similar tide-ways, is affected by the complex action of the tides and consequent currents.

It is much to be regretted that the economy or parsimony of the Government has caused a suspension for the present of the special survey of the currents, and has restricted the work to tidal observations, which, though of great value to the shipping interests, can only be considered as preliminary in regard to the investigation of the currents themselves, which lead to so many losses of property and life, and tend to high rates of insurance, injurious to the shipowners and merchants of Canada, and through them to those of an empire as a whole.

The present report, in addition to what can be done with the insufficient grant allowed, in the matter of tide-gauges and tide-tables, has reference to the behaviour of the gigantic tides of the Bay of Fundy, when confined by the converging coasts at the head of the bay, and their relation to the smaller tides on the opposite side of the isthmus connecting Nova Scotia and New Brunswick at Bay Verte on the Gulf of St. Lawrence. These and the phenomena of the "bore" at the head of the Bay of Fundy are here for the first time described, illustrated by maps and sections, and tabulated, and will be found of the greatest interest by all who desire information as to the exceptional tides of this region. J. W. DAWSON.

School Laboratory Plans.

As one who has had the privilege of seeing Mr. Dymond's excellent arrangement and outlay of money in his laboratory at Chelmsford, may I make a comment on his letter in your issue of July 13? I think the conditions of work in an average school laboratory show some points of difference from those in Mr. Dymond's laboratory. Of course qualitative analysis is now confined to quite senior boys, who can be persuaded not to treat the subject as if they were working from a cookery book; but though owning no allegiance to the Science and Art Department, I believe that drawers and lockers are valuable, not only in relieving the general stock of the laboratory (very heavy for descriptive and quantitative work) of some smaller apparatus in constant use, but also in conferring a feeling of ownership, which induces some care and respect in a boy for his belongings. With snap-locks answering to one master key, and the lockers of each class bearing a label of a distinctive colour, they may be at once opened by the assistant before a class, so that there need be no keys to lose and no depredations on neighbouring lockers. Mr. Dymond's objection to that most durable of woods—teak—or why it alone should be left in a dirty state, I do not understand. Admitting that in all but very elementary work some tuition in the way of lectures is necessary, a laboratory will generally possess a lecture room; and where this is a separate room, I grudge the space usually given to a demonstrator's table in the laboratory, because no large section of a practical class is ever doing the same experiment at the same time. Physics, again, is often involved in this question of arrangement in a school, since the two subjects may, I think, with little detriment and great economy often have a common lecture room. Considering the prodigal waste of space often seen in laboratories, and the number now being built by public bodies, some further views on this subject ought to be of value. A. E. MUNBY.

Felsted School.

Duties of Provincial Professors.

THE article in your issue of July 13 upon "The Duties of Provincial Professors" will be welcomed by all professors in local university colleges. It insists none too strongly upon the disadvantageous position they occupy with regard to the opportunity for the prosecution of original research, and the unfortunate result of compelling our best students to complete their scientific education in Germany.

It is not sufficiently recognised that the reputation of a university is advanced more by the contributions to science and literature produced by its staff than by the mere number of its students. Unfortunately, the staff of assistants in the university colleges is often totally inadequate to the work required, and the knowledge that their energies will be dissipated in elementary teaching, and no time given for continuing original investigation, is deterring men of really high academic distinction from accepting such appointments. The government of a local college is largely directed by business men, and the methods which ensure commercial success are hardly those best calculated to further the interests of true education. Salvation lies apparently in the fact of Government inspection; the Government grant is only given when the education is of an advanced university type; and, judging from the tenor of the Treasury Minute, "University Colleges, Great Britain—Grant in Aid," the fullest recognition is given to those colleges which offer opportunities for advanced work and research and can show an adequate educational equipment. "A PROFESSOR."

July 23.

IN the articles on "The Duties of Provincial Professors," it is stated: "In such cases students . . . may be called on to give evidence against their professors." This is almost incredible, but, to my great astonishment, I learnt quite lately that the only possible alteration in the statement consistent with truth would be the substitution of the words "have been" for "may be." The adoption of such a course must be fatal to good discipline in a college, and it leaves the members of the staff at the mercy of a few unruly and ignorant students whose disposition to learn may be small, though their capacity for agitation is great. From time to time students of this description will be found in every college. Apart altogether from these evils, there is another reason why the practice of allowing students to give evidence against a professor is decidedly objectionable; and that is, the lay members of the governing body of a provincial college are not likely to fully understand how incompetent the average pass student is to form an opinion as to the soundness of the teaching he receives.

