, may be prejudicial in epidemic times to the public health by increasing the risk of transference of pathogenic organisms from passenger to passenger.

Post scriptum. June, 1923.

Three years have elapsed since the completion of the work upon which the above report was based.

During this period improvements in the system of ventilation and of tunnel-cleansing, as well as in carriage construction, have been steadily progressive. The latter has replaced to some extent the older type of travelling compartment. Overcrowding, however, during rush hours, and the occasional use of the earlier type of carriage, referred to on pp. 138 and 140, have not yet been eliminated. Happily there has been no serious return of influenza in epidemic form.

Cordial thanks and indebtedness remain to be expressed to the authorities of the Electric Underground Railways for ready facilities afforded to the Collection of Air Samples; to Mr J. H. Coste, F.I.C., for use of his helpful suggestions incorporated on pp. 143 and 144; also to Mr J. Ramsbottom, of the British Museum, for his valuable work in the identification of moulds, similarly to Prof. D. Pinoy of the Pasteur Institute, Paris; and, finally, to Mr F. E. Fry and Mr E. S. Glass for the latter's skilful draughtmanship of diagrams and charts, and for their joint help in the laboratory as well as in the arduous work of collecting the air samples.

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Comparative Block Charts are attached showing:

III. Number of colonies obtained from each 5 litre sample cultivated at body temperature and room temperature from carriage air (*A*) and platform air (*B*) on each railway.

IV. Averages of total observations on carriage and platform air of each railway.

V. Results of 5 litre samples taken in the open air and total averages of III *A* and *B* and IV

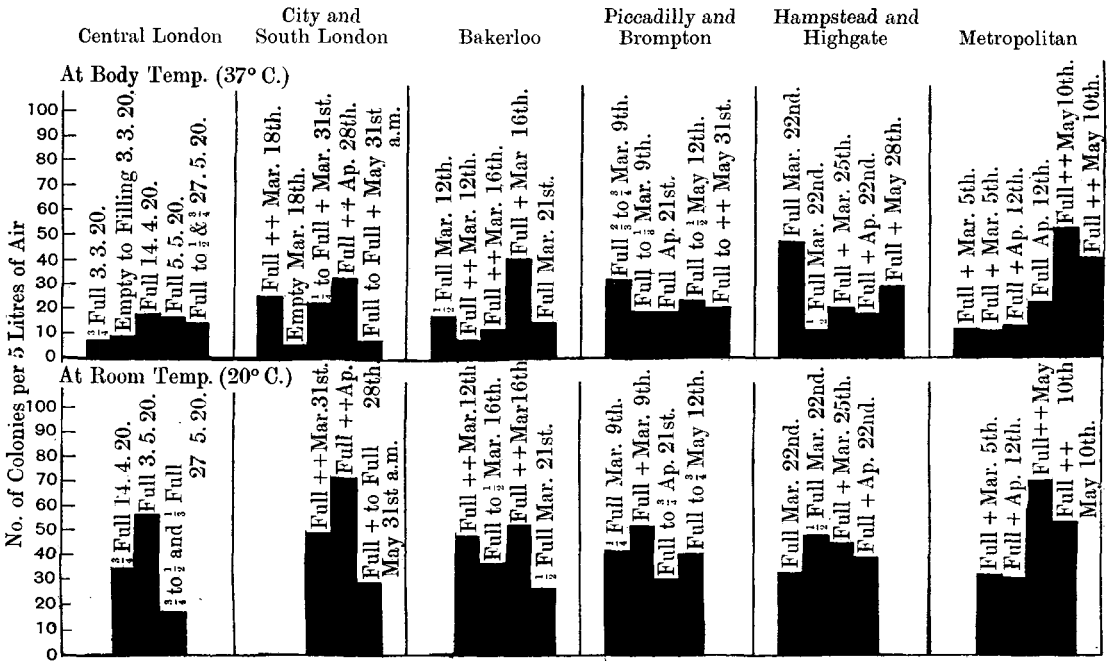

Chart III A showing numbers of colonies obtained from 5 litre samples of carriage air in the various Electric Railways.

