II. "On the Transport of Solid and Liquid Particles in Sewer Gases." By E. Frankland, F.R.S. Received January 6, 1877.

The suspension of vast aggregate quantities of solid and liquid particles in our atmosphere is the subject of daily remark. Cloud, fog, and smoke consist of such particles, whilst the observations made by the Astronomer Royal for Scotland, on the Peak of Teneriffe, afford evidence of the occasional existence of abundance of dust in the air even at great altitudes. I have already mentioned, in connexion with some winter observations in the Alps*, that, by placing the eye in shadow and then looking into the sunshine, I repeatedly saw at a distance of a few feet abundance of snow-crystals floating in the air, when the atmosphere was apparently perfectly clear and cloudless.

A very large proportion of the suspended particles in the London atmosphere consists of water and other volatile liquid or solid matter, as was, I conceive, proved by Professor Tyndall's observation, that the heat of boiling water is sufficient to dissipate them. That this is the true explanation of the disappearance of such particles by the application of a moderate degree of heat, and that it is not caused by the rarefied air from the heated body ascending and leaving behind the suspended matter, as suggested by Tyndall†, is, I think, conclusively proved by the following experiments.

Two large glass flasks were filled, the one with atmospheric air, the other with hydrogen. Two pieces of cotton-wool moistened, the one with five drops of strong solution of ammonia and the other with eight drops of strong hydrochloric acid, were plunged into each flask and allowed to remain there for a definite period. The time required for the settlement of the suspended particles of ammonic chloride was then noted and was found to be as follows:—

1. When the pieces of cotton-wool remained in the flasks for two minutes, the ammonic chloride settled down in that filled with air in eighteen minutes, and in that filled with hydrogen in ten minutes.

2. When the pieces of cotton-wool remained in the flasks to the end of the experiment, the settlement in the air-flask required thirty minutes for its completion, whilst that in the hydrogen flask was finished in seventeen minutes.

It is evident from these results that an atmosphere fourteen times as

* Proceedings of the Royal Society, vol. xxii. p. 317.

† Proceedings of the Royal Institution, vol. vi. p. 4. "What is the explanation? Simply this. The hot wire rarefied the air in contact with it, but it did not equally lighten the floating matter. The convection-current of pure air, therefore, passed upwards *among the inert particles*, dragging them after it right and left, but forming between them an impassable black partition. * * * Even when its temperature does not exceed that of boiling water, the wire produces a dark ascending current."

rare as that of London still offers sufficient resistance to the subsidence of minute suspended particles to prevent them from falling more rapidly than one inch per minute, the globular flasks in which the experiments were made being only about 8 inches in diameter. Such particles could not therefore be left behind by an ascending current of the slightly rarefied air produced by an increase of temperature to 100° C.*

In addition to these aqueous and other volatile particles which disappear by a gentle heat, there are also others which consist partly of organic and partly of mineral matters. But the organic seem greatly to preponderate in the air of towns, because such air becomes *apparently* perfectly clear after it has been ignited.

The processes of fermentation, putrefaction, and decay afford abundant evidence that zymotic and other living germs are present amongst the organic portion of the suspended matters; whilst many analyses of rain-water, made by myself and others, show that the salts of sea-water are amongst the mineral constituents floating in the atmosphere.

Of the zymotic matters, those which produce disease in man are obviously of the greatest importance; and it was chiefly with the object of ascertaining the conditions under which these poisons become suspended in the air that I undertook the experiments, the results of which I have now the honour to communicate to the Royal Society.

The outbreak of Asiatic cholera in Southampton in the year 1866 was traced by the late Professor Parkes, F.R.S., to the dispersion of infected sewage through the air. The sewage became infected by the intestinal discharges from some cholera patients who landed from the Peninsular and Oriental Company's steamship 'Poonah.'

In this case the dispersion was produced by the pumping of the infected sewage and its discharge, in a frothy condition, down an open channel 8 or 9 feet long. The effluvium disengaged from this seething stream was described as overpowering, and was bitterly complained of by the inhabitants of the adjacent clean and airy houses, amongst whom a virulent epidemic of Asiatic cholera broke out a few days after the sewage received the infected dejections. Nevertheless the discharge of the frothy liquid was kept up day and night for about a fortnight, and 107 persons perished. At length a closed iron pipe was substituted for the open conduit: from that day the number of cholera cases diminished, and within a week of the protection of the conduit the epidemic was virtually over.

* When this paper was read, Professor Stokes called my attention to the fact that the time of subsidence of solid particles in a gas depends upon the viscosity, and not upon the specific gravity, of the gas. The viscosity of gases is directly as their times of transpiration, and is increased when they are expanded by heat. The time of transpiration of hydrogen is nearly half that of air, and hence suspended matters ought to subside twice as quickly in hydrogen as in air. The slight excess of viscosity of the hydrogen used in these experiments was doubtless due to the almost unavoidable admixture of traces of air, for Graham found the transpiration time of hydrogen to be greatly prolonged by admixture with oxygen.—Feb. 17, 1877.

