[illegible] Exposition d'instruments et

d'images relatifs à l'histoire de la

Chronophotographie, par le Docteur

Marey, membre de l'Institut, [illegible]

Opuscule intitulé Musée Centennal de la

Classe 12 (Photographie) à l'Exposition

Universelle Internationale de 1900 à

Paris. Métrophotographie & Chronophoto-

graphie.

Extract from
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for 1893
pp. 609-627

The History of Chronophotography.

By Dr. Marey
Member of the Institute.

[Dr. Marey is what is usually called a Frenchman by birth, but his name is well known to many Americans as the inventor of the single-lens camera for picture taking.]

By chronophotography is meant a method which analyzes motions by means of a series of instantaneous photographs taken at very short and equal intervals of time. By thus representing, for example, the successive attitudes and positions of an animal, this art renders it possible to follow all the phases of the creature's gait, and even to construct exact drawings of it to scale. Of late years, chronophotography has taken another direction, that of the synthesis of motion. The analytic images are made to appear before the spectator

[Stamp: Smithsonian Institution]
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[Stamp: Annual Report of the Board of Regents of the Smithsonian Institution for 1893]
[Stamp: Appendix]

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this effect in uniform sequence, so as to produce the appearance of the motion itself. Everybody is familiar with such animated views.

The International Exhibition of 1900 enabled us to bring together the documents relating to the invention and successive improvements of chronophotography.

Part I.

Description of the Apparatus.

The principal instruments which, ~~different times~~ in the course of the development of chronophotography, have been devised by those who have pursued this art were collected in a large show-case. [Fig. I.] They were arranged according to the dates of their several inventions. In addition four large frames contained photographs resulting from the application of chronophotography to various branches of science.

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The small scale of the plate (Fig. 1) will hardly permit the details to be made out; but numbers have been attached to the different objects in chronological order.

No. 1 is Janssen's Astronomical Revolver, invented by that astronomer in 1873 in order to show successive positions of the planet Venus near the limb of the Sun, at her transits.

At the focus of a telescope pointed at the Sun was a photographic camera; and the sensitive plate, which was circular, turned about its center by leaps so as to bring into the field a different portion of its border every seventieth second of time. In that way a series of images were obtained (Fig. 2), which showed the successive positions of the planet on the Sun. She was seen to penetrate the limb, to cross the disk, and finally to depart; and the interval between the images being known, the velocity of the movement could be measured. This experiment seems to have been

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the earliest achievement of a *chronophotography*; for though others, before Janssen, conceived bolder attempts, there was in an exhibition of real things no place to show plans or ~~impracti~~ projects impracticable at the time of their invention. *a

*In an article on the Beginnings of the Cinematograph in *Camera Obscura* for February 1901, Mr. Charles Nievenglowski refers to an ingenious idea of 1857 of Charles ~~Adolphe~~ Reville of ~~making~~ bringing into a stereoscope a succession of double photographs of the phases of a phenomenon ~~appear in a stereograph~~. But for that purpose it would have been necessary to take the photographs of the objects in motion, which at that date would have been impossible, except at the lowest velocities. The same article figures an apparatus ~~imagined~~ devised in America about 1861 by Coleman Sellers. It was called a "Stereophantascope," and was intended to obtain the same result as Reville. The most remarkable

~~I would suggest that before this goes to print Mr. Sellers be asked whether it did go further than being imagined.~~

conception was, by all odds, that of M. Ducros du Hauron who in March, 1864, took out a patent for an apparatus for photographing any scene with all the transformations which it might go through in a given time. How to take the photographs and how to project them in animated form is thoroughly explained and figured in the patent of M. Ducros du Hauron. But the idea was entirely impracticable at the time. si 354

It may be added in all these apparatus, the perception of movement is due to the persistence of retinal impressions which was the principle of Plateau's phenakistoscope of 1833.

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Smithsonian! Will you please ask some [illegible] man what the English [illegible] is. In the [illegible] there were [illegible] [illegible] white horses are walked up and down by the side of a wall.

No. 2: Analysis of the motions of animals by the method of Muybridge, 1878. This celebrated photographer of San Francisco succeeded in fixing in successive instantaneous photographs all the phases of the gaits of a horse, even at the swiftest gallop. He studied by the same method the motions of man, as well as the principal types of ~~animal~~ quadruped locomotion. [illegible]

His arrangement was as follows: Multiple cameras, numbering from 12 to 24 according to circumstances, were arranged in series and parallel on a piste where a horse was galloping. Each camera had a quick-acting shutter worked by electricity. In passing along the piste, the horse successively broke a series of wires each of which in breaking set free the shutter of one of the cameras. Things were so arranged that, as he passed along, the animal caused the successive production of a series of instantaneous photographs. Fig. 3 & 4

Muybridge's method was shortly after used by Anschütz of Lissa, who also [illegible] made some improvements in it. In particular [illegible] [illegible] fortune in being able to use the recently discovered plates of gelatino-bromide of silver. Some fine [illegible] photographs by Anschütz were ~~[illegible]~~ shown in the glass case.

