and others don't notice it.' This man was very nervous about crossing the divide at all while it was thundering, and plainly said if there was lightning he must wait for fair weather."

Possibly, sound might have accompanied this discharge, but the noise of our wheels would have drowned it.

Holmwood, Putney Hill, May 19. DAN. PIDGEON.

Rain-Clouds.

THE rain-cloud which Mr. Abercromby sketches in NATURE of May 2 (p. 12) is often seen in Upper Austria in summer. I have given a rough sketch of these thunder-clouds in the Austrian *Meteorological Journal*, vol. viii., 1873, p. 104.

Vienna, Hohe Warte 38. JULIUS HANN.

THE MUYBRIDGE PHOTOGRAPHS.[1]

MR. MUYBRIDGE is of English birth, a citizen of the Great Republic, and a professional photographer. Long before he applied his knowledge and skill to the subject of instantaneous photography of moving animals and human beings, he had obtained recognition by his work in producing valuable views of Californian scenery, of Panama and the West Indies. In 1872 he made the first lateral photograph of a horse trotting at full speed, for the purpose of settling a controversy among horsemen as to "whether all the feet of a horse while trotting were entirely clear of the ground" at at any one instant of time. It was not until 1877, however, that he conceived the idea that animal locomotion, which was then attracting considerable attention through the experiments of Prof. Marey, of the Collège de France, might be investigated by means of instantaneous photography, with results of value both to the artist and to the naturalist.

Marey's investigations were made by means of elastic cushions, or *tambours*, which were placed on the feet of the moving animal, and connected by flexible tubes to pencils writing on a chronograph. A record of the impact of each foot on the ground was thus obtained, and important information was deduced from these records as to the succession of footfalls and the time-intervals separating them in the various "gaits" of the horse.

Mr. Muybridge proposed to settle this and similar problems once for all by a complete and demonstrative graphic method. He arranged a number of cameras side by side, parallel to the track along which a horse was to be ridden. Each camera was provided with a specially contrived "exposer" (the word suggested by Mr. Muybridge in place of "shutter"), which could be let go by the pulling of a string. The strings connected with the "exposers" were placed across the path of the horse, so that they must be broken by him successively in his passage. At the instant of the breaking of the string, the exposer was brought into play in the corresponding camera, and thus the horse was photographed in a succession of intervals of about 14 inches, representing, according to the rate of progression of the horse, a time-interval of more or less than one-twentieth of a second.

In this way, in 1878, with the wet plates then in use a few sets of horses moving with various gaits were taken by Mr. Muybridge. The results were astonishing and conclusive. They were published at the expense of Mr. Leland Standford, under the title of "The Horse in Motion," and were exhibited in Europe in 1882 by Mr. Muybridge, together with other photographs taken in 1879. The reception which Mr. Muybridge met with on his visit to Paris and London was a great encouragement to him to proceed with his work. Meissonier, the great French painter, was enthusiastic in his admission of the value of the photographs as a guide to the observation required for all true artistic work, and the story goes that a particular attitude of the horse presented by him in one of his best known pictures which had been objected to by the critics as unnatural, was demonstrated by the Muybridge photographs to be perfectly correct. The series of little black *silhouettes*, which were at that time the form in which Mr. Muybridge obtained his pictures, were so contradictory of all preconceived notions as to what were the actual phases of attitude passed through by a trotting or a galloping horse, and so difficult to reconcile with the conventional representations of what is of course a totally different thing, viz. what we see when a trotting or galloping horse crosses our field of vision, that Mr. Muybridge determined on his return to America in 1883 to pursue the subject, and to apply improved methods of photography to the study of the rapid movements of a variety of animals and of man. The new dry plates now made it possible to obtain in exposures of 1/5000 of a second and less an amount of detail which was previously impossible. New automatic methods of registration and exposure were to be employed, larger pictures obtained, and the selected series printed without re-touching by a permanent photogravure process. The funds necessary to carry out this scheme were beyond Mr. Muybridge's own resources, and he for some time failed to obtain the necessary aid from any publisher or scientific institution. A Committee of the University of Pennsylvania thereupon came forward and placed £6000 at Mr. Muybridge's disposal, solely on condition that the first proceeds of the sale of the photographs when ready for publication should be assigned to the reimbursement of this sum. The words of Dr. William Pepper, the Provost of the University, in recording this most worthy action, are remarkable, and ably state that conception of the part of the University in the life of the State which we have so often advocated in these pages. "The function of a University," says Dr. Pepper, "is not limited to the mere instruction of students. Researches and original investigations, conducted by the mature scholars composing its Faculties, are an important part of its work; and in a larger conception of its duty should be included the aid which it can extend to investigators engaged in researches too costly or elaborate to be accomplished by private means. When ample provision is made in these several directions, we shall have the University adequately equipped and prepared to exert fully her great function as a discoverer and teacher of truth."

