XV.—*On the Formation of Small Clear Spaces in Dusty Air.* By Mr John Aitken. (Plate XXXVIII.)

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The dust particles floating in our atmosphere are every day demanding more and more attention. As our knowledge of these unseen particles increases, our interest deepens, and I might almost say gives place to anxiety, when we realise the vast importance these dust particles have on life, whether it be those inorganic ones so small as to be beyond the powers of the microscope, or those larger organic ones which float unseen through our atmosphere, and which, though invisible, are yet the messengers of sickness and of death to many—messengers far more real and certain than poet or painter has ever conceived.

As the great importance of these dust particles is gradually being realised, we are from time to time increasing our efforts to protect ourselves from these invisible enemies. Professor, now Sir Joseph, Lister has shown us how to contend successfully with those organic germs, which, falling on our wounds, there find a suitable resting-place, and, if not killed, germinate and grow to our destruction. Sanitary societies are every day being formed, one of whose objects is to combat these floating particles by better appliances directed towards the prevention of the conditions suitable for the germination, growth, and increase of these germs, and against their spread from infected centres, while other societies are directing their energies against the artificial production of those inorganic forms of dust which pollute our atmosphere.

The immense importance of everything connected with dust must be my excuse for bringing before this Society observations on phenomena which I fear must appear to many as trivial and uninteresting; as the clear spaces to which I shall direct attention are on almost a microscopic scale, and require to be magnified to enable us to see them clearly.

Professor Tyndall has made many experiments on the light-reflecting particles floating in our atmosphere. He found these particles were destroyed by heat, and that by placing a flame under a brilliant beam of light, which revealed by illuminating the dust in the air, there was seen rising from the flame wreaths of darkness resembling intensely black smoke. He then found it was not necessary to burn the particles to produce this stream of darkness. This was observed when a hot metal ball was placed under the beam of light, and permitted to remain till its temperature had fallen below that of boiling water. It was then found that, though the dark current was much enfeebled, it was still produced. To study this effect, Professor TYNDALL stretched a platinum wire transversely under the beam, the two ends of the wire being connected with the poles of a voltaic battery, and the necessary appliances for regulating the strength of the current. "Beginning with a feeble current, the temperature of the wire was gradually augmented; but long before it reached the heat of ignition a flat stream of air rose from it, which, when looked at edgeways, appeared darker and sharper than one of the blackest lines of FRAUNHOFER in a purified spectrum" (see fig. 5). He goes on to say—"Right and left of this dark vertical band the floating matter rose upwards, bounding definitely the non-luminous stream of air. 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." *

This explanation of Professor TYNDALL'S has been received by most of us without question; yet I think that if we try to form a mental picture of the process which is here supposed to go on, we shall have some difficulty in doing so. Professor TYNDALL supposes the distribution of the floating matter is due to the heat, which lightens the air, but does not in the same degree lighten the floating dust; the tendency, therefore, he says, is to start a current of clear air through the mote-filled air. No doubt the lightening of the air will slightly increase the tendency of the motes to fall, but the increased freedom to fall from this cause will be extremely slight and inappreciable, and will be entirely negatived and overruled by the upward movement of the hotter air, and the result will be simply to cause the particles to lag a little behind the air in their movements.

Our confidence in Professor TYNDALL'S explanation was not, however, shaken till Lord RAYLEIGH, in going over Professor TYNDALL'S experiments and extending them, discovered that the explanation given of the formation of the dark plane was not correct, and showed that it could not be due to heat lightening the air, and so enabling it to shake itself free from the dust motes, because he discovered that cooling the air produced a precisely similar result (see fig. 2). Lord RAYLEIGH introduced a cold glass rod into smoky air, and then found that "a dark plane extending *downwards* from the rod, clearly developed itself, and persisted for a long while." † He says—"This result not merely shows that the dark plane is not due to evaporation, but also excludes any explanation depending upon an augmentation in the difference of densities of fluid and

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* *Proc. Roy. Inst.*, vol. vi. p. 3, 1870; also *Essays on the Floating Matter in the Air*, p. 5. Longmans, Green, & Co., 1881.

† Paper read before Royal Society, December 21, 1882; also *Nature*, vol. xxviii. p. 139.

foreign matter." Lord RAYLEIGH also offers as a suggestion that the particles may be thrown out by the centrifugal force, as the mixture flows in curved lines round the obstacle.

In a letter to *Nature* of July 26, 1883, Dr LODGE gives an account of some experiments he made on the dark plane and on dusty air. Dr LODGE says—"We are now pretty well convinced that differences of temperature have nothing to do with the real nature of the phenomenon; *we find that solid bodies have sharply defined dust-free coats or films of uniform thickness always surrounding them*, and that these coats can be continually taken off them, and as continually renewed, by any current of air." Dr LODGE also describes a number of interesting electrical experiments on the dust, and makes many very valuable suggestions, but comes to no definite conclusion. He says—"*Why* the air near a solid is free from dust we are not prepared to say."

From these quotations it will be seen that the whole matter is involved in considerable obscurity; and as the subject already had considerable attractions for me, I determined to undertake an investigation in this particular direction. My experiments were begun in summer, but it was not till November that the greater part of the work was done.

I have considerable difficulty in determining how it will be best for me to place the result of this investigation on record. As a rule, it is best to take the reader over the road traversed by the investigator, as the probability is the difficulties of the one will be the same as those of the other, and the results generally unfold themselves best when treated in this way. In the present occasion this method is not suitable. The subject, though apparently simple enough, was found to be much more intricate and complicated than was expected. The result was, many a false scent was followed only to be given up, so that I would be taking the reader to my conclusions by a long, winding, and uninteresting path. It will therefore be better for me simply to describe the result of the investigation from my present point of view.

Apparatus used.

The apparatus used was all of the simplest and least expensive kind. The dust-box in which the experiments were made was a cigar-box, the lid of which was removed and a piece of glass put in its place. When in use the box was placed on its end, with the glass to the front. A window was cut out of the left side of the box, extending from close to the bottom to near the top, and coming close to the front of the box. The box was then painted black inside. Holes were cut in the back of the box, or wherever required for the introduction of the different pieces of apparatus, which shall be afterwards described. As a source of illumination, two gas jets, placed close to each other, were used; these jets were enclosed in a dark lantern, having an opening towards the dust-box. To concentrate the light, two double convex lenses were fitted into a short tube. This tube was loosely attached to the front of the dark lantern, and could be directed to, and focused on, any part in the interior of the dust-box. For observing the phenomena two magnifying glasses were employed —one a simple double convex lens, which was used for getting a general view of the phenomena; the other a more powerful compound glass, strong enough to enable me to see and follow the movements of the individual dust particles.

For observations on the effects of slight differences of temperature, metal or glass tubes in some form or other were generally used. Straight tubes closed at one end were found most convenient; these tubes were introduced through the back of the box, and the closed end projected inwards to within a short distance of the glass front, so as to admit of observation under the strong magnifying glass. The tubes were heated or cooled by means of water or steam introduced into them through a small tube which passed down their interior. This small tube was connected by an india-rubber tube to a glass filler, into which the water was poured, and from which it flowed down the small tube to the front end of the experimental one, and returned to the outside of the box by the space between the tubes. In this way the experimental tube could be easily heated or cooled, and the space all round it left free for observation. For higher temperatures, a fine platinum wire, heated by means of a small bichromate of potash battery, was employed.

Different kinds of dust were used in the experiments, such as dust made in the usual manner with hydrochloric acid and ammonia, and by burning sulphur in the presence of ammonia; this last was used when very dense fogging was required; smoke of paper and other substances were experimented with; also dusts made by burning sodium or magnesium; and for experiments with dust which would not change with heat, calcined magnesia and lime were employed. Charcoal powder was also used in some experiments. The powders of these last three substances were stirred up by means of a jet of air. These dusts were also varied by the addition of water vapour.

Suppose now that the gas is lit in the lantern, and the dust-box in its place Let us introduce into the box through the opening in the back one of the glass or metal tubes, closed at the front end, and introduce into this tube from the back the smaller one, and connect this latter with the filler, so as to enable us to pour hot or cold water through the tube, to heat or cool it. If we are going to use smoke, a piece of smouldering brown paper is introduced into the box, by removing the glass front, which is kept easily removable for this and other purposes; or, if we are going to use sal-ammoniac dust, the ammonia and hydrochloric acid can be introduced on glass or wooden rods through small openings in the box, or the acid and ammonia may be placed in small open vessels inside the box. If the dense sulphate dust is required, the sulphur may be placed on a match and introduced into the box after being lighted. When the dust is thick enough, and uniformly distributed through the box, bring the light to a focus on the tube. For the present the tube must be neither heated nor cooled. Using the magnifying glass; it will in all probability be found that there is a clear space all round the tube or on some part of it, and that the air currents are carrying off the clear space in an irregular manner, or there may be seen rising over the tube a regular dark plane, depending on the relative temperatures of the air and the tube.

Now remove the beam of light from the dust-box and leave it for some time. If left long enough, and the box kept free from changes of temperature, it will be found that all air currents have ceased, and a close examination of the experimental tube will show that the dust is now in contact with it at the sides and on the top. But if we look on the under side of the tube we shall there see a clear space, like that shown in fig. 1, which represents the tube seen endways.[*] It will be observed that this does not agree with Dr LODGE's observations; but I think I have taken every precaution, and the conclusion which I have come to is, that bodies have not sharply defined dust-free coats, and that when the bodies and the air have the same temperature, the dust comes into contact with the sides and top of the bodies.[†] Now what is the cause of this clear space under the tube? Clearly

Gravitation,

which brings me to the first of the causes of the dark plane. When the air comes to rest, the temperature of the air and the tube being the same, there is nothing to keep the dust from coming into contact with the tube. But gravitation is at work on the particles, and while the air is still the particles are all falling, and as the upper surface of the tube stops those falling on it, there are no particles to supply the place of those falling from the space under the tube, and the result is that a dustless space is here formed. If now we pour into the tube some cold water we can study the

Effects of Cold.