[illegible] experiments of Muybridge along with those of [illegible] photographs [illegible] the [illegible] experiments [illegible] [illegible] taking [illegible] photographs [illegible] to the [illegible] of the [illegible] equilibrium [illegible] [illegible] [illegible] [illegible] [illegible] before [illegible] took place. [illegible] [illegible] [illegible] [illegible] the [illegible] [illegible] did not succeed in satisfactorily overcoming [illegible] [illegible] of the [illegible] independently of the horse's motion.

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N° 3. Chronophotography on a plate fixed before a camera obscura. Marey, 1882. — The analysis of motion by chronophotography was already worthy of attention in 1882. The apparatus was, however, too costly; while the measures of distances and times were defective. The writer endeavored to simplify the experiments and at the same time to give them precision. The principle of the first method employed was as follows:

Suppose an ordinary camera to be pointed at a perfectly dark field and that an opaque disk in front of the lens is pierced with narrow openings and turns about its centre. Every time an opening passes before the objective the light would be admitted if there were any light in the field. But there being no light, none penetrates the camera; and when the plate is developed, it is seen not to have been affected. If a strongly lighted man or animal were to cross the dark field, each admission of light would produce an image of the [illegible], and as the latter moved

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photographs of it would be taken on the plate at different S I 30.
places and in different attitudes. Such an arrangement, however, would not answer. Fig. 4 shows the apparatus in its real form. Within a cubical box is seen the camera with its lens. Behind it is the plate holder, or back, C, which slides in grooves. Between the plate holder and the camera revolves the slotted disk grazing the sensitive plate, — in short, what is called a plate-shutter. This disk, which is dotted in the figure, is worked by a clock-movement furnished with a ~~regulator governor of its velocity~~ speed-governor, and is set in motion by a handle. Figure 5 shows the flight of a white duck which passes before the ~~dark field~~ dead black background. The succession of images is from left to right. Eight different attitudes are shown during one complete stroke of the wings. They reveal the details of the mechanism of flight. In order to appreciate the dimensions of the animal and the extent of its flight, a divided rule is placed before the dark field. It is photographed and serves as a scale. Finally, in order to show the intervals of time between

In point of fact it is not dotted in the figure. But I translate the text as it is.

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the successive images, at the lower right hand corner of the dark field is placed a chronograph, consisting of a dial, which has a white hand completing an entire revolution in a second. Everytime the shutter-disk admits light, and ~~photographs the~~ causes a photograph of the bird, this hand is ~~also~~ likewise photographed. Since it ~~will be~~ is seen to occupy eight successive equidistant positions on the dial, it is evident that the intervals have all been sensibly one eighth of a second.

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No 4. Dark field for chronophotography on a fixed plate.

No body is quite black. Chevreul showed that absolute blackness can only be procured by means of hole into a cavity with ~~walls~~ blackened walls, upon which ~~papers with black paper~~ no light ~~is~~ allowed to shine. [That is there should be another black hole facing the first.] ~~upon its walls~~. In order to approximate to these ideal conditions, the writer constructed a deep shed tapistried with black velvet and ~~so lumined~~ facing so that no light ~~shines into~~ penetrates it. In that way very sharp images are obtained upon an ~~invisible~~

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unclouded background.

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No. 5. Figures in relief obtained conformably to (d'après) chronophotography. A single apparatus only gives the projection of the motions on a plane perpendicular to the optical axis of the instrument. But if three chronophotographs are pointed on ~~dark fields~~ dark fields or dead black backgrounds, perpendicularly to one another (Fig 6), the animal represented will be seen from ~~under~~ three different ~~aspects~~ points of view, which will enable us to understand his real attitudes by reference to the three dimensions of space. Fig. 7 shows a series of statuettes of bronze united ~~together~~ each to the next, and representing the successive attitudes of a gull (goéland) in flight.

It is very badly expressed. S.Y. had better be less literal & not take him as he says but as he means.

No. 6. Photographic gun, 1882. In the study of the flight of birds, the necessity of operating before a dark field or dead black background restricts extremely the number of possible experiments. In order to analyze free flight, it was needful to

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be able to operate in case of mood on the bright sky and to arrange an apparatus capable of being aimed at a bird like a gun. The photographic gun (Fig. 8) contains in its barrel a long-focus objective. In its breech there turns a circular plate which presents to the focus of the objective different points of its border. In short, the apparatus is analogous to the astronomical revolver of Janssen, with this difference, that it produces pictures about 800 times more frequently, which calls for a pretty delicate mechanism. Figure 9 shows the photograph of a gull in free flight.