As a result of the action of the University of Pennsylvania in providing Mr. Muybridge with the means to carry out his experiments, we have a really marvellous set of plates—781 in number—each containing a series of from twelve to thirty pictures representing successive instantaneous phases of movement. About 500 of the plates represent men, women, and children, nude and semi-nude, in successive phases of walking, running, jumping, dancing, bathing, fencing, wrestling, boxing, and other such exercises. The rest of the plates give similar studies of the various gaits of horses, asses, mules, oxen, deer, elephants, camels, raccoons, apes, sloths, and other quadrupeds, as well as of the flight of birds. Many of these photographs have been, this spring, exhibited in London by Mr. Muybridge, projected on the screen by electric light—at the Royal Society, the Royal Institution, the Royal Academy, and the South Kensington Art School. The whole series can now be obtained by those who desire to possess them, and to assist the University of of Pennsylvania by bearing a portion of the expense of their production. Series of not less than one hundred plates are also to be disposed of, and may be seen on application to Mr. Muybridge, who is at present in London.

The interest which these photographs present from the scientific point of view is threefold:—

(A) They, first of all, are important as examples of a very nearly perfect method of investigation by photographic and electrical appliances.

[1] "Animal Locomotion: an Electro-photographic Investigation of Consecutive Phases of Animal Movements." By Eadweard Muybridge. (Published under the auspices of the University of Pennsylvania, 1883.)

(B) They have also a great value on account of the actual facts of natural history and physiology which they record.

(C) They have, thirdly, a quite distinct and perhaps their most definite interest in their relation to psychology.

It seems, indeed, that the most interesting problems which are brought before us in the Muybridge photographs of the galloping horse are not so much those of animal locomotion itself as these, viz. how is it that this (which is demonstrated by the photograph to be the actual series of attitudes assumed by the galloping horse) has given rise through the human eye and brain to the conventional representation with outstretched fore and hind legs? Can the conventional representation be justified? If it cannot, what do we really *see* as opposed to what really *is*? What is the objective fact—the brain-picture—as opposed to the objective fact—the sun-picture? for it is the former which the painter struggles to reproduce. Here, in fact, science and art are absolutely united in one common search after truth.[1] On this subject I hope to say more in a subsequent article.

With regard to the method and apparatus employed by Mr. Muybridge in the present series of photographs, it is to be noted that they are different from those employed in 1878–79. As in his earlier photographs, so in the later series, Mr. Muybridge's object was to obtain successive clear and separate pictures. In this respect his method differs altogether from the simpler and much cheaper one used by Marey since the publication of Muybridge's first results. Marey's method is, no doubt, efficient, and in a certain sense sufficient, for the purpose of determining some of the main facts as to the phases of the limbs in locomotion. The object to be studied moves in sunlight before a dark background. A photographic camera faces it. A large disk with one or more openings in it is rapidly revolved in front of the lens. Whilst the opening is passing the lens, the moving object is photographed; then there is darkness in the camera until an opening again passes the lens. The moving object has now a new position, and is photographed anew on the same plate; and so on, again and again, as often as required, or until the object has moved beyond the range of the plate. Thus on the same plate are developed a series of images, readily compared and faithfully depicting phases of the movement studied at definite intervals of time. The advantage of this method consists in the simplicity of the apparatus required; its defect is that with rapidly moving objects the amount of light necessary is not easily obtained together with a sufficiently dark background.

Mr. Muybridge's perfected apparatus consists of three batteries, each of twelve (or more) cameras. One battery is parallel to the track, a second looks up it from behind the moving object, a third faces the moving object. Each camera is provided with a specially contrived "exposer" or shutter (so called) which is "let off" by means of an electric current. The exposure thus given is as small as the 1/5000 of a second. The electric connection is such that in each of the batteries A, B, C, a camera, A1, is exposed absolutely synchronously with cameras B1 and C1. So, too, with regard to cameras A2 B2, and C2, and with the rest up to A12, B12, and C12. Each exposure thus gives a group of three synchronous pictures recording lateral, fore, and hind views of the moving object. The intervals between the exposures of the successive trios of cameras, ABC1, ABC2, ABC3, &c., is determined by the rotation of a wheel carrying a metallic brush in front of a circular plate, on the circumference of which are placed equidistant metal studs, one connected with the wires going to each trio. The circuit is completed by the contact of the metal studs with the moving metallic brush. The wheel can, by a special mechanism, be rotated so that a revolution is effected in one second or in any fraction of a second. During one revolution the twelve studs make contact at equal intervals of time, and twelve groups of three photographs each, exposed for the 1/5000 of a second and separated from one another by one-twelfth of the time occupied by a revolution, are taken. Usually, Mr. Muybridge found it convenient to set the wheel so that it should rotate at such a rate as to give 1/30 of a second between the contact of the twelve studs, but longer intervals were also employed. Behind the track along which the object was made to move was a black screen divided by white threads into squares of about 2 inches to the side. The bright sunlight of the open space was the illuminating agent, no artificial light being sufficiently powerful. A full account of the apparatus will be found by those specially interested in the subject in a book published by Lippincott Company of Philadelphia in 1888, entitled "The Muybridge Work at the University of Pennsylvania—the Method and the Result." Enough has been said here to give an idea of the perfection attained in the apparatus.