At once a downward current is started, and this downward current carries with it the clear air under the tube; the two currents of dustless air from the sides

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[*] In the figs. the white surface represents the light-reflecting dusty air, while the black represents the transparent air, free from reflecting particles.

[†] The only reason I can imagine for this difference between Dr LODGE's results and mine is that he worked with more powerful sources of illumination than I did. He used either the sun's light, an oxyhydrogen lamp, or a SERRIN arc-lamp, while I only used gas. Now one result of this difference would evidently be that the illuminating beam used by him would have a much greater heating effect than the one used in my experiments, and would therefore heat the surfaces under examination. I found this effect even with gas. If the body had a small capacity for heat, it was only necessary to keep the light focused on it for a short time to heat it sufficiently to cause a clear space to form over the part where the light acted.

of the tube meet underneath it, and form a dark plane in the centre of the descending current, as represented in fig. 2.

It might be thought that gravitation would not act quickly enough to keep up a supply of dustless air sufficient for this purpose. This however does not seem to be the case, and gravitation appears to be the only cause of the distribution of the dust, causing this dark plane in the descending current. One reason for supposing this is, that if we only cool the tube very slightly, the dark plane is very thick and well marked; but the more we cool the tube the thinner does the dark plane become, intead of thicker, which would be the result if it was due to difference of temperature. The effect of the increased cold is to increase the velocity of the descending current, and draw out and thin down the dark plane. Further, if we closely examine the air round the tube with the strong magnifying glass, we shall see the particles of dust descending and settling on the horizontal part on the top of the tube, while the particles which fall a little to each side of the centre line are carried on by the current, and continue to clasp the tube closely till the current begins to turn under the tube, where the particles being free to fall, drop away from the tube, and leave a clear space (see fig. 2). This clear space only begins to be perceptible when the current begins to turn underneath the tube, and gradually becomes thicker as it travels underneath towards the centre where the two currents join, and form the descending dark plane.

The rate at which dust settles out of air by gravitation is much quicker than we might imagine. Dust is kept in suspension by ascending currents, and when these are removed it settles remarkably quickly. There was an opportunity for seeing this in these experiments. If the experimental tube was cooled, then the cold gave rise to currents descending on the side of the box where the tube was, and rising on the other side; but the rising current only came up to the height of the tube, and all the air above the tube was still and currentless, because its temperature increased towards the top of the box, and then was produced a condition of stable equilibrium. Under these circumstances, I have frequently seen the whole of the upper part of the box above the cold tube become quite clear, and with a sharp line of demarcation between the clear still air above, and the dusty currents underneath. It is, of course, the vertical component of the currents that keeps the dust in suspension, the horizontal component having no such action. This may be seen when we cause a current of dusty air to flow along the under side of a horizontal flat surface. At the point where the current starts, the dust is in contact with the under surface of the body, but falls further and further from it as it flows along.

In order to study the effect of temperature alone, it was necessary to arrange the experiment so as to get rid of this gravitation effect. For this purpose I prepared another piece of apparatus. The ideal shape of body for this purpose would be one having some length and breadth, but infinitely thin and flat, so that when placed vertically, the air in passing over it would never have to move in a horizontal direction. The nearest approach I could make to this was made with a piece of copper foil folded on itself, soldered all round its edges, and fixed to the end of a brass tube. It was heated and cooled by passing into it hot or cold water. This instrument presented at the front edge extremely little thickness, and was found to answer well, but was rather delicate and easily put out of shape. As it is only necessary to examine one side of the test plane or surface, a different form of apparatus was afterwards adopted. It was made of a piece of brass tube the same as used in the previous experiments, and a flat plate of copper was soldered to one side of it at the front end. This plate was filed perfectly flat and smooth, and sharpened at the top and bottom edges, all the bevel being on the tube side of the plate. The side of the plate presented towards the source of illumination was thus a perfectly flat surface, and when placed vertically, the air passing over the front surface could not have its dust separated from it by gravitation, as *all* the horizontal movement went to the back of the plate.

Placing either of these test surfaces in the dust-box with the plate vertical, cold was applied. At once a downward current was produced, but no dark space was formed on the vertical test surface; and if the copper foil apparatus, which is flat on both sides, is used, no dark plane whatever is formed, as shown in fig. 3. More intense cold was tried, and a temperature of – 10° C. in air of a temperature of 15° C. was found to produce no effect save an increased rate of current, and an increased brightness in the particles near the plate, due to water vapour being deposited on them by the lowering of the temperature, an effect observed by Lord RAYLEIGH on the dust bounding his cold dark plane. Different dusts were tried, and the experiment varied in many ways, but when the gravitation effect was removed, not the slightest tendency to the formation of a dark plane by cold could be detected. The tendency seemed to be the other way. The dust particles in all cases tended to keep close to the cold body. This indicates that Lord RAYLEIGH'S dark plane formed in the descending current from a cold body is not an effect of the cold, but is due to the separating action of gravitation.

What I am about to state may at first seem a contradiction of this conclusion. When varying the conditions of the experiment, and altering the amount of water vapour present, I was much surprised to find that under certain conditions the dark plane had a decided tendency to make its appearance in the descending current even from a thin vertical surface. On repeating the experiment and varying it, it was found that the conditions best suited for getting this dark plane were when there was nothing but ordinary atmospheric dust in the box, and the air was saturated with water vapour. Under these conditions, there was generally all through the box a haziness, but in the space in front of the cold test surface the cold thickened this haziness into a dense cloudiness, which extended for some distance from the plate and showered down from it. But between the fog and the test surface there was a well-marked dark space. To what was this due ? I had already satisfied myself that cold did not tend to drive away the particles. Then why did these particles conduct themselves differently from the others ? While the test surface was vertical, the motion of the particles was too quick to be followed with the magnifying glass. The surface was, therefore, placed nearly horizontal, with a slight slope towards the light (see fig. 4). Still the dark space remained, and the current flowed on, but the particles did not come close up to the plate, though gravitation was acting on them. The cold could surely not be repelling the particles and keeping them off the plate. A short examination with the strong magnifying glass, which it was now possible to use as the particles were moving slowly enough, showed that this was not the case. The particles were seen flowing along in the current, but at the same time they were seen falling into the dark space and disappearing when they came within a certain distance of the surface. The explanation was evident. The surface, by its very low temperature, had robbed the air close to it of its moisture, which it deposited on itself in ice crystals. Into this cold but drier air the particles evaporated as they fell, and in this case the dark plane would contain the dust of the atmosphere, which, however, is black, compared with the brilliancy of the surrounding fog. In this case the dark plane was produced by

Evaporation,

and this explains why it is not visible when artificial dusts are present, the larger particles of the artificial dusts not being sufficiently reduced by evaporation to make them comparatively invisible. We shall now pass on to consider the

Effects of Heat.

For this purpose let us remove the flat test surface from the smoke-box, and put in its place a round tube of metal or glass. A glass one is preferable, as it permits the illuminating beam to pass through it, and we are thus enabled to see what is taking place all round. After the box is filled with dust, leave it for some time, till the tube has acquired the same temperature as the air. On examination we shall find, as before, the particles evenly distributed, and coming close up to the surface of the tube on the top and at the sides, while underneath we shall see the clear space produced by gravitation. We shall first examine what the effect is of a slight difference of temperature. For this purpose we shall pour some slightly heated water through the tube, so as to raise its temperature a very little—a degree or two. When this is done the equilibrium is destroyed, and currents begin to form. The clear space formed by gravitation under the tube rises up, closely clasping and encircling the tube in a dustless envelope. The two currents of clear air which started from the under side of the tube, reunite at the top after passing round the sides, and ascending in the centre of the upward current, form a well-marked dark plane (see fig. 5). Here again gravitation seems to be the principal cause of the distribution of the particles. This certainly is the case when the difference or temperature is very slight, but we shall see that, as the temperature rises, the gravitation effect bears a less and less proportion to the heat effects, which we shall presently consider. It will be as well to note here the difference in the clear space surrounding the tube in this case and when cold was applied, as shown in figs. 2 and 5. When cold was applied (fig. 2), the dark space was only on the under side of the tube; but with heat it is all round the tube, because it has its origin in the air under the tube.

When making these experiments a somewhat peculiar effect was often noticed, which seems worth recording, as it forms a good illustration of the influences at work here. If, after the tube had been warmed and a well-marked dark plane formed over it, no more hot water was added, and the tube allowed to cool, the upward current became sluggish after a time, and the dark space presented the appearance shown in fig. 6. The two sides of the tube now differed. The left side was bounded by a clear space, which ascended as before, but on the other side, the dark space did not continue to the top of the tube. As shown, the particles here came into the dark space and obliterated it. The explanation of this peculiar effect, which so often repeated itself, is this. The falling temperature had allowed the current on the right side to become so slow that gravitation had time to act on the particles after the current turned to the upper side of the tube, and the particles had time to fall through the clear space before they were carried into the ascending current over the tube. In other words, gravitation undid on the upper part over the tube what it did at the under. The left side of the tube continued to keep its clear space, because the light used for illuminating it was focused on this side; it, therefore, was slightly warmer than the other.

Gravitation, while it explains the formation of the dark plane in such cases as above described, where the difference of temperature is slight, is evidently not the whole explanation. Gravitation can obviously have little to do with the formation of the dark plane formed over a thin wire, as the time occupied in horizontal movement when going round so small a body is not enough for it to have any appreciable effect. In order to study the effects of heat apart from those of gravitation, the tube with the flat surface fixed on it, employed in the experiment with cold, was used, as it eliminates the gravitation effect and shows the heat effect alone. Fixing this piece of apparatus in the smoke-box with the test surface carefully adjusted in a vertical plane, heat was slowly applied to it. An upward current at once started, and it was noticed that at the same time a clear space was formed on the hot surface, and rose up from it, producing a dark plane in the ascending current (fig. 7). This clear space was evidently entirely due to the heat in some way driving the particles away from the hot surface.