In the interests, not merely of the provincial colleges, but of higher education throughout the country, it is desirable that professors should not, for any except very grave reasons, and then only after a perfectly fair trial, be forced to resign their offices. P.

THE REDE LECTURE.[1]

THE WAVE THEORY OF LIGHT: ITS INFLUENCE ON MODERN PHYSICS.

OUR era is distinguished from preceding ages by wonderful utilisation of natural forces; man, that weak and defenceless being, has been enabled by his genius to acquire an extraordinary power, and to bend to his use those subtle yet dreadful agents whose very existence was unknown to our ancestors. This marvellous increase of his material power in modern times is due only to the patient and profound study of natural phenomena, to the exact knowledge of the laws that governed them, and to the skilful combining of their effects. But what is peculiarly instructive is the disproportion between the primitive phenomenon and the greatness of the effects which industry has drawn from it. Thus, those formidable engines, based on electricity or steam, grew neither from lightning nor the volcano; they had their birth from scarcely perceptible phenomena which would have remained for ever hidden from the vulgar eye, but that penetrating observers were able to recognise and appreciate. This humble origin of most of the great discoveries which are to-day a benefit to the

[1] Besides the interest presented by a glance on the progress and the influence of optical science, this lecture offers the conclusions of a careful study on Newton's treatise of optics. It will be seen that the thought of the great physicist has been singularly altered by a sort of legendary interpretation developed in the elementary treatises where the emission-theory is expounded. In order to make the theory of fits clearer, the commentators have imagined to materialise the luminous molecule under the form of a rotating arrow offering now its head, now its side. This mode of exposition has contributed to lead to the belief that the whole emission-theory was comprehended in this rather childish image.

Nowhere in his treatise does Newton give a mechanical illustration of the luminous molecule: he confines himself to the description of facts, and sums them up in an empirical statement without any hypothetical explanation. Moreover, he denies the opinion that he raises any theory, though he holds occasionally as very probable the intervention of the waves excited in the ether.

So that the general impression resulting from the reading of the treatise and above all of the "queries" in the 3rd Book, is the following: Newton, far from being the adversary of the Cartesian system, as he is commonly represented, looks, on the contrary, very favourably at the principles of this system. Struck by the resources which the undulatory hypothesis would offer for the explanation of the luminous phenomena, he would have adopted it, if the grave objection concerning the rectilinear propagation of light (only recently solved by Fresnel) had not prevented him.

whole human race, shows us plainly that the scientific spirit is at present the mainspring of the life of nations, and that it is in the onward march of pure science that we are to look for the secret of the growing power of the modern world. Whence a series of questions which demand more and more the attentions of all. How did this taste towards the study of natural philosophy, so dear to the ancient philosophers, abandoned for centuries, again revive and grow? What are the phases of its advance? How appeared the new notions which have so deeply modified our ideas on the mechanism of nature's forces? What paths, rich in discoveries, lead us gradually unawares to those admirable generalisations in accordance with the vast plan foreseen by the founders of modern physics? These are the questions which as a physicist I intend to inquire into before you. The subject is rather abstract, I might say severe. But no other has seemed more worthy of your attention during the *fête* which the University of Cambridge celebrates to-day in honour of the Lucasian Professorship Jubilee of Sir Geo. Gabriel Stokes, who in his fine career has laid a master-hand on the very problems which seemed to me the most conducive to the progress of natural philosophy. The subject is all the more fitted here, as in citing the names of those great minds to whom modern science is most indebted, we found amongst those who most honoured the University of Cambridge—its Professors and Fellows—Sir Isaac Newton, Thomas Young, George Green, Sir George Airy, Lord Kelvin, Clerk Maxwell, Lord Rayleigh, and the memory of that glory which links to-day back through the centuries would add lustre to the present ceremony.

