ON ELECTRIC SPARK PHOTOGRAPHS; OR, PHOTOGRAPHY OF FLYING BULLETS, &c., BY THE LIGHT OF THE ELECTRIC SPARK.[1]

II.

GOING back now to the photographs, the next one was taken with the view of illustrating the effect on the inclination of the waves of the velocity of the bullet. In this case the bullet was aluminium; it was only one-seventh the weight of the regulation bullet. In consequence of its lightness it travelled about half as fast again as the ordinary bullet (not $\sqrt{7}$ times as fast as it would have done if the pressure of the powder-gases had been the same in the two cases), and in consequence of the higher speed the inclination of the waves is still greater than in the previous case. Further, in this case the bullet was made to pierce a piece of card shortly before it was photographed. The little pieces that were cut out were driven forward at a high speed, but, being lighter than the bullet, they soon lost a large part of their velocity; they had in consequence lagged behind when they were photographed, but though travelling more slowly (they were still going at more than 1100 feet a second) they yet made each its own air wave, which became less and less inclined as the bits lagged more and more behind; each, moreover, produced its own trail of vortices like that following the bullet. The well-known fact that moving things tend to take the position of greatest resistance, to avoid the effect of which the bullet has to be made to spin, is also illustrated in the photograph. The little pieces that are large enough to be clearly seen are moving broadside on, and not edgeways, as might be expected.

In order to illustrate the other fact that the angle of the waves also depends on the velocity of sound in the gas, I filled the box with a mixture of carbonic acid gas, and the vapour of ether, a mixture which is very dense, and through which sound in consequence travels only about half as fast as it does in air, and which will not explode or even catch fire when an electric spark is made within it, or directly act injuriously upon the photographic plate. The increased inclination of the waves is very evident in Fig. 10.

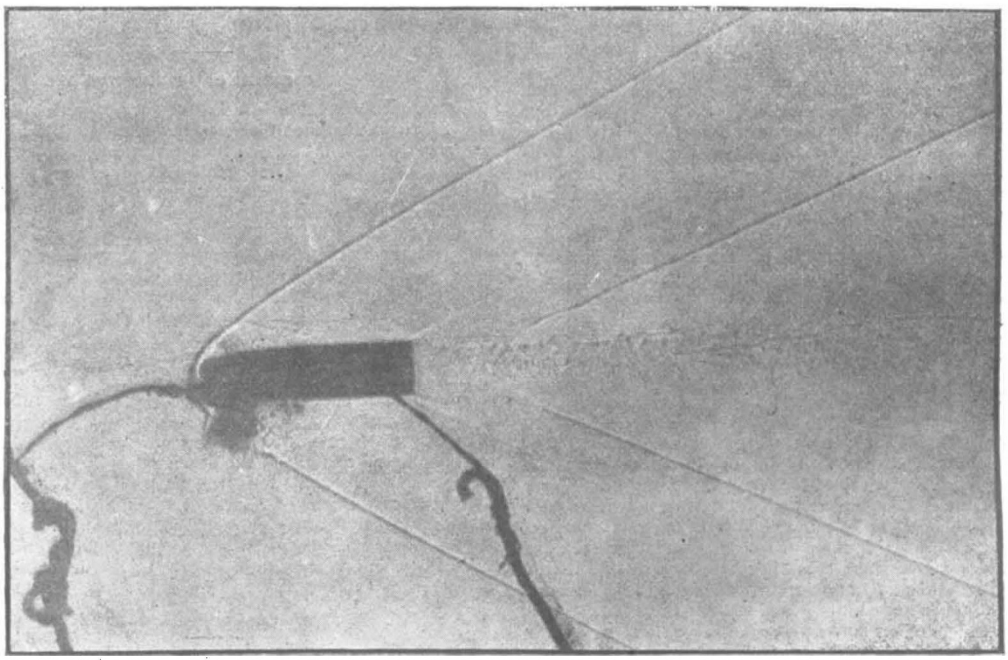

FIG. 10.

These waves, revealed by photography, have a very important effect on the flight of projectiles. Just as in the case of waves produced by the motion of a ship, which, as is well known, become enormously more energetic as the velocity increases, and which at high velocities produce as a matter of fact an effect of resistance to the motion of the ship of far greater importance than the skin friction, so in the case of the air waves produced by bullets; in its flight the resistance which the bullet meets with increases very rapidly when the velocity is raised beyond the point at which these waves begin to be formed. This being the case, I have thought it might be interesting to see whether the analogy between the behaviour of the two classes of waves might be even nearer than has already appeared, and on turning to the beautiful researches of Mr. Scott Russell, published in the Report of the British Association for the year 1844, in which he gives a very full report on water waves and their properties, I found that he had made experiments and had given a diagram showing what happens when a solitary wave meets a vertical wall. The wave, as would be expected, is, under ordinary conditions, reflected perfectly, making an angle of reflection equal to the angle of incidence, and the reflected and incident waves are alike in all respects. This continues to be the case as the angle gets more and more nearly equal to a right angle, *i.e.* until the wave front, nearly perpendicular to the wall, runs along nearly parallel to it. It then at last ceases to be reflected at all. The part of the wave near the wall instead gathers strength, it gets higher, it therefore travels faster, and so causes the wave near the wall to run ahead of its proper position, producing a bend in the wave front, and this goes on until at last the wave near the wall becomes a breaker.

