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Marey, Etienne-Jules. - A study in locomotion ["Moteurs animés; expériences de physiologie graphique"]

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and July which might apply to the object seen by De Vico, assuming it to have been an intra-Mercurial planet. Leverrier did not attempt to discuss these observations, confining his attention to those made about the equinoxes, clearly belonging to a different body.

GEOGRAPHICAL NOTES

SOME of our contemporaries have been a little premature in appointing the Earl of Northbrook to the presidency of the Royal Geographical Society, for at the time when the announcement was first made his lordship was not even a fellow of the Society. The fact, we believe, is that Lord Northbrook has expressed his willingness to accept his nomination by the Council, but there is no likelihood of any election taking place till the anniversary meeting on May 26th.

AT the meeting of the Geographical Society on Monday evening Dr. James Stewart, of the Livingstonia Mission, East Africa, read a paper on the "Second Circumnavigation of Lake Nyassa." The voyage was undertaken in the little steamer *Ilala* in the latter part of 1877. It was found that Lake Nyassa has hitherto been laid down on our maps too far to the east, and that its position ought to be shifted at the north end as much as thirty miles to the westward. Dr. James Stewart was also fortunate in discovering two harbours such as were needed for the safe navigation of the lake; the one Rombashi inlet or river on the northern coast, and the other the Kambwe lagoon a little to the south of it on the west coast. Mr. James Stevenson afterwards gave a few particulars respecting the explorations now being carried on by Dr. Laws and Mr. James Stewart, of the Bengal Civil Service, in the country on the western side of Lake Nyassa.

THE Abbé Debaize, the leader of the French expedition to Central Africa, sends to M. Richard Cortambert a letter, rejoicing at the success of his expedition so far. He writes from Taboro, in Unyamwezi, and states that hitherto he has been completely successful; there have been no desertions, little expenditure, and no misfortunes of any kind. This good fortune he ascribes to his own excellent health, to his firm discipline, and his personal superintendence of all arrangements. He has a very poor opinion of Mirambo, and thinks the English are striving hard to become masters in Central Africa; indeed he hints that "annexation" is not far off. At Mwapwa, where the sole white population are an English "reverend, a mason, and a carpenter," there are already four stone houses, while there are English stations in Ukrewe, Uganda, and at Ujiji.

THE *Daily News* Lisbon correspondent states that the Portuguese Minister of Marine has informed the Cortes that he has received a telegram stating that the Portuguese African explorer Pinto, who was separated from his companions at Bihe, has succeeded in traversing Africa from west to east, having reached the Transvaal.

FRANCE and the United States will soon establish a comparison of the longitude of Paris and Washington by cable. As is known, these operations lead to a determination of the velocity of propagation of electric waves. Commander Perrier and M. Lœwy have recently published a volume giving the details of the comparison between Paris, Marseilles, and Algiers.

MR. STANFORD has just published a very fine stereographical map of Zululand, with portions of the adjoining territories. On the bases of what observations there are as to the physical conformation of the country, together with the pretty fair notions we have of the courses of the rivers, a good general notion is conveyed of the character of the surface and its various levels. The map conveys, moreover, a great amount of information in a clear and striking manner, that will be extremely useful to those

who wish to understand the history and bearings of the Zulu difficulty.

UNDER the title of "Le Maroc" the current number of the *Tour du Monde* contains the commencement of a translation of M. Edmondo de Amicis' account of his experiences in Morocco in 1875. The present instalment deals with Tangier, and is accompanied by several illustrations.

WE understand that Prof. Geikie, of Edinburgh, will probably deliver a lecture on Geographical Evolution before the Royal Geographical Society on Monday, March 24.

THE Emperor of Austria has presented Captain von Oestreicher with the medal for letters and arts (*litteris et artibus*) in recognition of his recent highly interesting geographical work, "Aus fernem Osten und Westen."

DURING last year the following journeys were made by Russian explorers in Central Asia:—Generals Stolyetoff and Razgonoff were accompanied during their mission to Kaboul by several topographers and explorers; M. Oshanin has made explorations in Karategin and Hissar; M. Matséeff in Badakshan and Eastern Afghanistan; M. Grodékoff in Western Afghanistan and Herat; M. Bykoff has explored the Amu darya River from Kobadian to Khiva; M. Yavarsky has traversed for the fourth time the region between Tashkend and Kaboul; M. Mayeff has visited for the second time the hilly track between Karshi, Keliff (on Amu darya), Kobadian, and Hissar; and, finally, the steamer *Samarband* has navigated the Amu, from Petro-Alexandrovsk to Khodja-Sale.

UNDER the title of Société de Géographie de l'Est, there has been founded at Nancy a new geographical society.

A STUDY IN LOCOMOTION¹

IF the interest of a scientific expositor ought to be measured by the importance of the subject, I shall be applauded for my choice. In fact, there are few questions which touch more closely the very existence of man than that of animated motors—those docile helps whose power or speed he uses at his pleasure, which enjoy to some extent his intimacy, and accompany him in his labours and his pleasures. The species of animal whose co-operation we borrow are numerous, and vary according to latitude and climate. But whether we employ the horse, the ass, the camel, or the reindeer, the same problem is always presented: to get from the animal as much work as possible, sparing him, as far as we can, fatigue and suffering. This identity of standpoint will much simplify my task, as it will enable me to confine the study of animated motors to a single species; I have chosen the horse as the most interesting type. Even with this restriction the subject is still very vast, as all know who are occupied with the different questions connected therewith. In studying the *force of traction* of the horse, and the best methods of utilising it, we encounter all the problems connected with teams and the construction of vehicles. But on a subject which has engaged the attention of humanity for thousands of years, it seems difficult to find anything new to say.

If in the employment of the horse we consider *its speed* and the means of increasing it, the subject does not appear less exhausted. Since the chariot races, of which Greek and Roman antiquity were passionately fond, to our modern horse-races, men have never ceased to pursue with a lively interest the problem of rapid locomotion. What tests and comparisons have not been made to discover what race has most speed, what other most bottom,

¹ "Moteurs animés; Expériences de Physiologie graphique." [Lecture by Prof. Marey at the Paris meeting of the French Association, August 29 1878.]

what crossings, what training give reason to expect still more speed?

Lastly, as to what is called the exterior of the horse, and his varied paces, specialists have for long devoted themselves to this department. The horseman is trained to distinguish between these different paces, to correct by the education of the horse those which seem to him defective, to fix by habit those which give to his mount more pleasant reactions or a much greater stability. The artist, in attempting to represent the horse, seeks to transfer his attitudes more and more faithfully, to express better and better the force, the suppleness, and the grace of his motions.

These questions, so complicated, I wish to bring before you by a new method, and I hope to show you that the *graphic method* makes light of difficulties which seem insurmountable, discerns what escapes the most attentive observation; finally, it expresses clearly to the eyes, and engraves upon the memory the most complicated notions. The graphic method was almost unknown twenty-five years ago; to-day it is wide-spread. Thus, in almost all countries, recourse is had to the employment of graphic curves as the best mode of expression to represent clearly the movement of administrative, industrial and commercial statistics. In all observatories apparatus known as *registering or recording*, trace on paper the curves of variation of the thermometer, the barometer, rain, wind, and even atmospheric electricity. Physiology utilises still more largely recording apparatus; but I shall only require to show you a very small number of these instruments, those which serve to record forces, rates of speed, or to note the rhythms and the relations of succession of very complicated movements.

1. *Of the Force of Traction of the Horse, and the best Means of Utilising it.*—When a carriage is badly constructed and badly yoked the traveller is jolted, the road is injured, the horse is fatigued more than is necessary, and is often wounded by parts of the harness. Science and industry have long sought to discover these inconveniences, to find out their causes in order to get rid of them. But it is only in our own time that great progress has been made in this respect. When we complain of being jolted in a humble cab, we ought to go back in thought to the time when people knew nothing of the hanging of carriages. No roughness of the road then escaped the traveller. A Roman emperor mounted on his triumphant chariot was, in the midst of his glory, as ill at ease as the peasant in his cart. Except some improvements, such as the use of softer cushions, things went on thus till the invention of steel springs such as are now employed, for the leather braces of old-fashioned carriages still left much to desire.

