Royal Institution of Great Britain.

WEEKLY EVENING MEETING,

Friday, May 30, 1924.

Sir James Crichton-Browne, J.P. M.D. LL.D. D.Sc. F.R.S.,
Vice-President and Treasurer, in the Chair.

M. Lucien Bull, Sub-Director, Institut Marey.

Recent Developments in High-Speed Cinematography.

I should like to show you this evening some of the latest improvements we have been able to make at the Marey Institute in high-speed cinematography. For those—and I fear there are a great many—who have never heard of the Marey Institute, I just wish to say that Marey was one of the leading French physiologists and was born in 1830. During the latter part of his life he devoted a great deal of attention to the study of animal motion, in the pursuit of which he made a most extensive use of cinematography. Marey may be rightly considered as the inventor of the cinematograph, as he was the first to construct and to use, as far back as 1890, apparatus based on exactly the same principle as the modern machines; his projecting instrument was not perfect enough, however, for the results to be shown at that time to the general public.

Shortly before he died, in 1904, he founded the Institute which bears his name, and of which I can show you a photograph. It is remarkable as being, perhaps, one of the ugliest buildings in one of the prettiest suburbs of Paris, on the edge of the Bois de Boulogne. It is situated, however, in a large garden, and is particularly well adapted for carrying on experiments that require absence of noise and vibration. It is here that, in spite of very narrow financial resources, we continue a good deal of Marey's original researches on motion, where naturally the cinematograph plays the most important part.

The cinematograph, as everyone is aware, is used, firstly, for analyzing motion—that is to say, registering photographically the different phases of a movement; and, secondly, for the purpose of demonstration, by reproducing the movement on the screen. But there are limits to its powers of investigation. In the ordinary, everyday instrument pictures are taken at the rate of fifteen or sixteen a second, which is amply sufficient for the motion in the social dramas we are accustomed to see on the screen. But in scientific research we come across movements so rapid or so short in

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duration that they may only last for 1/100th of a second, or even less. For study in these cases the ordinary cinematograph is completely useless; the movement we wish to investigate being liable to take place in the interval between two pictures, and to leave no record at all of its occurrence. We consequently require for scientific research an instrument capable of working at a much higher frequency than fifteen or twenty pictures a second.

Now, I don't suppose for an instant that there is anyone here who is not more or less acquainted with the mechanism of the cinematograph; but in case I were mistaken I am going to show you on the screen a short film illustrating the principle of its action.

The photos are taken on this long strip of perforated celluloid film which is drawn through the apparatus, in this case, by a pair of little steel teeth that on their downward course enter into two holes in the film and draw it along. On their upward course the teeth move away from the film and leave it motionless for an instant, during which the shutter opens and the photograph is taken. The mechanism varies in different instruments, but the principle is always the same, the film receiving an intermittent motion, being arrested during the exposure, and then suddenly moved on for the next picture.

Now, this intermittent motion can be given to a film fifteen or twenty times a second very easily. One of my colleagues at the Marey Institute, Mr. Nogues, has recently constructed an instrument in which the film can be stopped and then moved on again 300 times in a second; but this is probably the limit. It would be difficult to conceive a mechanism capable of stopping and starting a film a thousand times or more in a second, which would be what we should require for certain investigations. To attain these high frequencies it is absolutely necessary to cut out the stops and let the film run continuously.

Here, of course, we meet with a difficulty. How can the pictures be sharp if the film on which they are taken moves during the exposure? There are two methods by which this may be realised. One is to displace optically the image during the exposure, in the same direction and at the same speed as the film. The image and the film, although both are moving, are at rest, relatively, to one another, and under these conditions the photographs can be perfectly sharp. This method has been applied in several high-speed cinematographs, and, in spite of certain drawbacks, seems to have given definite results.