Let us then, in a rapid glance of the scientific revival, point out the secret but mighty influence which has been the directing force of modern physics. I am inclined to attribute to the study of light, and to the attraction it has for the highest minds, one of the most effective causes of the return of ideas towards natural philosophy, and consider optics as having exercised on the advance of science an influence it would be difficult to exaggerate. This influence, already clear at the dawn of the experimental philosophy under Galileo, grew so rapidly that to-day it is easy to foresee a vast synthesis of natural forces founded on the principles of the wave theory of light. This influence is easy to understand if we reflect that light is the way by which knowledge of the exterior world reaches our intelligence. It is, in fact, to sight that we owe the quickest and most perfect notions of the objects around us: our other senses, hearing, feeling, also bring their share of learning, but sight alone affords us abundant means of simultaneous information such as no other sense can. It is, therefore, not surprising that light, this lasting link between us and the outward world, should intervene with the varied sources of its inner constitution to render more precise the observation of natural phenomena. Thus each discovery concerning new properties of light has had an immediate effect on the other branches of human knowledge, and has indeed determined the birth of new sciences by affording new means of investigation of unexpected power and delicacy.

Optics are really a modern science. The ancient philosophers had no idea of the complexity of what is vulgarly called light; they confounded in the same name what is proper to man, and what is exterior. They had, however, perceived one of the characteristic properties of the link, which exists between the source of light and the eye, which receives the impression, "Light moves in a straight line." Common experience had revealed this axiom through the observation of the shining trains that the sun throws across the skies, piercing misty clouds, or penetrating into some dark space. Hence arises two empirical notions—the definition of the ray of light, and that of the straight line. The one became the basis of optics, the other that of geometry.

Very little remains to us of the ancient books upon optics. Yet we are aware that they knew the reflection of the luminous rays on polished surfaces, and the geometrical explanation of the images formed by mirrors.

We must wait many centuries until the scientific revival for a new progress in optics (but then a very considerable one) opens the new era; it is the invention of the telescope.

The new era begins with Galileo, Boyle and Descartes, the founders of experimental philosophy. All devote their life to meditations on light, colours, and forces. Galileo lays the base of mechanics and with the refracting telescope that of astro-physics. Boyle improves experimentation. As to Descartes, he embraces with his penetrating mind the whole of natural philosophy; he throws away the occult causes admitted by the scholastics, and proclaims as a principle that all phenomena are governed by the laws of mechanics. In his system of the universe, light plays a prominent part[1]: it is produced by the waves excited in the subtle matter which, according to his view, pervades space. This subtle matter (which represents what we call to-day the ether) is considered by him as formed of particles in immediate contact; it constitutes thus at the same time the vehicle of the forces existing between the material bodies which are plunged in it. We recognise the famous "vortices of Descartes," sometimes admired, sometimes baffled during the last centuries, but to which skilful contemporaneous physicists have rendered the importance they deserve.

Whatever may be the opinions granted to the exactness of the deductions of this great philosopher, we must be struck by the boldness with which he proclaims the connection of the great cosmical problems, and fortells the solutions which actual generations did not yet entirely accept but drew insensibly to.

In Descartes' view the mechanism of light and that of gravitation are inseparable; the seat of corresponding phenomena is this subtle matter which pervades the universe, and their propagation is performed by waves around the acting centres.

This conception of the nature of light shocked the opinions in vogue; it raised strong opposition. Since the oldest times it was the habit to imagine the luminous ray as the trajectory of rapid projectiles thrown by the radiant source. Their shock on the nerves of the eye produce vision; their resistance or changes of speed, reflection or refraction. The Cartesian theory had, however, some seductive aspects which brought defenders. The waves excited on the surface of still water offer so clear an image of a propagated motion around a disturbing centre! On the other hand, do not the sonorous impressions reach our ear by waves? Our mind feels yet a real satisfaction in thinking that our most sharp and delicate organs are both impressed by a mechanism of the same nature.

Yet a serious difference arose. Sound does not necessarily travel in straight lines as light does. It travels round any object opposed to it, and will follow the most circuitous routes with scarcely any loss of strength. Physicists were thus divided into two camps. In one the partisans of emission, in the other those of the wave theory, each system boasting itself superior, and indeed each being so in certain respects. Other phenomena had to be examined in order to decide between them.

The chance of discovery brought to view several phenomena which ought to have decided in favour of wave theory, as was proved a century later; but the simplest truth does not prevail without long endeavour.

A strange compromise was effected between the two systems, helped on by a name great among the greatest, and for a century the theory of emission triumphed.