No. 7. M. Londe's apparatus with multiple objectives, 1889. Returning to the method of Muybridge with a very important improvement, M. Londe, aided by M. Dessoudeix constructed an apparatus in which a series of twelve objectives form their images upon different parts of a rectangular plate of large size. An ingenious arrangement causes the successive opening of these objectives at equal intervals as short as may be

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derived. The analysis of the motion is consequently very perfect. The order of the images cannot be deranged, since they are all obtained on one plate. But the number of pictures is limited by the necessity of having a separate objective for each.

Gen.l Sébert by a similar method analyzes the phases of the motion of torpedoes.

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№ 8. Multiplication of the number of pictures; 1. Partial photographs. 2. Dissociation of the images before the dark field. 3. Photographs on fixed sensitive film in motion. 1887–1888.

A perfect analysis of motion requires that the photographs of all be taken at as short intervals as may be, yet for as long a time as possible. If we merely make the rotation of the shutter disk faster, the number of images will, it is true, be augmented, but the animal's locomotion not being thereby accelerated, the result will be that the photographs will be taken so close together that they interfere with one another, and produce the confused effect seen in Fig. 7.

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A first way of avoiding this confusion is to photograph not the entire body of the subject but only certain points or lines whose position is significant of the facts we desire to know. A man dressed completely in black (fig. 10) and so invisible upon the dead black background, wears certain bright points and lines, stripes of silver lace attached to his clothes along the axes of his limbs. So rigged when this man passes in front of the apparatus & photographed will result that will be accurate diagrams of the pictures of the upper and lower arms, thighs, lower legs, and feet at each instant, as well as the oscillations of the head and of the hips. The method also allows the play of the joints to be studied.

He says "hips". But perhaps should have written "shoulders".

Still, it was desirable to multiply the images while showing the whole body. For that purpose we have the insufficiency of the advance of the subject has to be made up for by displacement of the image on the plate. This can be brought

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about in several ways. In the first place, the ~~whole~~ equipment ~~and~~ with its attachments, can be pivoted on its support and caused to turn about a vertical axis. The difficulty of moving the considerable mass ~~with regularity~~ uniformly caused, however, the abandonment of this method, in favor of the rotation ~~motion~~ of a S.I. 368 mirror by clockwork, causing ~~the~~ reflection to strike ~~thus strikes~~ different points of the plate. In this way a series of complete photographs are obtained following ~~which~~ follow one another at extremely short intervals of time. Indeed ~~In this way~~ the frequency of the photographs may be made very great. Their total number is, however, restricted because the optical axis of the instrument, being displaced along the black background ~~dark field~~, soon reaches the end of it. A final solution was to take the photographs upon different points of a long fillet which moves along the focal plane of the camera and is stopped ~~arrested for each~~ long enough for each exposure.

I have translated literally though I don't see the sense of it.

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Chronophotography on a ~~fillet of film~~ film ribbon. Marey, 1887.

S I 564

~~The inventions of the Kodak had ... resulted in~~

In consequence of the invention of the Kodak, long paper fillets of gelatino bromide of silver had become articles of commerce. ~~Soon after~~ A little later transparent films made their appearance; and these were still more appropriate for the chronophotography of long series of pictures. Three patterns of apparatus were exhibited in the case under No. 8. These showed the successive steps of invention.

Type a: The apparatus (Fig. 12) worked in the red light of the dark room. The objective is pointed outwards across a conical shade. In the place of the ordinary plate holder was ~~slipped~~ placed a ~~table~~ shelf carrying a clockwork R which led a long paper ribbon over rollers. The rotation of the disk made an electric contact at each passage of a slit, in consequence of which an electro-magnet squeezed the band and stopped it long enough for the exposure.

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Type b: It was necessary to avoid the extreme inconvenience of only being able to photograph within the dark room. A small portable box, B, was therefore made (for the film) which having been filled in the dark room could be carried out with the rest of the chronophotographic apparatus, as shown in Fig. 13. The results were more satisfactory.

Type c: Ultimately the application of electricity was given up, and the motion and stoppages of the film, instead of being governed by an independent clockwork, were connected with the movements of the disk.

No. 9. Double-action chronophotography. With a view of obtaining an apparatus which should, at pleasure, either work upon a fixed plate or upon a moving film, an instrument was constructed represented by No 9 in the glass case. This apparatus (Fig. 14) is composed of a fore part which slides in grooves.

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Marey's careless style makes him say that the objective is cut to carry the shutter disk. But I don't think this could have been the case, so have inserted the "and".

