ON THE MINUTE MEASUREMENTS OF MODERN SCIENCE.

By ALFRED M. MAYER.

ARTICLE XVII.

On the Application of Rotating Mirrors to the Measurements of Minute Lengths, Angles, and Times.

ON WHEATSTONE'S EXPERIMENTS TO MEASURE THE VELOCITY OF ELECTRICITY AND THE DURATION OF THE ELECTRIC DISCHARGE.

In our first article we stated that this series would end with two remarkable applications, in which the various methods and instruments described in this series would be

Fig. 51

combined and brought to bear on problems whose solution, at first sight, appears beyond human power. The two problems which we have selected from the extensive array found in the annals of science are: The Measurement of the Velocity of Electricity and the Duration of the Electric Discharge, and the Measurements of the Wave-Lengths of Light. In giving accounts of these problems I will show how men of science have discovered, minutely examined, and measured actions of physical forces which take place in a space less than the 1-10,000th of an inch and endure but a few billionths of a second. Such actions are the flash of the electric discharge and the undulation of a wave of ether in a beam of light.

In 1834 Charles Wheatstone, of London, read a paper before the Royal Society which marks an era in the history of experimental physics. He then first described the application of the rotating mirror to the examination of the nature and duration of phenomena which last but a few thousandths or millionths of a second. This paper of Wheatstone had more effect on the progress of science, from the publication of the method of observing and measuring with the rotating mirror, than by reason of the new facts in the nature of electricity which it gave to the world, though the latter were at that time of the first importance.

The first new application of the revolving mirror was proposed by Arago in 1838. With it he proposed to measure the relative velocities of light in air and in water, and thus to decide whether light in its nature is the rapid translation through space of very minute particles of matter, or whether it is of the nature of undulations or pulses, rapidly transmitted through a rare and highly elastic medium, which must be supposed to exist throughout the universe. If light be of the nature first described it must move more rapidly through water than through air; if of the nature of undulations of an elastic medium, it must move less rapidly in water than in air.

We cannot do better than here let Arago speak for himself on this subject. The following is what he said before the Academy of Sciences of Paris, at the meeting in which he proposed this experiment:

"I propose to show how it is possible to decide, unequivocally, whether light be composed of little particles emanating from radiant bodies, as Newton supposes, and as the greater part of modern geometers admit, or whether it is simply the result of the undulations of a very rare and very elastic medium, which physicists have agreed to call ether. The system of experiments which I am about to describe will no longer permit, it seems to me, to hesitate between these two rival theories. It will decide, mathematically (I use designedly this expression)—it will decide, mathematically, one of the grandest and most debated questions of natural philosophy.

"Besides, my communication is the fulfilling a sort of engagement to the Academy I accepted at one of its last secret sittings.

"I discussed the admirable method, by the aid of which Mr. Wheatstone attempted the solution of the problem of the velocity of electricity over metallic conductors. I had hardly enumerated the important results obtained by that ingenious physicist, when several of our members, whose

Fig. 52

names are authority in such matters, stated that my report was far too approbative. 'In supposing it well determined, the inferior limit assigned by Mr. Wheatstone to the velocity of electricity will not have,' said one, 'any marked influences on the progress of the sciences; besides, limits of the same order, and even more extensive, can be deduced indirectly from various electric and magnetic phenomena. As to the method of the revolving mirrors, it does not seem to be susceptible of application, but to the simple questions already studied by the inventor.' I tried to refute this last opinion. I believed myself that the new instrument, suitably modified, would lead to results that Mr. Wheatstone was not aware of. I already foresaw that, even in supposing it inclosed in the narrow limits of a small room, it could

serve to measure the comparative velocities of light moving through air and through a liquid. I was not slow in learning, and without having hardly the right to be astonished or to complain, that my assertion had been received with incredulity. Nevertheless, I intend to vindicate it to-day in all its parts."

Arago then enters into the most minute details of all the parts of the experiment. The velocity of rotation that can be given to the mirror, the visibility of the image formed by light after having traversed the necessary length of liquid, the possibility of reducing that length of liquid, or the velocity of rotation of the mirror by employing simultaneously several rotating mirrors from which the light would be successively reflected, and also in substituting for water bisulphide of carbon, which acts more powerfully on the velocity of light, are, on his part, the objects of a thorough examination. After the publication of this remarkable communication no one could doubt the success of the experiment which it so carefully and so minutely described.

Failing sight and the infirmities of age prevented Arago from ever putting his proposed experiment to actual test, but, presenting his method to his younger scientific brethren to work out, it was reserved for the talented and lamented Foucault to have the honor of solving the experimental problem with an apparatus similar in principle to that proposed by Arago, but simpler in construction and more precise in its measures. With apparatus Foucault first proved that light moves slower in water than in air, and thereby gave to the undulatory theory of light one of its main supports.

The following is the letter, in which Foucault gave the first news of the success of this noble and ever-memorable experiment:

"To the Editor of the *Journal des Débats*—Sir: I will not wait for the expiration of the fortnight to give you an account of what most occupied the Academy of Sciences during their meeting of yesterday. All knew that M. Arago was to continue the account of his beautiful researches in polarization and photometry. The attendance was large, and the Academy recorded at its session a foreign associate and two corresponding members—Sir David Brewster, Lord Brougham, and M. De la Rive, of Geneva. But

Fig. 53

WHEATSTONE'S WHIRLING APPARATUS.

what was not expected was, that M. Arago recalled attention to one of the most beautiful projected experiments that the genius of a savant has ever produced, and he declared that, after having conceived it, he had left to the young generation the care and the honor of performing it. The experiment has more than once occupied the attention of the Academy; it proposes to decide, by means of a revolving mirror, whether light moves faster in air than in water, and to seek, in the probable result of this experiment, the confirmation of the theory at present adopted to explain all optical phenomena. You may judge, Sir, of the emotion with which I heard this generous declaration—I, who for several days had in my hands the experimental solution of this great problem! Nevertheless I thought it proper to postpone to the next meeting the reading of the paper in which I have recorded my results. In the meantime permit me, sir, to announce, in a few words, the results which I have observed.