One of the most perfect instruments of this type, and probably the most expensive cinematograph in the world, is the Heape and Grylls High Speed Rapid Cinema Machine, with which over a thousand photos can be obtained per second. In this apparatus a number of lenses—forty, if I am not mistaken—are fixed around the circumference

of a disc rotating in front of a continuously moving film, the speed of the lenses being the same as that of the film. The weak point of this device is that the lenses do not move in a straight line like the film, but along the arc of a circle; the effect of this can only be sufficiently attenuated by giving a very short exposure to the pictures. This, of course, is attended by a number of drawbacks, and limits the speed at which the apparatus can be used.

The other method for obtaining sharp photos on a moving film consists in simply reducing the exposure to such an extent that the movement of the film during that time is too small to be noticeable. I hardly need to state that the exposure in this case must be extraordinarily short. To take a thousand photos per second the film must move along at a speed of sixty feet per second, and to obtain sharp pictures under these conditions the exposure must not exceed 1/200,000th of a second. If a higher frequency is desired the exposure must be reduced accordingly.

Now, in the first place, no mechanical shutter can give exposures as short as this; and if it could it would not be of much use, because daylight, even direct sunlight, is not powerful enough to give a photographic image in so short a space of time.

Fortunately, however, we possess the most wonderful source of light for our purpose. We may well say wonderful, because it combines in really a most marvellous manner the two properties we require—extraordinary brilliancy and extreme instantaneousness; it is the electric spark.

The brilliancy of the small electric sparks I am producing with the induction coil and the small Leyden jar I have here, is more than ten times that of the sun. By brilliancy I do not mean, of course, the total amount of light given off, which is, as you can see, very minute on account of the small size of the spark; I mean its intrinsic brightness per unit of surface, which is at least ten times that of the sun. And it is this intrinsic brightness that is of importance in these experiments.

The duration of these sparks—that is, time that the illumination lasts—depends on the capacity of the circuit represented by the small Leyden jar, and does not exceed in the present case 1/10,000,000th of a second.

It is difficult to convey a very clear idea of what 1/10,000,000th of a second represents without an example of some description. It means, for instance, that in order to obtain the value of only one entire second of light from these sparks, we should have to emit 10,000,000 of them. I can produce with this coil a constant stream of sparks at the rate of about 200 a second. Well, if we had started this coil running this morning at nine o'clock, we should not yet have obtained this evening the value of one single second of light from the sparks. The illumination seems perfectly continuous to the eye, and yet each spark is separated from the following one by an interval of time relatively enormous. The proportion between the duration of each spark to the interval between them is exactly the same as if the sun were to shine upon the earth for one day, and then to go down, leaving us in darkness for more than a hundred years before rising again.

These wonderful properties of the electric spark have often been used for instantaneous photographic purposes, as they completely do away with the necessity of a mechanical shutter. All that is necessary is to operate in a darkened room with the lens of the camera open, and to illuminate with a single spark the object we wish to photograph. I hardly need mention—they are so well known—the remarkable photographs taken in this manner by Professor Mach in Vienna and Professor Boys in London of rifle bullets in full flight. These bullets, moving at a speed of 1,500 feet per second, appear perfectly motionless when viewed by the light of a spark, and consequently come out perfectly sharp in a photograph.

For cinematographic purposes the proceedings may be reversed; instead of using a motionless photographic plate and a single spark, we can run a film at any speed we like past our lens, and with a stream of sparks obtain a whole series of photographs. As far as the sharp definition of the pictures is concerned, the problem is solved; and, at the same time, the mechanism of the cinematograph is enormously simplified by not having to stop the film.