[illegible]

carries the objective and is cut so as to ~~allow~~ the shutter disk to pass. The movement of the latter is governed by a rod of (variable length (was to permit focussing)) connecting with clockwork ~~[illegible]~~ within the after part of the apparatus. In this 36 after part can be placed an ordinary plate-holder for chronophotography on a fixed plate; or, if desired, the plate-holder being removed, movable films may be introduced. These go into a ~~[illegible]~~ under chamber the open ~~cover~~ lid of which is shown in the figure. The film-ribbons could be inserted in day ~~put in the~~ light, in consequence of their being ~~p~~ being prolonged at both ends by ribbons of opaque paper (Fig 15). When the whole was wound ~~up~~ round ~~[illegible] was rolled on~~ its spool before being put in, the film was protected from light by outer layers of opaque paper, and when the work was done and the film was wound ~~rolled~~ upon the other spool, it was equally protected by the other terminal of opaque paper, so that it could be removed from the apparatus in the light,

mike — becoming obsolete.

This apparatus, which was easily used, sufficed for two years for the writer's researches into the motions of man and of animals. Like Muybridge, Anschütz, and Demeny, he aimed to obtain, by Plateau's method, the reproduction of the analyzed motions. At the Exhibition of 1889, a zoetrope moved by electricity showed animals in motion, acrobats, men, birds, horses at different gaits. But since the zoetrope does not allow many figures to be shown, the writer was incited to exhibit short movements. He therefore cast about for methods of showing scenes of long duration.

No. 10. Chronophotographic projector, 1893. This apparatus carries an endless belt of photographs to the focus of an objective which projects them upon a screen. Fig. 16 shows the path of the rays in the projector. A pencil of parallel rays reflected by a heliostat comes from S, and falls upon a convex lens L1. This pencil brought to a focus, passes at L

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through a hole in a disk figure 9, meets the shutter-arm 2, which is turned by a crank, passes through one of the windows that carries, then diverges and, meeting the lens in 12 similar to the first, regains its parallelism, is reflected at 45° from a mirror forming the lid of the box, falls vertically upon another mirror at the same inclination, and now passes to the objective. But in this last part of its course, it traverses the film, i, which carries the positive photographs; and these photographs, magnified by the objective, are thrown upon the screen.

The motion of the film at its halts at each flash is brought about by an apparatus not shown in the figure. It is similar to that of the simple chronophotographic apparatus, with the difference that the positive film, having its ends fastened together to make an endless belt, passes over a series of rollers which stretch it long last. The principal imperfection of the chronophotographic projector was a jerkiness due to

Marey 20 | to imperfect equality of the intervals. 369

No 11. Edison's kinetoscope, 1894. Mr. Edison found a means of equalizing the intervals. It was to perforate the ~~film~~ sensitive film by a series of equidistant holes and gear it to a pin-cylinder. It was impossible to procure the kinetoscope to exhibit in the glass case; but everybody, of late years, has seen this remarkable instrument in action. It shows living ~~[illegible]~~ scenes acted out for more than a minute with absolute precision. In Edison's apparatus, the film-ribbon never was arrested; but the ~~sharpness~~ of the ~~photogr~~ images ~~images was obtained~~ were rendered sharp by the extreme brevity of the illumination, which was only 1/7000 of a second. A single spectator, looking through eyepieces, could see the living picture of the kinetoscope.

No 12 Lumière's cinematograph, 1895. This instrument finally gave the desired result, that is to say, the projection on a screen of living scenes visible to an

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~~audience~~ assembly and presenting a ~~perfect~~ perfect illusion. The success of this invention was immense and has not passed away. Fig 67 shows the cinematograph open and arranged for taking photographs. A film, perforated like that of Edison, is rolled up in a closed box cc on the top of the apparatus. It passes, in an intermittent manner, to the focus of the objective, being drawn forward by a system of claws which ~~engage~~ catch ~~themselves~~ in the holes of the film. The reciprocating motion of ~~these~~ claws gives ~~the~~ intermittency to the motion of the ~~film~~ ribbon. After exposure, the film is received in another closed box invisible in the figure. It was important to ~~give the claws~~ make ~~the velocity~~ of the claws ~~at the moments of seizure and of separation as~~ acquire and lose their velocity as gradually as possible so as not to tear the film. The Messrs Lumière ~~have~~ succeeded in effecting this by means of a triangular cam which is the essential part of the apparatus. During two thirds of

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the [illegible] times the film is at rest.

For the perfection of the pictures, the Messrs Lumière make use of a special arrangement. A powerful electric lamp brilliantly illuminates the film. In this way, very bright projections are obtained of 25 by 19 feet (7.75 by 5.80), the figures on the film being only 11 by 8 mm (25 by 18 mm). In the glass case, by the sides of the cinematograph, several ribbons printed on paper showed the perfection and happy choice of the photographs obtained with this instrument.