"Light employs more time to run over the same path in water than in air, and the time which it takes to traverse these two different media is shown by the deviation of a ray which is reflected at a given moment from a mirror revolving with a great velocity. All things remaining equal, the deviations were found to be proportional to the indices of refraction of air and water. It is not possible to entertain the least doubt as to the reality of these results; they have been obtained by two different methods. The two deviations were first observed successively, and were found unequal for the same velocity of the mirror. They were then observed simultaneously, which rendered the observation still more certain.

LÉON FOUCAULT."

In 1862 Foucault added various improvements to his apparatus, and brought its measurements to such precision that he measured the velocity of light with accuracy.

"This is an admirable experiment in physics, in which, by the power of intellect and manual skill, he succeeded in not only rendering sensible, but even measurable, the time employed by light to run over a path of 20 meters, although this time barely equals the 1-15,000,000th of a second. . . .

"We would be unjust if we did not mention that the success of the experiment of Foucault was greatly indebted to Froment, the able constructor of the various parts of the

apparatus. The clockwork which gave to the toothed disk a uniform motion of one revolution per second, and the revolving mirror put in motion by the little air-turbine or siren, ought to take rank among the numerous mechanical wonders which have proceeded from his hands. The most ingenious conceptions remain unrealized if they do not find an artist capable of executing them. Thus history has taken care to treasure the memory of eminent mechanicians, to whom are due the delicate constructions which have given important progress to science. The name of the illus-

Fig. 54.

trious English clockmaker, Graham, remains forever associated with the discovery of aberration and nutation, made by Bradley with an instrument constructed by that artist; in the same manner the name of Froment will remain inseparable from the beautiful and refined experiment of which we have just spoken, and for which he constructed the important and ingenious improvements added by Foucault to the original apparatus devised by Arago."

In like manner the name of Joseph Saxton should ever remain associated with Wheatstone's celebrated experiments with the revolving mirror, for to the skill of this eminent American mechanician Wheatstone was indebted for the construction of his apparatus and for valuable assistance given him during his experiments with it. Also, it is not improbable that the fact of Saxton's having previously used the revolving mirror in the examination of phenomena of momentary duration may have suggested to Wheatstone the application of the revolving mirror to the investigation on the velocity of electricity and the duration of the electric discharge. This investigation we will now proceed to describe.

It will render easier the understanding of Wheatstone's experiments by prefacing our description of his work with a fact or two in physiological optics which lie at the foundation of his method of experimenting.

Imagine a minute bright spark, or dot of light, which appears but for an instant—say that it lasts only the 1-100,000th of a second. The eye, of course, can receive light from this spark only during that minute interval of time, yet the sensation produced by the light from the spark lasts much longer; so that after the spark has really ceased to exist the eye perceives the spark as existing. The duration of this apparent existence of the spark depends on the intensity of its light, and may last from 1-10th of a second to over a whole second of time. It is therefore evident that the unassisted eye can never determine the actual duration of flashes of light which have minute periods of existence; for in a series of sparks, all of the same intensity of light, and whose durations extend from 1-100,000th of a second to one-half of a second, the eye will see each spark, lasting the half of a second, if this is the duration of the sensation of light of the intensity of the sparks.

The eye, therefore, has to call in instrumental aid. This is afforded by some contrivance which will move either the spark or its image, and if the spark has a duration at all comparable to the time during which it has been moved, it will be drawn out into a line which has its length in the direction in which the spark or its image has been moved. Thus, for example, suppose that the spark is a mere dot of light—not a line—and has lasted 1-100th of a second, and that during this 1-100th of a second the spark was moved from

Fig. 55

right to left through one inch. Then, on account of the persistence of the sensation of light on the eye, the spark will appear as a horizontal line of one inch in length. If the velocity of the motion of translation remains the same and the spark lasts only a fraction of 1-100th of a

* See "Essay on the Velocity of Light," by Delaunay. Translated by the writer and published in Smithsonian Report, 1864.

second, then it will appear drawn out into a line whose length is the same fraction of an inch.

Now, imagine that the spark is not a dot of light, appearing stationary at one point in space, but is a dot which moves between two points in the manner in which we may suppose an electric spark to move from one brass ball to another. Look at Figs. 51 and 52, and imagine that an electric spark flashes between the balls placed at A and B, then this spark will appear to you as a line of light drawn between A and B. Now suppose that the spark really goes downward from A to B, as in Fig. 51, and in the time it takes to go from A to B, the balls, A and B, have moved from right to left over the distance equal to B from C, then the line of light will not longer appear as a vertical line, A B, but will be seen as the inclined line, A C. If the spark moves upward from B to A, as in Fig. 52, while the balls, as before, go from right to left over the distance, B C, then the spark will appear as the inclined line, B D, of Fig. 52.

Wheatstone having failed to produce any change in the vertical direction of the spark during its lateral motion, varied his mode of experimenting, and, instead of moving the spark apparatus, he allowed it to remain stationary, and moved laterally with great rapidity the image of the spark by viewing its reflection from a revolving mirror, whose axis of rotation was parallel to the line traced by the spark. The advantages of this method of experimenting are various. A small angular deflection in the plane of the mirror produces a large deflection in the reflected image of the spark, for the angular motion of the image is double that of the mirror. (See the description of Fig. 33 in Article XI.) Also, the same mirror may be used in different researches, and, indeed, forms an instrument universally applicable to the examination of the nature of various transient phenomena.

Two forms of rotating mirrors are proposed by Wheatstone. One of these is represented in Fig. 54. It rotates

"I successively presented to the mirror sparks four inches in length, drawn from the prime conductor of a powerful electrical machine; the explosions of a charged jar; a glass tube four feet in length, exhibiting a spiral of electric sparks passing between dots of tin foil; an exhausted glass tube six feet in length, through which the spark passed, and produced an unbroken line of attenuated electric light; various pictures, such as birds, stars, etc., formed of electric sparks. But in all these cases, when the reflected images occurred within the field of view, they appeared perfectly unaltered, and precisely as they would have done had they been reflected from the mirror while at rest.