With regard to the results, in the form of facts recorded of interest to the naturalist and physiologist, it is not easy to speak in the brief space at my disposal. The branch of inquiry opened out by this method of instantaneous photography is in its infancy, and generalizations of any consequence can hardly be looked for at present. The questions to be answered—the hypotheses which it will be necessary to test—have not yet been formulated. What we have in Mr. Muybridge's published plates is a number of individual studies. By far the most complete investigation is that of the various gaits of the horse, which may be considered as very nearly exhaustive. An interesting generalization which perhaps might have been arrived at without the aid of the camera—but could not have been clearly demonstrated without it—is that the walking gait of all Mammalia is the same, including the quadrupedal crawl of the infant man, and the progression of the sloth as it hangs from a horizontal pole. An apparent exception to this rule is found in the baboon, which instead of extending one pair of "diagonals"[1] simultaneously and then bringing them together beneath the body whilst the other pair is extended, exhibits the simultaneous extension of a lateral pair followed by their approximation whilst the opposite lateral pair are extended. The analysis of various gaits involves many points besides the mere swing of the limbs, the most obvious and important of which are the succession of the footfalls, the weight of impact, and its exact period (which need not coincide with visible contact of foot and ground), the exact mechanical value of the complex stroke given by the limb, and the exact period at which it is applied (which need not altogether coincide with that part of it given by the foot as it leaves the ground). Another factor to be studied is the rotation of the various segments of the limb.

Information and suggestion on these points are furnished by the photographs, but it is by no means to be supposed that it is possible that once for all these problems can be settled by any set of photographs, however elaborate. The turning of the quill-feathers of the bird's wing during the upward movement or recovery of the wing, so that they cut the air instead of pressing it with a broad surface, is one of the prettiest demonstrations which Mr. Muybridge has obtained. That such a movement takes place seems to have been observed by the ordinary man in the remote past, for the word "feathering," applied to the similar movement of an oar in rowing, implies a knowledge of the setting of the feathers in the upward movement of the bird's wing.

[1] Mr. Francis Galton, in NATURE, vol. xxvi. p. 228, has made a valuable suggestion on this subject—which is repeated by Mr. George Snell in the *Century* in 1883—to the effect that the brain-picture consists of a blending of the extreme positions of extension of the hind limbs and the fore limbs, which, although not actually coincident in time, are longest in duration of all the phases passed through.

[1] The "diagonals" are the right fore limb and the left hind limb, and the left fore limb and the right hind limb; the "laterals" are the right fore and hind limbs and the left fore and hind limbs.

Whilst the photographs furnish abundant material for the further study and consideration of the normal movements of a variety of animals and of man, there are some in the series which are especially suggestive of new lines of research. Amongst these are the series illustrating locomotion in man in diseased conditions, such as locomotor ataxia, and lateral sclerosis. A distinct line of scientific inquiry is suggested by those photographs which represent men, women, or children, in the course of movement which is associated with emotion. A new chapter in Mr. Darwin's "Expression of the Emotions" could be written by the aid of some of these series, and a most interesting line of investigation, to be followed up by new photographic analysis, is indicated. Not only is the play of facial muscles connected with the series of emotions of the base-ball player recorded in half a dozen pictures taken between the moment of raising the bat and striking the ball, but in other photographs we have unconscious expression of mental condition exhibited by rapidly transient movements of the whole body. These are especially noticeable in the series of a naked child approaching a stranger in order to offer to her a bunch of flowers, and in the three or four phases of movement of the young woman springing from her bath after she has been unexpectedly "douched" from head to foot with a bucket of ice-cold water.

It is clear enough that the correlation of movements of facial and limb muscles in the expression of emotion can be best studied by such instantaneous photographic series as the Muybridge publication contains; and, as Darwin, with his marvellous insight, showed, such study of emotional states furnishes some of the most important evidence with regard to the relationship of man and animals.

