THE VELOCITY OF LIGHT[1]

THE correct determination of the velocity of light is a result on which so much in physical science depends that there is good reason for us to give a description of the details of the apparatus used for the purpose of obtaining the exact value. Until the time that M. Cornu undertook experiments with this object in view the generally received value of the velocity in question was 298,000 kilometres per second. This depended on the experiments of M. Foucault, who used a rotating mirror on which the rays of light from cross-wires fell, and while the mirror was in a certain position were reflected by it to a concave mirror at a distance of 13½ feet, having the revolving mirror at its centre of curvature and so fixed as to return the rays of light to the latter, which reflected them to the point of departure. While however the rotating mirror was in rapid motion, a ray of light reflected by it to the distant mirror and back from it, would not, unless the passage of light were instantaneous, reach the rotating mirror until the latter had moved from its position of first reflection, and would not therefore return to the point of departure, but to some point near it, depending on the angle through which the rotating mirror had moved in the time between its reflecting the ray to the concave mirror and the return of that ray. By placing the cross-wires in the principal focus of a convex lens the rays proceed in a parallel beam, and on returning form an image of the wires, removed from the wires themselves, a distance depending on the angular velocity of the mirror and the velocity of light. The cross-wires and their images are rendered visible by viewing them by means of a diagonal reflector of plain glass in front, which at the same time allows sufficient light to pass through to illuminate them.[2]

In 1849 M. Fizeau devised a method differing from that just described by which he measured the time a ray took to travel from Suresnes to Montmartre and back. The apparatus consisted of a toothed wheel which could be rotated with a known velocity, and having the teeth and intervals equal in size. A pencil of rays was sent through the interval between two teeth to a reflector at Montmartre 28,334 feet distant, which caused the ray to return on itself. So long as the wheel is at rest and the rays pass through an interval, they will be returned through that same interval, but when the wheel turns with sufficient velocity a tooth takes the place of an interval before the ray has time to return from Montmartre and get through, and is therefore interrupted. By rotating this wheel faster the next interval will take the place of the preceding one on the return of the ray, which will again get through, and so on passing and being interrupted as the velocity of rotation increases.

It is obvious, then, that if we know the number of teeth on the wheel and the number of turns per second, say at the instant of reappearance of the spot of light after a disappearance, we shall know the interval between the passing away of the ray by the edge of one tooth to its return by the corresponding edge of the next ; and this is the time the ray has taken to traverse the distance to the reflecting station and back, and from this the velocity of light follows. From these experiments M. Fizeau obtained a velocity of 315,000 kilometres = 196,000 miles per second.

At that time the velocity of light deduced from the observations of eclipses of Jupiter's satellites, combined with the then accepted solar parallax, was 190,000 miles per second, closely agreeing with M. Fizeau's result ; later determinations of solar parallax have given a smaller result than former ones, and consequently the velocity of light deduced therefrom becomes reduced, which again closely agrees with M. Foucault's direct determination.

In the year 1874 the Council of the Paris Observatory, on the proposition of M. Leverrier and M. Fizeau, decided on the execution of experiments for the direct determination of the velocity of light, and offered the use of the scientific apparatus at the observatory for the purpose, together with funds for the construction of the necessary instruments. To M. Cornu was entrusted the execution of the operations ; and after due consideration and experimental comparison, he adopted the method of M. Fizeau in preference to the revolving mirror of M. Foucault. A preliminary series of experiments were carried out in 1871 and 1872, between the École Polytechnique and Mont Valérien, a distance of 10,310 meters, giving a result of 185,370 miles per second as the velocity of light, with a probable error of less than $\frac{1}{100}$. M. Cornu then commenced more careful experiments between the Observatory and the Tour de Montlhéry, a distance of 22,910 metres. The principle of M. Cornu's arrangement we have already described, it being the same as that of M. Fizeau, but the details of the apparatus are somewhat elaborate, and in his Memoir occupy seven large sheets of plates ; we can, however, to a certain extent describe them. Rays of light from a highly luminous source issuing from a small hole in a diaphragm, pass through a convex lens, and after reflection at an angle of 45 from the surface of a plain piece of glass, are brought to a focus at the circumference of the toothed wheel ; the light then traverses an object-glass of fourteen inches diameter, and the parallel rays travel to the reflecting station ; here they are received by an object-glass of six-inch aperture, and about six feet focal length, at the principal focus of which is a reflecting mirror of silvered glass. From this mirror the rays are returned to the toothed wheel, where an image is formed coinciding with the original image of the hole in the illuminated diaphragm, the rays if not intercepted by a tooth, pass onwards, and the greater part of them traverse the diagonal reflector of plain glass and an eyepiece beyond, through which the image formed by reflection from the distant station is viewed. So far we have given an outline of the optical part of the apparatus as well as we can without the use of the drawings by which the details can only be made intelligible. We next come to the toothed wheel, and here certain conditions must be fulfilled : first a velocity of rotation must be obtained capable of admitting a considerable number of orders of extinction ; secondly, the motive power must be such that the observer can easily control the velocity of the wheel ; thirdly, there must be a means of recording the velocity at any instant of time. The motive power is a weight which drives a train of wheels which rotate the toothed wheel, the latter being constructed of aluminium from $\frac{1}{10}$ to $\frac{1}{15}$ millimetre in thickness ; wheels of different diameters were used varying from 35 to 48 millimetres. The velocity is recorded on the surface of smoked paper on a roller of about one metre in circumference and half a metre in length, turning on a horizontal axis. The records are made by the action of electro-magnets on light tracers pressing against the surface of the smoked paper. The velocity of the cylinder carrying the paper is such that a line 20 mm. is traced in a second, and during each revolution the tracers are moved on horizontally 15 mm. One of the tracers is put into action at every second by electric communication with a standard clock ; a second is put into action at every $\frac{1}{10}$ second by a trembler governed by the pendulum of the clock ; the third moves at each fortieth or four hundredth revolution of the toothed wheel, and the fourth is under the control of the observer. Each of the four tracers is continually in contact with the smoked surface of the paper, and so long as it is not moved sidewise by the electro-magnet, traces a continuous line round the cylinder, but on the passing of a current round the