"When sparks were made to follow each other quickly several reflected images were simultaneously seen in different positions, owing to the images having been renewed before the visual impression caused by the first had disappeared. The exhausted tube being held near a prime conductor, when looked at directly, will sometimes appear to

WHEATSTONE'S APPARATUS FOR DETERMINING THE VELOCITY OF LIGHT.

In Wheatstone's first trials he actually made an apparatus do what we have just described, the balls moving rapidly across the line of sight while the spark was passing between them. The following is his description of the apparatus and the experiments:

"Fig. 53 represents the apparatus employed, which was screwed at A to the spindle of a whirling machine, so that a rapid rotatory motion might be given to it. The upper and lower parts, which were all of brass except the wooden disk, B C, were insulated from each other by a stout glass rod, D E; a strip of tin foil connected the ball, H, with A, and the upper ball, G, was capable of adjustment to various distances from the lower one, H. When the ball, F, was placed within striking distance of the prime conductor of an electrical machine, a spark passed between them, and also between the balls, G and H, which could be separated to the distance of four inches, so as to exhibit a spark of

about a vertical axis, and this motion successively brings its reflecting surface into every vertical plane. As the angular motion of the reflected image is double that of the mirror, it follows that a reflected image, such as that of a candle flame, will go over an entire circumference while the mirror makes one-half of a revolution; and if the mirror be silvered on its back as well as on its front, then one entire revolution of the mirror on its axis will cause the reflected image of the flame to go over two entire circles. If the mirror rotates with sufficient rapidity the observer will see the reflected image of a luminous point drawn out into a horizontal line, which line is a part of the entire circumference traced by the reflected point; in other words, is an arc of the circle described. This arc is larger in extent in proportion as the eye is nearer the mirror.

If, while this mirror is rotating, a luminous point, viewed in it, should move in a vertical direction, that is,

gleam with a continuous light, but, examined in the mirror, this apparent continuity is seen to be owing to a rapid succession of transient flashes."

At this point of our study of these phenomena, and of the means of investigating their nature, we have very carefully to distinguish between two things to be observed and interpreted in the appearance of the moving spark when viewed in the rotating mirror, which we have just described; viz., first, the breadth of the line traced by the spark, and, secondly, the amount of deflection, or inclination, of this line. The first of these appearances is produced when the duration of the spark is appreciable when timed by the motion of the mirror, and the second is seen when the velocity of the spark is so low that the mirror has had time to move the spark's image laterally while the spark is going from one electrode to the other.

It is evident that, if the spark is really seen as a line of

Fig. 57.

that length. It is obvious that, if the angular motion of the balls were in any sensible proportion to the velocity of electricity, there would be a deviation between the upper and lower terminations of the line. The instrument moving from left to right, if the motion of the spark be downward, the deflection of the line should be as in Fig. 51, and if its motion be upward, it should be deflected, as in Fig. 52.

"When the apparatus was made to revolve rapidly the sparks passed in the same manner as when it was at rest, and no deviation of the extremities of either of the two sparks from the same vertical line was observed. The apparatus revolved fifty times in a second, and as a difference of the twentieth part of the circumference described by the balls could easily have been observed had it existed, we may safely conclude that the spark passed jointly through the air and the metallic conductor in less time than the 1-1,000th of a second."

parallel to the axis of the mirror, it is evident that this motion would be combined with the lateral motion of the point, produced by reflection, and a resultant motion would be produced, as has already been described in connection with Figs. 51 and 52. Knowing the number of rotations made by the mirror in a second and the direction of its rotation, we can compute the velocity and direction of the moving luminous point.

Wheatstone fastened the axis of this mirror to a machine with multiplying wheels, and made the mirror revolve fifty times in a second. This velocity of rotation caused the reflected image of a luminous point to go over one-half of a degree of arc, or 1-720th part of the circumference, in the 1-72,000th of a second. This luminous arc of one-half of a degree is easily perceived by the unaided eye, and is about equal to an inch in length, seen at a distance of ten feet.

Of the results of this new experiment, Wheatstone says:

Fig. 58

light joining the two balls (or other electrodes), it must have an entire duration equal to the time it has taken to go over the space separating the electrodes. Yet the spark, at each point of its path between the electrodes, may have so small a duration that the mirror may not be able to appreciably widen its trace; especially when the lateral deflection or inclination of the whole vertical trace of the spark is just sufficient to be detected and measured in the rotating mirror. So we have to look for and to measure two dimensions in the image of the spark. Its change in width compared to what it has when at rest gives the duration of the spark's existence at each point in its path, while the measure of the lateral deflection of the track of the spark gives us the means of computing its velocity. These are points to be well understood in order to interpret the appearances given by experiment on the electric discharge.

The second arrangement of rotating mirror proposed by

Wheatstone is shown in Fig. 55. The reflecting surface of this mirror is inclined to the axis of rotation and nearly perpendicular to it. If a luminous point be placed anywhere in the prolongation of the axis of rotation it will be reflected, so that by the rotation of the mirror and the persistence of visual impressions, it will appear in a smoky room as a luminous cone, and the base of this cone will appear on the ceiling as a luminous ring, forming a circumference of a circle, whose center is on the axis of the mirror prolonged. In this form of experiment the angular velocity of the image is equal to that of the mirror, and both move in the same direction.

Wheatstone thus describes his experiments with this mirror: "The flame of a candle presented to it appears as a broad luminous ring; the image of the sun is converted into a magnificent fiery belt, etc. A series of minute sparks made to pass between two points, or between a point and the prime conductor of a machine, presents to the eye, from the rapidity of their succession, the appearance of a permanent star of light. When this star is placed in the prolongation of the axis of the revolving mirror, the successive sparks of which it consists are reflected to the eye, each from a different part of the surface, and they are exhibited arranged at regular distances in a circle. When the intermissions are rapid, the appearance is extremely beautiful.