In this example a potent cause of the suspension of the zymotic poison in the air was obvious; but in the many alleged instances of the propagation of typhoid fever by sewer gases, the condition of dispersion is not so evident. Does the flow of sewage in a properly constructed sewer produce sufficient agitation to disperse liquid particles through the air-space of the sewer? I endeavoured to answer this question by violently agitating a solution of lithic chloride in a glass cylinder 3 inches in diameter and 30 inches high, with a wooden rod, and ascertaining whether the atmosphere at the mouth of the cylinder became impregnated with the liquid, by testing it with the flame of a Bunsen burner; but no trace of lithium could be detected at the mouth of the jar, even after an agitation much in excess of what would ordinarily occur in a sewer. Before making this and the subsequent experiments, it was ascertained that no lithic chloride is carried off by aqueous vapour from a saturated solution of this salt at ordinary temperatures, first, by placing a shallow porcelain basin containing the solution under a bell-jar, and then spectroscopically examining induction-sparks passed through the atmosphere of the bell-jar; secondly, by burning a mixture of coal-gas and air under a ventilating tube beneath the bell-jar in such a way as to cause a circulation of air through the jar and then testing the effluent air for lithium as before; and thirdly, by passing air from a gas-holder over a saturated solution of lithic chloride contained in a Woulfe's bottle, and testing the air as it issued from the bottle.

The results of the experiment in the glass cylinder render it exceedingly improbable that the mere flow of foul liquid through sewers can impregnate the circumambient air with suspended particles.

There is, however, another kind of agitation to which sewage is subject that may produce a very different result: I allude to the development of gases during the processes of fermentation and putrefaction. It is well known that the bursting of minute bubbles of gas at the surface of an effervescing liquid causes the projection of visible liquid particles into the air to the height of several inches. Such visible particles are seen to fall back again immediately into the liquid; but it appeared to me not unlikely that other particles, too minute to be seen, might be simultaneously projected, and, by reason of the smallness of their masses in relation to their sectional areas, might continue suspended in the air for a long time. To ascertain the truth or fallacy of this supposition I made the following experiments.

A quantity of a strong solution of lithic chloride was placed in a shallow basin and acidulated with hydrochloric acid; fragments of white marble were then added, and a paper tube 5 inches in diameter and 5 feet high was placed vertically above the basin. So long as the effervescence continued, abundance of particles of lithium were visible in a Bunsen flame held at the upper end of the tube. A tinplate tube 3 inches in diameter and 12 feet long was now placed in such a position as to bring one of its

open ends over the top of the paper tube. The tin tube was nearly horizontal but slightly inclined upwards from the paper tube, so as to cause a gentle draught of air to pass through it when it was slightly heated externally near its lower extremity. A Bunsen flame placed at the end of this tube furthest away from the effervescing liquid showed that the suspended particles of solution of lithic chloride were not perceptibly less numerous than at the mouth of the paper tube; neither were they much diminished at the further end of the tin tube when the height of the paper tube was increased to $9\frac{1}{2}$ feet. There can, I think, be little doubt that these particles, which had thus been carried along by a gentle current of air for a distance of 21 feet, would be similarly conveyed to very much greater distances.

In some of my earlier experiments I had noticed that the suspended particles in a current of air were diminished in number, or sometimes altogether removed, when the current had to pass a right-angled bend in a tube; and it therefore appeared to be not unlikely that a stratum of small fragments of charcoal would arrest them. This surmise, however, did not prove to be correct; for the particles of lithic chloride solution suspended in air, when the latter was moving very slowly, passed easily through a stratum 2 inches thick, composed of fragments of charcoal varying in size from $\frac{1}{4}$ to 1 cubic inch; and even when the thickness of the stratum was increased to 5 inches, the particles still came through although in greatly diminished numbers.

The following conclusions as to the behaviour of flowing sewage may be drawn from these experiments:—

1. The moderate agitation of a liquid does not cause the suspension of liquid particles capable of transport by the circumambient air; and therefore the flow of fresh sewage through a properly constructed sewer is not likely to be attended by the suspension of zymotic matters in the air of the sewer.

2. The breaking of minute gas-bubbles on the surface of a liquid consequent upon the generation of gas within the body of the liquid is a potent cause of the suspension of transportable liquid particles in the surrounding air; and therefore when, through the stagnation of sewage or constructive defects which allow of the retention of excrementitious matters for several days in the sewer, putrefaction sets in and causes the generation of gases, the suspension of zymotic matters in the air of the sewer is extremely likely to occur.

3. It is therefore of the greatest importance to the health of towns, villages, and even isolated houses, that foul liquids should pass freely and quickly through sewers and drain-pipes, so as to secure their discharge from the sewerage system before putrefaction sets in.