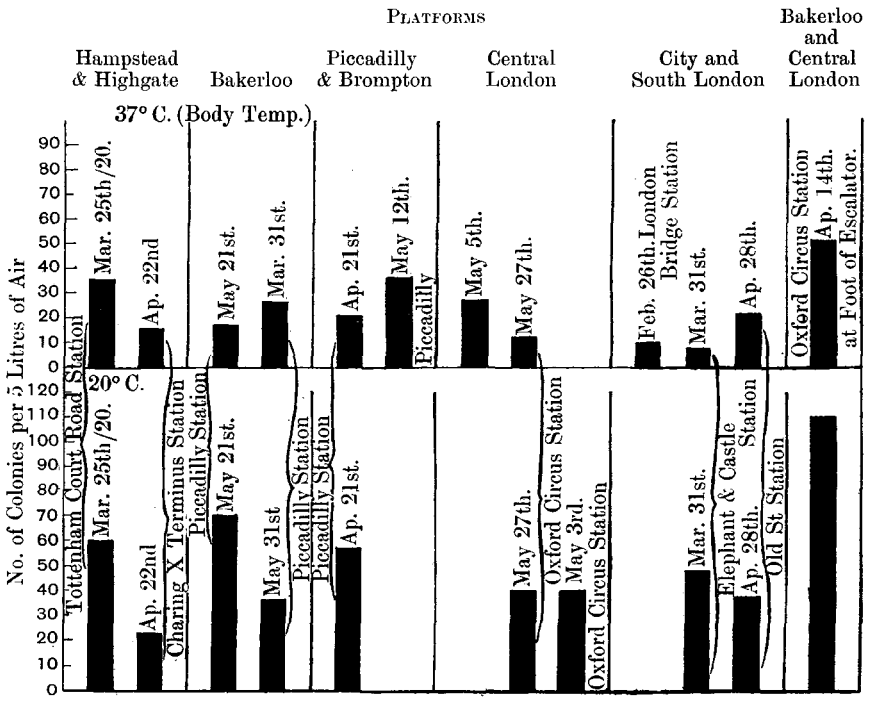

Chart III B showing numbers of colonies obtained from 5 litre samples of air taken on platforms.

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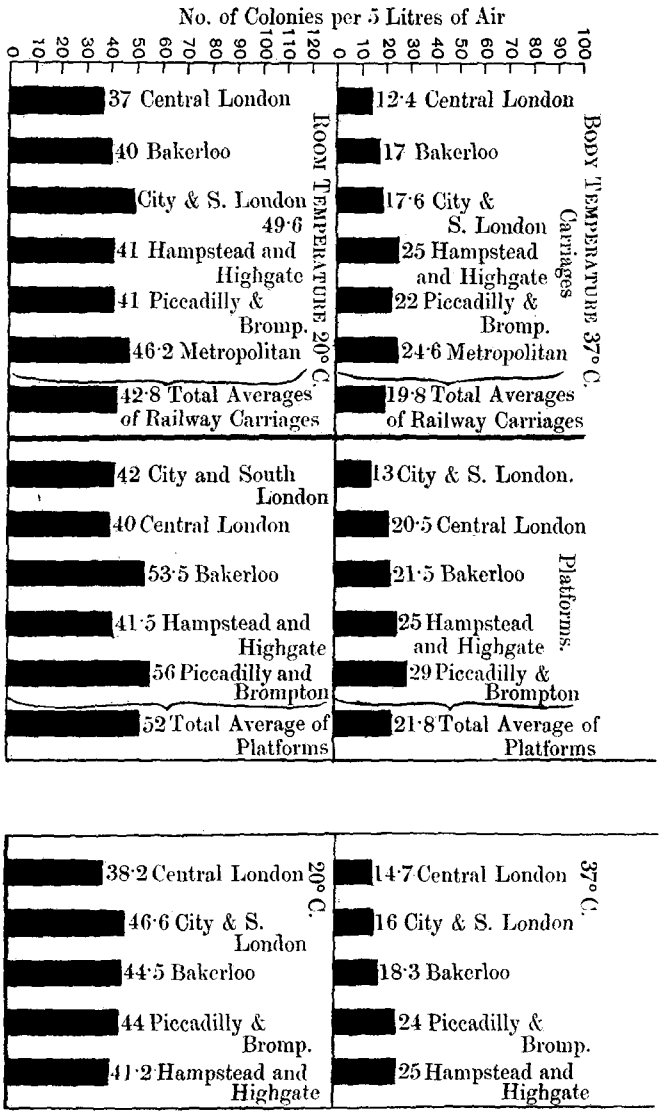