FIG. 59.

"The brush of light which appears on a point when presented at some distance from the conductor, is also by this means shown to be an intermittent action, notwithstanding its permanent appearance; its reflected images present, however, this remarkable peculiarity, they are elongated in the direction of the motion, proving that the brush is not so transient as a spark, and that the emissions which constitute it last during one interval of time measurable by the motion of the mirror.

"But this instrument is not confined to observe merely the intermissions of electric light; whenever a rapid succession of alterations occurs in an object which does not change its place, they may be separately examined by this means. Vibrating bodies afford many instances for investigation; one among them is perhaps worthy to be mentioned. A flame of hydrogen gas burning in the open air presents a continuous circle in the mirror; but while producing a sound within a glass tube, regular intermissions of intensity are observed, which present a chain-like appearance, and indicate alternate contractions and dilatations of the flame corresponding with the sonorous vibrations of the column of air."

To increase the chances of observation of sparks, etc., when their appearance cannot be commanded at the instant when the mirror is in the position to reflect them to the eye, Wheatstone proposes the use of a mirror formed of a hexagonal prism with polished faces, as shown in Fig. 60, where A B is the axis of rotation, and C, D, E, three of the reflect-

Fig 60.

ing facets. With this mirror the observer will have six chances of seeing the reflected image instead of only one, as he has when using a rotating mirror with one polished surface.

On the Determination of the Velocity of Electricity through Conducting Bodies.—In the trials made to find out the velocity of electricity previous to Wheatstone's experiment, they used a long conductor, whose two ends were brought near each other so as to form a nearly closed circuit. One of these ends was placed at a short distance from a wire which went to earth, the other end was placed near a conductor leading to an electrical machine, or battery of jars. The experimenters had hoped to have seen an appreciable interval between the passage of the spark to one end of the conductor, and its appearance at the other end on its way across the space to the wire which led to the earth. In one experiment made near London in 1747, they used four miles of conductor, and the discharges at the two ends of the circuit appeared to be simultaneous to the experimenters; and naturally so, for if they had been separated by the 1-10th of a second the discharges would have appeared simultaneous by reason of the persistence of the sensation of light; and though they might have detected by the ear an interval of 1-10th of a second separating the sounds of the discharges, yet they would not have been able to detect an interval of silence between discharges separated by 1-100th of a second. It follows that in a circuit of four miles the detection of a

velocity of only a few miles a second would be the limit to such methods of observation, even allowing that the method under any circumstances would give a result indicating an actual transfer of electricity from one end of the conductor to the other.

Wheatstone, after speaking of these trials, says, "I determined, therefore, to repeat a similar experiment, substituting for the imperfect judgment of the eye a revolving mirror, but more rapid in its motion and accurate in its indications than any I had previously employed. The instrument I am about to describe will, unless there be some error in the estimate, which I have not been able to perceive, measure beyond the millionths of a second; and this degree of minuteness may be yet far surpassed by more costly instruments and more careful observations."

It is often stated in text-books that Wheatstone's experiment on the velocity of electricity favors the hypothesis of two electric fluids. That this opinion should be so generally diffused is not a little remarkable, and when the reader has perused the following paragraph he will see that Wheatstone says distinctly that the expected result of his experiment is as readily explained by the hypothesis of one fluid as by that of two fluids. "But," speaking of the experiment of 1747, "as it is only on the hypothesis of an actual transfer of a fluid from one end of the wire to the other

that a difference of time between the two sparks at its opposite extremities might be expected to be observed, in order to render the proposed experiment independent of this theoretical view, I took the necessary precaution of bringing a third spark, formed by disconnecting the middle of the wire near to and in a line with the extreme sparks. For on the supposition of the transfer of two fluids in opposite directions, the extreme sparks would be simultaneous, but the middle spark later in its occurrence; the same appearances would also accord with the theory of one electricity, if we admit that a disturbance of electric equilibrium is simultaneously propagated from each end, arising in the one case from successive additions to, and in the other from successive subtractions from, the neutral quantity in the conducting wire."

The experiment of Wheatstone's was made in the Adelaide Gallery of Practical Science, London, where our countryman, Saxton—who aided Wheatstone in these experiments—was then exhibiting his magneto-electric machine and other ingenious inventions. The total length of wire used was half a mile. This was stretched between the balustrades (A B and C D of Fig. 57) of the gallery in 20 parallel lengths, each 120 feet long. The ends of the wire marked 2, 3, 4, 5, of Fig. 57, were connected to the similarly numbered wires of the spark board, shown in Fig. 58. This spark board was fixed against the wall, so that the six balls (shown as circles in the figure) should be in a horizontal direction and parallel to the axis of the rotating mirror. The distance shot over by the sparks was 1-10th of an inch. The conducting wire was of copper and 1-15th inch in diameter.

Fig. 56 gives a general view of the apparatus to rotate the mirror and its electrical connections with the Leyden jar, M, and the conducting wire and spark board through the wires marked 1 and 2. Fig. 59 is an enlarged view of the mirror and the attachments thereto which Wheatstone used to obtain the spark at the right instant for observation, and to determine the number of revolutions made in a second by the axis of the rotating mirror. Similar parts in the two figures bear the same letters. The mirror, E, is of polished steel, one inch in diameter, and mounted on the shaft, F G, so that the plane of reflection of the mirror is in line with the axis of rotation of the shaft. The mirror was rotated by a cord going over the wheel, K L, and a groove in the axis, F G. This wheel, K L, was so large that, if the cord is supposed not to slip, the axis, F G, will make 1,800 revolutions to one of the wheel. M is a small Leyden jar, which is kept constantly charged with positive or negative electricity by means of the chain, N, connected with an electrical machine. From the inner coating of the jar leads a bent wire to the two insulated rods, O and P. The ball on the end of P is quite close to the knob, Q, on the axle, F G, when this knob comes opposite the ball on O in the rotation of this axle. In order to confine to narrow limits the spark which passes over this interval, Wheatstone placed between the knob, Q, and the ball on O a piece of mica, S, with a narrow horizontal slit in it. When the plane of the mirror is stationary and at 45° with the horizon he saw, on looking down vertically into it, the image of the balls on the spark board. Charging the jar, M, and rotating the mirror, the observer saw three sparks pass on the spark board and another pass from the knob, Q, through the slit in the mica to the ball on O. The path of the electricity may be supposed, for simplicity of explanation, to go from the outside surface of jar by the wire 1 to the wire 1 on the spark board; thence, with a spark to wire 2, and through half of the stretched parallel wires to 3; thence with a spark to wire 4; thence through the remaining half of the stretched wire to 5; thence with a spark to 6, and back to wire 6, attached to the standard of rotating apparatus and to the inner coating of the jar.