When working with this flat test surface it is necessary to be careful about the adjustment of it in a vertical plane. If the surface leans either to the one side or to the other, a clear space is, of course, formed on the side to which it inclines by the separating action of gravitation, and gravitation also acts on the particles on the other side, and tends to counteract the effect of the heat. Further, if the surface is inclined enough, the gravitation effect overcomes the heat effect, and destroys the dark space by causing the particles to fall towards the hot surface. At the same time, the gravitation dark space on the under side becomes thicker and thicker the more the plane of the test surface approaches the horizontal. This instrument may be made capable of measuring the relative effects of different temperatures, &c., by providing it with a scale to indicate its angle with the vertical. The greater the angle at which the dark space is visible the greater will be the repelling force.

By the construction of the instrument, when placed vertically, the gravitation effect is entirely removed. The dust particles can be seen coming straight up, and no purified current coming from the under side (compare figs. 5 and 7). The clear space begins to show itself with a very slight rise of temperature. Indeed, it would appear that it is formed by the slightest rise of temperature, as it always begins to be visible just when the temperature is high enough to cause an ascending current. With a slight difference of temperature it is extremely thin, and requires careful observation to detect it, but as the temperature rises it becomes thicker and thicker. For the present I shall not enter into the question as to why the dust particles move away from a hot body, but shall leave the consideration of this subject till after describing some experiments which seem to throw some light on the mechanism of these movements. For the present I shall simply speak of it as repulsion due to heat.

The following experiments will help us to understand the action of this repulsion. Fix a piece of glass in front of, and parallel to, our flat test surface, and at a distance from it of two or three millimetres. Glass is used because it is transparent, and allows the illuminating beam to penetrate and show us what is taking place at the different surfaces. If we now warm the test surface, the dust particles all move away from it towards the glass plate, and many of them attach themselves to the glass. After a short time the glass gets warmed by radiation, &c., from the hot test surface. If we now cool the test surface a change takes place, the dust particles move away from the glass, and crowd up towards the colder test surface.

A better form of the experiment is shown at figs. 8 and 9. A glass plate

A, 12 cm. long and about 4 cm. broad is attached by means of cement, near its upper end, to a metal tube, to enable us to heat it while in the dust-box. Another plate of glass B, of the same size as A, is placed opposite and parallel to it, at a distance of about 5 mm. The plate attached to the tube is first put in its place in the box, and after it has acquired the temperature of the air, the other plate B is warmed and put in its place, opposite to A, as shown in sketch. The box is now filled with dust. If we now carefully examine the air between the two glass plates, we shall find that the warm plate B (fig. 8) is bounded on each side by a clear space, its high temperature having driven all the dust particles to a distance, while the other plate has no clear space round it. Now let us put a little warm water into the tube to heat the upper part of the cold glass plate A, and note the change in the distribution of the dust. As before, the lower part of B is bounded by a clear space (see fig. 9), but the upper part of A being now warmer than B, the dust is driven from A towards B, and a clear space opened in front of the hot part of A, while the clear space formerly in front of the upper part of B is closed. The heat has thus caused the dust particles to move across the direction of motion of the air. These experiments have been made with different dusts, and always with the same result.

For the purpose of studying the effects of higher temperatures than that of boiling water, a fine platinum wire was fitted up inside the dust-box and heated by means of a small bichromate battery. The arrangement of wire which I prefer for this purpose is made by bending it into a U-shape and bringing the two legs close together, say one or two millimetres apart. The wire is placed horizontally in the dust-box, with the bend to the front, and the legs at the same level, the two copper wires to which it is attached being carried backward and out of the box. By this arrangement a clear end-view is obtained all round the wire, and the effect of the heat conveniently observed, and further, the wire doubled in this manner, tells us more than a single wire can.

In experimenting with this arrangement of apparatus, the results are as varied as the dusts employed. Each dust gives a different size of dark plane for the same temperature. The previous experiments with less intense heat seemed to point to repulsion as the cause of the clearing away of the particles. If this were the case, it seemed very unlikely that some dusts would be repelled further away than others, at least to the extent that actually took place. To see if repulsion was the explanation in this case also, instead of a single wire, which I used in my first experiments, I doubled the wire into a U-shape, as already explained, and placed the length horizontally, with the legs at the same level. When this wire was heated in the sal-ammoniac or in sulphate dust, it was at once evident that repulsion was not the cause of the dark plane in these dusts. With either of them, when the temperature of the wire was not very high, the dark plane rising over each leg was very thin (see fig. 10), but as the temperature rose, the planes extended on each side till the two planes met and formed one large one (see fig. 11). An examination by means of a magnifying glass showed that this broad dark plane was due to the evaporation, or to the disintegration of the particles, as they could be seen streaming upwards and disappearing into the dark space under the wires. They there arrived at a space the temperature of which was sufficient to convert them into gases or vapours. The dark plane in this case was thus due to a change of the particles from the solid to the gaseous state. Hence the great differences in the size of the dark planes of different dusts, each kind of dust having a different temperature at which it evaporates or becomes disintegrated. The sulphate dust, for instance, gives a smaller dark plane than the chloride, because the sulphate requires a higher temperature to drive it into the gaseous state than the chloride.

This result is quite different from that got with temperatures which were not sufficient to vaporise the particles and make them invisible. It was therefore now desirable to make experiments with some substance which a high temperature could not destroy. For this purpose I selected calcined magnesia and calcined lime, also soda and magnesia dusts, produced by burning the metals. With these dusts a different result was obtained. A high temperature had no other effect than forming a thin dark plane over each wire (see fig. 10). But even these stable forms of dust were subjected to a repulsion, the particles passing near the wire being driven to a small distance from it on each side. It may be possible that some of the particles of these dusts are vaporised, but if so, the amount must be very small, and can have but little influence on the formation of the dark plane.

Another effect noticed in these, and in the experiments at lower temperatures, was that whenever there was much water vapour present, there was a faintly indicated dark plane formed by the evaporation of the water from the particles. If nothing but the dust of the air was present in a fog formed with steam, then the wires were surrounded by a very thick dark plane, due to the evaporation of the fog particles; and if any artificial dust was present, then the thick dark plane was still visible, but not black, as the particles were only reduced in size by the evaporation of the water from them. All these different effects of the hot wire can be illustrated at one time, if we put into the dust-box some indestructible dust, also some sal-ammoniac and sulphate dusts, in proper proportion, and then add some water vapour. When the wire is heated in such a mixture, we get a result like that shown in fig. 12. In the centre we have the true dark plane, in the wider space there is only the indestructible powder present. The next boundary shows the vaporising zone of the sulphate, the next the vaporising zone of the sal-ammoniac dust, and the last that of water. In fig. 12, *a* is the true dark plane, in which there is nothing but gases and vapours; in the wider space *b*, both the chloride and sulphate dusts are vaporised, and we have nothing visible save the indestructible dust; in the next space *c* the chloride is vaporised, and there are present the sulphate and indestructible dusts; while in the space *d* all the dusts are present, but dry, the condensed water being evaporated.

Conclusion.

The conclusion we have arrived at from these experiments is, that for the formation of the dark plane in dusty air, there are various causes which may be classed under the following heads:—With cold, producing the downward dark plane, we have—1st, the distributing effect of gravitation; and 2nd, the disappearance of the particles by evaporation, when falling into a space rendered dry by condensation produced by cold. With heat, producing the upward dark plane, we have—1st, the distributing action of gravitation; 2nd, the distributing action of repulsion due to heat; 3rd, evaporation of the particles; and 4th, disintegration of the dust. In the last two cases the dust is rendered invisible by the heat changing it from the solid light-reflecting condition to the transparent gaseous state.

Effect of Centrifugal Force.

We may here ask ourselves, Are these the only ways in which the dark plane may be produced? It is, of course, impossible to give a definite answer to such a question. There are, no doubt, other ways in which it seems possible that this phenomenon might be produced, and it seemed worth while to consider Lord Rayleigh's suggestion as to the effect of centrifugal force. On considering the action of this force in the experiments described, it is evident that it can have but little to do with the distribution of the particles, because the air, in rising and passing round the wires and tubes, is curved first in one direction, and before it again takes up its original direction of motion, it is curved to an equal amount in the opposite way. So that whatever sifting action the centrifugal force may have at the one part of its course, will be undone at the other. I, however, thought it worth while to arrange an experiment, to see if the particles really were thrown out by centrifugal force at any part of their passage. With this object, I fixed inside the dust-box a piece of thin sheet metal, with its plane vertical. Arrangements were made so that a current of dusty air was caused to flow down the one side of the plate, round the lower edge, and up the other side. In this way the air was caused to curve through an angle of 180°, and no curving in the opposite direction took place. When this was done, it was seen to be possible to give an appearance very like as if the centrifugal force did throw the particles away from the centre of motion. In front, and just above the lower edge of the plate, there was formed a clear space, very near the centre of rotation of the air. On examination, however, it was seen that this was caused by an eddy, due to the upward channel in which the air was confined being wider than the space under the plate. In the eddy so formed the particles were soon sifted out by gravitation, and a clear space formed. On contracting the breadth of the upward channel, and making it equal to the passage under the plate, this eddy disappeared, and the clear space was no longer formed. In this experiment, though the air was caused to curve through a considerable angle, yet there was no satisfactory evidence of any distributing action due to centrifugal force. It seems probable that, even under these conditions, a certain amount of sifting action does take place, though not enough to make it observable; and though there are reasons for supposing that if the particles were heavy enough, and the velocity of the current great enough, there would be a visible effect, yet it is evident that centrifugal force plays no part in the formation of the dark plane, in the experiments with heat and cold. The fact that the dark plane has a sharply defined boundary is proof that centrifugal force is not the cause of the distribution, as this force would not give such a result. Its tendency would be to throw the heaviest particles furthest out, and thus give rise to a shaded outline.

Effect of Electricity.