In order to see if anything similar happens in the case

[1] Lecture delivered at the Edinburgh meeting of the British Association by C. V. Boys, F.R.S. Continued from page 421.

of air waves, I arranged the three reflecting surfaces of sheet copper seen in Fig. 11, and photographed a magazine rifle bullet when it had got to the position seen. Below the bullet two waves strike the reflector at a low angle, and they are perfectly reflected, the dark and the light lines changing places as they obviously ought to do. The left side of the V-shaped reflector was met at a nearly grazing incidence; there there is no reflection, but, as is clear on the photograph, the wave near the reflector is of greater intensity, it has bent itself ahead of its proper position as the water wave was found to do, but it cannot form a breaker, as there is no such thing in an air wave. The same photograph shows two other phenomena which are of interest. The stern wave has a piece cut out of it by the lower reflector, and bent up at the same angle. Now if a wave was a mere advancing thing the end of the bent-up piece would leave off suddenly, and the break in the direct wave would do the same. But according to the view of wave propagation put forward by Huygens, the wave at any epoque is the resultant of all the disturbances which may be considered to have started from all points of the wave front at any preceding epoque. The reflector, where it has cut this wave, may be considered as a series of points of disturbance arranged continuously in a line, each, however, coming into operation just after the neighbour on one side and just before the neighbour on the other. The reflected wave is the envelope of a series of spheres beginning with a point at the place where the wave and the reflector cut, growing up to a finite sphere about the end of the reflector as a centre; beyond this there are no more centres of disturbance, the envelope of all the spheres projected upon the plate, that is, the photograph of the reflected wave, is not therefore a straight line leaving off abruptly, but it curls round, as is very clearly shown, dying gradually away to nothing. The same is the case, but it is less marked, at the end of the direct wave near the part that has been cut out.

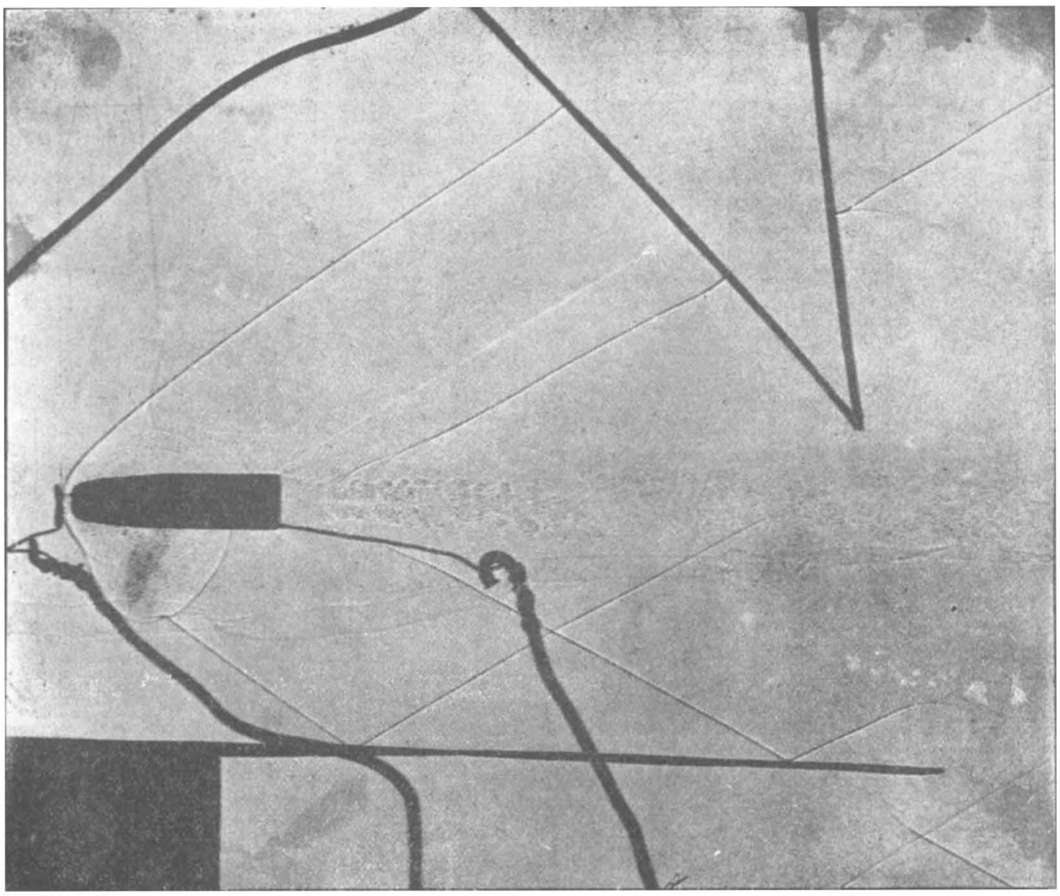

FIG. 11.