Without a knowledge of the exact number of revolutions made by the mirror in a second one cannot compute the value of deflections of the sparks in case they should be appreciable, and Wheatstone spent much time in the endeavor to get the exact velocity of the mirror. At first he used a siren, shown in Fig. 59, at T, attached to the axle, F G. With 800 revolutions to the axle, and leading air to the siren even through a few holes, the sound produced was so acute that it was either inaudible or its pitch was so high that the ears could not determine the note, and when the number of holes were reduced so as to lower the pitch the sound was too feeble to be distinctly heard. He then simply placed a small

piece of paper so that the arm, P (which acts as a counterpoise to the arm and knob, Q), would strike it once at each revolution of the shaft of the mirror. When the mirror was now revolved with the maximum velocity the knob striking against the paper caused the sound G—4, which showed that the mirror was making 800 revolutions in one second of time. In subsequent experiments Wheatstone used a counter attached to the shaft of the mirror, and when thus retarded by this additional work put on it, the shaft made 600 revolutions per second.

Of the extraordinary powers of this apparatus as an instrument of research, and of the results of his experiments with it, Wheatstone speaks as follows: "Let us now consider what is the shortest duration of the electric light, and the greatest velocity of transmission through the wire, that can be detected by means of the instrument I have described. The mirror revolves 800 times in a second; and during this time the image of a stationary point would describe 1,600 circles: the elongation of a spark through half a degree, a quantity obviously visible, and equal to one inch seen at the distance of ten feet, would therefore indicate that it exists the 1-1,152,000th part of a second. The deviation of half a degree between the two extreme sparks, the wire being, as above stated, half a mile in length, would indicate a velocity of 576,000 miles in a second. This estimated velocity is on the supposition that the electricity passes from one end of the wire to the other; if, however, the two fluids in one theory, or the disturbances of equilibrium in the other, travel simultaneously from the two ends of the wire, the two external sparks (on the spark board) will keep their relative positions, the middle one will be alone deflected, and the velocity measured will be only one half that in the former case, viz., 288,000 miles in a second.

Repeated experiments gave the following results. In all cases, when the velocity of the mirror exceeded a certain limit, the three sparks were elongated into three parallel lines, and the lengths became greater as the velocity of the motion was increased. The greatest elongation observed was about 24°, indicating a duration of about the 1-24,000th of a second. The lines did not always commence at the same places; sometimes they appeared immediately below the eye, sometimes to the right, at other times to the left, and occasionally they were out of view altogether. This indetermination is owing to the arm, 2, of Fig. 59, not always taking the spark at the same distance from the discharger: several discharges are therefore required to be made before the eye can distinctly observe the appearances. When the velocity was low the terminating points (i.e., the ends of the luminous lines of the elongated spark images) appeared in the same horizontal line; but when the velocity was considerable, and the upper edge of the mirror was revolving from the observer, the lines assumed this appearance

|||; when the top border of the mirror revolved toward the observer the lines appeared thus |||. In no case did I see

them thus |||, or thus |||, as required in the actual

transfer of a single fluid. The spark board in all these experiments was placed at the distance of ten feet from the mirror.

The interpretation of these appearances observed by Wheatstone in his mirror is as follows: First, the mirror in its revolution had time to turn 12°, while the spark lasted between the balls on the spark board, and as the mirror produces in the image double the angular deflection of its own motion, the spark appeared elongated over an arc of a circle equal to 24°. Since the mirror, by one revolution, spreads a reflected image out into two complete circles, or $2 \times 360^\circ = 720^\circ$, it follows that 800 turns per second of the mirror spreads out a reflected image into $800 \times 720^\circ$, or

$\frac{576,000}{24} = 24,000$. Which gives 1-24,000th second for the duration of the spark on the spark board in Wheatstone's experiment.

The observer sees another peculiarity of these elongated sparks; they are parallel, but they do not have their origin on the same horizontal line. When the mirror in its motion is deflecting the spark image downwards, they present this appearance: |||, which shows that the sparks at the beginning

and the end of the wire, or circuit, took place at the same instant, and that a small interval elapsed before the spark made its appearance at the broken place in the middle of the wire, and that during this small interval which elapsed the mirror had time to get a slightly greater tilt than that which it had when the side sparks appeared, so the middle spark line appears as pushed downward between the two side spark lines. When the mirror revolves so that the images of the sparks are drawn out in an upward direction, then the middle spark line appears slid upward, between the two side lines, by the same quantity that it was slid downward by the same velocity and opposite direction of rotation of the mirror.

Wheatstone states that the amount of downward or upward displacement of the middle spark line amounted to not more than one half of a degree. Now, as an elongation of 24° in the spark line gave 1-24,000th of a second for their duration on the spark board, it follows that the displacement of half of a degree gives us 1-48 of 1-24,000th of a second, or 1-1,152,000th of a second, for the time it took the electricity to go over $\frac{1}{48}$ th of a mile, or half of the entire length of the copper wire; hence in one second, electricity, according to Wheatstone's experiment, will travel

$\frac{1,152,000}{4}$, or 288,000 miles of copper wire.