Electricity is another force which might be supposed to play some part in the formation of the dark plane. It was difficult to believe that the attraction of the particles was a thermal effect when making the experiments with the hot and cold surfaces placed opposite each other, and observing the way in which the particles were repelled by the one plate and attracted to the other; and on making other experiments, which will be presently described, in which the dust rising in the current from the heated platinum wires was attracted to, and deposited itself on, the surfaces of bodies placed in its path. The dust particles conducted themselves in a way strongly suggestive of electrical disturbance. They seemed to be attracted by the cold surfaces in exactly the same way as if they had become electrified at the hot surface. It was, therefore, thought advisable to make experiments to ascertain whether electricity had anything to do with the formation of the dark plane. Experiments were first made to see if the hot surface became electrified in the dust-box by the passage of the air over it, or from other causes. For this purpose I used a small cylindrical conductor of solid metal, about 1 cm. in diameter, and with rounded ends. This conductor was fixed to the end of a glass tube, and a conducting wire connected to it and carried through the tube. The conductor was then introduced into the dust-box through an opening in the back, after which its connecting wire was joined to a gold-leaf electroscope. Before the conductor was put in its place it was heated, and the box was filled with dust. Examined with the magnifying glass in the usual way, the dark plane was found to be well marked and the repulsion going on as usual, but not the slightest sign of electrification showed itself at the electroscope. No signs of electricity having shown themselves at the hot surface, it was sought for in the ascending current. This was done by first removing the insulated heater and putting in its place the platinum wire, to get a more intense effect from the high temperature. Over the wire was placed a large insulated flat-shaped conductor for the dust to deposit itself upon. The conductor was then connected to the electroscope, the box filled with dust, and the electric current turned on to heat the wire. The leaves of the electroscope, however, remained close together, so that the dust deposited on the conductor could not have been charged with electricity.

It may be objected to these experiments that the electroscope used was not sensitive enough for the purpose, and that if a more sensitive instrument had been employed, signs of electricity might have been obtained. It is quite possible that another instrument might have shown signs of electrical disturbance, but I think that if electricity was the cause of these phenomena, and was sufficiently strong to repel the particles and to cause them to adhere to bodies, it would be quite powerful enough to separate the leaves of the electroscope. Any electrification less than would affect the leaves would only be a secondary matter, and could not be the cause of the phenomena. Another reason for supposing that electricity has little to do with these effects is that the dust tends to settle only on cold surfaces.

Experiments were now made to see what the effect is of electrifying the hot surface. The small cylindrical conductor was heated, placed in the box, and connected with the electroscope. A Leyden jar charged very slightly, but enough to cause the full divergence of the leaves of the electroscope, was then connected with the apparatus, and the effect on the dust surrounding the electrified conductor noted. While the body was hot enough to cause a well-marked dark plane, there was not the slightest effect produced by the electricity, though the leaves of the electroscope were wide apart, and showed that the hot surface had a decided charge. The electroscope was then removed, and a much higher charge given to the conductor. This time an effect was evident, but it was difficult to say what was taking place. The general appearance of the air round the hot conductor had quite changed. The sharp outline of the clear space round it was destroyed, and the dark plane over it had lost its clear and sharp outline, and had become much thicker, though not so dark, as before. All round the conductor there seemed to rage miniature storms, and the particles had much the appearance as if they were seen all out of focus. This effect was produced by either positive or negative charge.

To find out what was taking place in the air round the electrified body, I had recourse to large-sized particles of dust to enable me to follow the movement of each particle. Calcined magnesia was selected for this purpose. When the air in the dust-box was filled with this powder, the reason of the change in the dark space at once became evident. The particles in the ascending current could be seen rushing towards the electrified surface and adhering to it. The dark space was thus broken in upon, and its outline destroyed by the attracted particles; the air round the body was at the same time deprived of a great quantity of its dust; and over the conductor there rose a thick and ill-defined band of clearer air, the particles which formerly were in it having attached themselves to the electrified body. All the particles did not seem to be equally attracted, but some much more than others. This gave rise to the irregular movements seen all round the body. The dust particles frequently deposited themselves on the conductor in small needle-like radial columns, which grew by the addition of the particles till they got to a certain size, when they were shot off and flew through the air with surprising velocity. If, after the conductor had been electrified a short time, the supply of electricity was cut off and the conductor connected with the electroscope, the charge given to the air and the dust in the box was given back. The leaves of the electroscope expanded quickly, and if discharged, rapidly became charged again, the dust at the same time being attracted to and deposited on the conductor in needle-like columns.

After looking at this last experiment, and seeing the tendency which particles in electrified air have to deposit themselves on bodies, we cannot help asking the question, Does this experiment throw any light on the well-known tendency to the development of certain forms of bacteria resulting in the putrefaction of our foods, and in the appearance of increased quantities of certain ferments during thundery weather? Can it be that the germs of these forms of life floating in our atmosphere have a far greater tendency to settle upon the surface of bodies from electrified air than when there is no electrical disturbance? No doubt this electrical attraction must have some effect in this direction, but whether it is the principal cause or not I shall not venture to say.

If we use still higher degrees of electrification than those used in the above experiments, other effects are produced, but they have no relation whatever to the formation of the dark plane. From the experiments described it will be seen that the effects of electricity are of quite a different kind from those of heat. The electrified body, instead of repelling the particles like a hot one, attracts them, and clears the air in a partial way by attracting some of the particles to itself, while heat acts by repelling all of them to a distance. This antagonism between the two forces may be illustrated by heating the conductor and electrifying it slightly. At first no effect is produced by the electricity; the dark plane remains quite clear, but as the temperature falls, a stage is arrived at when the electrical effect overcomes the heat effect, and the particles break in on the dark space and destroy it.

In making electrical experiments, most of us have noticed the tendency which dust in the room has to settle on the different parts of the electrical apparatus, and to destroy the insulation, and many have noticed the excited and rapid movements of electrified dust. Dr LODGE, in the letter already referred to, remarks on the rapidity with which the dust-box, in his experiments, was cleared of its dust by means of electrified bodies placed inside it. I have made some experiments on this subject, to determine the conditions most favourable for the clearing of air by means of electricity. For these experiments I preferred to use a large glass flask about 30 cm. in diameter. Placing this flask with its mouth downwards, I introduced into it an insulated metal rod, fixed vertically, and passing through the open neck of the flask. If a dense cloudiness was made in the flask with any dust, by preference it was generally made by burning sulphur and adding a little ammonia. After a dense whiteness had been produced, the conductor was electrified. Seen from a distance, no change seemed to have taken place, but on examination it was found that all the dust was deposited on the inside of the flask in a nearly uniform white coating. To enable me to see what was taking place, the inside of the flask was wetted. When the electrification began, the dust could now be seen driven about as by a violent wind, and, after a few turns of the machine, it had disappeared from the flask. The conditions found most suitable for producing this result quickly were a rapid discharge of the electricity into the dusty air by means of a point or points. If the conductor terminates in a ball inside the flask, the electrification has but little effect. In addition to the conductor terminating in a point, it is also necessary to have near the electrified point surfaces to aid in the rapid electrification of the dust. When the point is surrounded by surfaces the air currents are violent, but if we remove the surfaces the currents are not nearly so strong. This may be seen by allowing a cloud of dust to rise round a conductor placed in an open space, when but little effect will be observed on electrification. After the dust has been electrified, it ought to be brought near some surface, towards which it may be attracted, otherwise it may lose its charge before meeting a place to deposit itself.

Experiments have also been made to determine whether the very fine and invisible dust of the atmosphere is also caused to deposit itself when electrified. With this object the large glass flask had an india-rubber stopper fitted to it, through which passed a tube to connect the interior of the flask with an air-pump, to test the condition of the air in the flask by reducing its pressure, while it was kept moist by the presence of water, and to observe whether any cloudy condensation took place after electrification. A conductor insulated in a glass tube passed through the stopper, and terminated in a point inside the flask. Means were taken to insure the insulation of this conductor inside the flask. This was done by surrounding the insulating tube with another tube, and causing the entering dry air to pass into the flask through the space between the tubes. The insulation was thereby kept good, and the glow of the discharge at the point was quite visible in the midst of the moist air.

On experimenting with this apparatus, it was found that electrification for a short time by means of an ordinary cylindrical electrical machine was sufficient to deposit almost all the dust, only the very slightest signs of condensation being visible after electrification. What formed the nuclei of the very few cloud particles which appeared it is difficult to say. Whether they were undeposited dust particles, or particles thrown off the conductor, or some product of the electric discharge, this experiment does not determine. That they may be some product formed from the air by the electric discharge is suggested by the following experiment. First purify the air in the flask, either by passing it through a cotton-wool filter, or by electrification, then reduce the pressure to supersaturate it, and now electrify. At once a cloud forms all round the conductor, and extends to near the sides of the vessel. This cloud is evidently not formed by anything thrown off the conductor, forming nuclei, as it appears at the same moment all round the point. It is more probable that the nuclei of these cloud particles are formed by the discharge of the electricity producing in the air nitric acid, or ozone, on which the supersaturated vapour condenses. That the nuclei so formed are not solid particles there seems to be but little doubt, because if we allow filtered air to enter so as to increase the pressure and evaporate the particles, cloudiness does not reappear on again reducing the pressure, which it certainly would do if the nuclei had been solid particles. The number of nuclei that remain after electrification is very small, if the air is not supersaturated with vapour; and practically we may say that electrification deposits all the very fine dust, and I may remark here that it does it in a very rapid manner. The air in the flask can be purified much quicker by means of electricity than by the air-pump and cotton-wool filter. It may be noted here that the dust of the atmosphere has but little effect on the brilliancy of the glow of the point discharge. With a large amount of dust, with the ordinary dust, with no dust, and with the electrification used, no difference of importance in the brightness of the glow was detected.

The Lungs and Dust.