But, before going further, I must explain briefly how the light of the sparks is employed. As you have noticed, the total amount of light given off by each spark is very small, and totally insufficient for illuminating anything in the ordinary way, like the sun, for instance. The spark must be placed in the focus of a large glass condenser, which concentrates all the light it receives into the lens of the photographic apparatus, and forms at the same time a brilliantly illuminated field. The subject we wish to photograph must be placed near the surface of the condenser, like the slide in a magic-lantern, where it stands sharply outlined against the bright background. In this manner a minute spark like those you have seen can illuminate a large surface, a yard or more in diameter, although in the laboratory we are obliged to content ourselves with smaller fields of view, a foot or eighteen inches in diameter, on account of the expense of these large optical pieces. Instead of a glass condenser we may use a concave mirror of silvered glass, which is more efficient from the point of view of illumination, and is cheaper; but it has some drawbacks: the spark has to be placed in front of the mirror, and is consequently visible in the centre of each photograph. In certain cases a combination of the two, condenser and mirror, has advantages.

The most important part of this method of cinematography is the device for procuring a regular stream of sparks at the necessary frequency. With the induction coil I have here you have seen we can obtain sparks at the rate of 200 a second. With a suitable contact-breaker it might be possible to double this frequency, but it would be difficult to exceed, I imagine, 400 or 500 sparks a second. A more suitable arrangement is the one we have used in our first electric spark cinematograph, constructed in 1904, and which held the record for high-speed cinematography for some years.

Here is a diagram of the apparatus. The film, about a yard in length, is wrapped around the circumference of a drum which revolves inside a closed box, carrying the lens in front. On the axle of the drum is a rotary interrupter, something like the collector of a dynamo, which by means of these two brushes makes and breaks the primary circuit of the induction coil fifty times for every turn of the drum. The sparks obtained from the secondary circuit, intensified as usual with a small Leyden jar, are placed here behind the condenser, which forms the illuminated field against which the subject—an insect—stands out.

This is the photograph of the camera alone, showing the rotary interrupter with its brushes, two lenses and two films wound side by side around the drum. The object of this arrangement is to obtain stereoscopic photographs. For this we are obliged to produce two sparks simultaneously; these are obtained by simply making two gaps in the secondary circuit for the current to spark across instead of one.

This photograph shows the whole installation as mounted originally on a table for cinematographing the flight of insects. From what you have already seen the different parts of the apparatus are easily recognised—the sparking gap, the field lens with the subject (an insect) in front, the electric motor for turning the drum, etc.

With this arrangement, rotary interrupter and induction coil, we have been able to produce up to 3000 sparks per second, and to obtain consequently a series of pictures at a frequency of 3000 a second on a film a yard in length. The apparatus having been specially constructed for the study of animal flight, this speed was sufficient for those insects that do not beat their wings too rapidly.

I am going to show you now two films taken with this apparatus. The first film is of a small blue dragon-fly flying vertically upwards from the support to which it was attached; the second shows the bursting of a soap-bubble caused by a paper pellet shot from a little spring gun. These films are extremely short, and in order to give you time to see them each will be projected three times in succession.

For analyzing more rapid movements than these this apparatus proved unsuitable. Our attempts, with a rotary interrupter and an induction coil, to attain a higher frequency than 3000 per second were unsuccessful.

In 1907 Captain Cranz, a German officer, took up the study of firearms with electric spark cinematography. He also used an induction coil, but instead of using an interrupter he sent into the primary of his coil a high-frequency alternating current from a specially constructed dynamo. With this device he was able to obtain 5000 sparks per second, and consequently to obtain a series of photographs at the same rate.

Notwithstanding this high frequency, it is still relatively low for the study of such rapid movements as those of a bullet from a rifle or even from a pistol. A bullet that is travelling at a speed of a thousand feet a second, and they can go faster than that, covers a foot in 1/1000th of a second. If the diameter of our field of view is not larger than a foot in diameter, it is crossed completely in that time by the bullet, of which we can consequently only get five or six photographs, and this is rather short for cinematographic work.

Fortunately the development of wireless telegraphy has put into our hands other and much simpler methods of producing electric sparks at almost unlimited frequency. One of the simplest and most efficient I shall now explain to you, as it is the one of which we have made the most extensive use. It is extremely simple, in the sense that it entails no mechanical or moving parts at all.