The very large elongation of 24° in the sparks produced in the peculiar and unusual conditions of these experiments led Wheatstone to hope to be able to elongate sparks as they are ordinarily produced by the discharges of electrical machines or Leyden jars through short conductors of very slight resistance; but he observed no elongation in the sparks even when the mirror was urged to the greatest velocity of rotation. This shows that electric discharges taking place under the above conditions cannot have an existence as long as the 1-1,152,000th of a second; for if they had had a duration of that length then Wheatstone would have caused an appreciable elongation in them. Frequently we meet with the statement that Wheatstone showed that the discharge of a Leyden jar lasts the 1-24,000th of a second. We see that Wheatstone distinctly

states that this is the duration of the discharge in the conditions of his experiment, and that in the usual conditions of discharge its duration is not equal to the 1:1,000,000th of a second. Indeed usually the spark has an existence which is only stated in billionths of a second, as we shall see in our next article, where we will give an account of the remarkable researches of Rood, Feddersen, and others.

Wheatstone thus explains the extraordinary durations of the sparks from his apparatus: "The elongation of the sparks at the interruptions of the wire above noticed were no doubt owing to this circumstance, that the diameter of the wire was not sufficiently great to allow the charge of the jar to pass through it except in a successive manner. The duration of the discharge in the cases of these sparks appeared to be longer than the time required for the electricity to pass through many miles of wire."

"The sparks from the great magnet constructed by Mr. Saxton, which is at the Gallery in Adelaide Street, were considerably elongated, even when the mirror was moving with a comparatively low velocity."

Wheatstone closes his remarkable paper with these words: The instantaneousness of the light of electricity of high tension, rendered evident by the preceding investigations, affords the means of observing rapidly changing phenomena during a single instant of their continued action, and of making a variety of experiments relating to the motions of bodies when their successive positions follow each other too quickly to be seen under ordinary circumstances.

A few obvious instances will at present suffice. A rapidly revolving wheel, or a revolving disk on which any object is painted, seems perfectly stationary when illuminated by the explosion of a charged jar. Insects on the wing appear, by the same means, fixed in the air. Vibrating strings are seen at rest in their deflected positions. A rapid succession of drops of water, appearing to the eye a continuous stream, is seen to be what it really is, not what it ordinarily appears to be, etc.

The preceding experiments having been directed rather to detect elongations and deviations than to measure them, I am not prepared to state the results with numerical accuracy. I shall endeavor to supply this deficiency in further investigations, but must at present content myself with stating the following general conclusions, deduced from the appearance which I have observed, though, I must allow, more accurately performed experiments are required before they can be considered as fully established.

1st. The velocity of electricity through a copper wire exceeds that of light through the planetary space.

2d. The disturbance of electric equilibrium in a wire communicating at its extremities with the two coatings of a charged jar, travels with equal velocity from the two ends of the wire, and occurs latest in the middle of the circuit.

3d. The light of electricity in a state of high tension has a less duration than the millionth part of a second.

4th. The eye is capable of perceiving objects distinctly, which are presented to it during the same small interval of time.

By prosecuting these researches with instruments of higher power, and of greater accuracy in their indications, numerical laws may be established for a large class of phenomena, the relations of which we have hitherto no means of observing. The relative velocities of electricity in different metallic wires; the modifications in the velocity of electricity in different states of tension when passing through the same conductor, if any such differences exist; the duration of the electric spark under different circumstances of tension and quantity, etc., will be among these objects of investigation.

THE PHONEIDOSCOPE.

THE object of the phoneidoscope is to show, optically, the delicate particularities of sonorous vibratory movement. A thin film of liquid glycerine is formed on a small opening made in a piece of blackened brass, and it reflects the light of a lamp in producing, either on the retina direct or by projection on a screen, the well known iridescent effects of thin transparent plates. As long as the film is motionless, the simple colors of iridescence are alone visible. But if, by means of a bent tube, the vibrations of a sustained sound are conducted underneath that film, by the voice or otherwise, the film begins to vibrate and the colors are distributed geometrically, producing on the surface fixed bands and moving rings, the disposition of which varies with the depth of the tone and the nature of the harmony accompanying it—that is to say, the pitch. At a recent meeting of the French Physical Society, the inventor, M. Taylor, showed by projection that the acoustic figures thus obtained become more and more complicated as the tone emitted rises, or when, the height remaining constant, different vowels are pronounced. The colors thrown on the screen diffused during the experiment in proportion as the film became thinner by evaporation, but the acoustic figures did not vary. The results obtained are extremely curious and of varied appearance, according as apertures of different form are used. M. Taylor projected the phenomena produced by openings, triangular, square, and round, by means of the Drummond light. The considerable heat which accompanies that process of lighting causes, after a certain time, the evaporation of the film of glycerine, and terminates the experiment. But its duration may be augmented by passing the luminous rays through a glass flask filled with water, which deprives them of the greater portion of the qualities absorbable by the liquid glycerine.

EXPERIMENTS WITH THE SILICATED CARBON AND SPONGY IRON FILTERS.