When we see a beam of sunlight shining into a darkened room through a small opening, and revealing, by illuminating, the suspended dust, making the beam look like a solid body, we have great difficulty in realising that our atmosphere can be so full of dust, as this experiment shows it to be, as it escapes our observation under ordinary conditions of lighting, and it gives us a feeling of discomfort to realise that we are breathing that dust-laden air. This uneasiness was by no means decreased when my experiments on cloudy condensation revealed the fact that, in addition to that mass of visible dust, there are enormous multitudes of particles so small that even the concentrated light of the sun does not reveal them. These minute particles are so numerous that hundreds of them are crowded into every cubic centimetre of air. On realising these facts our feelings are those of wonder that our lungs can keep so clean as they do, while such vast quantities of impurities are constantly ebbing and flowing through them. At that time I was not aware that there is an influence ever at work tending to protect the lungs by preventing, to a certain extent, the particles of dust coming into contact with their surfaces,—that nature had provided a subtle form of mechanism possessing some of the advantages of a filter without any of its disadvantages. The experiments here described show that a hot surface repels the dust particles in the air. The heat of our bodies will, therefore, exert a protective influence on the lungs, and tend to keep them free from dust.

Our lungs, however, are not only hot, they are also wet. What influence will the constant evaporation which takes place at the surface of the tubes and passages have on the dust? To answer this question, I fitted the flat test surface in the dust-box, and through an opening in the top introduced a brush dipped in water, with which one-half of the surface was kept wet, the other half being dry, to compare the effects under the two conditions. When the surface was heated a few degrees, to even less than the temperature of our bodies, the result was most decided, the dust being driven more than twice as far from the plate in front of the wet part as it was from the dry. The evaporation, therefore, of the water from the surface of the bronchial tubes tends strongly to ward off the dust, and keep it from coming into contact with their surfaces. We must not, however, imagine that the heat, or the heat and the evaporation, are sufficient entirely to prevent the dust coming into contact with the surfaces of our bronchial tubes and passages, because dust really does come into contact with them, but it does not do so nearly to the extent to which we have been in the habit of supposing.

The necessary conditions for this repulsive effect to be active are, that the air is acquiring heat and moisture. If the air has the same temperature as our bodies, and is saturated with vapour, this force no longer exists, and gravitation and other forces are free to act.

Although the repulsion due to heat and evaporation are not powerful enough to form a perfect protection to the lung surfaces against the contamination of dust, yet it is very evident that their protective influence will have a most important effect on the condition of our lungs, and one towards which I wish to direct the attention of those who make this organ a special study. There seems to be but little doubt that we have here an explanation of some of the effects of different climates. For instance, what a difference there must be in the amount of dust deposited on the lungs from air breathed at, say, St Moritz or Davos Platz, and at such places as Madeira or other similar health resorts! These remarks are altogether apart from the question of the amount of dust in the air at the different places, and refer only to the action of the lungs on the dust which may be present.* In the Alpine resorts the air is cold and dry, and the tidal air, which flows backwards and forwards through the bronchial tubes, is in the very best condition for preventing the dust coming into contact with their surfaces, as the difference in temperature between the air and the body is great, and the air is also capable of causing a rapid evaporation. Whereas, at such places as Madeira, where the air is hot and moist, the repelling forces are both at a minimum. The effects of these different conditions on the lungs seems well worth study.

In illustration of the protective influence of heat and moisture many experiments may be made, but the following is perhaps the easiest. Take an ordinary paraffin lamp, raise the flame till a very dense cloud of smoke rises from it. Over the lamp place a very tall metal chimney, to produce a quick current of air and also to cool it. Have ready two porous cylindrical jars (porous jars are used because they keep up a supply of water for evaporation), one jar filled with water slightly heated, and the other with cold water. Cover both jars with wet white paper. Now introduce the hot one into the top of the chimney, and leave the black wreaths of smoke to stream over it for say half a minute, then take it out and put in its place the cold one, and leave it for the same length of time. The result will be, the hot one will be quite clean, not a speck of soot on it, while the cold one is covered with soot. It is not, however, so black as a cold dry surface would be, as the slight evaporation from its surface tends to protect it.

We must not, however, suppose that the lung surfaces are so well protected as the paper in this experiment. In the lungs the currents are quicker, they do not flow over such uniform surfaces, and further, they pass round curves, so that in the lungs dust tends to deposit where the currents flow quickly where they strike on the concave side of curved passages and on projecting edges. Further, all dust which penetrates beyond the tidal air and gets into the residual air will ultimately fall on the surfaces of the tubes and air-

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* The amount of dust breathed by invalids at the two places will not be greatly different, as most of their time is spent in the house, and the air in the rooms at the two places will be nearly equally dusty. The higher temperature inside will slightly reduce the thermal effect, but will not diminish the rate of evaporation.

cells. This tendency of the dust in the residual air to settle is increased by the load of water deposited on it by the moist air.

The amount to which our lungs are protected by heat and evaporation can scarcely be solved in a physical laboratory, and will be best determined by anatomical examinations of lungs which have lived under different conditions of temperature and moisture.

A Thermic Filter.

Having observed that the dust particles tended to move away from hot bodies and to attach themselves to cold ones, I made some experiments on the subject to study the movements of dust particles when placed between hot and cold surfaces. Most interesting results were obtained by placing near the hot platinum wires, already referred to, a piece of glass or a plate of metal, and getting the dust deposited upon it. One arrangement of the experiment is to place the glass with its plane vertical and transversely over the wires, at such a height that its lower edge almost touches the wires, and fill the box with dust by blowing up some calcined magnesia or other fine powder. After all the currents have settled, and while the air is still full of dust, the electric current is turned on and the wire heated. A well-marked dark plane at once rises over the wire, and in its upward passage it is cut transversely by the glass plate. After the plate has been left for some time with the air current streaming over its surface, it is found to have a very beautiful impression of the dark plane imprinted on it. The warm air, in streaming upwards over the surface of the glass, deposited its dust on it, and the fact of there being no dust in the dark plane is recorded by a well-defined line of clear glass, the deposit of dust on each side of the clean line being thickest just along the edge, and thinning away on each side. These impressions of the dark plane may be made permanent by causing the dust to be deposited on a plate newly coated with black varnish, and used while the varnish is still soft.

It is not necessary to put anything on the surface of the glass to cause the dust to adhere, as it attaches itself to a clean surface of glass with considerable firmness, but some adhesive substance on the plate enables the impression to stand rougher treatment. Impressions of the dark plane have also been made with charcoal dust deposited on opal glass. These black impressions are, of course, "negatives" of the magnesia ones, the plane in the former case being white, surrounded by black dust. The charcoal dust was securely fixed by first coating the glass with a thin solution of gum, which was dried before the dust was deposited on it, and the dust fixed by breathing on the surface.

If in place of putting a plate vertically over the wires, we place two plates vertically—one at each side of the wire—we then get the dust deposited on the plates, thickest opposite to the wires and thinner higher up. Arrangements were made for studying the action of surfaces placed on both sides of the wires. Fixing the plates parallel to each other, and at a distance of 2 or 3 mm. apart, with the platinum wire between them, I carefully watched the motions of the particles carried up in the air current. As the particles approached the wires they gradually changed the direction of their motion, and instead of coming straight up they curved towards the sides, some of the particles striking and adhering to the side plates at a point below the wire. Some rose higher and stuck opposite to it, others went higher still, while others passed on to the top and escaped.

I had for some time been trying to arrange an experiment in which I should be able to watch the movements of the individual particles of dust, so as to see them moving away from the hot surface. My intention was to examine the movements of the particles with a microscope of low power, or with a powerful magnifying glass. My great difficulty, however, was to get the movements due to the convection currents sufficiently slow to enable me to follow the moving particles when much magnified. After making the experiment last described, I saw it was possible to arrange for this much-desired observation. The use of the large particles of magnesia enabled me to dispense with the microscope, and use only a magnifying glass of moderate power; and by bringing the plates on each side of the wire close together, the velocity of the upward convection current could be greatly reduced by the friction of these surfaces, and by their cooling effect on the gases. The two side plates of glass were accordingly brought closer together, to a distance of about 1 millimetre. Fig. 13 represents the arrangement magnified five times, the U-shaped wire being shown in section between the plates. The ascending current was now very slow, and no difficulty was experienced in following the movements of the individual particles, so I had at last the satisfaction of seeing the particles being repelled by the hot wire.

When the wire, heated to a red heat in air filled with magnesia dust, was examined by means of a magnifying glass, the spectacle which presented itself was most curious and interesting. At a distance below the wires, the particles could be seen coming straight up between the glass plates, but as they approached the wires they seemed to get uneasy, and as if wishing to avoid the heat, some of them attached themselves quickly to the glass, others went further up, but soon curved towards the sides and adhered to them; while others boldly advanced straight up, almost to the wires, when their motion was suddenly arrested and they were driven downwards and sideways, and attached themselves to the glass. If the wires were hot enough, not a single particle got past them, and the glass plates had each a patch of magnesian powder adhering to its surface *below* the level of the wires. The direction of movement of the particles is roughly indicated by the lines in fig. 13.