The success of the cinematograph gave birth to many forms of apparatus for the projection of living pictures. Most of them differ very little from the instrument of Messrs Lumière, and were not shown. Two types, however, marked with originality merit special mention.

N° 14. Captain Gossart's apparatus with oscillating objective. 1895. This instrument gives photographs of very large dimensions. The author has applied it to the study of

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No. 23

the gait of the horse. Fine specimens of its work were exhibited.
It is not adapted to projections. S.I. 372

No. 15. The Alethorama of Messrs. Chéri-Rousseau and Mortier, 1897.[1] This is a projecting apparatus in which the perforated film-ribbons, as they pass along, give reflections of their pictures from a series of prisms. The projections are ~~most~~ exceedingly bright and steady, and altogether make a fine effect. The apparatus, however, seems to be hard to adjust and does not appear to have been taken up practically.

No. 16. Analyzing and projecting chronophotograph, Marey, 1898.[1] The writer has pushed the improvement of his chronophotographic apparatus, so as to obtain perfect equidistance of the views; and has succeeded in doing so while preserving the main principle of not perforating the films. For perforation, besides wearing, so as no longer to bring the pictures round regularly, also ~~uses~~ occupies a zone of $\frac{1}{10}$ of an inch (2.5 mm)

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on each edge of the ribbon, this [illegible] a loss which is more important the narrower the film is. The writer has succeeded in obtaining perfect regularity in the exposures by modifying the first pair of rollers which takes the film. The apparatus is shown in Fig. 19. S I 373

"There is also a difficulty in the projections. Namely, the positive film undergoes some shrinkage in the successive developments requisite to obtaining it; in consequence of which, the pictures, being too near together, pass by too soon and tend to leave the field of the screen. A simple drag (frénage) upon the magazine-spool corrects this fault. Positive ribbons of different breadths were exhibited, showing the sharpness and equidistance of the photographs.

I only note the word frénage; but I assume that it comes from frein = brake.

No 15. Microscopic chronophotography, 1899. Jan

The writer has adapted the chronophotograph to the study of motions which take place in the field of the microscope. In order to avoid exposing the animals

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studied in the field of an intense illumination, an arrangement was adopted in which the shutter-disk only produced the lighting up of the preparation during the time of exposure, which is about (1/500) of a second. This done, the brightest light no longer produced any injurious effects. Numerous photographs were exhibited beside the instrument.

№ 18. Chronophotographic gun with a film-ribbon, 1882.

In its original form, the photographic gun only gave twelve views. For a more extended series, an instrument of a new type (Fig 20) was constructed in which the photographs are taken on a band 66 feet (20 m) long. The shutter is formed of a light-work (cabinet à lumière) which is far less cumbrous than a disk. In the stock of the gun (la crosse), is a clockwork movement which is set in motion by a dynamo. Whenever the trigger is pulled, the circuit is closed and the film begins to moving, and does not stop until the trigger is let go. Light accumulators or a

However the expression "cabinet à lumière" is if it were a familiar one; but I never heard of such things. It presumably refers throughout chronophotography on the principle of a faucet.

portable pile furnish the necessary current.

Part II) ... S I 875

SECOND PART:

Scientific Applications of Chronophotography.

Animated projections, interesting as they are, are of little advantage to science; for they only show what we see better with our own eyes. At best, they serve to slow a motion which is too quick for ~~the~~ direct observation, or to accelerate it if its ~~slow motion cannot~~ extreme slowness causes us to miss some of its features.

In the former case photographs are taken at the rate of 40 or 50 to the second and are projected in three or four times the original time. We can thus show a horse galloping or a bird flying so slowly that the eye can follow the motions of the limbs. In the other case, the photographs are taken at very long intervals, and are projected in rapid succession. For this purpose, the

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writer's chronophotograph (Fig 19) is furnished with an arbor upon which, if the ~~b~~ crank is fitted, the effect is that only one photograph is taken at each turn. The slowest, almost imperceptible motions of clouds taken at long intervals and rapidly projected, are translated into a rapid and striking agitation.

S I 376

He ought to show the movements of climbing plants and the growth of a child from the cradle to old age.

What is generally important in the study of a motion is to obtain a geometrical ~~diagram~~ drawing of it. Chronophotography upon a fixed plate gives such a drawing to scale exactly. Chronophotography on a movable film may do so by the aid of certain devices which will be described below. Chronophotography on a fixed plate has furnished the experimental solution of many problems of geometry, mechanics, physics, and physiology that no other method could so readily have resolved.