MR. G. W. WIGNER, F.C.S., has recently made a series of experiments with the spongy iron and silicated carbon filters, and the following appeared from his pen in the *Analyst*:—The Margate water, besides being evidently contaminated by infiltration from the sea, has a very unpleasant smell and taste, and the microscope shows a variety of objects which might be more readily passed in surface drainage than in drinking water. It was therefore fairly suitable for such an experiment. The two filters chosen were perfectly new and bought direct from the makers. I did not consider it of any use to test these filters while quite new, as it must be evident that if they were not capable of working satisfactory for a few weeks on such water as that used the experiment was concluded. They were therefore put up side by side—filled regularly as nearly as possible with the same quantity of water, and at the same time, the amount being two gallons per day each and allowed to work thus for five weeks. During this time I found that the silicated water was always preferred for table use. Even those who were entirely ignorant of the fact that filters were used, would sometimes complain of a flat taste in the spongy iron

water. Each filter possesses advantages peculiar to itself, so I determined, in addition to testing the water which had simply passed through each filter, to test samples which had passed through both, and as it seemed possible that the order in which the filters were used might make some difference, it was decided to try with silicated filter first and with spongy iron first. I therefore had in all five samples, viz.:—(1) Water from main; (2) water filtered through silicated carbon filter; (3) water filtered through spongy iron filter; (4) water filtered first through silicated carbon and secondly through spongy iron; (5) water filtered first through spongy iron, and secondly through silicated carbon. The samples were distilled for ammonia as soon as possible. The following are the results of five analyses:—

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
	Tap in main.	Silicated carbon filter.	Spongy iron filter.	First, silicated. Second, spongy.	First, spongy. Second, silicated.
Colour	Yellow green, slightly opaque.	Pale blue.	Pale blue.	Opaque blue.	Chalky blue.
Suspended matter ..	Traces.	None.	None.	Traces.	Slight traces.
Smell	Offensive.	Very slight.	Offensive.	Decidedly offensive.	Decidedly offensive.
Taste	Slightly offensive.	Saline.	Saline and offensively flat.	Unpleasant and very flat.	Excessively flat and objectionable.
Hardness before boiling ..	27.2 deg.	16.9 deg.	11.6 deg.	14.0 deg.	17.1 deg.
Hardness after boiling ..	9.4 deg.	5.3 deg.	9.8 deg.	10.7 deg.	7.2 deg.
Total solids ..	69.60	66.90	58.35	60.70	58.75
Loss on ignition ..	5.0	6.80	5.35	4.50	9.40
Tot. mineral matter ..	63.80	60.10	53.00	55.90	50.55
Chlorine as chloride of sodium ..	36.66	36.66	36.46	36.50	36.50
Nitrogen as ammonia ..	None.	None.	.0728	.0875	.0149
Do. albuminoid ammonia ..	.0033	None.	.0161	.0140	.0051
Do. nitrates ..	.7500	.7800	.6600	.6800	.7300
Do. nitrites ..	Traces.	Traces.	Traces.	Traces.	Traces.
Total nitrogen in these four forms ..	.7533	.7800	.7459	.7615	.7500
Oxygen absorbed from permanganate ..	None.	None.	.0030	.0314	.0183
Microscopical examination of residue ..	Very bad animal and vegetable debris. Some small spores. Quarts.	Organic debris minute traces only. Mineral matter traces.	Satisfactory. It was very free from suspended matter.	Satisfactory.	Satisfactory.

On looking at these results, the first general feature which deserves attention is that the two filters when used together do not appear to have effected any additional purification, but rather the reverse. It is very difficult to account for this fact. In both cases an ample quantity of the once filtered water was allowed to flow through the second filter so as to rinse it out, and the rinsings were rejected. It is true the filters were not continuously worked under these conditions for any length of time, but this ought hardly to be an essential for this experiment. Leaving this I would next point out the special features shown by columns No. 2 and No. 3, which are the two filtered waters, as compared with column No. 1, which is the unfiltered. Both filters have equally removed the yellow green color of the water and the suspended matter. The silicated filter has greatly reduced the smell, but the spongy iron has merely changed its character, so that instead of resembling decaying vegetable matter it is a sort of indescribable smell, perhaps more resembling the smell of impure hydrogen produced by the action of acid on iron than anything else, but of course very faint, though offensive. The taste has apparently been affected in a similar way. The silicated removed the offensive taste, and left only the saline. The spongy iron left the saline, but added to it a taste a little worse than if the water had been boiled, that is there was something besides the flat taste. Bischof has alluded to a gas which he has observed within the bulk of spongy iron after it had been in use some time, which gas he says is sometimes explosive, sometimes not, and on one occasion he found this gas to contain a hydrocarbon; may not this hydrocarbon be the cause of this smell and taste? The effects of the hardness are singular. The silicated reduced the temporary hardness by 6.2 deg., and the permanent hardness by 4.1 deg., total reduction 10.3 deg. The spongy iron reduced the temporary hardness by 15.5 deg., but only reduced the permanent hardness by a decimal. The spongy iron reduces the total hardness the most, but bearing in mind the greater importance of permanent hardness, there is probably little to choose. It is remarkable that the reduction of total mineral matter does not more closely follow this reduction of hardness. I have not yet made full mineral analyses of the residues to determine this point. It is, however, in the ammonia and albuminoid ammonia, which are so often viewed as almost the sole proof of purity or otherwise, that the most important results appear. The silicated removes even the small proportion of albuminoid ammonia which was present, but the spongy iron produces a very marked proportion of free ammonia and so much albuminoid ammonia that the water would probably be condemned by those who trust mainly to that determination. This result is a serious one, in whichever light we view it. If the albuminoid ammonia determination is of value, then *pro tanto* the filtered water is worse than the unfiltered. If the filter is a good one, and certainly many other experiments have pointed out that it is, then any analyst who reported on such a water, in ignorance of the fact that it had been through spongy iron, might be deceived. But still further, if spongy iron acts in this way, is it possible that metallic iron may in a less degree? In considering this point all the special circumstances of the case must be borne in mind. For instance, the very saline character of the water, and the fact that this salt is partly due, in all probability, to the infiltration from the sea, but still the fact remains. It is unnecessary to go at length through the other columns. It is well, however, to point out that when two filters were used, in the case where the spongy iron was last the ammonia and albuminoid ammonia were almost as high as in No. 3, while, where the silicated was last, they were far less, though not so low as when the water passed through the silicated only. It would be very desirable to have reports of similar trials on the water supply of other places, but I hope it will be possible to take the precaution of using new filters and keeping them at work for a month before taking the samples.

THE ARTIFICIAL SYNTHESIS OF ORGANIC COMPOUNDS.

EXTRACT from a paper read before the California Academy of Sciences, by John M. Stillman, of the University of California.