The electric spark of which we make use is caused by the sudden discharge of the small capacity Leyden jar in the circuit. This discharge occurs automatically when the electric tension to which we raise the jar attains a certain limit, a limit which is determined by the size of the gap that the spark has to jump across. Now, the discharge of the jar through the spark is almost instantaneous, whereas to charge up the jar again takes a short but appreciable time, especially if we place a resistance in the circuit.

So if we have at our disposal a direct current of sufficiently high tension, say 10,000 volts, we have only to turn it on to our sparking circuit through a very high resistance, and this is what happens: the electrical charge of the Leyden jar rises slowly with the current flowing in from the source, until the spark strikes across the gap; this discharges the jar instantaneously. Its charge begins to rise again till the next spark strikes, and so on automatically. By regulating the resistance in the circuit and the tension of the source of current, it is possible to obtain by this method series of sparks at almost any frequency, even up to 100,000 a second, so from this point of view our cinematographical wants are more than fulfilled. I must add that one thing is absolutely essential in using this method, that is to blow a stream of highly compressed air through the spark-gap during the experiment. Otherwise on account of the heat developed by the first sparks the electrical resistance of the spark-gap would be lowered to such an extent that an arc would be formed and the discharge would become continuous instead of being divided up into separate sparks.

Of course the necessary current of 10,000 volts is not usually to be found in laboratories. I might perhaps add that it is a good thing, because working in a room where there is a constant source of current of this voltage would be something like working in a room with a loaded pistol turned towards one all the time. Of course a well-constructed loaded pistol does not go off spontaneously as a rule, but still it is not very pleasant to be in its proximity constantly. It is preferable to use a means of producing the really small amount of high-tension current necessary for an experiment at the moment it is required. We can do this with a large condenser, or rather a battery of condensers, which can be readily charged up to any desired voltage with an induction coil and a valve. When the experiment is over the battery of condensers can be discharged, and is rendered quite harmless.

Another very simple and interesting way of producing high-tension direct current for a very short time has been proposed by Professor Abraham in Paris. It consists in the use of an electrical step-up transformer, the larger the better, with a closed iron circuit. On closing the primary circuit, we can get for a fraction of a second —that is, while the magnetic flux is rising—a direct current of almost any desired tension from the secondary circuit. There are certain advantages however in the condenser method, and we have adopted it more or less exclusively. I shall now show you one or two photographs of the electrical part of our installation.

We have here on the left three large condensers made of plates of window-glass covered on each side with sheets of tin-foil, the capacity of each being about 1/10th of a micro-farad. On top is the induction coil and in front the valve, with which we can charge up the condensers to the desired tension. Above is an electrostatic volt-meter which indicates the tension, and which it is good to consult before going too near the condensers. To prevent the latter from receiving by any chance too great a charge, an automatic discharger here empties them silently before the tension reaches a dangerous point. On the wall here is the resistance which allows us to regulate the frequency of the sparks. It consists of a glass tube filled with water and two copper rods, the distance between which can be modified so as to increase or diminish the length of the column of water the current has to pass through. This is a transformer, not actually in use, and on which is mounted the sparking lantern with its collecting lenses. Behind it is a small auxiliary coil which is extremely useful on account of its being able to give a continuous stream of sparks for focussing or centring the optical system. Below, on the ground, is a steel tube in which we can compress a small quantity of air with a bicycle pump, because I am sorry to say that we have no compressed air-mains at the Marey Institute.

This photograph shows the large glass lens or condenser which forms the field of view. In front can be seen a revolver ready to shoot a bullet across the field, and the arrangement for starting and stopping the stream of sparks at the right moment.

Now that we can get any number of sparks that we require, there still remains one difficulty, and the greatest difficulty of all—that is, the question of moving the film fast enough. As long as we were satisfied with two or three thousand photos a second this was quite simple. The film, fastened on a revolving drum, could be spun around at a speed of 300 ft. a second, which was amply sufficient for separating the photos. But with 10,000 or 20,000 sparks a second, the film at this speed only moves through a small fraction of an inch, which only allows us to get very narrow pictures. These can be very interesting all the same, as I can show you.