The other point to which I would refer is the dark line between the nose of the bullet and the wire placed to receive it. This is the feeble spark due to the discharge of the small condenser which clearly must have been on the point of going off of its own accord. The feeble spark precedes—or is to all intents and purposes simultaneous with, it cannot follow—the main spark which makes the photograph. The feeble spark heated the air, and the light from the main spark coming through this line of heated air was dispersed, leaving a clear black shadow on the plate. One spark casts a shadow of the other. Now it is evident that if the spark at the nose of the bullet had followed instead of having preceded the main spark by even so much as a three-hundred-millionth of a second, the time that light took to travel from one to the other, it would not have been able to cast a shadow. We have the means of telling, therefore, which of two sparks actually took place first, or perhaps the order of several, even though the difference of time is so minute. Perhaps this method might be of some use in researches now attracting so much interest in connection with the propagation of electrical waves.

On returning to the non-reflection of the air wave in the upper part of the figure we have here, I imagine, optical evidence of what goes on in a whispering gallery. The sound is probably not reflected at all, but runs round almost on the surface of the wall from one part to another.

We are now in a position to see how the reflection or non-reflection of air waves produced by a passing bullet, when they meet with some solid body, may produce a practical result which might be of importance in some cases. Suppose a bullet to be passing near and parallel to a wall. Then if the velocity of the bullet and its distance from the wall are such that the head wave meets the wall at an angle at which it can be reflected, especially, as in the case of Fig. 11, if the reflected ray can only return into the path of the bullet after it has gone, then no influence whatever can be exerted upon the bullet by its proximity to the wall. If, however, the head wave would, if undisturbed, meet the wall at such an angle that it could not be reflected, as for instance, in Fig. 12, when the head wave can be reflected by neither of the walls between which the bullet is passing, obviously the wave will become stronger and the resistance which it offers will, I imagine, become greater, and if in this case the upper plate be removed this extra resistance will be one-sided and must tend to deflect the bullet. This is quite distinct from the well-known effect of a bayonet upon the path of a bullet; when a bayonet is fixed the rush of powder gases between the bullet and the bayonet is quite sufficient to account for the deflection which every practised marksman allows for.

I have devised a method by which a problem of some difficulty, about which authorities are, I believe, by no means in accord, may be solved with a fair degree of certainty. The problem is this, to find what proportion of the velocity of a bullet is given to it after it has left the barrel, or, what comes to the same thing, to find the position in front of the barrel at which the speed is a maximum. The cause of this is evident. When the bullet has left the muzzle the imprisoned powder gases, under enormous pressure, rush out, making a draught past the bullet of the most tremendous intensity tending obviously to drive it forward. While this draught does most assuredly hurry the bullet on its forward course, it does not tend to make it spin round any faster. Now if the bullet were not hurried on at all after it left the muzzle it would, travelling as in a screw of the same pitch all the way from the breach of the rifle up to the point at which it is photographed, have turned round a certain number of times which depend upon the distance travelled and the pitch of the screw. If, however, the longitudinal motion is hurried and the rotational is left unaltered the pitch will be lengthened outside the barrel and the rotation will have been less for any position than it would have been if the bullet had not been accelerated in this way. If, therefore, we can find to what extent the bullet has turned actually at the place at which it has been photographed, we can find the apparent rotational lag and so working backwards get a measure of the velocity acquired after leaving the muzzle. In order to accomplish this I drilled a series of holes transversely through the bullet, each one at an angle to the previous one, the whole series being such that to whatever extent the bullet had twisted, one at least, and perhaps two, would allow the light of the spark to shine through it upon the photographic plate. Then from the photograph it is easy to see through which hole the light shone, and knowing in what position this was in the breach, it is easy to find what fraction of half a turn over or above any whole number of half turns the bullet has twisted. Strictly the measure should be made at different distances to eliminate all uncertainty, but the only shot I have taken was sufficient to show that there was a rotational lag equivalent, according to the measure made by Mr. Barton, to something under a two per cent. acceleration outside the barrel. I do not attach any importance to this figure; the experiment was made with a view to see if the method was practicable and this it certainly is. I would recommend, where accuracy is required, that having found as above about how much the