Geometry. Formation in space of ~~figures~~ geometrical figures of three dimensions. [1] Geometers define ~~this~~ sort of figures by saying that they are generated by straight

[illegible] [illegible] definition [illegible]

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His [illegible] language is intermediate. He does not mean displacement but a motion.

lines or curves of different forms displaced in different ways. Chronophotography realizes this conception completely. Before the pitch-dark field, a white rod, lighted up and subjected to a displacement in space, leaves on the photographic plate the vestiges of its successive positions. It generates on the 377 plane of the plate the projection of the figure in three dimensions which it has formed. In that way has been obtained (Fig 21) the projection of a sphere on a plane. A band of paper, white on one side, black on the other, was ~~twisted~~ curved into a semicircular form ~~and turned~~ rotated about its chord. The figure so formed would have altogether the appearance of a solid sphere if a greater frequency of the illuminations had prevented the discontinuity of the surface generated.

Figure 22, the projection of a [one-sheeted] hyperboloid of revolution, was generated by a strip ~~obliquely~~ placed oblique to the vertical axis round which it turned.

If figures with their relief are sought, the photographs should be taken with a stereoscopic apparatus. Fig. 23

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shows in this way a hyperboloid with its asymptotic cone. These examples, taken from very simple cases of geometry, enable us to imagine what variety of forms would be obtained with complex curves subjected to varied motions. There would be very simple experimental solutions of problems of geometry sometimes most complicated. S I 378

[The method might be an aid to the imagination, though it could never solve a problem of any account, if it were applied to suitable geometrical subjects. But as for the illustrations given, they are absolutely useless. The conception of the one-sheeted hyperboloid is far better got with a string model. It does not apply to anything of that sort to any advantage on account of the transformations being confined to such as can actually be brought about. For the study of four dimensional space it might be a great aid.]

I would not have written this if I had known what a charlatan this creature was to show himself &c.

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Mechanics. Mechanics is founded on the laws of motion, laws of spaces described, of velocities, and of accelerations. The difficulties which Galileo and Atwood surmounted to determine these laws will for the future be saved in all analogous cases for those who shall employ chronophotography for the purpose. One will only have to allow the body whose motion (fig. 24) is to be studied to fall before the dark field and its positions will be marked upon the sensitive plate: the chronograph will give the interval of time which elapses between the body's arrivals at the positions figured; the scale of millimetres will measure the distances described. The same arrangement enables us to make interesting studies of the resistance of the air.

Hydrodynamics is commonly taken to be one of the most complicated sciences. The nature of waves, the nature of violent waves (rapids), the internal motions of molecules in a shallow liquid, the manner in which streamlines behave when they meet obstacles of different forms,

(This is unspeakable rot!! It disgraces any educated man. As if there ever could be an analogous situation to that of Galileo!! Is the camera going to supply intelligence & genius? Does not this mark the degeneracy of a Frenchman? This man to be member de l'Institut. This is enough for me. I want to hear no more of this charlatan.)

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all these ~~fuel~~ questions are still discussed as if they were difficult. All these problems find their experimental solution in chronophotography.

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All that is wanted is to render visible, and alone visible, before a dark ~~field~~ background, those parts of the liquid of which we wish to know the motion. For that purpose, into a canal formed of transparent plate glass is to be poured some very clear water. A mirror inclined at a convenient angle and placed under this canal reflects the light of the sun which then traverses the liquid mass from below upwards. The water is not illuminated, but at the surface of the water, at the point where the wall of the glass is moistened by the liquid, a meniscus is formed, and the under convex surface of this meniscus sends by total reflection a very bright thread of light which oscillates like the surface of the liquid itself. The photographic objective will ~~draw~~ make upon the sensitive plate a photo-

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graph of this line with all its movements.

The interior of the liquid is not lighted up. In order to render certain points of this mass and to perceive the displacements which they undergo, it is only necessary to put into suspension in the water small silvered pearls to which has been given the precise specific gravity of the liquid. These pearls by the agitation which they undergo will express the motion of the molecules of the water at different parts of the mass (fig 23).

Other phenomena of the same class can be studied by chronophotography. Thus, a thin inclined plane being presented to a liquid current, the bright pearls will express by the direction of their course, the motion of liquid fillets. By the distances between their images they will express the rapidity of the current. A scale of millimetres immersed in the water will measure the extent of the motions, while the known interval of time which separates the flashes afford the means of evaluating the velocity. That having been explained,

Here 25 33

A glance at the scale-diagram (Fig. 26) will suffice to show what movements will take place at the surfaces of liquids under conditions however varied and also how the molecules themselves will move at the different points throughout the mass. Si 289

Motions of the air. An analogous arrangement makes it possible to render visible by means of smoke certain fillets of air in the midst of a regular current. We ascertain in that case by the chronophotography the changes of direction and of velocity of this current when it meets obstacles of different forms.