[1] "Détermination de la Vitesse de la Lumière d'après des Expériences exécutés en 1874, entre l'Observatoire et Montlhéry." Par M. A. Cornu. (Paris : Gauthier Villars, 1876.)

[2] From the experiments of M. Foucault in 1862 a velocity of 298,000 kilometres = 185,157 miles per second was deduced.

electro-magnet, the tracer makes a short mark at right angles to line, and a zig-zag line caused by the vibration of the tracer, back to its original position; the first two lines, therefore, show seconds and tenths of seconds, the third, the instants of completion of forty or 400 revolutions, according to the desire of the operator, of the toothed wheel; a comparison, therefore, at once gives the number of revolutions per second, while on the fourth line are marked the instants of disappearance or reappearance of the light, and the velocities at those instants are then at once known. To make an experiment the aperture in the diaphragm is illuminated by a lime-light or sometimes with sunlight by means of a heliostat. The necessary adjustments in the direction of the rays of light to the distant station are then made by bringing the distant collimator into the centre of the field of the observing apparatus, and the point of light—the luminous echo—is made to accurately coincide with its original at

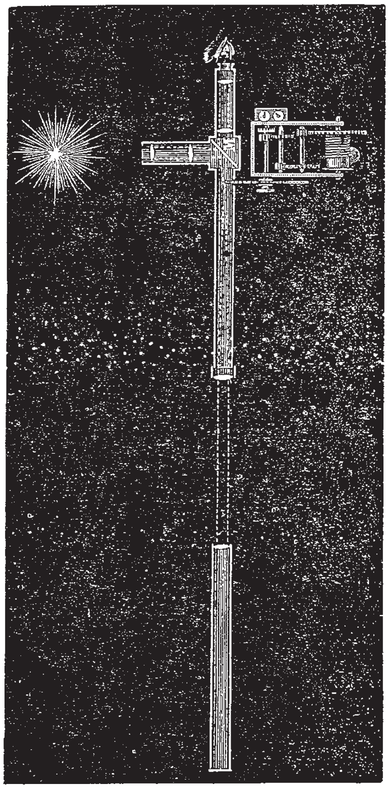

FIG. 1.—Plan of M. Fizeau's Apparatus.

the circumference of the toothed wheel. Particulars of the experiment, as to number of teeth of wheel, direction of rotation, &c., are entered on the paper on the cylinder, and the latter is then set in motion; the observer then sets the toothed wheel going and watches the luminous echo, and on its disappearing touches a key which sends an electric current to the electro-magnet controlling the fourth tracer, which therefore registers the instant the velocity is sufficient to cause a disappearance. As the velocity of the wheel increases, the luminous echo again appears and the key is pressed; a further increase in velocity causes another disappearance and so on to the higher orders, each of which is registered. The velocities at the different instants are read off by a micrometer to $\frac{1}{100}$ of a second.