These experiments naturally suggested the possibility of constructing an air filter on thermic principles. They showed that the visible particles of dust could be thrown out of the air, as the particles tended to move from the hot parts, and to attach themselves to cold surfaces. But the question which naturally suggested itself was, Are the very small invisible particles also arrested? If the thermic filter turned out to be a success, it appeared to me it would also be the best way to get an answer to this question. In order to filter air on thermic principles, all that appeared necessary was to pass the air through a space or channel, the two sides of which were kept at different temperatures. In this way I hoped the dust would be driven from the hot side and attach itself to the cold one. Practically to carry out this idea, the simplest method that suggested itself was to pass the air through the space between two concentric tubes, the one tube being kept hot, and the other cold. In the preliminary instruments which have been made, the distance between the tubes forming the space through which the air passes, is in one instrument less than 1 mm., but in other instruments this space is nearly as much as 3 mm. The length of the passage in the different instruments is about 35 cm. One of these instruments has the outer tube jacketed by means of a larger pipe for the purpose of heating it with steam. The other instruments were heated simply by means of a gas flame. The filter is shown in section, fig. 14. A is a tube about 13 mm. diameter. B is another tube slightly larger, and allowing a space C, between the two for the passage of the air to be filtered, which enters and leaves by the tubes D, D. The outer tube E forms a steam jacket round B. F, F are pipes for steam entering, and for condensed water leaving the jacket. The pipe A is kept cold by means of a stream of water. In working the instrument it is not, however, necessary to keep to this arrangement; steam may be admitted to the centre tube A, and cold water to the outside jacket; both arrangements do equally well. For the purpose of cleaning and examining the surfaces of the air channel, the centre tube was not permanently fixed in its place, but was so arranged that it could be easily taken out, and the joints were made tight by means of the short pieces of india-rubber tube H, H. The air, after passing through the space C, was conveyed by means of a tube to a glass flask, in which there was a little water. The flask in turn was connected by means of another tube to an air-pump, in order to test the condition of the air after passing through the instrument. If cloudy condensation is produced when the pressure is reduced in the flask, we know that the air is not filtered; and, on the other hand, if the air remains perfectly clear on exhausting, we know that no dust, not even the invisible particles, have passed into it.

The apparatus was fitted up for trial, all the connections being made and tested. Using the instrument heated with flame, the first effect of the heat, as expected, was a great increase in the fogging. The temperature was raised as high as it safely could be, to cleanse the instrument thoroughly; after which, as we know, it will cease to give off nuclei at a lower temperature. When the tube was thoroughly cleansed by means of heat, and all the impurities swept out of it by a current of air, the temperature was lowered slightly, and the air allowed to pass slowly through the tube on its way to the test-flask. After this, the fogging in the flask gradually diminished, and after passing through the rainy stage, it ceased entirely, proving that the filter was doing its work thoroughly, not a single particle—not even one of the very minute and invisible ones—escaping it. On equalising the temperature, either making both tubes hot or both cold, the filtering action of course ceased.

It does seem somewhat strange that air should be freed from all its dust in passing through a channel large enough for a fly to pass, if it has sufficient intelligence to keep always on the cold side. All who have experimented on this subject know that dust can get through any opening, however small. On testing this filter for the first time, I failed to get a satisfactory result. I however felt convinced that it ought to work, and the failure was attributed to some imperfection in the tubing or joints. Arrangements were therefore made for testing the tightness of the whole apparatus. The one end of the filter being connected, as described, to the glass flask in which the air was tested, I now connected a cotton-wool filter to the other end of the thermic filter, and proceeded to test if all was tight, by drawing in air from the cotton-wool filter through the apparatus, while it was cold. At first, I could not succeed in getting air free from dust; fogging always took place on reducing the pressure in the flask, showing that dusty air was leaking in somewhere, and mixing with the filtered air. After much time spent in remaking all the joints, it was discovered that the air-pump valve was not quite tight; by allowing the leakage to bubble through the water in the flask, it was found to be very slight, only about 2 or 3 c.cm. per minute. After this was put right, fogging still appeared, showing that there was still leakage. This time it was traced to the stop-cock between the filter and the test-flask. This leakage was smaller than the other, yet it let in dust. After all leakages had been stopped, the cotton-wool filter was removed, and the thermic filter being heated, was now found to do its work satisfactorily, though more slowly than a cotton-wool filter. The ease with which dust passes through small openings is surprising; indeed, I have found that any opening which admits air, also allows these less than microscopic particles to pass, and yet the air in its passage through the wide channel of this filter had every particle of dust taken out of it by the thermal conditions to which it was subjected.

If we cause the filter to purify air into which we have intentionally put a good deal of dust, such as dust of calcined magnesia, we find all the dust collected on the surface of the cold tube, near the end where the air entered, while the hot tube is quite clean. If we send the smoke of a cigar through the filter, nothing but perfectly transparent gases come out at the other end. The effect of coating the cold surface with glycerine has been tried, as it seemed possible that the dust deposited on the clean surface might be carried on by the air current. The dust, however, seems to be firmly held on a cold clean surface, and no decided improvement was got by the addition of the glycerine. No accurate experiments have been made to determine the best size of the filtering channel. The filters with very narrow passages and those with much wider ones all work well, but no quantitative experiments have been made as to their relative values.

It is not easy to determine what influence difference of temperature has on the action of a cotton-wool filter. Heating the cotton-wool has little effect in reducing its filtering powers. We might expect this, as the cotton and the air passing through it rapidly acquire the same temperature; and it is extremely difficult to say how much of the action of this filter depends on the slight differences of temperature produced by the air in passing through the cotton.

Diffusion Effects.

I shall now describe two experiments on diffusion, which were made in the hope they would throw some light on this repelling action of hot bodies. For this purpose a tube similar to those used in the previous experiments was taken, and an opening made in the side of it, at the front end. Into this opening was fitted a thin plug of plaster of paris. The surface of the plug was made flat, and when put in the dust-box was placed vertically, as in the experiments on the heat effect, to get rid of the distribution due to gravitation. This diffusion diaphragm was blackened, to enable the effect to be better observed, as a white surface reflects so much light, it makes it difficult to see what is taking place.

After the diffusion apparatus was fitted in its place, the dust-box was filled with sulphate dust, and left till everything had acquired the same temperature. Carbonic acid gas was then introduced into the tube. At once a downward current was produced in front of the diaphragm, the dust particles kept close up to its surface, and if there was any tendency to the formation of a clear space the carbonic acid at once closed it. The apparatus for supplying the carbonic acid gas was then removed, and a small pipe connected with the gas pipes was then led into the diffusion tube, so as to get the effect due to the diffusion of gases lighter than air. The effect in this case was the opposite of that given by the carbonic acid. An upward current at once started, and a thin clear space formed in front of the diffusion diaphragm. These experiments prove *that the dust particles move in the direction in which the greatest rate of diffusion takes place.* This at first sight looks very self-evident; but we must remember that in front of the diffusion diaphragm, when hydrogen is coming through it, that the ascending clear space is not composed entirely of the lighter gas which has come through the diaphragm. In that clear space the larger proportion of the molecules are air molecules; and while the air molecules advance up to and pass through the diaphragm, the dust particles are driven away from it. I shall presently have to refer to this.

When speaking of the action of heat and moisture in protecting the lung surfaces from contact with the suspended dust in our atmosphere, no mention was made of this diffusion effect, as it can be better considered here. In our lungs the small quantity of tidal air, which flows backwards and forwards, carrying in the oxygen, and out the carbonic acid, never gets further than the main bronchial tubes, and does not penetrate to the air-cells; the carbonic acid, set free into the residual air in these cells, is carried outwards to the tidal air by diffusion, and at the same time oxygen is diffused from the tidal air towards the residual air. Now, what is the effect of this diffusion on the distribution of the dust? We have seen that in diffusion through a porous diaphragm the dust moved towards the carbonic acid. If this was the case in our lungs, then the dust would tend to penetrate towards the air-cells and come into contact with their surfaces. In our lungs the exchange between the carbonic acid and the oxygen does not, however, follow the law of diffusion through a porous diaphragm, but those of osmose; and the rate of passage of these gases through the lung surfaces does not depend upon their relative densities, but on much more complicated conditions, of which solubility is in this case one of the principal. The result is, that in our lungs for every volume of oxygen that passes inwards, exactly or almost exactly one volume of carbonic acid passes outwards. These diffusion effects balance each other, and the result is that diffusion has no tendency to cause dust to penetrate towards the air-cells, or to adhere to the surfaces of our lungs.

Repulsion due to Heat.

We shall now consider the cause of the repulsion of the dust particles by hot bodies, and see if we can make out the mechanism by which the particles are driven away. This is a subject of considerable difficulty, and one on which I fear there will be much difference of opinion, and I shall simply state here what appears to me at present to be the cause of the particles moving away from a hot and towards a cold surface. The simplest explanation, and the one which offered itself first, was that possibly it might be a radiation effect, and that the particles are repelled in the same way as the vanes of a Crookes' radiometer by the reaction of the heated gas molecules in the way explained by Professors TAIT and DEWAR. We might suppose the side of the particles next the hot surface to be warmed by radiation, and the gaseous molecules on that side getting heated by contact, would rebound from it with greater velocity than those on the other side, the dust particles being thus driven away in a sort of rocket fashion. On examination, however, this explanation does not appear satisfactory; because the particles are so very near the hot surface that they will not be heated principally by radiation, but by contact with the hot gases near the heating surface, radiation having but a slight effect.

So far as I have been able to form a mental picture of the mechanism of this repulsion, it seems to be produced in the following way:—First, let us go back to the diffusion experiments. We saw that when hydrogen was diffused into air, a clear space was formed over the diffusing surface. Now why was this? The air molecules were moving towards the diaphragm and passing through it, yet they did not carry any dust particles with them. The reason seems to be this. In the air in front of the diaphragm there are two currents of molecules—one of hydrogen, moving outwards from the diaphragm, and one of air, moving inwards; but as the hydrogen current is the stronger, it carries the dust particles along with it, and the difference in the strength of these two currents in this case gives rise to a thin clear space over the diffusing surface.