Does this mean that the present mode of suspending carriages by four and even eight springs is the final step of progress? Certainly not. Our present springs diminish the force of jolts, transform a sudden shock into a long vibration; but the perfect spring ought always to maintain a constant elastic force, to allow wheels and axles all the vibrations which the ground demands of them, without allowing any of these shocks to reach the carriage itself. The search for this ideal spring has engaged the attention of one of our most eminent engineers. M. Marcel Deprez has found happy solutions to the problem of perfect suspension; he will, doubtless soon apply these in practice.

A good suspension also saves the carriage by suppressing the shocks which put it out of order and destroy it in a short time. Finally, suspension saves the wheel itself. On this subject let me recall a remarkable experiment of General Morin. On a high road, in good condition, he drove a diligence with four horses at the trot, and laden with ballast instead of passengers. The springs of the vehicle were raised so that the body rested on the axles. After the diligence had passed and repassed a

certain number of times, it was found that the road on which it was running was notably deteriorated. The springs of the carriage were replaced and the same movements were repeated on another part of the road; the marked deterioration was no longer produced. It is thus clearly proved that a good suspension is favourable to a good condition of the roads.

But with non-suspended vehicles, in order thus to shock the passengers, disjoint the carriage, and abuse the road, force is necessary. It is the horse which must supply this; so that, independently of the useful work which we demand of them, the animal supplies still other work which gives rise to a multitude of shocks, and has only injurious effects. The employment of suspending springs has rendered the double service of suppressing injurious vibrations and of collecting into a useful form all the work which they represent.

Is this all? Do there not remain, even with the best carriages, other vibrations and other shocks which must be pursued and destroyed in order to render more perfect the conditions of traction? You have all experienced, at the moment of the sudden start of a carriage, and even at each stroke of the whip on a living horse, horizontal shocks which sometimes throw you to the bottom of the carriage. In a less degree, shocks of the same kind are produced at each instant of traction, for the speed of the horse is far from being uniform, and the traces are subjected to alternate tension and slackness. Here are veritable shocks which use up part of the work of the horse in giving only hurtful effects which bruise and contuse the breast of the animal, injuring his muscles, and, in spite of the padding of the collar, sometimes wounding him. To prove the disadvantages of this kind of shocks, some experiments are necessary. I have borrowed one from Poncelet; it is easily made, and any one may repeat it. I attach a weight of 5 kilos to the extremity of a small string; taking hold of the free extremity of this, if I gently raise the weight, you see that the cord resists the weight of 5 kilos and holds it suspended. But if I attempt to raise the same weight more rapidly, I bruise my fingers, the cord breaks, and the weight has not budged. The effort which I have made has been greater than the preceding, since it has exceeded the resistance of the cord; but the duration of this effort has been too short, and the inertia of the weight not being overcome, all my exertion has been expended in injurious work. If, instead of an inextensible cord, I had attached to the weight a cord a little extensible, the sudden effort of elevation which I made would have been transformed into an action more prolonged, and the weight would have been raised without breaking the cord and bruising my fingers. To render the phenomenon more easy of comprehension, I shall make a new experiment under conditions a little different.

You see on a vertical support (Fig. 1) a sort of balance-beam, which bears on one of its arms a weight of 100 grammes, on the other a weight of 10 grammes suspended at the end of a cord one metre long. Between these two unequal weights the beam is maintained by a spring-catch, which prevents it from falling to the side of the heavier weight, but which, on the other hand permits the beam to incline in the opposite direction, if we bring to bear on the end of the cord an effort greater than the weight of 100 grammes. But, by letting the smaller weight fall from a sufficient height, at the moment when this reaches the end of its course, it will stretch the cord which holds it, and will develop what is called a *viva viva*, capable of raising the weight of 100 grammes to certain height; but this elevation will only take place on condition that the application of this force does not give rise to a shock. If the cord which sustains the weight of 100 grammes is inextensible, and if that which bears the weight of 10 grammes is the same, at the moment of the fall of the latter, you will hear a snap; a shock agitat

the whole apparatus, but the weight of 100 grammes is not raised.

Now suspend this weight of 100 grammes to an india-rubber cord or an elastic spring, and repeat the experiment. You see each time that the weight falls that the 100-gramme weight is raised to a certain extent. But this elevation is effected under peculiar conditions. At the moment when the weight falls and the cord is stretched, the balance inclines, stretching the elastic spring, but the mass of 100 grammes does not yet move; it is only when this spring is stretched that the mass, obedient to the prolonged action of this elastic spring,

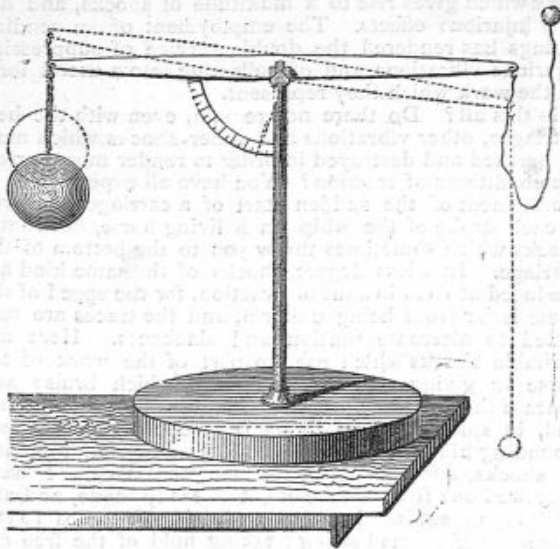


FIG. 1.—Apparatus to show that a *vis viva* directly applied to the displacement of a mass is lost in a shock, while the same force transmitted by an elastic medium may perform work.

begins to move and rises, representing a certain amount of work accomplished.

Thus, the suppression of shock in traction, economises a certain part of the moving labour; it is *then* advantageous to give to the traces of a carriage a certain elasticity. One of the most simple methods consists in interposing between the trace and the carriage an elastic medium. Here are some of these elastic pieces, which I call *tractors*. One of the patterns has been made by M. Tatin; it is composed of a spring which is compressed by traction and deadens the shock. The other is formed of a similar spring placed in the very inside of the carriage-trace.

If you wish to be convinced of the advantage of this mode of traction, yoke yourself to a hand-barrow by

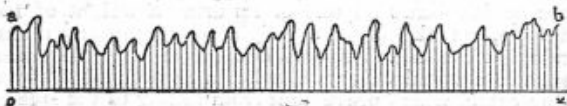


FIG. 2.—Tracing of the dynamograph for a vehicle drawn by a horse.

means of a rigid leather strap, such as you see used in the streets of Paris or London, where too often man is employed to drag burdens. When you have well noted the painful shocks which this mode of traction transmits to the shoulders, place between the strap and the barrow the elastic tractor and repeat the experiment. After that no doubt is possible; the shoulders are no longer bruised by the shaking of the pavement, and a comfort is experienced which will evidently be experienced in the same degree by a horse placed in conditions of elastic traction.

To obviate suffering to men and animals is unfortunately not a motive sufficient to induce everybody to

modify the old system of harnessing. To certain minds known as *positive*, it is necessary to prove that elastic traction has economical advantages, and that a horse thus harnessed is able to draw heavier loads. This fact, which results from the experiments which you have seen, requires, to be rigorously proved, the aid of the graphic method. It is to the genius of Poncelet that we owe the record of work expended by different motors.

Everybody knows what a dynamometer is, viz., a spring which, yielding to tractions exerted upon it, is deformed in proportion to the efforts developed. Let us adapt to a spring of this kind a pencil which touches a strip of paper, and let us so arrange things that the movements of the wheel of a carriage shall impress upon the paper a motion of translation. While the effort of traction of the horse will communicate to the spring movements more or less extended, the progress of the carriage will

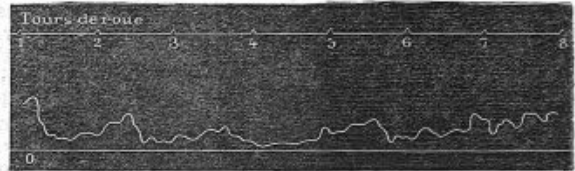


FIG. 3.—Tracing of the dynamograph for a vehicle drawn with an elastic intermediary.

draw out the paper, and from these combined movements will result a curve (Fig. 2), which can be resolved into a series of ordinates or vertical lines in juxtaposition, expressing by their unequal heights the series of efforts resulting from each element of the road traversed. The sum of these elementary efforts, otherwise the surface of paper limited in height by the flexures of the curve, will be the measure of the work expended. If we record in a comparative manner the work done by the same vehicle harnessed with rigid traces or supplied with elastic tractors, we see (Figs. 3 and 4) that the *area* of the curve is greater, that is, that there has been more work expended, while rigid traces have been used. In the most favourable cases that I have met with, the economy of work by elastic traction has been 26 per cent.