This slide shows a series of images of a bullet leaving the barrel of a revolver and going through a thin plank of wood. They are taken at the rate of 13,000 a second, and as you see are very narrow on account of the speed of the film not being sufficiently rapid.

This slide shows a few photographs of a 1½-inch shell about 3 ft. from the muzzle of the gun. The photographs are wider here, but they are taken at a frequency of only 7000 or 8000 per second.

In spite of their interest, these photos are rather disappointing on account of their narrowness, which would be quite unsuitable for many subjects. To get wider images we must absolutely increase the speed of our film. Not being able to do this in any appreciable manner, we have adopted in our latest camera quite another method. It consists in not moving the film at all. The film remains perfectly motionless, and, what gives exactly the same result, the images are optically displaced instead. This is how it is done.

The film is fixed around the inside circumference of a large metallic ring of about a yard in diameter, the sensitive surface turned towards the centre. The centre is occupied by the lens and, immediately behind it, a right-angled prism that can be made to revolve. The rays issuing from the lens are taken up by the prism, bent through a right angle, and reflected on to the film. When the prism revolves, in one turn the reflected rays sweep over the whole length of the film, about 10 ft. As it is much easier to rotate a prism of relatively small diameter, about 2½ inches, than a large drum, it is possible even with a small electric motor to attain very high speeds indeed. If the prism makes 200 revolutions a second, the speed of the light rays sweeping over the film is 2000 ft. per second—that is, more than 20 miles a minute: a speed which it would be impossible to impart to a film. This device consequently allows us to obtain cinematographic images of normal width, ¾ of an inch, at much higher frequencies than with any other method. I shall now show you photographs of the apparatus itself.

This is a view of the outside of the apparatus. As you see, it is a little like a clothes-press with a lens in the centre.

This is a view taken with the doors open and the lens removed so as to show the prism. The motor for rotating the prism is at the back, and consequently is not visible.

It is not possible to imagine a simpler and more efficient apparatus than this, and it has only one drawback. This is that the photographs, as they are being taken, revolve around their own centre. That is to say, when the film is developed, instead of finding all the images parallel to one another as in an ordinary film, we find each image has rotated through a small angle compared to the preceding one. This rotation continues all along the film, the angle increasing gradually, so that in the centre of the film we find the images completely upside down; the last image alone is parallel to the first, having made a complete turn.

If our aim is simply to analyze motion, this rotation of the images is of no consequence, but for projection purposes it would be intolerable, of course, and a special device had to be contrived that rectifies the angle of each picture when the positive film is being printed.

I shall now show you two or three films taken with this apparatus at speeds varying from 18,000 to 20,000 pictures a second. I hope I have not conveyed to my audience the very false idea that they are going to see 20,000 photos that have been obtained in a second; these films will appear unfortunately very short, as they are taken at this high frequency only during a very small fraction of a second, not much more than 1/5000th. The expense would prevent us in any case from doing much more, for the cost of running the apparatus in film alone is not much less per second than that of the late war against Germany, and I am sure that no one would care to keep up an experiment like that for very long. The projection of these films consequently only lasts for a few seconds, although time, in these experiments, is lengthened out more than a thousand times. I had hoped to have been able to obtain some films of the flight of insects, a most interesting subject, but Spring has been so cold this year that, in Paris at least, no insects were available. I have had to fall back consequently on a less interesting, but much more convenient, subject, a revolver bullet. The principal interest of the films you are going to see is that to-night is the first time, as far as I am aware, that cinema pictures taken at this frequency have ever been shown in public on the screen.

The first film shows simply the discharge of the revolver, with smokeless powder; the second shows the bullet passing rapidly through an ordinary incandescent lamp; in the third you will see the bullet going through a plate of window-glass; and in the fourth through a thin wooden board. Each film will be repeated three times, so as to allow you to see and to understand them more easily.

[L. B.]

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