the best bond, should not be painted. The members asking for information in regard to the conditions of the air in the Subway were referred to a communication by Dr. George A. Soper (*below*), who had been specially retained by the Transit Commission to report on such matters. It should be remembered that not only were there many more trains in the New York subway than in any similar railway, but these trains generated more power, namely, 2,000 HP. on each express and 1,200 HP. on each local train. Nearly all this energy was dissipated as heat. In conclusion, the Author desired to express his appreciation of the reception of the Paper by the members of The Institution, and of their references to the work it described. Naturally much had been said in the discussion in comparison with tubes, and as to the possibility of shallow construction in London, on which opinion seemed to be divided. He had presented the Paper in order to record a work executed under conditions differing in many respects from those existing in London. The difficulties peculiar to London were many and great. Whether they could be overcome, and, if overcome, whether a shallow subway would be profitable, as had been accomplished on a large scale in New York, Boston, Berlin and Paris, was not for the Author to discuss within the limits of the Paper. The Author.

Correspondence.

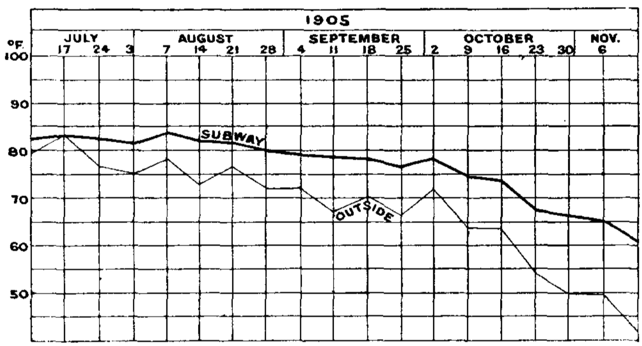
Dr. George A. Soper, of New York, communicated the following observations upon the ventilation of the subway :—Shortly after the subway was opened, reports appeared in the Press to the effect that the ventilation was defective. These reports were made by volunteer investigators who claimed to have analysed the air and found it to be alarmingly impure. Upon inquiry, these investigators turned out to be unreliable persons and their results untrustworthy. But harm had been done, and a considerable number of people had come to regard the air with suspicion. In the hope of establishing the truth about the air, Professor Charles F. Chandler, of Columbia University, made a number of accurate analyses. He pronounced the air good. This allayed suspicion for a time, but soon the heat, which became noticeable about 5 months after the line was put in service, revived the belief that the air was vitiated. At this point Dr. Soper was Dr. Soper.

Dr. Soper. invited by the Board of Rapid Transit Railroad Commissioners to make a careful study of the whole question in order to discover whether any injurious conditions existed, and if so, how to get rid of them. The investigation extended over about 18 months and was divided into two periods. The first, which might be called the analytical part, extended over the 6 months from June, 1905 to January, 1906. In this period about 50,000 determinations of temperature and humidity were made, and finally a system of automatic thermometric records was established. About 2,000 samples of air were collected and analysed for carbon dioxide and oxygen. About 3,000 bacteriological examinations were made. Microscopic examinations were made of the dust which settled from the air, and, by a special device, the weight of dust in a given volume of air was determined. Careful studies were made of the force and direction of the air-currents set up by the moving trains. The utility of large fans was studied at several points in the subway where fans were installed for experimental purposes. The effects of the processes of cleaning employed by the operating company were also critically examined. Numerous special experiments were made, as, for example, the determination of the efficiency of certain chemical disinfectants, the effects of oil on bacteria and the longevity of pathogenic bacteria under subway conditions. Two condensed official reports were made on this first part of the investigation.[1] The second period of the investigation began in March, 1906, and ended in March, 1907. The object of the second part was to determine, by examining the physiological condition of the people who worked in the subway, whether any injury was being done to health. The time during which the subway had been in service was too short for any evil effects to be plainly visible, but it was thought desirable to undertake the inquiry at this early date in order to discover impending dangers, if any existed. The work involved a minute study of the physiological condition of one hundred subway employees, all of whom had been engaged in subway work for at least a year. The bodies of employees who happened to be killed during the course of the investigation were autopsied. In order to determine the physiological condition of average men of similar social condition to the subway employees, but engaged in other occupations, 200 men from various walks of life were examined. After the completion of the second part of the investigation, Dr. Soper was requested by the Interborough Rapid

[1] See the Annual Reports of the Rapid Transit Commission, 1905, pp. 142–147 and 1906, pp. 210–232.