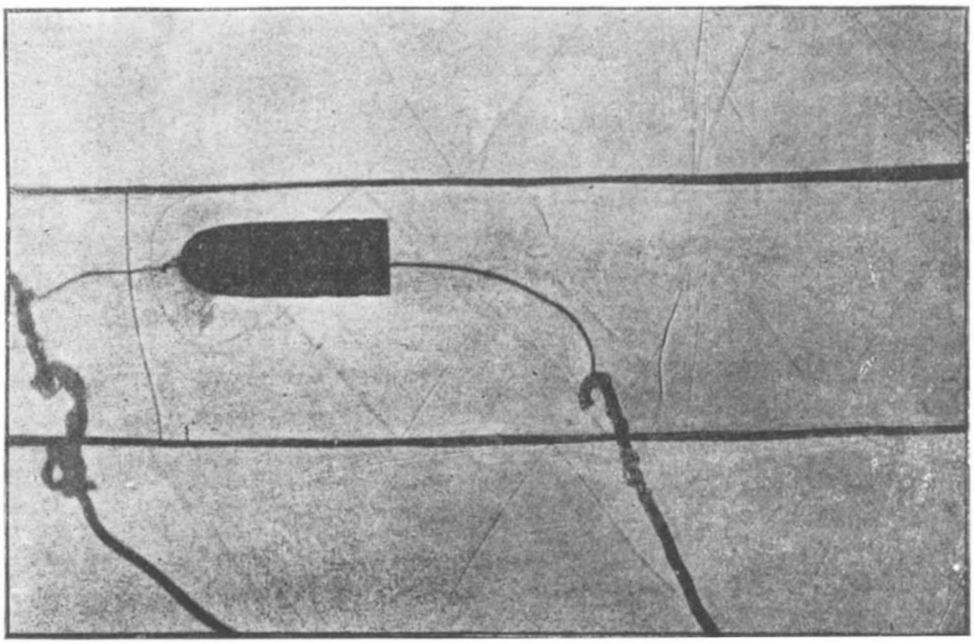

FIG. 12.

bullet has turned, that a second bullet should be drilled with a series of holes at about the corresponding position differing very slightly from one another in angular position, so that several would let the light through and thus give a more accurate measure of the rotation.

There is a point of interest to sportsmen which has given rise to a controversy which the spark photographs supply the means of settling. The action of the choke bore has been disputed, some having held that the shot are made to travel more compactly altogether, while others, while they admit that the shot are less scattered laterally, as may be proved by firing at a target, assert that they are spread out longitudinally, so that if this is the case the improved target pattern is no criterion of harder hitting, especially in the case of a bird flying rapidly across the direction of aim.

shot is filled with air waves of the greatest complexity. They are not due to the cause already explained, but are, I believe, formed by the imperfect mixture of air with powder gases still accompanying the shot. The imperfect mixture of the two gases causes light to be deflected in its passage, thus producing striæ just as at the first mixing of whisky and water, striæ are seen (sometimes attributed to oil), which disappear when the mixture is complete. I would mention, for the benefit of any one who may be tempted to continue these experiments, that a pair of wires such as are found to do so well when bullets have to be caught are not suitable, as one is sure to be shot away before such a bridge of shot is made between them as will allow a spark to pass. However, by using thick copper wires, one bent in the form of a screw, with the other along the axis, no such failure can occur and every shot that I have taken in this way