But, it may be objected, the recording dynamometer itself constitutes an elastic intermediary which suppresses

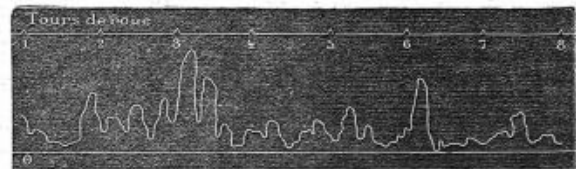


FIG. 4.—Tracing of the dynamograph for a hand-barrow drawn by a rigid trace.

the shocks. But it is not the ordinary dynamometer which I have used in my experiments, but a special dynamometer which undergoes under the strongest tractions only an almost insignificant elongation. This elongation, amplified by certain organs and transmitted to a distance by a lever fitted with a pen, is recorded in the form of a wavy curve in conditions referred to above. To sum up, in the employment of animated motors for the drawing of burdens, to find out wherever they produce shocks and vibrations, and to absorb them in elastic springs which restores to useful work a force that seemed only to destroy vehicles, tear up the roads, cause the animals to suffer—such is the direction in which much progress has been realised, and much more may still be realised.

2. *Of the Speed of Animated Motors.*—I shall per-

haps astonish many of you by saying that the speed of a vehicle is one of the things most imperfectly known. It is generally believed to be sufficiently expressed by stating how much way has been made and how much time has been occupied for that. I have come, you may say, from the Pont de Sèvres to the Madeleine in $41\frac{1}{2}$ minutes; the

road is well mile-stoned, I possess a good watch; what greater precision do you require? Assuredly you have measured accurately the space traversed and the time employed, but that constitutes only the expression of a mean speed resulting from a series of variable speeds, of accelerations, of retardations, and sometimes of stoppages

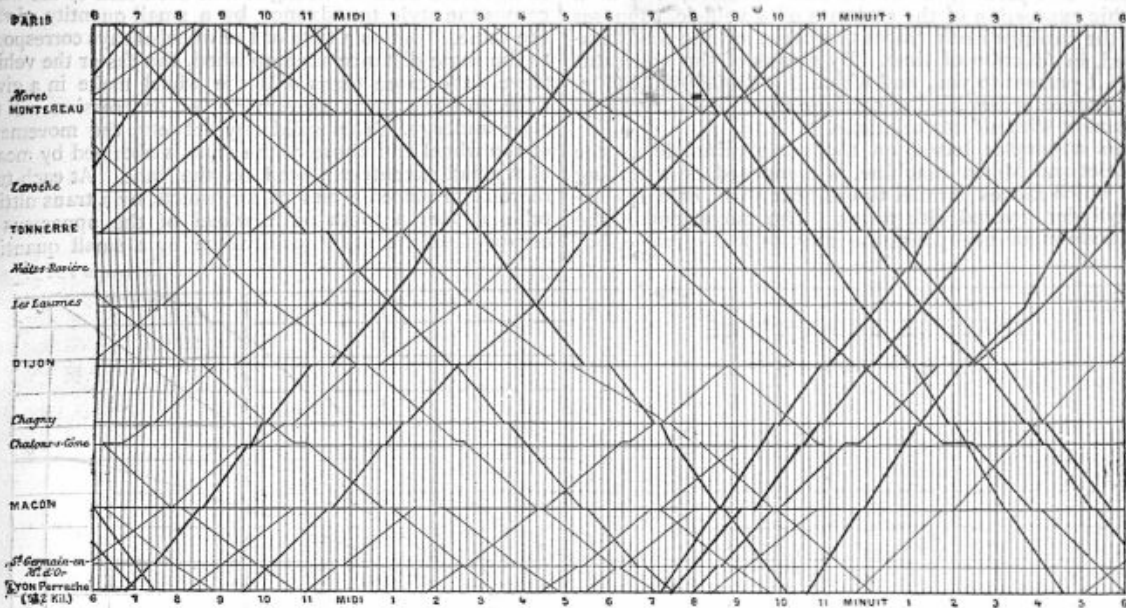


FIG. 5.—Graphic of the progress of trains upon a railway, after Iby's method.—When we place the figure before us we read from the left, on the axis of the ordinates, the series of stations, that is, the divisions to be run over; the distance between the stations on the paper is proportional to the kilometers which separate them. In the horizontal direction, that is, on the axis of the abscissae, are counted the divisions of time in hours, themselves subdivided into spaces of ten minutes each. The breadth of the table is such that the twenty-four hours of the day are represented on it, commencing at 6 A.M., and ending next day at the same hour. If we wish to express that a train is on a certain point of the line at a certain hour, we shall point out its position on the table, opposite the station or any point of the line which it occupies and on the properly chosen division of time. A single point of the table satisfies these conditions. At successive instants the train will occupy points on the table always different; the series of these points will give rise to a line which will be descending and oblique from left to right for trains coming from Paris, while it will be ascending and oblique in the same direction for trains going to Paris. The line which corresponds to each of the trains expresses the hours of departure and arrival, the relative and absolute rates of the trains, the instant of passing each of the stations, and the duration of stoppages. In fact, if we consider any particular train, we see that a train starts from the station at Paris at 11 A.M.; if we follow this train in its progress, we find that it has seven stoppages (during which it is not displaced in space, but only in time). These stoppages are translated by the horizontal direction of the line, opposite the station where they take place; the length of this horizontal line measures the duration of the stoppages. The line of the train, followed to the end, shows that the arrival takes place at 6 P.M.; but, if we reckon the distance on the axis of the ordinates, we see that 512 kilometres have been traversed in eleven hours ten minutes, stoppages included, which gives a mean rate of about 46 kilometres per hour.

where time is quite unknown. A rigorous measurement of rates supposes the road traversed by the vehicle at each instant; in other words, the position which it occupies upon the road. It is thus that physicists have determined the accelerated motion of the fall of bodies—Galileo and Atwood, by means of successive measurements, Poncelet and Morin by means of that admirable apparatus which traces by a single stroke the curve of a movement.

This machine is now too well known to need description; however, I shall make it work before you in order to interpret its language and to show how a graphic curve translates all the phases of a movement. The parabolic curve traced expresses for each of its points the position in which the body is found at each of the instants of its fall; it thus supplies the most complete information on the nature of the movement. But if, knowing only the space run over and the time employed, we join the two extreme points of departure and arrival by a straight line, that line, which will express the mean rate of the fall, will not correspond to any of the rates which the body has successively possessed.

The expression of movement by a curve has been put into practice. An engineer named Iby has devised a method of representing graphically the progress of trains upon a railway. This mode of representation, incomparably more explicit than the tables of figures of our railway indicators, has not yet got into the hands of the public; and this is to be regretted, for it gives a genuine

interest to a journey, as you may see by inspection of one of these graphics.

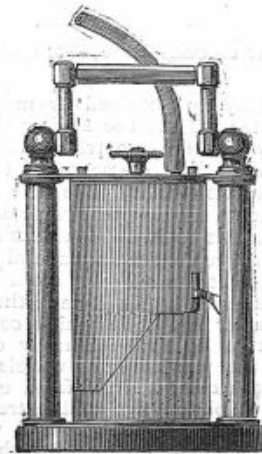


FIG. 6.—Odograph, reduced to one-third of its diameter.

The table which you see (Fig. 5) is prepared by engineers according to the regulation progress of trains

a progress supposed uniform; we see, in fact, that the lines of progress are all straight, joining to each other the two points which express the place and time of departure, the place and time of arrival. It does not then take into account the real movement of the train, which is accelerated or retarded under a great number of influences. The problem which we seek to solve, that of a graphic expression of the real rate of a vehicle, supposes that the carriage itself traces the curve of the roads traversed, in function of time. By means of the apparatus which I present to you, and which I call *Odograph* (Fig. 6), a waggon or any kind of carriage traces the curve of its movement with all its variations.