Transit Company to make a study of the sanitary condition of the air and ventilation of subways in Europe, a task which occupied about 3 months in the summer of 1907. During this final investigation, practically all the large subways in Europe were visited. The principal results of the inquiry were the following. The air of the New York subway did not differ much from the air of most subways, as far as he was aware, except as to temperature and dust. The temperature was high because of the extraordinarily large amount of heat generated by the consumption of electrical energy; the heat from the bodies of the passengers had practically nothing to do with it. The most objectionable feature of the heat was less the actual elevation of temperature than the fact that the subway remained warm continually while the city streets became Dr. Soper.

Fig. 24.

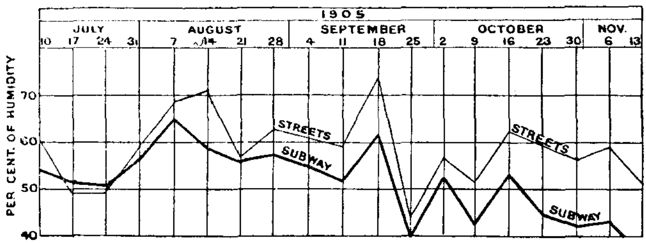


WEEKLY AVERAGE TEMPERATURES IN THE SUBWAY AND STREETS, 10 JULY–13 NOVEMBER, 1905. (*From 47,476 Observations.*)

relatively cool during the nights and mornings of summer. It was at such times that the greatest inconvenience was experienced from the heat. In winter the heat given off by the trains was advantageous, since, if low temperatures occurred they would, with the strong draughts, render the air uncomfortable. The hottest week during the period of the writer's investigation was that of the 4th–10th August, 1905. The average daily temperature in the subway during that week was 83·4° F.; in the streets 78·2°; difference 5·2°. Averages for 18 weeks were given in *Fig. 24*. The relative humidity was slight. The actual weight, or tension, of aqueous vapour was practically the same in the New York subway as in the air of the streets under which the subway ran. Since the temperature was higher in the subway, the humidity there was less noticeable. This

Dr. Soper. dryness was excellent testimony of the thoroughness with which the work of waterproofing had been carried out. Had the subway been wet it would have been excessively uncomfortable in summer. The relative humidity of the subway and streets for about 4 months was given in *Fig. 25.* The chemical analyses showed that the general

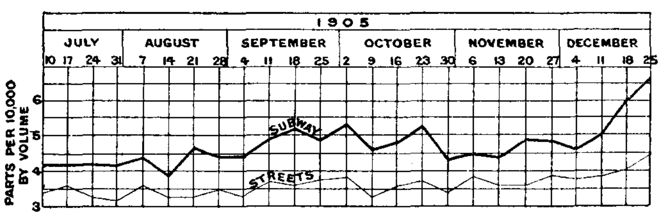
Fig. 25.



WEEKLY AVERAGE RELATIVE HUMIDITY IN THE SUBWAY AND STREETS, 10 JULY–13 NOVEMBER, 1905. (*From 47,456 Observations.*)

air of the subway was by no means deficient in oxygen nor was the carbon dioxide from the lungs of passengers present to an objectionable extent. The highest amount of carbon dioxide found was 8·89 parts per 10,000, the average being 4·81, and the average for the street air 3·67. The amount of carbon dioxide varied with the place, hour, and season. The method of analysis was

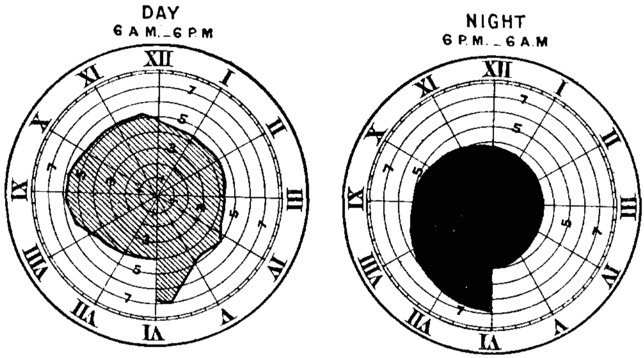
Fig. 26.



WEEKLY AVERAGE CARBON DIOXIDE IN THE SUBWAY AND STREETS, 10 JULY–25 DECEMBER, 1905. (*From 1,772 Determinations.*)

accurate to within 0·03 part in 10,000. The CO_2 found in the subway and streets over about 6 months was given in *Fig. 26.* Hourly variations due to differences in the number of passengers carried were shown by *Figs. 27.* The bacterial analyses showed that there were about half as many bacteria in the air of the subway as in street-air, the average being 3,200 bacteria per cubic metre of air in the subway as compared with 6,500 bacteria per cubic metre of air in the street. Some results of bacterial analyses by the familiar plate method were given in *Fig. 28.* The impurity which was most Dr. Soper.