Let us now apply the same reasoning to the heat effect. When we remember that hot and cold gases tend to diffuse into each other, the explanation given does not require to be greatly altered. The molecules of air on the surface of the hot body get heated by contact, and these molecules tend to diffuse themselves outwards into the colder molecules. In imagination, let us look at a section of the air close to the hot body. The air there is no longer homogeneous. Some of the particles have more kinetic energy than others. Those molecules with the greatest kinetic energy have the greatest amount of their motion in a direction away from the hot surface, while the cold ones have the greater amount of their motion in a direction towards the hot surface. Now what will happen to any particle of matter hung among these heterogeneous molecules? The side of the particle next the hot body will be bombarded by a larger proportion of hot molecules than the other side, and the result will be to drive the particle away from the hot body. It may be objected that, as the air pressure is the same on the front and back of the particles, therefore the total energy of the molecules on the front and on the back must be the same, and therefore there will be no tendency to cause the particles to move. I think, however, this does not correctly represent the case. Near the heating surface the hot molecules are moving outwards and the cold ones inwards. If there were more cold ones moving inwards than hot ones outwards, so that the total energy of the inward moving ones was equal to the total energy of the outward moving ones, which would be necessary in order that the pressures might be equal, then no motion would be produced in the dust particles. We must, however, remember that there are exactly the same number of molecules moving each way. One effect of the hot surface seems to be to differentiate the movements of the molecules, causing the greater amount of the movement of the hot ones to be outward and of the cold ones inward, and the outward moving molecules, having the greater kinetic energy, exert a greater pressure on the dust particles and drive them outwards. In the hydrogen diffusion effect the particles of dust were driven away, because a greater number of hydrogen molecules were moving one way than air ones the other. In the heat effect they are driven away, because the molecules moving *from* the hot surface have a greater kinetic energy than those moving towards it, and the particles are bombarded on the one side by a greater number of hot molecules than on the other.

We have the same effect intensified when the hot surface is wet. When this is the case, the vapour molecules diffusing outwards carry with them the dust particles to a much greater distance than the heat alone, as there is no inward current of vapour molecules to contend with the outward one, and tending to drive the dust particles inward; the result is, we get a dark plane at least twice as thick with heat and vapour as with heat alone. Of the two, the vapour seems to be the more powerful, as very little heat with moisture gives a thicker dark plane than double the heat would do. If we carefully fix the experimental test surface in a vertical position and simply wet it, the effect is to cool it by evaporation, and a downward current is produced; but, at the same time, a clear space is formed, showing that in this case the outward effect of the vapour is greater than the inward effect of the cold.

There seemed to be a possibility of getting an answer by experiment as to whether the radiation or the diffusion theory is the correct one. If radiation is the cause of the repulsion, then we should expect that a good radiator would cause the particles to be driven further away, and thus cause a thicker dark plane than a bad radiator. For the purpose of testing this, another experimental flat test-surface was prepared. This test-surface was made of silver and highly polished. One-half of it was then covered with lamp-black. After the test-surface was fixed in the dust-box heat was applied to it, and the thickness of the clear space over the two halves of the test-surface carefully noted. To do this, the dust-box was so arranged that I could look down the test-surface—not across it as usual—and could thus see down the boundary line between the dark plane over the polished surface and over the lamp-black. The result was, not the slightest difference could be detected between the two. The boundary line of the dark space in front of the plate was a straight line parallel to the surface of the plate. This experiment, while it gives no support to the diffusion theory, shows us that radiation is not the principal cause of the dark plane.

If the explanation here given of the repulsion of the dust by a hot surface is correct, then this effect is not produced in the same way as the repulsion of the discs of a Crookes' radiometer when heat is falling on them, but is similar to the repulsion of the discs by a hot surface placed *inside* the radiometer bulb, as in the apparatus described by Mr CROOKES in *Nature*, vol. xv. p. 301. In this radiometer the vanes were made of very clear mica, and they did not rotate when light fell on them. Inside the bulb, and just clear of the discs, was fixed in a vertical plane a blackened plate of mica. When the light was allowed to fall on this fixed and black plate, the vanes instantly rotated as if a wind were issuing from this surface. The energy which causes the repulsion of the dust and of the discs of this radiometer is transferred in both cases from the hot surface to the repelled surface by the kinetic energy of the gas molecules, and not by radiation.

Another consideration which indicates that the force causing the movement of the dust is not transferred by radiation is the well-known fact that radiant heat is not much intercepted by dust. When we concentrate a strong beam of light and heat in dusty air by means of a lens, perhaps one of the things which strikes us most is the very slight heating effect which is developed at the focus. The dust is not destroyed, and no rapid upward current is formed. But if we place a piece of paper at the same focus it is at once charred, and a rapid current of air rises from its heated surface.

The rate at which vapour molecules diffuse under the conditions existing in the experiments is very great, and seems to be quite sufficient to account for the results. Take, for instance, the water molecules when they pass into vapour. Vapour molecules are selected because we can follow their movements. In a small fraction of a second they diffuse to a distance of nearly 1 cm. This can be seen in the experiment described with the flat test-surface when moistened. With a slight rise of temperature, fog particles are seen forming in the current, rising in front of the wet surface. Even at the lower edge of the plate these particles are seen at some distance from the plate, and separated from it by a dark space, showing that even at that point the vapour molecules have already diffused outwards to a distance and far beyond the dark space, while probably other molecules have gone further than the fog boundary, but are under conditions which keep them in the state of vapour.

Or take the reverse of this diffusion process, seen in the evaporation of fog particles. Let us blow some steam into the dust-box, so as to form a regular fog, but without adding any dust. Into this fog introduce a piece of very dry wood; if it is charred so much the better, as its blackness enables us to see more easily what is taking place. It will be observed that there is formed all round the wood a clear space, in which not a particle of fog can be seen. If we watch the air currents we shall see the particles approaching, but vanishing at some distance from the wood, and over the wood the particles will be seen falling into the clear space and disappearing. This clear space is caused by the wood absorbing the vapour in the air near it, thus surrounding itself with a space of dry air, into which the fog particles evaporate as they approach, and so rapid is the diffusion towards the wood that the air is kept dry enough to evaporate the particles as quickly as they approach.

Attraction Due to Cold.

To explain the attraction of the dust particles by cold surfaces, we have only to reverse the explanation given of the repulsion due to heat. At the cold surface the outward moving molecules of air have less kinetic energy than the warmer inward moving ones, and the dust is thus driven towards the cold surface by the greater energy of the hot molecules.

This explanation of the action of hot and cold surfaces may not at first sight seem satisfactorily to account for the peculiar movements of the dust particles as they approached the hot wire, in the experiment shown in fig. 13. We might here ask ourselves, for instance, Why were some of the particles carried close to the wire, and then driven away from it? The inertia of the particles is clearly not sufficient to cause them to advance against the force which produced their rapid repulsion. Then why did they approach so close to the wire, and then appear driven away with such violence? It looks as if the particles had become heated to a temperature sufficient to drive off their occluded gases and condensed vapours, and that the repulsion in this case was due to the rapid escape of these gases and vapours. No doubt, something will be due to their escape, but I do not think it is the principal cause of the repulsion, because the particles are so small, the gases and vapours will escape from their surfaces all round them, and their effects will therefore nearly balance. Further, the escape of these gases will not explain why the particles were always driven towards cold surfaces. The following seems to be the principal reason why the particles are always driven sideways and not downwards. The rate at which a particle of dust will be repelled from the surface of a body is not necessarily the same in all directions round the body, but will depend on the closeness of the isothermal lines at the different places; and as in the experiment the temperature varies very much more rapidly towards the cold glass at the sides than it does downwards, the result is, a more powerful impulse is given sideways than downwards; and further, the cold glass surfaces differentiate the molecular movements near them, and cause an attraction.

Let me illustrate this point further, and show by a parallel case in the action of gravitation, why it is that the particles of dust when repelled move towards the side, and not downwards. Suppose there is a very long, but narrow and regularly shaped mountain, with its highest point near the middle, and the sides sloping regularly and quickly to the summit, while the ridge descends slowly. In ascending such a mountain, we can either go up the long easy slope of the ridge, or up the steep sides. Now, suppose a stone to be rolled up the ridge of this mountain, by a force acting in a direction along the ridge, it is evident that if the stone gets off the ridge, that it will fall down the quicker slope towards the side; and if the stone keeps the ridge, and we succeed in rolling it nearly to the summit, but there meet a slope too steep for us to push the stone up, then the stone will obviously be in a position of unstable equilibrium, and the slightest fall will cause it to leave the easy slope of the ridge, and, once started on the quick descent of the sides, its motion will be rapidly accelerated in a direction at right angles to that in which we are pushing; thus the stone will descend the quick slope of the side with great velocity, even while the force which pushed it up the ridge is still acting on it. The direction in which the force now acts on the stone is such that it no longer tends to prevent it falling; and further, supposing it was directly opposed to its motion, it would have but little effect against the steep slope of the side. Now draw the contour lines of this mountain. It will be found that they exactly correspond to the isothermal lines round the hot wire placed between the cold plates. The dust and the stone each fall towards the side, because that is the direction of steepest slope.

General Remarks.

This tendency which the dust in our atmosphere has to move away from hot bodies, and attach itself to cold ones, will, I have no doubt, help to explain many phenomena which are not at present well understood. No doubt, many things will suggest themselves to different minds as receiving their explanation in this somewhat curious liking of dust for lodging in cold places. Among other things, it explains the reason why stove and hot-air heated rooms are always so much dirtier than those warmed by open fires. In a stove-heated room the air is warmer than the walls and than the objects in the room, the dust therefore tends to leave the air, and to deposit itself on every object colder than itself in the room; whereas, in a room warmed with an open fire, the heating being principally done by radiation, the walls and furniture are hotter than the air, they therefore tend to throw off the dust, and even when it does fall on them, it does not adhere with that firmness with which it does to a cold surface, and any breath of air easily removes it.

Diffusion also, no doubt, plays some part in determining whether dust shall or shall not adhere to the walls and ceilings of rooms.

Again, a knowledge of this tendency of dust to settle on cold surfaces is necessary to enable us fully to explain why so much soot adheres to the inside surfaces of chimneys. If the smoke were cold, so much soot would not settle in the chimneys, nor would it adhere so firmly.