The tale is a strange one. In 1661 a young scholar,

[1] *Le Monde de M. Descartes, ou le Traité de la Lumière* (Paris, 1664).

full of eagerness and penetration, enters Trinity College, Cambridge; his name is Isaac Newton. He has already in his village read Kepler's "Optics." Almost immediately, and while following Barrow's lectures upon optics, he studies the geometry of Descartes with passionate care; with his savings he buys a prism that he might examine the properties of colour and meditate deeply on the causes of gravitation. Eight years later his masters think him worthy to succeed Barrow in the Lucasian Professorship, and in his turn he also teaches optics. The pupil soon becomes greater than his teacher, and he gives out this great result: White light which seemed the type of pure light is not homogeneous; it consists of rays of different refrangibility, and he demonstrates it by the celebrated experiment of the solar spectrum, in which a ray of white light is decomposed into a series of coloured rays like a rainbow; each shade of the colour is simple, for the prism does not decompose the shade. This is the origin of the spectral analysis. This analysis of white light brought Newton to explain the colours of the thin plates which are, for instance, observed in soap-bubbles. The fundamental experiment, that of Newton's rings, is one of the most instructive in optics, while the laws that govern it are of admirable simplicity.

The theory was expounded in a discourse addressed to the Royal Society with the title, "A New Hypothesis concerning Light and Colour."

This discourse called forth from Hooke a sharp complaint. Hooke also had already examined the colour of thin plates, and endeavoured to explain them in the wave system. He had the merit, which Newton himself readily granted, to substitute for the progressive wave of Descartes a vibrating one—a new and extremely important notion. He had even noticed the part of the two reflecting surfaces of the thin plate, and the mutual action of the reflected waves. Consequently Hooke should have been the very forerunner of the modern theory if he had had, as Newton, the clear intelligence of the simple rays. But his vague reasoning to explain the colours takes away all demonstrative value from his theory.

Newton is very affected by this complaint of priority, and combats the arguments of his adversary by remarking that the wave theory is inadmissible because it does not explain the existence of the luminous ray and of the shadows. He denies the opinion that he has raised a theory; he certifies that he does not admit either the wave hypothesis or the emission, but he says "He shall sometimes, to avoid circumlocution and to represent it conveniently, speak of it as if he assumed it and propounded it to be believed." And, really, in the Proposition XII. (second book of his Optics),[1] which constitutes what was since called the theory of fits, Newton remains absolutely on the ground of facts. He says simply, the phenomena of thin plates prove that the luminous ray is put alternatively in a certain state or fit of easy reflexion and of easy transmission. He adds, however, that if an explanation of these alternative states is required they can be attributed to the vibrations excited by the shock of the corpuscles, and propagated under the form of a wave in ether.[2]

After all, notwithstanding his desire to remain on the firm ground of facts, Newton cannot help trying a rational explanation. He has too carefully read the writings of Descartes not to be heartily, as Huygens, a partisan of the universal mechanism and not to wish secretly to find in the pure undulations the explanation of the beautiful phenomena he has reduced to such simple laws. But his third book on optics more especially proves his Cartesian aspirations, and, above all, his perplexity. His famous "Queries" expose so forcibly his argument in favour of the wave theory of light that Thos. Young will later cite them as proof of the final conversion of Newton to the wave theory. Newton would certainly have yielded to this secret inclination had the inflexible logic of his mind allowed him to do so; but when after enumerating the arguments the wave theory of light offers in explanation of the intimate nature of light, when he arrived at the last "queries" he stops, as if seized by a sudden remorse, and throws it away. And the sole argument is that he does not see the possibility of explaining the rectilinear transmission of light.[1] Viewed from this standpoint the third book of *Optiks* is no longer only an

[1] Prop. XII.—Every Ray of Light in its passage through any refracting Surface is put into a certain transient constitution or state, which in the progress of the Ray returns at equal Intervals, and disposes the Ray at every return to be easily transmitted through the next refracting Surface, and between the returns to be easily reflected by it. (Sir Isaac Newton, "*Opticks*: or a *Treatise* of the Reflections, Refractions, Inflexions and Colours of *Light*." London, 1718. Second edition, with additions. P. 293.

[2] *Loc. cit.*, p. 299.

[1] First, here is an extract from the "Queries" which prove the leaning of Newton's views towards the undulatory theory and the Cartesian ideas.