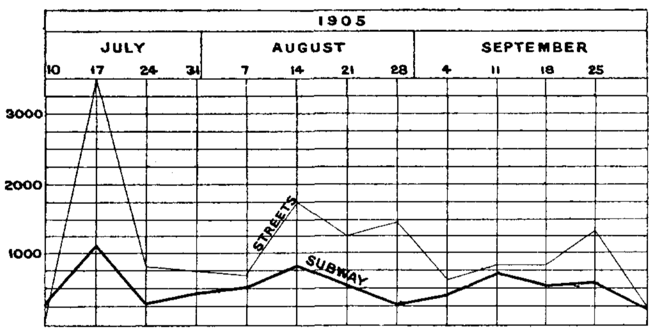
Figs. 27.



HOURLY VARIATIONS IN THE AMOUNT OF CARBON DIOXIDE IN THE AIR OF THE SUBWAY. (*Average of 1,244 Analyses.*)

suggestive of danger to health was iron-dust. This dust was produced by the wear and tear of metallic surfaces, especially brake-shoes. The consumption of brake-shoes alone amounted to about

Fig. 28.

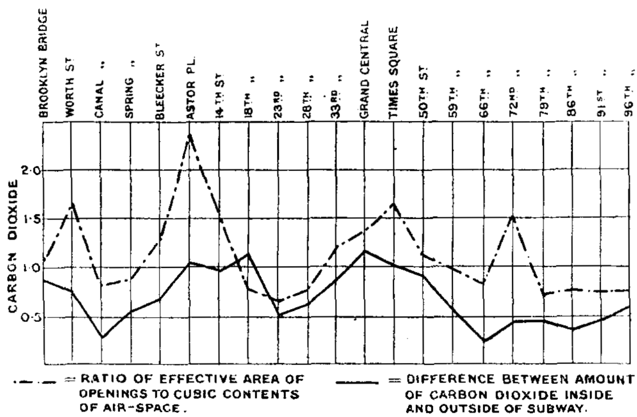


AVERAGE NUMBERS OF BACTERIA WHICH SUBSIDED FROM THE AIR PER SQUARE FOOT PER MINUTE IN THE SUBWAY AND STREETS. 10 JULY–2 OCTOBER, 1905. (*Samples Represented, 2,742.*)

1 ton for each mile of road per month. There was no difficulty in finding the metallic particles in the air or in the dust of the subway. He had found metallic dust of similar character in all the subways

Dr. Soper. which he had visited. The amount produced in the New York subway appeared to be but little in excess of the amount produced in the congested parts of the Metropolitan Railway of Paris. By the use of fibre brake-shoes the quantity of metallic dust had been reduced on the Underground Electric Railways, according to Mr. James R. Chapman, Chief Engineer, by about 80 per cent. The examinations of employees did not show that such dust, or any property of subway air, was producing injury to health; but Dr. Soper was strongly of opinion that these physiological investigations should be repeated, in order to determine whether effects might be visible after a longer period of exposure. The examinations of employees revealed an unexpectedly large amount of dry pleurisy. About 53 per cent. of the train-men exhibited this condition to an unmistakeable extent. The explanation of this pleurisy was the most difficult question involved in the whole investigation. It seemed to have no connection with subway conditions; and he at length concluded that the condition of the men was due to attacks of pleurisy, sometimes mild and unnoticed at the time, which the men had experienced previous to entering upon their subway work. It was taken to be a significant fact that practically all of the men examined had served as drivers or firemen for many years on outside steam-railways. In that work they had been much exposed to pleurisy through over-heating and chill. Much had been said about the odour of the New York subway. It was not to be denied that the subway had an unpleasant odour, as had all subways with which he had any acquaintance. The odour of the New York subway was due largely to the trap-rock ballast of which the road-bed was made, and to oil which had dripped from the machinery of the cars upon the road-bed. The peculiar odour characteristic of all electrically-worked cars was present also. Other odours existed, but those mentioned were the most prominent. Unlike most European underground railways—particularly some of the London tubes—peculiar musty odours due to excessive growths of moulds did not occur. The offensive odour of spent disinfectants, common in European subways, was not present. By Dr. Soper's advice the extensive use of disinfectants was discontinued at an early date and several hundred so-called disinfecting-machines were removed from the New York subway as useless and offensive. The sprinkling of station-platforms with water, which was a common practice in Europe, was soon discontinued in the New York subway. The cooling effect of the evaporation upon the atmosphere was negligible, the moisture on the cement platforms made the foot-hold uncertain, and the escaping water-vapour added to the discomfort due to the heat. Ventilation took place through the action of the trains upon the atmosphere moving freely through large openings to the outside air. It had been found that for a given volume of air-space in any section of the subway a certain area of opening was necessary and sufficient for good ventilation (*Fig. 29*). The secret of ventilating a subway of this type lay, in his opinion, in arranging openings to the outside air so that they should be of proper area and location. Experience with the New York subway had shown that, beside the amount of ventilation which could take place in this way, the exchange of air which could be produced under practical conditions by means of mechanically propelled blowing-devices was immaterial. At first the principal air-openings in the New York subway were at the stairways at the Dr. Soper.