It is no doubt true that the immediate result of Mr. Muybridge's work, from the scientific point of view, is the desire which they evoke to apply this method systematically and experimentally to a variety of subjects of investigation. The present pictures have great value, and many of them great—indeed astonishing—beauty (*e.g.* the wrestling boys). They should be purchased by those who can afford them for the purpose of bearing a share in the expense of so important an experiment as that set agoing by the University of Philadelphia. But we should like to see the batteries turned on again, and a number of new subjects investigated. Terrestrial locomotion has been gradually developed through an amphibious transition from aquatic locomotion. The movements of fishes, of tadpoles, salamanders, turtles, and crocodiles should be included in the scope of any study of vertebrate limb-play. But even more necessary is it that in future the scientific method, of theory, test hypothesis, and experiment, should be followed in the application of the photographic batteries, so that each set of photographs may definitely prove some particular point or points in the orderly development of a general doctrine.

For my own part, I should greatly like to apply Mr. Muybridge's cameras, or a similar set of batteries, to the investigation of a phenomenon more puzzling even than that of "the galloping horse." I allude to the problem of "the running centipede." I have a series of drawings made from large West Indian specimens which I kept alive for some time in my laboratory at University College. At the same time I made drawings and recorded as well as I could the movements of the legs of *Peripatus capensis*, which was also (through Mr. Sedgwick's kindness) living in my laboratory. I am anxious to compare with these movements the rapid rhythmical actions of the parapodia of such Chætopods as Phyllodoce and Nephthys on the one hand, and the curious "gait" of the Hexapod insects, of which Prof. Lloyd Morgan has already written a few words in NATURE. Passing on to scorpions and spiders, and then to shrimps, lobsters, and crabs, we should eventually possess the outlines of an investigation of Arthropod locomotion. There is no doubt that the Muybridge battery would be the one effective means of study in the case of the centipede and marine worms, although in some cases a good deal may be done by intent observation and hand-drawn records. The difficulty of this investigation, and the disastrous results in the way of perplexity which follow from too close an application to it *without* the aid of Mr. Muybridge, is set forth in certain lines, the authorship of which is unknown to me or to the friend who kindly sent them to me on hearing that I was studying the limb-play of centipedes. May I be pardoned for quoting them, and associating in this way fancy with fact, whilst expressing the hope that Mr. Muybridge will take steps to prevent any such catastrophe in the future as these lines record!

A centipede was happy—quite!
Until a toad in fun
Said, "Pray which leg moves after which?"
This raised her doubts to such a pitch,
She fell exhausted in the ditch,
Not knowing how to run.

E. RAY LANKESTER.

ON THE DETERMINATION OF MASSES IN ASTRONOMY.

IN the *Annuaire du Bureau des Longitudes* for 1889 occurs an interesting article by M. Tisserand on the methods employed in the measurement of the masses of the heavenly bodies. The writer begins with an explanation of the elementary principles leading to the law of Newton that *all bodies attract one another with a force which is proportional to their masses and inversely as the square of the distance between them.* He proves, in a popular manner, that this force is equal to the product of mass into acceleration; and therefore, speaking theoretically, to compare the masses of two bodies it is only necessary to apply directly to each of them the same force and to measure the acceleration produced; or, if a body be placed in succession at the same distance from the sun and the earth it will be attracted towards each with a force which is proportional to their masses. Hence, since the space traversed by a body is directly proportional to the acceleration, if during the first second the body fell 330 metres towards the sun, and 1 millimetre towards the earth, it would be obvious that the sun had a mass 330,000 times greater than the earth. Similarly, by applying the law of inverse squares, the relative masses of the sun and earth might be found when the distance of the body from each was not the same. We find that the earth falls towards the sun 10·60 metres in a minute, and that our moon falls towards the earth 4·90 metres in the same time. But the earth is 386 times nearer the moon than it is to the sun, so correcting for difference of distance we get $\frac{4 \cdot 9}{(386)^2} =$ 0·0000328 metre as the fall of the moon towards the earth in a minute. Therefore the sun's mass is to the earth's mass as 10·6 is to 0·0000328—that is, 1/323,000. This method is, however, dependent on our knowledge of the distance of the sun and moon. The same calculation may be employed, without modification, to find the mass of a planet having a satellite. Kepler's third law is used for expressing the mass m of a planet in terms of the sun's mass M. The formula being:—

$$\frac{m}{M} = \left(\frac{a'}{a}\right)^3 \left(\frac{T}{T'}\right)^2,$$

where a is the semi-major axis of the planet's orbit and T the time of revolution round the sun; a' and T' representing similar terms for the satellite.

In the case of Jupiter, observations of the four satellites may be made and the mean result taken. A recent determination by M. Schur gives the value 1/1047·232 as compared with the sun.