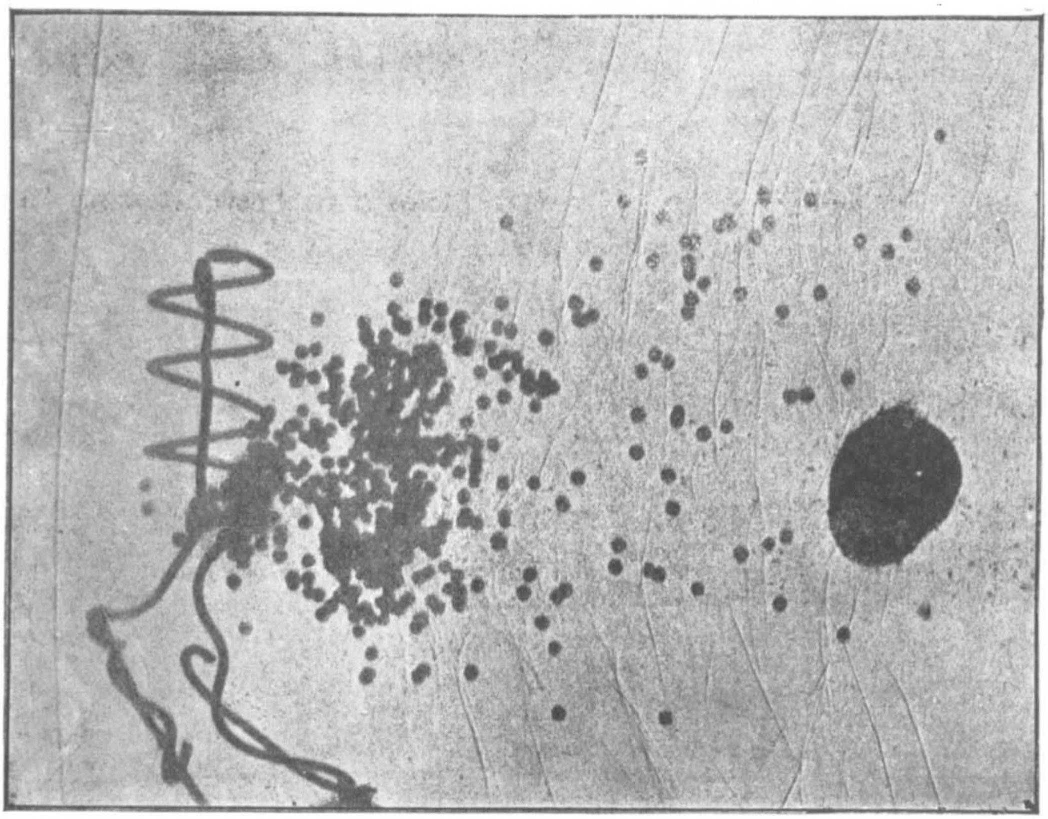

FIG. 13.

I was unfortunately not able, in the limited space and time that I have been able to employ, to take photographs of the shot at a reasonable distance from the gun, but I have taken comparative photographs at three or four yards only in which every shot is clearly defined, and in which it is even easy to see on the negative where the shot have been jammed into one another and dented. The difference in the scattering at this short distance is not sufficient for the results to give any information beyond this, that shot are as easily photographed as bullets, and that no difficulty need be apprehended in attempting to solve any question of the kind by this method. The photograph, Fig. 13, represents the shot from the cylindrical or right-hand barrel. The velocity now is so low that individual waves are no longer formed by each shot. The whole space, however, occupied by the

has been successful. One can of course test the action of any material mixed with the shot. For instance, in one case I mixed a few drops of liquid oil with the shot and found them more widely scattered in consequence, not, as has been stated, held together by the oil as if they were in a wire cartridge. Of course, solid grease or fat may, and no doubt does, produce such a result, but liquid oil certainly does not.

And now I wish to conclude with a series of photographs which show how completely the method is under control, how information of a kind that might seem to be outside the reach of experiment may be obtained from the electric spark photograph, and how phenomena of an unexpected nature are liable to appear when making any new experiment. The result, however, is otherwise of but little interest or importance.

I thought I should like to watch the process of the piercing of a glass plate by a bullet from the first shock step by step, until the bullet had at last emerged from

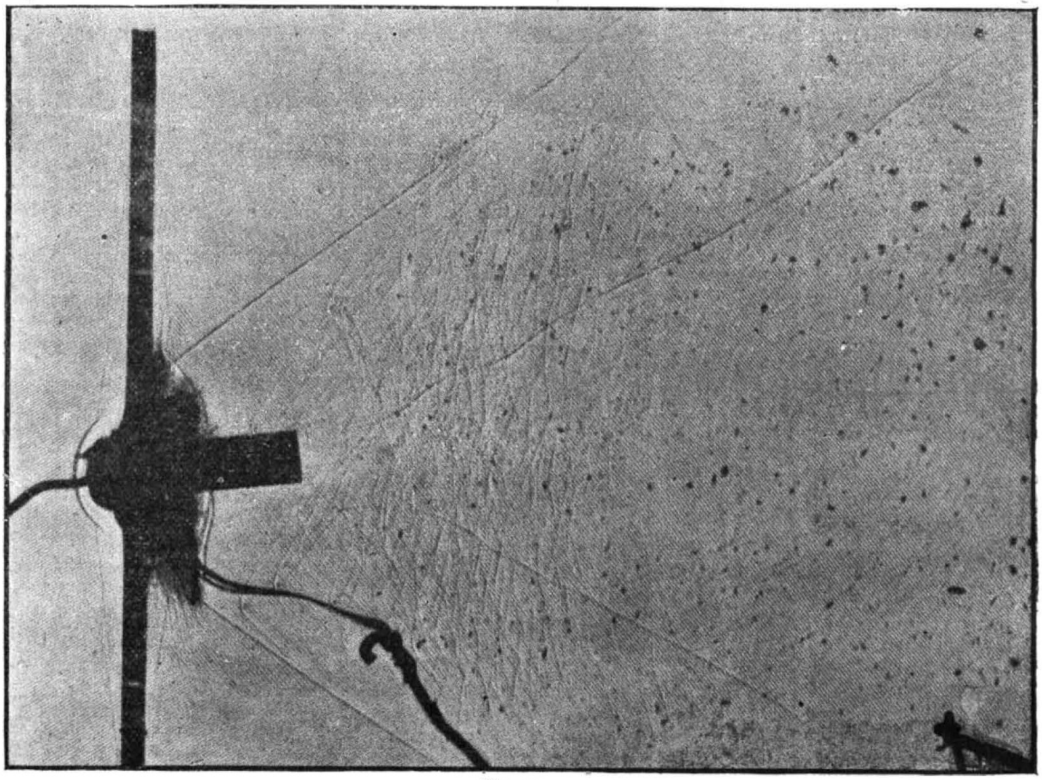

FIG. 14.