It is obvious that the state of the air must have a great effect on the definition of the luminous echo, and that although the observation appears extremely simple still there may be large errors due to irregular refraction of the air, causing a motion of the point of light, and a large amount of patience must be required. Two careful surveys showed the distance between the two stations to be 22909·77 metres, and the mean velocity obtained from a large number of observations after the various corrections were made was 300,400 metres per second of mean time.

The Memoir of M. Cornu contains a large amount of theoretical matter and formulæ of corrections which of course we cannot reproduce here.

We may, however, refer to the principal causes of error. The first is a personal error depending on the sensibility of the eye of the observer in determining the disappearance and reappearance of the light at the toothed wheel, and also depending on the intensity of the luminous source; secondly, accidental inequality in the size of the teeth of the wheel; thirdly, irregularity of motion; fourthly, excentricity of wheels; fifthly, optical errors due to imperfections in the adjustment of the lenses and reflector. The first of these is small and can theoretically be reduced indefinitely by increasing the velocity of the

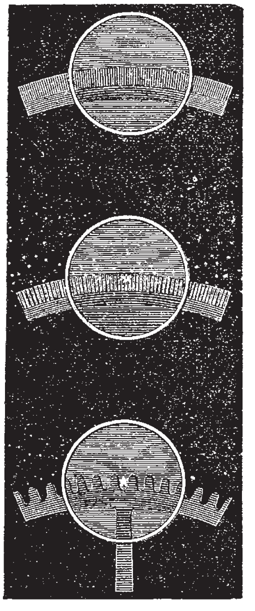

FIG. 2.—Details of Toothed Wheel.

toothed wheel and thereby observing the higher orders of extinction and reappearance of the light, but M. Cornu desires to be rigorously exact, and therefore the effect of this and the other errors is carefully calculated.

Considerable care was exercised in the choice of stations, and those adopted were fixed upon chiefly on account of the distance between them being more easily ascertained from previous triangulation. This distance was determined by Cassini and La Caille in 1740, the result being 22910·196 metres. From the observations of Delambre the same distance was computed to be 22909·34 metres; and 22910 metres, which is nearly the mean adopted by M. Cornu.

The corrected results of the experiments gave a velocity of 300,350 kilometres a second, but this was obtained in air, and therefore 82 kilometres must be added to this result to give the velocity *in vacuo*; and as the result of his experiments M. Cornu adopts a velocity *in vacuo* of 300,400 kilometres = 186,638 miles per second of mean time, with a probable error of $\frac{1}{1000}$, or 300 kilometres.

If from this value we deduce the solar parallax, we find the latter to be 8″·881, assuming the time required for light to travel from the sun to us to be 6m. 13·2 sec., as obtained from observations on Jupiter's satellites, and the radius of the earth 6378·233 kilometres.

Again, the sun's parallax deduced from M. Cornu's values of the velocity of light in conjunction with the value of aberration is, with Bradley's estimate of 20″·25, 8″·882, and with Struve's, of 20″·445, 8″·798. These values of parallax compare favourably with determination by other methods, of which we give a few examples. The value given by the transits of Venus in 1761 and 1769 was 8″·5776 computed by Encke, but increased to 8″·891 by Mr. Stone on a redetermination. By the record of an observation of the occultation of ψ_2 Aquarii on October 1, 1672, M. Leverrier obtained 8″·866; by meridian observations of Mars at Greenwich in 1862, 8″·932; by the latitude of Venus obtained from transits of 1761 and 1769, combined with present latitudes, M. Leverrier finds 8″·853; from the discussion of meridional observations of Venus in an interval of 106 years 8″·859; by the opposition of Mars in 1860 by M. Liais 8″·760; by opposition of Flora in 1873 by Prof. Galle 8″·873. Judging from these results the velocity of 186,638 miles per second is not very far from the mark, and the care in selection of methods and in computing results can scarcely be surpassed.

G. M. S.

EVOLUTION OF NERVES AND NERVO-SYSTEMS[1]

NERVE-TISSUE universally consists of two elementary structures, viz., very minute nerve-cells and very minute nerve-fibres. The nerve-fibres proceed to and from the nerve-cells, thus serving to unite the cells with one another, and also with distant parts of the animal body. Moreover, nerve-cells and fibres, wherever we meet with them, present very much the same appearances. Here, for instance, is a sketch of highly magnified nerve-tissue as we find it in the human brain, and here is one of my own drawings of nerve-tissue as I have found it in the jelly-fish; and you see how similar the drawings are—notwithstanding they are taken from the extreme limits of the animal kingdom within which nerve-tissue is known to occur.