In a large canal having walls of plate glass and before a dark background a draught of air is created by means of a ventilator. In order to regulate the current it is filtered through a very fine silk gauze. At the top of the canal, one sets free, by a series of little tubes, fillets of smoke which descend parallel to one another like the three cords of a lyre. Now

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if one places in the interior of the canal obstacles of different forms, we immediately see the threads bend on these obstacles, slide over them and form behind them eddies [or deadwater remous] of varied forms. Figures 27, 28, 29, show the same experiment under different conditions. In Figure 27, a magnesium flash-light illuminates the phenomenon for a very short time. We see how the fillets of air lick the plane, slide on it, and form backwater behind it. Figure 28 shows the same phenomenon with chrono-photographic indications. The series of little tubes which bring the smoke are made to vibrate ten times a second, so that the smoke no longer appears in rectilinear fillets but as sinusoidal undulations more or less elongated at each point according to the velocity of the current. The motion slows up upon approaching an obstacle and is accelerated at the sides of the obstacle. It will be remarked that the conceptions of time and space which are peculiar to

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chronophotography are brought together in this experiment. Finally in figure 35 the chronography is suppressed. The illumination is no longer instantaneous but is produced by the combustion of magnesium ribbon so that a sort of mean state of the current is recorded."

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Resistance of the air to volateurs [volateurs], a word I do not know of, so I take the nearest possible English form; it would seem. Duncan flying Top. One of the applications of the previous experiments is to make the action of the air on apparatus of different forms which move in this fluid, comprehensible. Fig 30 shows more directly the effects of this resistance. It shows how a little paper soarer (planeur, a word I never heard of, but planer is to soar) left to fall vertically behaves and how it receives from the resistance of the air changes of direction and of velocity which are faithfully represented.

Vibrations of cords. These motions are easily seen

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(This was not chronophotography)
out

upon bright cords vibrating before a dark background.
Our learned fellow academician A. Cornu succeeded in this way in rendering ~~visible~~ perceptible (saisissables, ~~the author's word is simply bad French for perceptible~~) in a cord vibrations of three kinds, the longitudinal, the transversal, and the torsionable. A ~~little~~ very light little mirror attached to the cord indicated these three kinds of motion on a plate having a uniform translation. Fig. 31 is the negative ~~obtained~~ resulting from this experiment.

Physiology. It is to the physiological study of the different gaits of animals and to the functional motions of their different organs that chronophotography has principally been applied. Some types of the experiments which it has rendered possible may here be illustrated.

Terrestrial locomotion. The series of photographs taken on moving films have represented all the phases of motion of man and of quadrupeds. Thus, Figs. 32, 33, 34 represent the three normal gaits of the horse. One can easily follow the succession of attitudes at the ~~progression~~ advance

of the animal. The sequence of time is from above downward.

A disputed case of animal mechanics was also [illegible] whether a cat turns over in falling, and how she does it without any application of external force. Experiment has proved that, as a fact, she does so, thus enabling mechanicians to correct a current error of classical treatises.

Locomotion in water has also been studied by film-photography. These photographs are brought together in order to facilitate render the comparison of them. The locomotion of the eel (Fig. 35) shows the progression of undulations of the body of the animal from head to tail. Lines are drawn to show the direction of motion and the advance of the animal.

In certain fish the undulations take place in the lateral fins. The ray (Fig 36) is shown in side view, swimming without advancing in consequence of being held back (sa progression étant entravée). The same fish seen from the front has motions which strongly recall those of a

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Flying birds.

Locomotion in the air. Not only the flight of birds, but that of insects, studied by chronophotography shows the details of its mechanism. The extreme rapidity of these motions — several hundred per second — requires extreme by short exposures. To avoid any defect of sharpness (flou) due to the velocity of the wing, the writer has reduced the duration of the flash to less than one twenty-thousandth of a second. Only isolated photographs have been obtained; but even these are highly instructive. Fig. 37 is a motionless crane-fly (tipule); fig. 38 shows it in flight. The torsion of the wing under the resistance of the air, a phenomenon which theory had predicted and which explains the mechanism of insect flight, is shown in the picture.

Functional motions. Independently of acts of locomotion, properly the different parts of the body execute various movements the observation of which is in some cases

There is probably some English word for flou; but I do not know it. It consists in the outlines not being absolutely linear but shading off from inside to outside through a sensible breadth.

I doubt the figures representing a genuine crane-fly. All entomologists have not seen to surmount difficulties in handling pictures.

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I don't know what the means by the branch which stands up

excessively
extremely difficult. In speech and in mastication, the lower
jaw has displacements that one would not have anticipated.
tapes
The ribs in respiration rise and separate in a way that was
of old unknown. In certain joints, the bones move about
a fixed centre, while in others there is a rolling motion of the
condyles over the surface in contact with them. Chronophoto-
graphy on the dead black background gives a drawing to scale
of all these motions. Small bright lines or points fixed to the
organ ~~exp~~ under examination interpret the trajectory upon
the photographic plate.