the confusion it had created. In Fig. 14 the glass plate is seen edgeways just after the bullet has struck it. It is clear at once that the splash of glass dust backwards is already four or five times as rapid as the motion of the bullet forwards. A new air wave is just beginning to be created in front of the glass-coated head of the bullet and two highly-inclined waves, one on either side of the glass, reaching about three-quarters of the way to the edge, have sprung into existence. These are more clearly seen in the next figure; meanwhile it may be well to point out that the fragments of paper which are following the bullets have in this case—as the card was much nearer to the glass plate than in those previously taken—some of them lost so much of their velocity and have in consequence lagged behind in a still higher proportion than the others, that they are travelling at less than 1100 feet a second; the more backward ones carry in consequence no air waves and there is no means of telling from the photograph that they are moving at all. In Fig. 15 the bullet has struggled about half way through the plate. The waves on either side of the plate have now reached the edge and are on their way back towards the centre again. They are caused in this way. When the bullet strikes the plate the violent shock produces a ripple or tremor in the glass which travels away radially in all directions, leaving the glass quiet behind. The rate at which this ripple travels may be found from the angle which these new air waves make with the plate, for taking any point on the plate and measuring up to the point where the air wave meets the plate and also the distance in air to the nearest point of the inclined air wave, we get two distances, the ratio of which is the ratio of the velocity of the disturbance in the glass to the velocity of sound in air. But much more than this is shown. An examination of the negatives or of a photographic print and even.but less clearly, of the print in the text shows that these inclined air waves are made up of a series of dark and light lines at a very slight

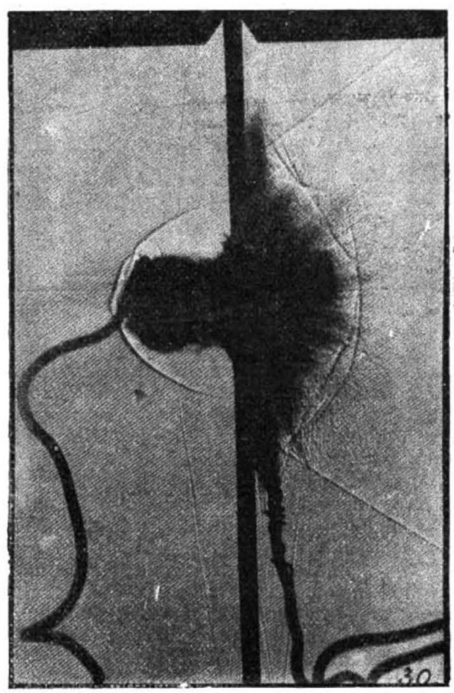

FIG. 15.

inclination to the air wave itself, so that as we travel

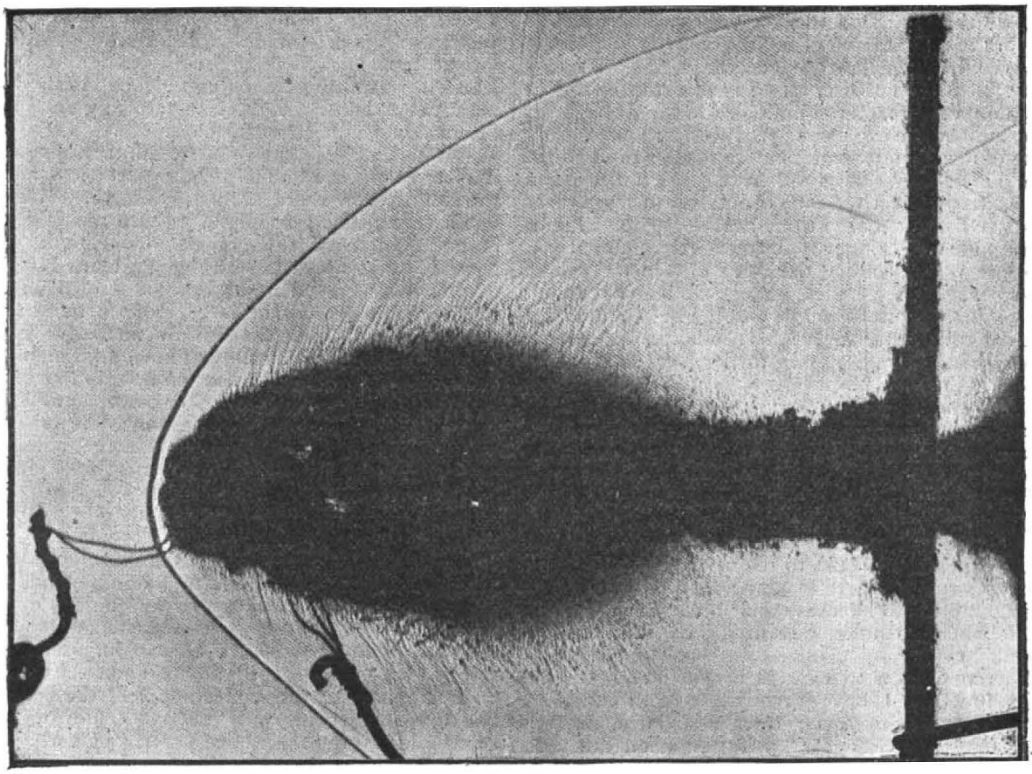

FIG. 16.