Nerve-cells are usually found collected together in aggregates which are called nerve-centres or ganglia, to and from which large bundles of nerve-fibres come and go. These large bundles of nerve-fibres are what we see with the naked eye as nerves, permeating the body in all directions. When such a bundle of nerve-fibres reaches a ganglion, or collection of nerve-cells, it splits up like the end of a rope which has been teased out, and the constituent fibres pass into and out of the nerve-cells, so interlacing with one another in all directions, as here diagrammatically represented. More true to nature is this diagram, which represents a magnified section of human brain—the human brain being itself nothing more than a collection of very large ganglia.

To explain the *function* of nerve-cells and nerve-fibres, I must begin by explaining what physiologists mean by the word "excitability." Suppose this to represent a muscle cut from the body of a freshly-killed animal. So long as you do not interfere with it in any way, so long will it remain quite passive. But every time you stimulate it either with a pinch, a burn, or, as represented in the diagram, with an electrical shock, the muscle will give a single contraction in response to every stimulation. Now it is this readiness of organic tissues to respond to a stimulus that physiologists designate by the term excitability.

Nerves, no less than muscles, present the property of being excitable. Suppose, for instance, that this is another muscle prepared in the same way as the last one, except that together with the muscle there is cut out the attached nerve. Every time you pinch, burn, or electrify any part of the nerve, the muscle will contract. But you will carefully observe there is this great difference between these two cases of response on the part of the muscle; viz., that while in the former case the muscle responded to a stimulus *applied directly to its own substance*, in the latter case the muscle responded to a stimulus *applied at a distance from its own substance*, which stimulus was then *conducted* to the muscle by the nerve. And here we perceive the characteristic function of nerve-fibres, viz., that of conducting stimuli to a distance. This is the function of nerve-*fibres*; but the function of nerve-*cells* is different, viz., that of accumulating nervous energy, and at fitting times of discharging this energy into the attached nerve-fibres. The nervous energy when thus discharged from the nerve-cells acts as a stimulus to the nerve-fibre; so that if a muscle is attached to the end of the fibre it contracts on receiving this stimulus. I may add that when nerve-cells are collected into ganglia they often appear to discharge their energy spontaneously, without any observable stimulus to cause the discharge; so that in all but the lowest animals, whenever we meet with apparently spontaneous action, we infer that ganglia are probably present. But the point which most of all I desire you to keep well in mind this evening is the distinction which I here draw between muscle and nerve. A stimulus applied to a nerveless muscle can only course through the muscle by giving rise to a visible wave of contraction, which spreads in all directions from the seat of stimulation as from a centre. A nerve, on the other hand, conducts the stimulus without undergoing any change of shape. Now in order not to forget this all-important distinction, I shall always to-night speak of muscle as conducting a visible wave of *contraction*, and of nerve as conducting an invisible or molecular wave of *stimulation*. Nerve-fibres, then, are functionally distinguished from muscle-fibres—and also, I may add, from protoplasm—by displaying the property of conducting invisible or molecular waves of stimulation from one part of an organism to another—so establishing physiological continuity between such parts *without the necessary passage of contractile waves*.

I will now conclude all that it is necessary to say about the function of nervous tissue by describing the mechanism of reflex action. Suppose this to represent any peripheral structure, such as a part of the skin of some animal, this a collection of nerve-cells or ganglion, and this a muscle. The part of the skin represented is united to the nerve-cells composing the ganglion by means of this in-coming nerve-trunk, while the nerve-cells in the ganglion are united to the muscle by means of this out-going nerve-trunk. Therefore when any stimulus falls on the skin where this in-coming nerve-trunk takes its origin, the nerve-trunk conveys the stimulus to the nerve-cells in the ganglion. When the nerve-cells receive the stimulus they liberate one of their characteristic discharges of nervous energy, which discharge then passes down this out-going nerve and so causes the muscle to contract. Now this particular kind of response is called response by reflex action, because the stimulus wave does not pass in a straight line from the seat of stimulation to the muscle, but passes in the first instance to the ganglion, and is from it *reflected* to the muscle. This, at first sight, appears to be a roundabout sort of a process, but in reality it is the most economic process available; for we must remember the enormous number and complexity of the stimuli to which every animal is more or less exposed, and the consequent necessity that arises in the case of highly organised animals of there being some organised system whereby these stimuli shall be suitably responded to. Or, to adopt a happy illustration of Prof. Bain, the stimuli are systematised on the same principle as the circulation of letters by post is systematised; for just as in the case of the letters there is no

[1] Abstract of a Lecture delivered at the Royal Institution on Friday evening, May 25, 1877. By George J. Romanes, M.A., F.L.S., &c.