I wish this evening to mention a few of the more striking examples of those discoveries of organic chemistry, where the products of nature have been produced by the hands of the chemist, and to show you the successive steps of the processes, that you may see for yourselves how completely the wall between organic and inorganic has been overthrown; what complex compounds may be obtained by care and patience in the domain of organic chemistry. I shall not allude to the immense number of compounds which organic chemistry has prepared, which have not been discovered in animal or vegetable organism, some of which, as the aniline dyes, have given rise to industries valued at the present day at millions of dollars, but shall confine myself to those products where the laboratory has succeeded in reproducing natural products of vital force in the animal or vegetable organism.

It is true that the artificial method of production is sometimes more expensive than that by which it is produced in nature's laboratory, but this is not always so, and there is always a prospect of new methods and new information giving a cheaper product than nature can produce.

In every case we will follow the process step by step from the elements themselves or from simple inorganic constituents, and every step shall be one which has actually been performed by chemists of repute. To commence with some of the simpler compounds, we will take first

FORMIC ACID.

This compound was first obtained from the bodies of ants by distilling with water; formed, therefore, under the influence of vital force in the animal organism.

In the laboratory it can be obtained readily by convenient methods from other organic compounds, but also by the action of CO and KHO, which gives formic acid in combination with potassium, (KHO + CO = KHCO₂) which, when treated with dilute sulphuric acid, gives the free formic acid, (2HK CO₂ + H₂SO₄ = H₂CO₂ + K₂SO₄), identical in all properties, physical and chemical, with the formic acid derived from the ants themselves; is, in fact, the same compound.

ALCOHOL

Is another product of organic life, and occurs in the decomposition of juices of plants containing sugar. It also can be built up from inorganic constituents, as follows:

Carbon and hydrogen unite directly to form acetylene, C₂H₂, under the influence of the electric spark.

This compound, acetylene, by the action of hydriodic acid gives ethane—C₂H₂ + 4HI = C₂H₆ + 4I, C₂H₆; and this in turn with chlorine gives C₂H₆ + Cl₂ = C₂H₅Cl + HCl, which when treated with AgOH gives alcohol, (C₂H₅Cl + AgOH = C₂H₅OH + AgCl) identical with the compound produced by fermentation.

By oxidizing alcohol we also obtain another compound, which is also an organic product, viz.: Acetic acid.

GLYCERINE

Can be obtained in the common method by decomposing fats and oils, where it exists in combination as a product formed under the influence of vital force. It also can be obtained from inorganic compounds by a series of simple steps.

If this compound ethane, which we just saw formed from inorganic constituents, be treated with iodine, we have ethyl iodide formed, and this, with zinc, gives zinc ethyl C₂H₅ + I₂ = C₂H₅I + HI, 2C₂H₅I + 2Zn = ZnI₂ + Tu (C₂H₅)₂. Again, if we heat CS₂, H₂S and Cu together, we have a compound (CH₃)₂ marsh gas, formed CS₂ + H₂S + 8Cu = 4Cu₂S + CH₄; this, with iodine, gives CH₃I, methyl iodide; CH₃ + I₂ = CH₃I + HI.

These two compounds, zinc ethyl and methyl iodide, when heated together, form zinc iodide and a new compound, propane, C₃H₈, Zn(C₂H₅)₂ + 2CH₃I = ZnI₂ + 2C₃H₈. This, with iodine, gives propyl iodide, C₃H₇ + I₂ = C₃H₇I + HI, and this, with KOH, gives KI, H₂O, and another substance, propylene, C₃H₆(C₂H₅)₂I + KOH = KI + H₂O + C₃H₆, and this treated with Cl and chloride of iodine, gives another compound, C₃H₇(Cl), C₃H₇ + Cl₂ = C₃H₇Cl + HCl, C₃H₇Cl + 2I₂ = C₃H₇Cl₂ + I₂, which, with much water at a high temperature, is changed to glycerine, C₃H₇Cl₂ + 3H₂O = C₃H₇(OH)₃ + 3HCl.

When glycerine now, which we have seen built up by means of inorganic reagents from the elements themselves, is treated with HI, an inorganic reagent, it forms allyl iodide, C₃H₇(OH)₃ + 3HI = 3H₂O + 2I + C₃H₇I, and this, again treated KSCN, which in turn is readily obtained from the elements, we have formed a new compound, C₃H₇Cl + KSCN = KI + C₃H₇SCN, which has the odor and general appearance of the chief constituent of the oil from the common mustard, and on closer examination proves to possess identical physical and chemical properties, the same boiling point, odor, taste, undergoes precisely the same changes with the same chemical reagents, and is in fact precisely the same substance as the natural mustard oil, but formed entirely from substances which have been obtained from inorganic constituents.

ANOTHER EXAMPLE.

We saw that by inorganic agencies we could obtain a substance, methyl iodide, CH₃I, and also that by the direct union of C and H we could obtain C₂H₂, acetylene. When this acetylene is simply heated intensely we obtain a small quantity of benzol, C₆H₆, which with bromine gives a compound, C₆H₅Br. This C₆H₅Br, together with the CH₃I treated with the metal sodium, gives a compound, toluol, C₆H₅Br + CH₃I + Na₂ = NaBr + NaI + C₆H₅CH₃, and this by heating gives anthracene, (C₁₄H₁₀). Anthracene when oxidized gives anthraquinone, C₁₄H₁₀ + 3O = H₂O + C₁₄H₈O₂, and anthraquinone when treated with H₂SO₄ gives a new product, which finally treated with KHO and HCl gives alizarine. Now this alizarine is found to be absolutely identical with the coloring material of the madder root, in composition, properties, and chemical action. Fortunately, also, the anthracene can be obtained in quantity by distilling coal tar so that the alizarine of the laboratory is much cheaper than the alizarine from the madder root itself, and is, of course, just as good, being identical with it, so that it has nearly forced the true madder out of commerce.

OIL OF BITTER ALMONDS.

Let us now start again from the same toluol, which we