along the air wave it is alternately dark outside and light outside. These indicate the successive positions in which

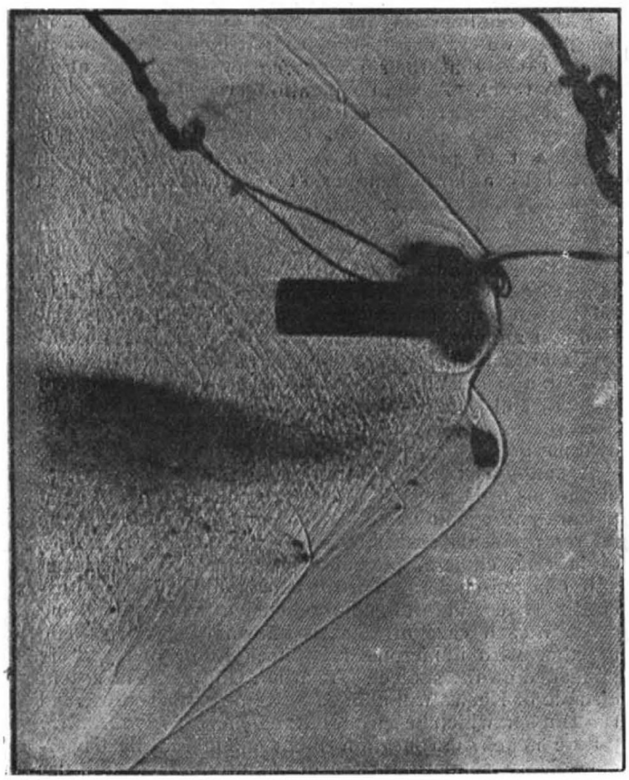

FIG. 17.

the glass first moved outwards to compress the air or first moved inwards to rarefy it so that the wave length of the ripple may thus be found, and finally it is seen that where the waves are waves of compression on one side of the plate they are waves to rarefaction on the other, indicating that it was a transverse and not a mere longitudinal disturbance that ran along the plate from the centre outwards and back again after reflection from the edge. In addition to this the fact that the reflected wave is still on its inward course proves that up to this time the plate is whole, as a wave cannot be propagated in a broken plate. Fig. 16 illustrates the state of affairs when the bullet has travelled about five inches beyond the plate. It has not yet emerged from the cloud of glass dust. The new head wave is very conspicuous. In the original negative, about half way between the bullet and the plate, the inclined waves due to the tremor in the glass plate may be detected, but they are too delicate to be reproduced by the printing process. They supply the information as to how long the plate remained whole or rather if the bullet had been caught a little sooner before these faint waves had lost so much of their distinctness they would supply this information with great exactness. Meanwhile the figure shows that the plate is now broken up completely. It is true it is still standing, and the stern air wave is seen reflected from the upper part of it, but this is because the different parts have not yet had time to get away; their grinding edges, however, have cast out from the surface little particles, and these are seen over the whole extent of the plate. After about fifteen inches the bullet is quite clear of the cloud of dust (Fig. 17); one piece only of the glass, no doubt the piece that was immediately struck, has been punched out and is travelling along above the bullet at a speed practically equal to its own. I am also able to show the plate itself in this and a still later stage, when at last the separate pieces have begun to be visibly moved out of their position and in some cases slightly turned round.

I have merely given this evening an account of a few experiments which in themselves perhaps are of little interest, but they at any rate show the capability of this method for the examination of subjects which would in the ordinary way be considered beyond the reach of experiment. It is hardly necessary to say that the examples given by no means reach the limit of what may be done, I have examined the explosions produced by fifteen-grain fulminate of mercury detonators and of heaps of iodide of nitrogen, a material which is rather unmanageable, as if a fly even walks over it it violently explodes. In these cases the explosive flash was used to make the B gap of Fig. 4 conducting, for which it answered perfectly. One might in the same way examine the form of the outrush of powder gases past the bullet, and so find at once their velocity with respect to the velocity of the bullet, and I see no great difficulty in tracing, if this should be desired, the whole course of a single bullet for perhaps as much as 100 yards by means of photographs taken every few inches on its way. Though it may not be evident that these or similar experiments are of any practical importance, there can be no doubt that information may be readily obtained by the aid of the spark photograph, as in fact has been shown by Prof. Mach, Lord Rayleigh, Mr. F. J. Smith, and others, which without its aid can only be surmised, and that if, as in other subjects, the first wish of the experimentalist is to see what he is doing, then in these cases surely, where in general people would not think of attempting to look with their natural eyes, it may be worth while to take advantage of this electro-photographic eye.