IV. Averages of total observations of numbers of colonies obtained from 5 litres of air.

V. Total averages of railway carriages and platforms

Charts IV and V showing averages and total averages of numbers of colonies obtained from 5 litre samples of air in the railway carriages and platforms.

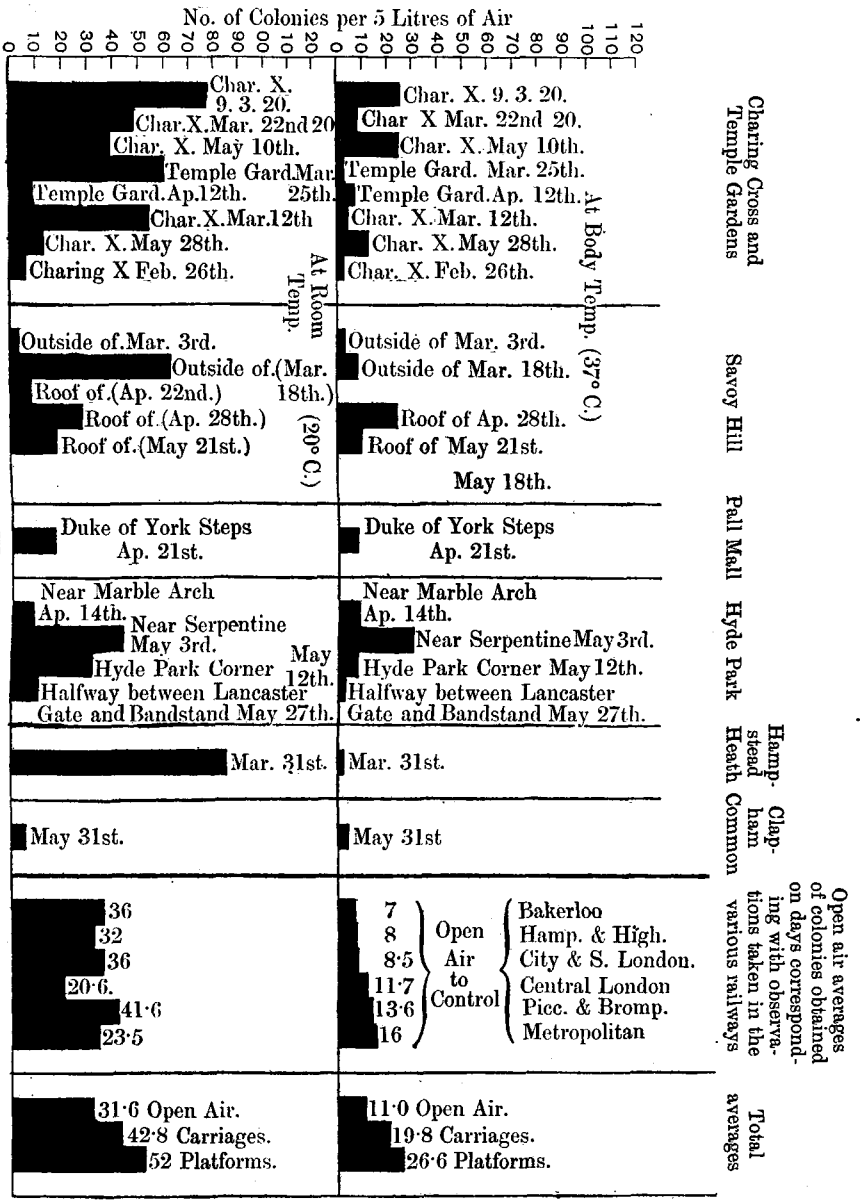

Chart VI. Open air samples.