This apparatus, based on the same principle as the Poncelet and Morin machine, is composed of a tracing style which moves parallel to the generatrix of a revolving cylinder covered with paper. The movement of the style follows all the phases of that of the carriage, but

on a very reduced scale, in order that the tracing of a distance of several myriametres may be contained in the dimensions of a sheet of paper. As to the movement of the cylinder, it is uniform, and commanded by clockwork placed in the interior. In order that the movement of the style may be proportional to that of the vehicle, things have been so arranged that each turn of the wheel causes the style to advance by a small quantity, always the same. But as a turn of the wheel always corresponds to the same distance accomplished, the faster the vehicle travels the more turns will the wheel make in a given time, and the more movements of progression will the style undergo. This solidarity between the movements of the wheel and those of the style is obtained by means of a small excentric placed on the vane. At each turn there is produced a puff of air, which, by a transmitting tube, causes a tooth of a wheel of the apparatus to escape, and the style to advance by a small quantity.

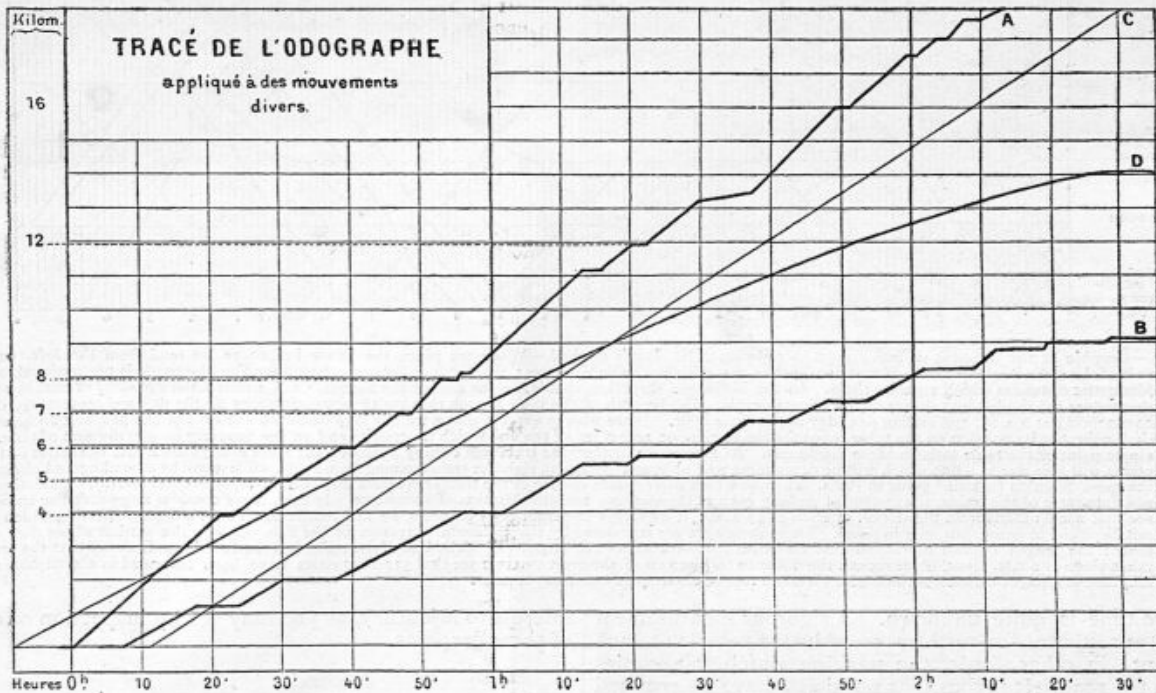


Fig. 7.—Tracings of the Odograph. A, rapid coach with stoppage; B, slow coach; C, gas meter, frequency of turns of the wheel; D, curve of the turns of a clock wheel-work with fly.

Similar effects may be obtained by means of electromagnetic apparatus. Thus the swifter the vehicle goes the more rapidly will the line traced ascend; the comparative slope of various elements of the tracing will express the variations of rate, as seen in Fig. 7.

If we wish to learn the absolute value of time and distance, it is sufficient to know that each minute corresponds to a millimetre counted horizontally on the paper, and that each kilometre corresponds to a certain number of millimetres traversed by the style in the vertical direction. The course of the style, which corresponds to a kilometre, ought to be experimentally determined for each vehicle, for the perimeter of wheels is not always the same. But it is clear that, if from each kilometre-stone to another we obtain five millimetres, for example, for the course of the style, this length will always be found to be traversed each kilometre by the same vehicle. Our apparatus is then a measurer of distances, and dispenses with the necessity of attending to the existence of kilometre-stones; it enables the distance traversed on

any road whatever to be estimated, and even when there is no beaten track. Thus in a journey of discovery we may measure the distance traversed by a cart. To remain in the conditions of ordinary life, have we not sometimes, in the country, a choice of two or three roads to go from one place to another? To know which is the shortest, we appeal to the watch, as if the least duration of a walk corresponded to the least distance. The odograph will give in this respect very precise information.

There is again a great number of questions which we ask daily without being able to solve them. Does such a draught horse go quicker than such another? Does this trot better to-day than yesterday? By increasing the ration of oats do we increase speed? Compare the slope of two curves of rates, and you will have the reply to all these questions without being obliged to make special experiments on a measured road, watch in hand.

It is not only to the speed of vehicles that the registering apparatus applies; it traces, though with less precision, the rate of progress of men and animals. We

slip into our boots a bellows sole, which is connected by a tube with a portable odograph. Each pace impresses on the style a small movement, as does each turn of the wheel of a carriage; and if the paces be absolutely equal, we may measure with certainty the distances travelled. In walking on level ground we take steps of astonishing regularity; but if the ground rises, the step gains in length; in descents, on the contrary, the steps are shortened. There may result from this slight errors in the distances traversed. Notwithstanding this, the employment of this apparatus will effect a great progress; it may be substituted with many advantages for the pedometer, which gives, at the end of a certain time, only the paces accomplished, without taking count of the stoppages or the changes of rate.

In short, when we make an experiment on a measured road, if there are produced variations in the length of the tracing represented by a kilometre, we conclude therefrom variations in the length of the pace. Such variations are observed under the influence of the slope of the country, the nature of the soil, the boots we wear, the rate of walking, or the weight carried. These studies in applied physiology have, I believe, a great practical importance, and numerous applications to the march of troops in a campaign.

(To be continued.)

WILLIAM KINGDON CLIFFORD

IT was with feelings of the deepest regret that we last week recorded the sad loss the scientific world and the country at large had sustained by the death, at the early age of thirty-three, of one of the deepest thinkers and most brilliant writers this century has seen. W. K. Clifford was the eldest son of the late Mr. William Clifford, J.P., of Exeter, and was born on May 4, 1845. Receiving his earlier education at the school of Mr. Templeton of that city, he proceeded to King's College, London. Here he at once gave evidence of his great powers by obtaining in his first year, 1861, the Junior Mathematical and Junior Classical Scholarships, as well as the Divinity prize. In the two succeeding years he gained the Classical and Mathematical Scholarships of the year, and in addition to the Inglis Scholarship for English language an extra prize for the English essay. Even at this time, whilst pursuing with such success so many branches of study, he sought a more genial occupation for his active mind in constantly reading in the college library the higher mathematical works to which he could obtain access, and towards the end of his school life, as also during his time as an undergraduate at Cambridge, he took great delight in solving and propounding problems in the *Educational Times*. While still in his eighteenth year the "Analogues of Pascal's Theorem" was written, and constitutes the first of his papers recorded in the Royal Society Catalogue. Passing from his school life, we find him entered at Trinity College, Cambridge, securing a Foundation Scholarship, college prizes in each academic year, and the English Declamation prize. Early in his career at the University he read such portions of the Tripos subjects as possessed any interest for him, and soon turned his attention to the study of the original writings of Sylvester, Cayley, Salmon, and some of the great Continental masters. In vain did his private tutor, the Rev. Percival Frost, who always had the highest admiration for him, and was anxious that he should attain his proper place in the Mathematical Tripos, urge him to devote a little more attention to examination subjects; his mind could tolerate no such restraint; nothing but the fresh and original thoughts of the greatest mathematical writers could satisfy his wants.