Fig. 29.



RELATION BETWEEN THE CHEMICAL CONDITION OF THE AIR IN THE SUBWAY AND THE RATIO OF THE EFFECTIVE AREA OF THE OPENINGS TO THE CUBIC CONTENTS OF THE AIR-SPACE AT DIFFERENT STATIONS.

stations, although there were some blow-holes in a part of the line above 59th Street. Later, many more blow-holes were opened through the roof. He had no knowledge of the need or efficiency of the automatic air-valves, electric fans, and cooling-apparatus which had been installed since the conclusion of his investigations. As nearly as could be judged without information as to the number of passengers carried at different times and in different parts of the subway, the analyses indicated that an amount of air entered and left the subway equivalent to a renewal of the whole atmosphere at least every $\frac{1}{2}$ hour. This was before any material changes were made in the original method of ventilation. Mr. Parsons's

Dr. Soper. arrangements for ventilation were, therefore, on the whole, abundant. To have installed fans or blowers would have been a useless waste of money. In order to improve local conditions it was only necessary to remove some of the vault-lights overhead. This could be done easily and quickly. Subways of this type breathed of themselves when given a chance. The removal of heat from a subway was an interesting problem. It was evident that the heat must pass through the walls and so be carried away by the surrounding material, or it must escape with the air. So long as a subway structure was surrounded by wet or moist material the conduction of heat through the walls might be considerable. With all subways it was so when the road was new; hence overheating did not occur at first. Most subways, however, gradually became warm with age, and it appeared that this rise in temperature was due to saturation of the structure and its surroundings by the heat which could not escape. Apparently there was only one way to prevent discomfort from heat in a deep subway, and that was by consuming less power. This was equivalent to saying that fewer trains must be run, they must be lighter, or they must be run at a lower speed. The economizing of power by regenerative control seemed not to offer sufficient advantages at the present time for extensive use in subways. In a subway of the type constructed by the Author, another method of keeping down the temperature was available. By providing very large openings to the outside air a substantial amount of relief could be afforded through ventilation. The quantity of air which could be moved in and out of a shallow subway under properly arranged conditions was enormous. The most important sanitary requirement in connection with subways was that they should be kept clean. He was not aware of any important subway in America or Europe that was maintained in such a way as to indicate that this necessity was fully appreciated.

Mr. Tait. Mr. W. A. Tait, having seen the work during construction, was greatly impressed with the enterprise that had been shown. At the same time, the ground passed through, in and near the busy parts of New York, seemed to be infinitely better, from a constructional point of view, than a great deal of the ground through which the Glasgow Central railway passed.[1] Regard must also be had to the facilities granted to and freely taken advantage of by the contractors for the temporary diversion of water- and other mains by means of trestles along the footpath. He did not recollect having ever seen similar facilities granted during the carrying out of underground railway-

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii, p. 120.

works. On the other hand, account must be taken of the frequent interruption of the works on account of labour-troubles, the intervention of the "strike-marshal" and so on. A good deal of the work, especially on the "down town" section seemed to him to be very light in design, and in view of the ever-increasing traffic overhead he could not help thinking that any renewals which might be required in future would be very troublesome to carry out. The sharpness of the curves at some stations, particularly at the one near to the Mayor's office, seemed to be objectionable and not altogether suitable for platforms which were liable at any time to be crowded. The long carriages which were in use necessarily left a considerable versed sine. No such arrangement would satisfy the Board of Trade. From American newspaper accounts of the flooding of the subway which took place in December, 1904, after the bursting of a 3-foot water-main at 86th Street, it was quite clear that this burst did very considerable damage in the subway, and for a whole day prevented the running of through traffic, as water accumulated to a considerable depth; indeed, at one station it appeared to have been running over the level of the platform. This water could only be removed by pumping in view of the gradients of the railway in the neighbourhood of the burst. Opinions differed as to whether underground railways should be deep or shallow, but it would seem not to be a point which could be decided off-hand. The lifts at several of the stations upon the London tubes were very inconveniently placed, and only brought passengers near to the platforms and to the street-level without bringing them actually to either. There was room for considerable improvement in this respect, though possibly a little additional expenditure on property would have been required if the widths of island platforms had been increased to make the necessary provision. In the cases of some underground railways, particularly the Caledonian in Glasgow, there was a great deal to be said in favour of a shallow railway. It was not likely that better tunnelling ground would have been obtained by going deeper on the line of streets, etc., actually chosen, while, on the other hand, the large sums spent by the Caledonian Railway Company on sewer-diversions had assisted materially in carrying out the works for the purification of the Clyde. Mr. Tait.