A simple experiment to illustrate this tendency of dust to leave warm, and to settle on cold surfaces, is made in the following way:—Take two narrow strips of glass mirror, any substance will do, but the mirror surface shows the result best. Arrange so as to hold these strips of glass face to face, and with their surfaces at a distance of a few millimetres, but before putting them in their places, heat one of them to a temperature of say 100° C. Have ready a tall glass vessel, large enough for the glass strips to enter freely. Now fill this vessel with some dust, by burning sodium or magnesium, or by shaking up some calcined magnesia or other powder. By the time the air in the vessel is settled and cooled, but before the dust settles, have ready the glass strips, one of them hot as directed, and placed in front of the other, face to face, with an air space between. Now put the mirrors into the vessel among the dust. After a minute or so examine them. The following will be the result. The hot one will be quite clean, while the cold one will be white with dust. That the dust has no tendency to settle on the cold one, may be proved by putting at the same time in the vessel another cold strip some distance from the hot one, when it will be seen that this one is almost entirely free from dust, depending upon whether it was a little hotter or colder than the dusty air.

When one looks at the enormous amount of dust deposited on the cold mirror in this experiment, we cannot help associating the result in some way with the condensation of vapours, and it takes some time before we can arrange our ideas and realise that the thick white deposit was truly thrown out of suspension and settled on the mirror in the solid state, and was not in the state of vapour before coming into contact with the cold glass.

A somewhat curious experiment may be made with light calcined magnesia powder, which shows the action of this force in a marked way. The magnesia is heated to a good red heat in an iron vessel. If we now take a metal rod 5 or 10 mm. diameter and heat it as hot as the powder. We may then dip in into the powder, and stir it as much as we please, but on taking the rod out, it will be found to be quite clean. But if the rod is cold, it comes out of the powder with a club-shaped mass of magnesia adhering to it, so thick that the magnesia-coated end is twice as thick as the rod itself. If the rod is kept in the hot powder for a short time, and then taken out, with its coating of powder adhering to it, whenever the powder gets outside the hot vessel, and exposed to the cold, it falls away, as the inside of the powder is now hotter than the outside.

Most of us have noticed when heating powders, particularly if they are light, that while they are heating they take on a peculiar semi-fluid appearance if stirred, or if the vessel is tilted back and forwards. This I have always supposed was due to the escape of occluded gases from the powder, keeping it in a state of semi-suspension. Now, however, I think this peculiar effect is a result of the repulsion due to heating. My reason for supposing this is, that if after the powder is heated it is cooled quickly, and again heated before there is time for it to absorb gases, the same semi-fluid appearance is again produced while heating. Further, if the powder, instead of being heated in a closed vessel, is placed in a cup, so that the under side of the powder is kept hot, while the top is cooled by radiation, so long as these conditions are kept up the powder retains its fluid-like properties, moving about on the slightest tilting of the cup, and conducting itself in a way very suggestive of the spheroidal condition, but without any generation of vapour to give rise to the irregular movements seen in liquids. It seems possible that something of the spheroidal condition may receive its explanation in this repulsion between hot and cold surfaces. This repulsion may be illustrated by placing a hot and a cold surface together. A piece of cold glass, for instance, slides about in a remarkably easy way on a hot surface of glass.

Many practical applications of this attraction and repulsion will no doubt be found. It might be easily applied to the condensation of those fumes from chemical works which at present are allowed to pollute the air. But perhaps the application of most general interest would be towards the prevention of smoke, or rather the prevention of the escape of smoke into the atmosphere. Whatever interest, however, it may have in this way, it is clear it can never meet with general adoption, save under compulsion, as it will effect no saving in fuel, such as would result from more perfect forms of combustion.

I have, however, made some experiments in this direction, and find that by placing a tall metal chimney over a very smoky paraffin lamp, surrounding this chimney with another tube slightly larger, and causing the products of combustion to rise up the centre tube, and descend through the annular space between the two tubes, the soot is all taken out, and nothing but a white vapour is seen escaping. On examining the tubes after they have been in use some time, the inside surface of the inner one is found to be slightly coated with soot, while its outer surface is perfectly clean and bright, not a speck of dust on it, and the inside of the outer tube, which is only a short distance from it, is thickly coated with soot. This arrangement, however, is too complicated, save for special purposes.

It has been already stated that the reason why so much soot collects in chimneys is that the gases are hotter than the sides of the chimney. In cases where the gases are allowed to escape at a high temperature advantage might be taken of this tendency. If we simply cooled the smoke in the presence of plenty of depositing surface, much of its soot would be trapped out, and the escaping smoke made less dense. The amount that might be trapped in this way will depend on the extent to which the gases could be cooled.

For works with large chimneys this plan evidently could not be adopted, and in their case the purification would require to be down at the bottom of the chimney. The evident objection to this is, that as the gases are cooled in the depositer, the draught in the chimney will be destroyed. This, however, can be avoided by the use of "regenerators." The impure air would be led to a cold regenerator, where it would be cooled and its impurities deposited; and when purified it would be led through another chamber, where it would be heated before being sent up the chimney. This arrangement would not require heat to be spent in working it, as the process would be reversed, and by simply reversing the direction of currents from time to time the heat stored up in cooling would be used for heating the purified gases before being sent up the chimney. This purifying process by heating and cooling would require to be done a number of times, and the air sent through a succession of regenerators before it could be made perfectly pure.

Fig. 1

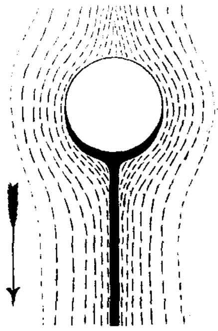

Fig. 2

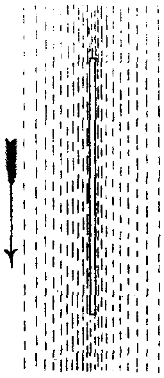

Fig. 3

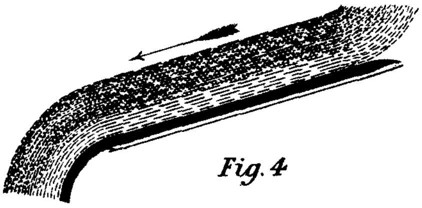

Fig. 4

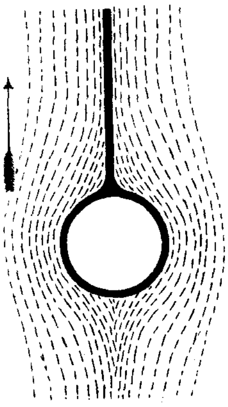

Fig. 5

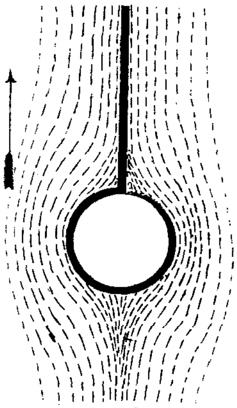

Fig. 6

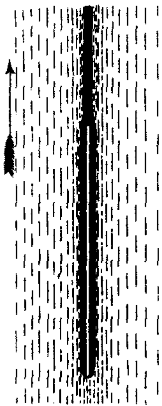

Fig. 7

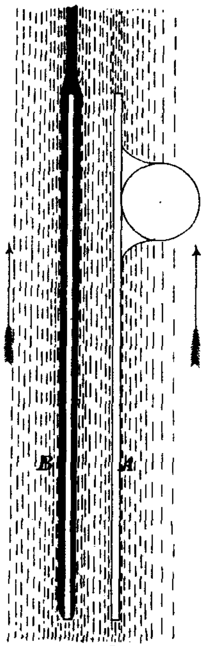

Fig. 8

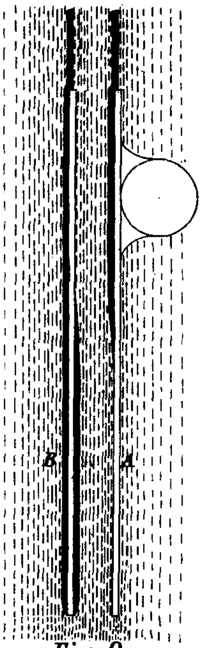

Fig. 9

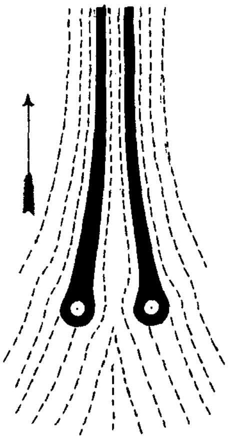

Fig. 10

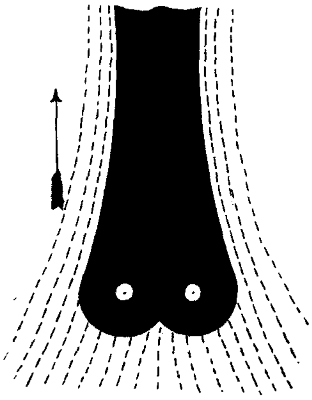

Fig. 11

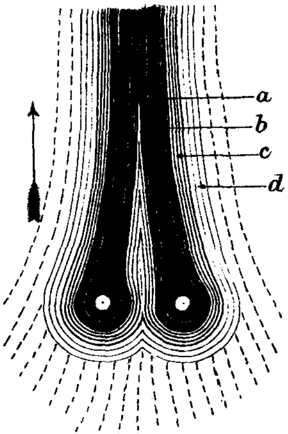

Fig. 12

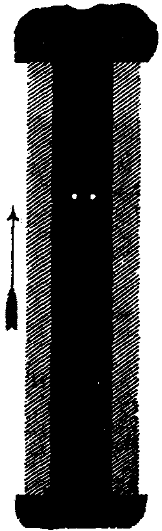

Fig. 13

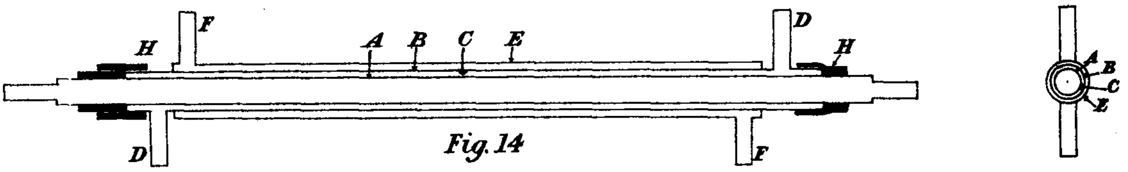

Fig. 14

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