His neglect of the examination subjects was such that

it is said he only once wrote out a paper of bookwork questions, and that under the impression that he was solving problems; many also, well qualified to judge, were agreeably surprised when he obtained the position of second Wrangler in the Mathematical Tripos of 1867, while his success in obtaining the second Smith's prize was doubtless anticipated from the wider scope for his talents afforded by that examination. During this period the course of his future work is clearly seen; divinity and classics, at one time so ardently studied, are laid aside, and the writings of the great philosophers divide his attention with the study of higher geometry. One of his longest and most fully worked out papers, "Analytical Metrics," published subsequently in the *Quarterly Journal of Mathematics*, was written at this time, 1864.

Of the circle of intimate friends Clifford formed at this time, nothing need here be said; two or three have gone before him, the remainder have watched with the deepest interest and pleasure his widening reputation and growing influence, and are now left with a blank no one can fill, and all bear in affectionate remembrance his ready sympathy, delicate sense of humour, and sweetness of disposition. His success in the Trinity Declamation prize, and his popularity in the debates at the Cambridge Union Society, showed him to be a speaker of no common order, but it was not until he delivered his first Friday evening lecture at the Royal Institution of London, the year after he took his degree, and subsequently at the Sunday Lecture Society, that crowded audiences bore testimony to his extraordinary power of lucid exposition. The Royal Institution lecture, "On some of the Conditions of Mental Development," delivered March 6, 1867, was the first time he addressed a large public audience, which included many of the leading thinkers of the time, and from that day he took a recognised position amongst them. A short extract from this lecture reflects the habit of his mind on leaving the University, and indicates plainly that the course of study pursued while an undergraduate, probably by many thought misguided, was, in reality, the expression of a deep inward conviction. Speaking of the mind, he says, "still less must it tremble before the conventionalism of one age, when its mission may be to form the whole life of the age succeeding. No amount of erudition, or technical skill, or critical power, can absolve the mind from the necessity of creating, if it would grow. . . . The first condition of mental development, then, is that the attitude of the mind should be creative, rather than acquisitive;" and again, "It is quite possible for conventional rules of action, and conventional habits of thought to get such power that progress is impossible." Two other Friday evening lectures were given later by Clifford, on "Theories of the Physical Forces," Feb. 18, 1870; and on "Babbage's Calculating Machines," May 24, 1872; in the latter case no pains were spared by him to thoroughly master all the mechanical details of those intricate machines, and for years afterwards he would occasionally discuss schemes for the completion of the analytical engine. In public lecturing his greatest success was probably the evening lecture at the meeting of the British Association at Brighton, August, 1872, "On the Aims and Instruments of Scientific Thought." Throughout this lecture the key-note of so much of Clifford's most powerful writing can readily be detected, as may be shown by a short extract:—"If you will allow me to define a reasonable question as one which is asked in terms of ideas justified by previous experience, without itself contradicting that experience, then we may say as the result of our investigation, that to every reasonable question there is an intelligible answer, which either we or posterity may know. . . . By scientific thought we mean the application of past experience to new circumstances, by means of an observed order of events. . . . Remember then that it (scientific thought) is the guide of action; that the truth which it arrives at is not that which

which probably remain submerged for ever; I have not yet ascertained whether these submerged flowers are fertile; if they are so, they can hardly fail to be cleistogamic. FRITZ MÜLLER

A STUDY IN LOCOMOTION¹
II.

III. *The Paces of the Horse.*—Every one can recognise whether a horse is walking, trotting, or galloping, and yet few would be able to point out the rhythm and order of succession of the movements of the limbs in different paces. These movements, in fact, succeed each other

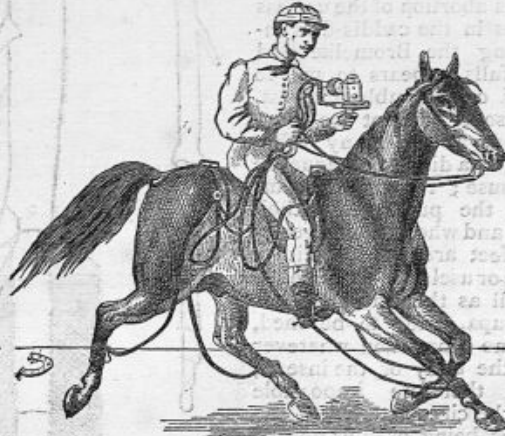


FIG. 8.—Registering apparatus for horse's paces.

too rapidly for the eye to follow them, and their rhythmic succession is more readily perceived by the ear than by the eye. It is indeed ordinarily by the ear that we become aware of a horse's pace. When at each return of the step (*revolution du pas*) we hear two distinct strokes of the hoofs, we call it an amble, or a trot; three

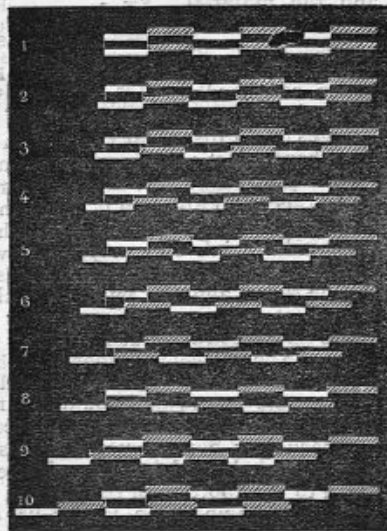


FIG. 9.—Synoptic table of the different paces of the horse, after the classic authors: 1, amble; 5, foot-pace; 8, trot, &c.

strokes unequally separated denote a gallop; lastly, four strokes indicate a foot pace. But these paces may be "Moteurs animés; Expériences de Physiologie graphique." Lecture by Prof. Marey at the Paris meeting of the French Association, August 27, 1878.

more or less irregular, variable, or crippled; besides that, when an animal passes in a very short space of time from one pace to another, how shall we decide upon the manner in which the transition is effected? To clear up these points great efforts have been made by horse-

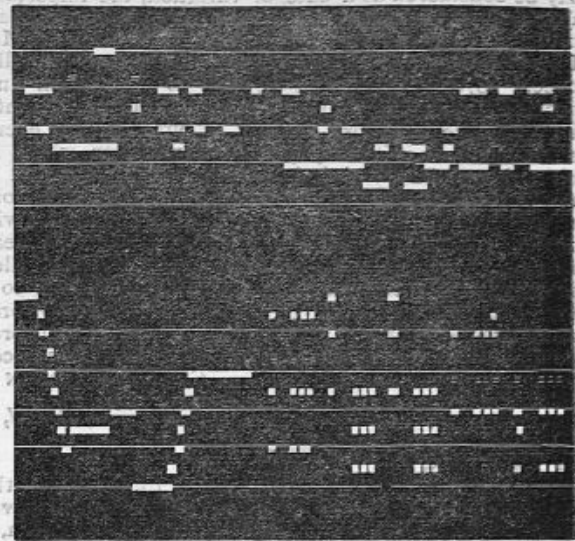
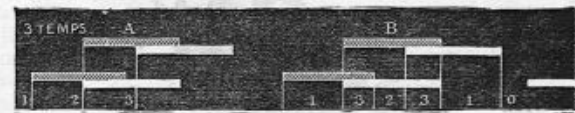


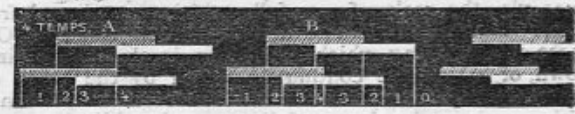
FIG. 10.—Notations of two airs, A and B, executed upon the keyboard of a harmonium.

trainers and veterinary surgeons, to whom the questions involved are of considerable importance.

Now, as I have just said, the ear judges better than the eye as to the rhythm of successive movements, but in order to demonstrate the production of these rhythmic strokes in twos, and threes, and fours, it is essential to know to which foot each separate sound is to be attributed. Ingenious experimenters have attached to the four feet of the horse bells of different tones, but in perfect harmony with each other. Varied melodies or harmonies are thus produced, according to the succession or synchronism of the strokes. But such an arrangement would certainly not give the length of time each foot remained upon the ground, therefore the question of the paces of the horse has not been entirely resolved even by this method. Turn to any special treatises on the subject, and you will see that beyond the amble, the downright



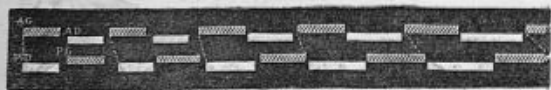
Gallop of 3 steps. A, indications of the three steps; B, indications of the number of feet which form the support of the body at each instant of the gallop of 3 steps.