I wish in conclusion to express my obligation to the gentlemen to whom I have already referred, to Messrs. Chapman and Colebrook for their assistance, and to Messrs. Moore and Grey for having supplied me with weapons and ammunition.

MICRO-ORGANISMS AND THEIR INVESTIGATION.[1]

AS the field of bacteriological investigation becomes extended, we have of necessity constant additions to the various methods rendering possible the pursuit of researches in these novel directions. We have only to look at the first edition of Hueppe's "Methoden der Bakterien-Forschung," published in 1885, consisting of 174 pages, and compare it with the bulky volume of 488 pages which forms the fifth edition, to see at a glance the advance which has been made in the matter of methods alone. In Flügge's "Die Mikro-organismen" we have another type of book, dealing exclusively with micro-organisms themselves, and the information which has been gathered together concerning them, whilst all details of bacteriological practice are purposely omitted. Dr. Günther has attempted a welding together of these two types of book, special attention being given to microscopical technique with which his name is indeed more particularly associated.

The first part is devoted to a survey of our knowledge concerning bacteria in general, commencing with the earliest observations of Leeuwenhoek in 1683. In this review we find an account of their morphology, the principles upon which their classification is attempted, &c., together with a detailed account of the most recent methods for their cultivation and subsequent study, including careful directions for the use of the microscope, and a most elaborate description of the available means for staining bacteria.

The second part is confined to a consideration of the best-known pathogenic and non-pathogenic micro-organisms.

There could not be a more admirable account of the numerous manipulations involved in bacteriological investigations; all the minutiæ are described with the utmost care, and what is usually left for the student to learn in "profiting by his experience" is here carefully anticipated, and if he tumbles into any pitfalls, it is not because he has been without warning.

With such a big task as Dr. Günther has set himself it is not surprising to find some parts less amply dealt with than they would seem to deserve. Thus we find but a very meagre supply of culture media given, there is no mention of the preparation of milk, or of the special solutions employed by Pasteur, Naegeli, and others, neither is there any account of Kühne's silica jelly, which since our knowledge of the fact that certain organisms will only flourish in media devoid of all organic matter, ought surely to have been included.

On the other hand a minute description is given of gelatine-plate, dish and tube cultures, as well as of the most modern methods for the anaërobic cultivation of bacteria, &c. In connection with the abstraction of certain colonies from gelatine-plates, mention may be made of a piece of apparatus (the description of which was only published after Dr. Günther's book appeared) originally devised by Fodor, and called "Bakterien-Fischer," which has been, under the name of "Bakterienharpune," more recently modified and considerably cheapened by Unna. Every one has experienced the difficulty of fishing out a particular colony in a crowded plate, how it is almost impossible to look through the microscope and fix upon the centre to be abstracted, and at the same time keep the needle steady and ensure touching only the one colony which is required. By using the above contrivance, which can be attached to the microscope, the fishing out of such centres is greatly facilitated.

The examination of air for micro-organisms is only very slightly touched upon, as is also the bacteriological investigation of water. It is a little rash to assert that "pathogenic micro-organisms can live for a long time in sterilised water," considering that it has been shown in some cases that their *immersion* only is sufficient to destroy them. Again, no mention is made of Hansen's special methods for the examination of particular waters; although they are opposed to the Koch school, this ought not to preclude a reference to what has been proved by a large number of investigations to be, in some cases, of great practical utility.

The second part opens with a short introduction, in which the nature of pathogenic organisms in general is described, and an account given of the rigid proof which is required before a particular organism may be said to be the cause of a particular disease. Protective inoculation and immunity are briefly referred to, and Metschnikoff's brilliant theories of phagocytosis summarily dismissed, and declared incapable of standing the test of the "careful experimental criticism to which they have been submitted by Flügge, Baumgarten, and the author's own pupils."

As many as twenty-seven different varieties of micro-organisms are described in the section on the most important pathogenic bacteria. Amongst these we find the micro-organisms associated with anthrax, tuberculosis, diphtheria, cholera, pneumonia, tetanus, typhoid fever, and chicken-cholera, more especially dealt with, an exceedingly useful and comprehensive summary being given in each case of what is known concerning them, together with numerous references to original papers published on the subject. That Dr. Günther is an ardent disciple of Koch's will at once be admitted, when we read the terms in which he speaks of the *Tuberculinum Kochii*: "Eine neue Aera begann nicht allein fur die Tuberculoselehre, sondern für die gesammte Medicin, mit der grossen Entdeckung Koch's der Heilung der Tuberculose."

[1] "Einführung in das Studium der Bakteriologie." By Dr. Carl Günther. Second Edition. (Leipzig: Georg Thieme.)
"Technique Bactériologique." By Dr. R. Wurtz. Encyclopédie Scientifique des Aide-Mémoire. (Paris: Gauthier-Villars et fils, 1892.)