Thus the motions of the lower jaw in the act of opening the
mouth are represented (fig 39) by those of a rod (tige)
bent at an angle and forced to move with the jaw. It will be
seen that the motion is not a rotation round the joint,
but takes place about instantaneous centres in the branche
which stands up (dans la branche montante), while the
condyle itself slides over the surface of the glenoid cavity which

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a curve characteristic.

In respiratory bright points stuck on the ribs are displaced with the latter and interpret the motions on a circular arc of the rising ribs.

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The heart of an animal, laid bare and brilliantly illuminated, gives on the moving film the succession of systole and diastole of its auricles and ventricles. The motions of the eyes themselves have been studied at the physiological station by M. Orchansky. He has chronophotographed the dotted trajectory of the eyes in reading, and in this motion has been able to distinguish the components due respectively to the ocular muscles and to the displacements of the head.

Motions of the air in the emission & utterance of the vowels.

The eminent physicist R. Koenig conceived the idea of making the sonorous vibrations due to instruments or to the voice act upon capsules with membranous walls placed on little gas-burners. These "manometric flames" vibrate in unison with the sonorous waves

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Their images dissociated in a revolving mirror appear with indented mantling (contours) of various forms according to the sound. But this fugitive phenomenon could not be fixed by photography until M. Marage, who has charge of the acoustic work at the Physiological Station, rendered the flames photogenic by substituting acetylene for ordinary illuminating gas. He has taken the photographs by chronophotography on a ribbon of sensitized paper having a translation of two metres per second (100 feet in in 0.254 minute) Fig. 40 shows the vibrations of the air for the French vowels i, u, ou, é, o, a. At the same time as the vibrations of the vowels, those of a tuning fork of 45 V.D. are photographed also, so as to determine the pitch.

Not accented in French. But it is in the figure.

Scale ~~pictures~~ ~~diagrams~~ of ~~movements~~ ~~movements~~ conforme

// Representations of emotions in scale pictures conformed to separate photographs // The documents of chronophotography on a moving film, complete as they are, are difficult to utilize.

Edgerton

on account of the difficulty of comparing the separate photographs. In some cases this comparison can be facilitated by tracing the photographs together (on reconnait ces tracings les uns des autres). But it would be more satisfactory to be able to arrange them, each in its place, on one picture to scale. The writer has accomplished this by means of successive projections and counter proofs on the same sheet of paper.

Let a gymnast throw a weight. [This is chronophotographed on a ribbon.] Let us project the first photograph and carefully counter-prove the form of the body. I suppose he means that the perverted negative is projected, or in some way that the projection is perverted; and that the projection is made on a board. This projection must show the fixed object V (at the left of the horizontal line) which is photographed from nature in all the photographs. He attaches, I suppose, to the board a sheet of carbon paper; and over

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it a sheet of drawing-paper face down. The projection appears on the back of the latter; and he marks with a pencil the outlines of the gymnast's body, the horizontal line, and the object r. These outlines are thus drawn correctly on the face of the drawing-paper. [That is how I understand his description. Translator.] After this first projection, let us project the second photograph upon the same sheet. [His words are, "Après cette première projection, faisons-en une seconde", which literally is, "After this first projection let us make a second of it."] and then a third, taking care to preserve the registry [en repérant exactement] exact, of fixed points which we have chosen. [That is, the horizontal line and object r will have been sharply drawn on the back of the drawing-paper; and in making subsequent projections, care is taken to have that line and object fall upon precisely the same places.] We shall thus have obtained a series of counter proofs representing the successive attitudes of the gymnast. Fig. 41 has been constructed in this way; it affords

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If he could draw each figure in a different color, there would be less confusion. I should like to see the positions of the legs between No 1 and No 2

complete information as to the extent and velocity of each of the motions represented.

In this case only every third photograph has been drawn in order to avoid confusion in the picture to scale. But while reducing the number of images of the athlete, we might show all the successive positions of the weight, which would then have been very numerous. The series of these positions would have given the law of the motion impressed on the projectile and the acceleration would have given in its turn the measure of the forces developed by the gymnast at each instant.

Very roughly

~~This last application of chronophotography is sometimes pretty laborious~~

We can even push the analysis of muscular action so far as to give, in the successive pictures to scale, the positions of the skeleton within the subject, with the phases of extension and contraction of the principal muscles whose

insertions upon the skeleton are of course known. Fig. 142 contains such details.

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This last application of chronophotography is ~~sometimes~~ somewhat ~~rather~~ laborious. ~~We only mention~~ It is only mentioned to show the extreme power of the method and the multiplicity of its applications.

In closing, it may be added that since the Exhibition new applications of chronophotography have been made at the Physiological Station, ~~been~~ which promise the experimental solution of ~~some~~ certain problems hitherto looked upon as insoluble

Marey
of the Institute.
President of Class 12.