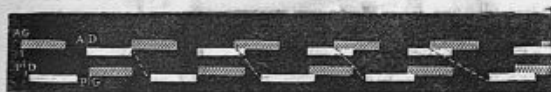
Gallop of 4 steps. FIG. 11.—Notations of the gallop of 3 and 4 steps.

trot, and the three-step gallop, there is, perhaps, not a single pace respecting which contradictory theories are not held. In face of the difficulties of this problem, you will doubtless foresee what will be my conclusion; it will be necessary to have recourse to the graphic method which will solve the question in the simplest manner possible.

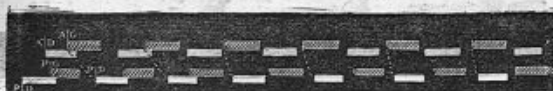
Let us take up the question at the point to which it has been brought by the experimenters to whom I have just alluded. The succession of the movements of the horse's legs, since it is rhythmical, and since also we produce



Transition from the trot to the foot-pace.



Transition from the trot to the gallop of 3 steps.



Transition from the gallop of 3 steps to the trot.

FIG. 12.—Transitions between different paces.

from each foot a different tone, forms a sort of music. Now this music is very simple, because it is only composed of four tones. The following arrangement will

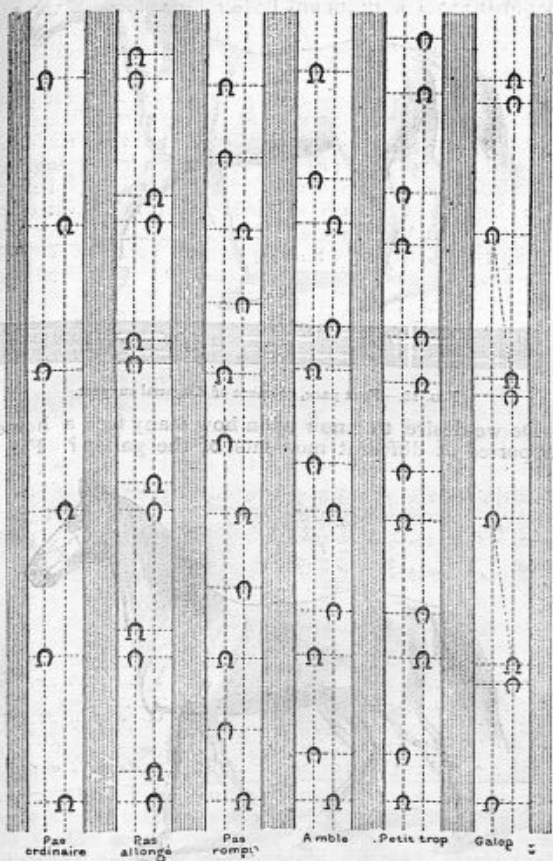


FIG. 13.—Diagram of the tracks of horses in different paces.

permit us to obtain the notation of this music, written by the horse himself. Under each of the horse's shoes we place a bag (*ampouille*) full of air, which, by means of a tube is connected with another similar small bag, which, by

its changes in bulk, acts upon a pencil. When the horse plants its foot upon the ground, it raises a pencil, which remains raised as long as the foot is kept down. Four pencils are placed in position, connected with the four under the horse's feet, and these pencils placed in a right line parallel with the axis of the cylinder, spontaneously trace the succession and duration of each setting down of a foot.

Fig. 8 shows the arrangement of the apparatus. The four limbs of the horse bear four india-rubber tubes, which converge to the hand of the jockey, and so to the inscribing apparatus on the cylinder which he holds.

The results thus obtained by the different paces are shown side by side to the number of ten in Fig. 9. Each foot, as in musical notation, has its characteristic sign, by the height of which the symbol of its stay on the ground is traced. We will agree that the fore feet shall mark upon the lines above, the rear feet upon the lines below. Now the horse can, with his four feet, execute the most rapid movements, and yet nothing will be wanting from the inscription. And in the first place, in order to give you confidence in the employment of this method, let us show you how it solves a problem still more difficult. When a clever pianist passes his fingers over the keyboard, who could describe the movements that he executes, say what note has been touched first, and for how long, then what notes followed, together or separately, with their rhythms and tones? But let us write down these movements, and when they are fixed upon paper we can analyse them with ease.

In the apparatus which I use, the keys act by pressure upon the bags of air connected by tubes with other bags, which cause pencils to move. See with what ease these little pencils reproduce all the movements of the fingers passing over the mute keyboard; you will presently see the instrument in operation. I present to you, first of all, what it has just written (Fig. 10). Observe these notes drawn up in gamuts and arpeggios, these varied accords, these changes of tone where sharps and flats reveal themselves by strokes drawn longitudinally. This instrument, which is now in action for the first time, has been constructed by our colleague, M. Tatin, whose skill has already excited the admiration of all who know him.

And now that you no longer doubt, I trust, the faithfulness of the method, let us analyse the tracings on the diagram I have just now shown you (Fig. 9). In order to understand it fully, let us borrow the ingenious idea of Dugès, and compare the horse or any other quadruped to two bipeds walking one behind the other. If the two walkers execute the same actions at the same time, that is to say, if they both simultaneously raise and set down the right foot and then the left, it is the *amble* (No. 1) which is produced. The ear only detects two sounds at each combined step, because two feet touch the ground together. This is an example of *lateral bipedal* movement. If the rearmost walker has half finished the resting of one of his feet when the foremost walker plants the same foot on the ground, it represents the *foot-pace*. Here the four footsteps are separate, and the ear distinguishes four equidistant sounds; the order of succession would be (commencing to count by the right foot), *foremost right, rearmost left, foremost left, rearmost right*. Let us imagine that the rearmost walker makes movements absolutely the reverse of those of the walker in front, that is to say, that one of the right feet strikes the ground when the other right foot rises from it, we shall then have the trot. Two feet will be always associated and will give but one sound, and these feet will exemplify *diagonal bipedal* motion.

Such, then, is our knowledge of the rhythm of paces, or at least the points upon which all are agreed. But if we desire to gather from divers authors the definition of more complicated paces, intermediary to those we have

just described, we shall only find, as I have before stated, a number of contradictions between writers holding different views. In the most rapid pace, the gallop, that of three steps,

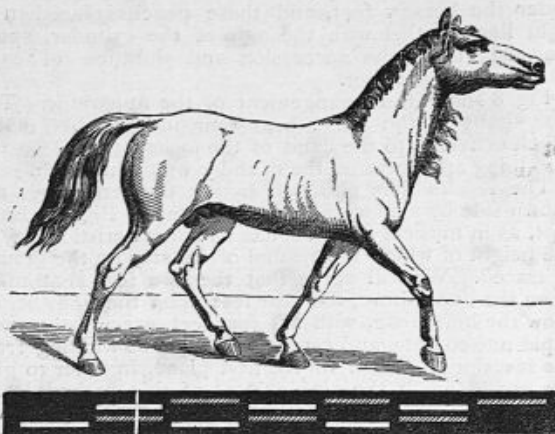


FIG. 14.—Trotting horse represented at the moment of diagonal support.

for example (Fig. 11), the first step is with the hind-foot, upon which the horse falls back after it has raised itself

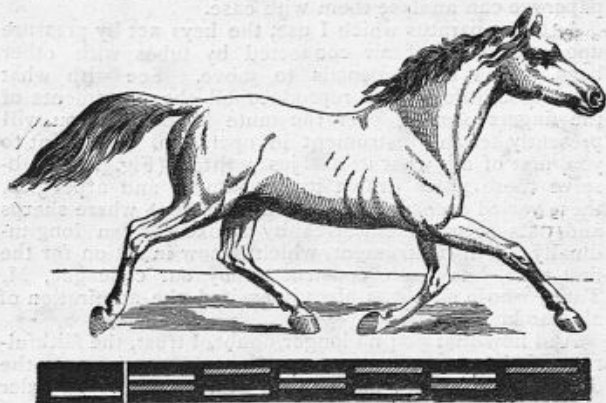


FIG. 15.—Trotting horse at the moment of suspension.

from the ground; then the other hind-foot and fore-foot which is associated with it diagonally fall together, and

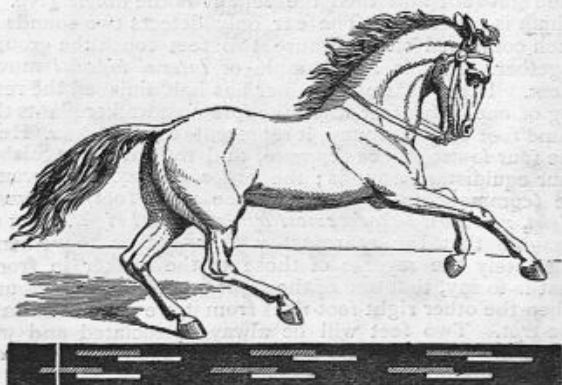


FIG. 16.—Horse at a gallop of three steps. Moment of the first step.

form the second step. Lastly, one hears the other fore-foot fall, and this is the third step.