Mr. F. J. Waring, referring to the statement (p. 96) as to the $\frac{3}{4}$-inch horizontal rods forming the tension-member of a longitudinal truss on the top of the walls, failed to see the object of such a truss in that position: perhaps the Author would further explain the matter. As the subway was specially designed for rapid transit, and much should therefore be subordinated to obtaining this, Mr. Waring Mr. Waring.

Mr. Waring. thought the designs of the station-platforms were susceptible of improvement. For express trains consisting of eight cars, each 51 feet 5 inches in length overall, and for local trains of five such cars, he observed that the length of the platforms at both local and express stations was more than 50 feet less than the length of the trains. In the most favourable circumstances, therefore, namely with the centre of the train brought to a standstill exactly opposite the centre of the platform there would be available only one doorway for each of the end carriages, and owing to the presence of columns close to the edge of the platforms in stations of type A it was conceivable that one of these doorways might be practically useless. Further, these columns were stated to be 15 feet apart, while from Figs. 21, Plate 6, it would appear that the distance between the centres of the doorways of the carriage was 45 feet; if, therefore, the train was brought to a standstill so that one doorway of any intermediate carriage was opposite to a column, the other one would be similarly blocked, and it was thus possible that in a local train four doors out of the total of ten might be practically unavailable for rapid entrance or exit. He also observed that the central portion of the platforms at stations of the A type was 20 feet wide for a length of 100 feet, the platforms for the rest of their length, namely 50 feet in each direction, being only 10 feet wide; the natural tendency of passengers waiting for a train would therefore be, he thought, to congregate at the central portion, and then, in the event of the central carriages of the train being full, there would be a rush to the narrow ends of the platform, which he thought must entail a certain amount of delay and risk that would have been obviated to a considerable extent had the ends of the platforms been wider and the platforms of a uniform width throughout. In England columns were not allowed within 6 feet of the edge of a platform, and on a railway constructed specially for rapid transit he thought that any reasonable expense in avoiding the use of the columns so near to the edge of the platform would have been well warranted. Upon a railway of this character the platforms were a very important detail, and perhaps the Author would kindly explain their construction, as Mr. Waring failed to find in the Paper any details of this. Some of the platforms on the Metropolitan District railway were of fine concrete or artificial stone laid in situ without joints. When the stone was first laid the surface was roughened, but the roughness wore off comparatively soon, and the platforms became dangerously slippery, especially near entrances and exits. He therefore thought that the use of this material was to be avoided. The superelevation of the outer rail on the curves, as calculated

Mr. Waring. by the formula given in the Paper, appeared to agree generally with that obtained by the usual formulas. Mr. Waring attached considerable value to the use of transition-curves, as enabling the superelevation of the outer rail to be gradually run out inversely to the radius of the curves, as it should be; but it was manifest that on mountain railways, where the use of reverse curves of the minimum radius permissible, with very short pieces of straight line between them, was often imperatively necessary, either from local conditions, or from the necessity of keeping down the cost of the work, the use of such transition-curves was impracticable. Mr. Waring was much interested in learning, from the results of the experiments described on pp. 125 and 126, that cement concrete broken up 24 hours after mixing and retempered would acquire an ultimate strength in excess of that of the same concrete left undisturbed, as this was quite contrary to the general experience of English engineers. Perhaps the Author could give some further information as to what this process of retempering was; but if, as Mr. Waring supposed, it meant merely working up again the partially-set concrete with only the addition of a little water, he thought the results obtained were very surprising.

The Author. The AUTHOR, in reply upon the Correspondence, observed that reference had been made to the platforms and columns. In practice columns set near the platform edge had not been of serious inconvenience, as the car-doors did not swing outwards, and trains were started by bell-cord signal and not by hand from the platform. It was better, of course, to omit platform columns, but this could not be done always. Passengers were not allowed to enter or leave by the end doors of the train, so that the length of the train could exceed that of the platforms.