The gallop of three steps may be distinguished in two forms; the right-hand gallop, in which the right-hand

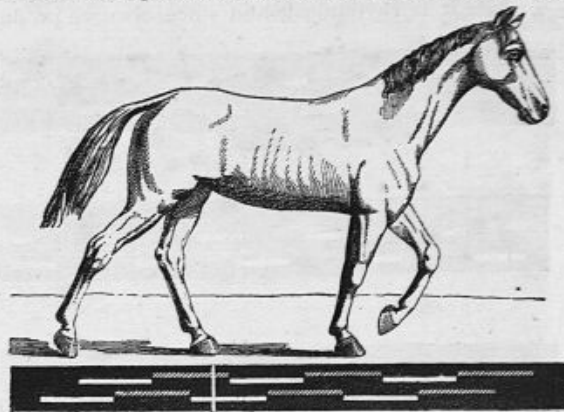


FIG. 17.—Foot pace, $\frac{3}{4}$ with effort of traction.

hind foot reaches the ground last; the left-hand gallop, in which the left fore-foot is the last to reach the ground.

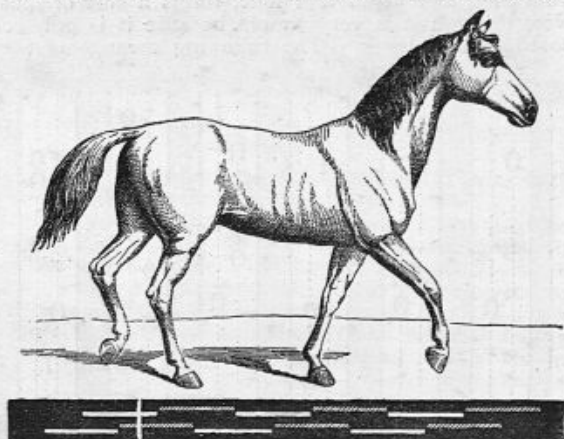


FIG. 18.—Foot pace, moment of diagonal support.

Do we desire to know upon how many feet a horse is supported at different moments of the gallop? Fig. 11

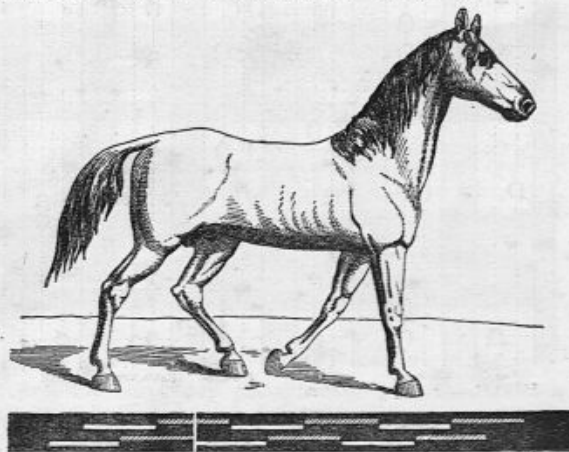


FIG. 19.—Foot pace, moment of lateral support.

responds to this question also. Just as the notation of a piece of music shows how many fingers rest at once upon

the notes on the keyboard, in the same way Fig. 11 shows that the horse, at the moment when he falls back upon the earth, is supported only by one foot; then, when the two diagonal feet strike the ground together in their turn, the horse has at this moment a triple support. Without the notation of paces we had certainly failed to distinguish this series of supports.

The gallop of the racecourse used generally to be considered as a pace of two steps, in which the horse struck the ground alternately with the two fore-feet and the two hind-feet. This gallop shows itself in the notation as a pace of four steps; the tracing dissociates the two fore-feet and the two hind-feet, although they follow each other at a very short interval.

The transition from one pace to another, impossible to determine by direct observation, is clearly inscribed in Fig. 12.

IV. *Artistic Representation of the Horse and other Animals.*—The artistic representation of animals requires a special and varied acquaintance with their peculiarities. Nothing can replace the patient study by which the painter or the sculptor acquires an anatomical knowledge of the limbs of animals and the aspects which they assume in different positions. But if the painter or the sculptor wishes to animate his work, if he wishes to show the horse putting forth its efforts in powerful traction, or to represent it urged rapidly forward in the race, it is necessary to have an exact acquaintance with different paces.

That which is true of the horse is equally so of other animals; but all present among themselves such great analogies in this respect, that if we are acquainted with the paces of the horse, we can represent those of any other animal.

The summary analysis we have just now made of the rhythms of steps in each pace is not yet sufficient to express the attitudes which represent them; we have as yet only examined in connection with these movements one of the two essential ideas. We are acquainted with the relations of time; it is necessary also to become acquainted with the relations of space, that is to say, to know at each moment in what place to find each of the members raised or planted upon the ground. Obligated to abridge this already long discourse, I will not tell you how one determines graphically the phases of the movement of a foot that is raised, but I will show you summarily how we determine the place where each foot is brought down. This indication is furnished by the imprint which the horse leaves upon the ground. M. de Curnieu, Capt. Raabe, and M. Lenoble du Teil have studied with particular care these imprints or tracks of the horse at different paces. The smooth sand of the sea-shore presents a surface admirably adapted for this study. Persons who have acquired the habit, easily decipher such imprints. But in order to render them easily read by every one, we have conceived the idea of giving a different form to the shoes of the fore-feet from those of the hind-feet by furnishing the latter with clamps. The principal paces represented by their tracks have been thrown together in Fig. 13, which I have borrowed from M. Lenoble du Teil. In combining with the idea of the rhythms, that of the place where each foot would be planted, the errors of attitude which disfigure so many *chefs d'œuvres*, would be avoided. You will, perhaps, say that few persons are capable of recognising faults of this kind. On this point one might repeat what Baron Dupin said with respect to perspective in its relation to the art of painting. "In proportion as exact knowledge becomes more widely diffused, many faults which to-day only shock a small number, will shock the general public, and artists will no longer be able to perpetrate them with impunity."

Those artists who at the present time make such praiseworthy efforts for the correct representation of the horse, would find great assistance from making use of the

notation of paces. Let us see in what way. Take, for example, the notation of *the trots*. We all grant, in the first place, the possibility of dividing each step into a series of successive instants, ten or twenty, for example. At each of these instants the horse will have a different attitude, but throughout the time the limbs diagonal to each other will be executing the same motions at the same time.

Let us take one of these instants at random and mark it by a vertical line (Fig. 14). The notation shows us that at this instant the right hind-foot and the left fore-foot are planted upon the ground, but that the right fore-foot and the left hind-foot are still raised, and are about to be set down. That is exactly as represented in the figure.

Upon another notation (Fig. 15) we have chosen another instant, that in which the horse is suspended in the air, and when the hind-feet have already quitted the ground, whilst the fore-feet do not yet touch it.

Let us pass on to the pace of the gallop (Fig. 16). The moment chosen is that in which the horse falling back upon the hind-foot has just made his first step. Two limbs in diagonal relationship are about to strike the ground at the same time, namely, the right hind-foot and the left fore-foot, represented as already being lowered towards the earth. As to the right fore-foot, that will strike the ground last, accordingly it is shown as still the furthest removed from the earth.

With regard to the foot pace, which is the most difficult to explain, three instants have been selected on the notation: 1. That where the hind-foot is about to be raised, and where the fore-foot is in the middle of its elevation (Fig. 17). At this moment there are three feet at rest, which only takes place with horses when making an effort of traction. 2. The moment in which the two diagonal feet are raised, the one having just quitted the ground and the other being about to be placed upon it (Fig. 18). 3. The moment when the animal, supported by two feet on the same side, is raising one of its fore-feet and is about to set down one of the hind-feet on the same side (Fig. 19).

These pictures have no other pretensions than to be correct as regards the position of the members; it would be the artist's duty to add elegance of form. But is it not something to have a simple and sure means of representing a horse in any pace and in any phase of the steps in that pace? The employment of the graphic notation would give to the artist the double advantage of representing the paces with truthfulness and of varying them to an extent almost illimitable. Now, imperfection in art is not displayed solely by errors that may be committed, for too often an artist who is thoroughly acquainted with a correct attitude repeats it with regrettable monotony.

(To be continued.)

GEOLOGY OF NATAL AND ZULULAND

SOME years have now passed since Mr. Griesbach gave to the Geological Society his paper and map illustrating the geology of Natal and the borders of Zululand. Passing events now give to his investigations the greatest interest, not simply due to the possible light that may be thrown on unsolved, or partly known, problems by the sojourn in that area of the contingent that has lately left our shores, but from the fact that the safety and success of our forces in great measure depends on the surface contour and physical character of the country to be traversed, which are necessarily directly dependent on its geological structure.

Few can have studied a geological map, without noticing the close connection between long lines of escarpment and belts of level plains with particular rocks, or noticing the marked uniformity in direction of strike of geological formations over large portions of the earth's surface; rock series after rock series plunging beneath its neigh-

A STUDY IN LOCOMOTION¹

III.

IT would be very interesting to pass in review the principal epochs of art and trace out the manner of representing horses in motion in various periods of progress or decadence. But such a study would fail to realise its full value unless carried out by an artist.

Col. Duhouset, who joins the skill of the draughtsman to a perfect acquaintance with the exterior of the horse, has essayed a work of this kind, and in a recent publica-

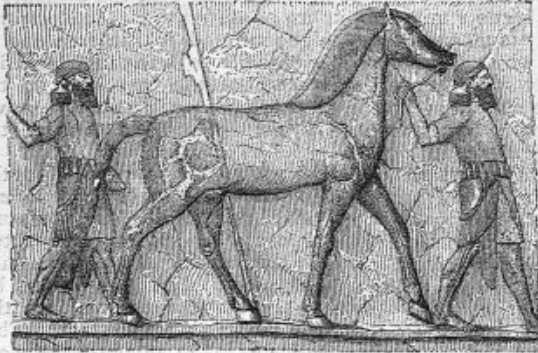


FIG. 20.—Assyrian bas-relief (British Museum). A horse ambling.

tion has pointed out the merits and defects of certain modern artistic performances. M. Duhouset has also gathered together a curious collection of representations of the horse at different epochs of art, and has entrusted to me a few specimens, which I will now exhibit to you. You will see that in a general manner art has progressed, proceeding from simple forms to more masterly delineations.

Figs. 20 and 21 represent horses ambling. Has the artist selected this pace because it was in general use at



FIG. 21.—Egyptian bas-relief (Medinet-Abou). Two horses attached to a chariot, and ambling.

that time? This is scarcely probable; it would seem more likely that he has chosen it because of its extreme simplicity. To seize the moment when the four feet all touch the ground, to repeat in the posterior limbs the attitude of the limbs in front, and, lastly, to represent all the horses harnessed together as keeping exact time in

¹ "Moteurs animés; Expériences de Physiologie graphique." Lecture by Prof. Marey at the Paris meeting of the French Association, August 29, 1878. Continued from p. 467.

their movements so as to draw them all with a single



FIG. 22.—"The Cavalier and Death," by Albrecht Dürer. Horse at the trot.

profile: this is certainly one way of eluding all the difficulties of the situation.

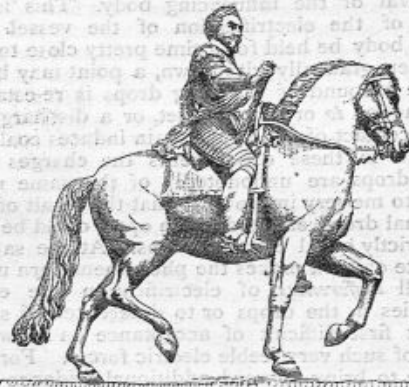


FIG. 23.—Statue of Henri IV. on the Pont Neuf. Example of the correct trot.

The pace of the *trot*, correctly represented in the



FIG. 24.—Assyrian bas-relief. Post-pace.

Roman epoch, in the equestrian statues of the Balbi

which adorn the Naples Museum, reappears in the six-



FIG. 25.—Bas-relief in baked earth, of the Volscian epoch (Velletri). Three horses harnessed together, walking at a foot-pace.

teenth century in a painting by Albrecht Dürer (Fig. 22,



FIG. 26.—Captain of the Guards riding at a foot-pace. (Column of Trajan.)

“The Cavalier and Death”). The classic statue of

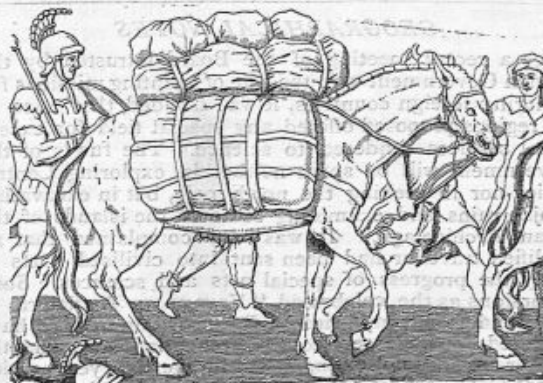


FIG. 27.—Mule laden with baggage, walking at a foot-pace. (Column of Trajan.)

Henri IV. on the Pont Neuf is an example of the correct trot (Fig. 23).

But the representation of the *foot-pace*, more difficult than the preceding, is rarely faithful. Examples, scarcely satisfactory, are found in all the epochs; take, for instances, Figs. 24 and 25.

The *foot-pace* is correctly represented in the two figures borrowed from the column of Trajan (Figs. 26 and 27). This column also displays oxen and other animals faithfully represented.

These paces, it should be noted, are a little varied with respect to the instant chosen; almost invariably the horse raises only one fore-foot.

The *gallop* is in general the pace of which the representation leaves most to be desired. Without speaking of contemporary art, I will refer only to the paintings of the two or three last centuries. The horses therein deemed to be galloping are represented in a sort of prancing attitude, posed upon the two hind-feet, and raising the two fore-feet to an equal height. We have seen, by the preceding notations, that this synchronous action of the right and left limbs does not exist.

In the grandest epoch of Greek art we find admirable representations of the gallop. Fig. 28 is an example. The attitude chosen is the first step of the gallop as in Fig. 16. The first step has been taken. The diagonal



FIG. 28.—Frieze of the Parthenon. (Bas-relief remaining at Athens.) Right hand gallop.

limbs which make the second step are approaching towards the ground, and the right hand fore-foot which will make the last step is held high in air.

I have already admired the reproduction in plaster of another bas-relief from the same frieze, in which a galloping horse is represented with equal correctness, and I was led to believe that in the age of Phidias, artists were in possession of the science of paces. But subsequently, in examining the reproductions of the entire frieze, I have become convinced that the results were obtained by a happy chance, for the greater part of the horses are represented in false attitudes, which is all the more to be regretted in contemplating the exquisite elegance of their forms.

It is incontestable that at the present day, artists make great efforts to represent the horse with truthfulness, and many among them succeed. But I will not permit myself to criticise the works of my contemporaries. Such, then, is the graphic method, and such are its numerous applications, extremely varied, and often of enormous importance. In this discourse, the length of which you will excuse, I have only shown you a little corner of the subject, but that will suffice, I hope, to give you a desire to study more deeply, and in its entirety, a method which appears to me to be full of promise, and to the development of which I have already consecrated much effort.