"Query 12.—Do not the Rays of light in falling upon the bottom of the eye excite Vibrations in the *Tunica Retina*? Which Vibrations, being propagated along the Solid Fibres of the optick nerves into the brain, cause the Sense of seeing. . ."

"Query 13.—Do not several sorts of Rays make Vibrations of several bignesses, which, according to their bignesses, excite sensations of several colours, much after the manner that the vibrations of the air, according to their several bignesses, excite sensation of several sounds? And particularly do not the most refrangible rays excite the shortest vibrations for making a sensation of deep violet, the least refrangible the largest for making a sensation of deep red, &c.? . . ."

"Query 18.— . . . Is not the heat of the warm room convey'd through *the vacuum* by the vibrations of a much subtiler medium than air, which, after the air was drawn out remained in the *vacuum*? [ether] and is not this medium the same with that medium by which light is refracted and reflected, and by whose vibrations light communicates heat to bodies, and is put into fits of easy reflection and easy transmission? . . . And is not this medium exceedingly more rare and subtile than the air, and exceedingly more elastic and active? and doth it not readily pervade all bodies? and is it not (by its elastick force) expanded through all the heavens?"

Newton, afterwards, considers the possible connection of this medium (ether) with the gravitation and the transmission of the sensations and motion in living creatures (queries 19 to 24).

The dissymetrical properties of the two rays propagated in the Iceland spar, draw equally his attention (query 25 to 29).

Here appears this sudden and unexpected going back, this sort of remorse from having too kindly expounded the resources of the Cartesian theory, based on the *plenum*; he makes an apology as follows:

"Query 27.—Are not all hypotheses erroneous which have hitherto been invented for explaining the phenomena of light, by new modifications of the rays? . . ."

"Query 28.—Are not all hypotheses erroneous in which light is supposed to consist in pression or motion, propagated through a fluid medium? . . . and if it (light) consisted in pression or motion, propagated either in an instant or in time, it would bend into shadow. For pression or motion cannot be propagated in a fluid in right lines beyond an obstacle, which stops part of the motion, but will bend and spread every way into the quiescent medium which lies beyond the obstacle. . . . For a bell or a canon may be heard beyond a hill which intercept the light of sounding body, and sounds are propagated as readily through crooked pipes as through straight ones. But light is never known to follow crooked passages nor to bend into the shadow. . . ."

Stopping before this objection Newton is forced to come back to the corpuscular theory.

"Query 29.—Are not the rays of light very small bodies emitted from shining substances? . . ."

"Query 30.—Are not gross bodies and light convertible into one another . . .? The changing of bodies into light and light into bodies, is very conformable to the course of nature, which seems delighted with transmutations. . . ."

Logic urges him to go on with the old hypothesis of the *vacuum* and *atoms*, and even to invoke the authority of the Greek and Phœnician philosophers in this matter (query 28, p. 343), therefore it is not surprising to see his perplexity expressed by the following words:—

"Query 31, and the last.—Have not the small particles of bodies certain powers, virtues, or forces, by which they act at a distance not only upon the rays of light for reflecting, refracting and inflecting them, but also upon one another for producing a great part of the phenomena of nature? . . ."

But he perceives that he is going rather far, and compromising himself, therefore his secret tendency, developed in the foremost queries, reappear a little while:—

". . . How these attractions may be performed I do not here consider. What I call attraction may be perform'd by impulse, or by some other means unknown to me . . ."

Many other curious remarks could be made on the state of mind of the great physicist, geometer and philosopher, which is artlessly revealed in those "queries." The preceding short extracts are sufficient, I believe, to justify the conclusion which I get from the study of the 3rd Book, namely, that Newton had not at all on the mechanism of light the definite ideas which have been attributed to him as founder of the emission-theory. Really, he is hesitating between the two opposite systems, perceiving clearly their insufficiency; and in this discussion he is endeavouring to go away as little as possible from the facts. That is the reason for which he has stated no dogmatic theory. It would be, therefore, unjust to make Newton responsible for every consequence which the emission partisans have sheltered under his authority.

impartial discussion of opposite systems; it appears as the painting of the suffering of a mighty genius, worried by doubt, now led away by the seductive suggestions of his imagination, now recalled by the imperious requirements of logic. It is a drama: the everlasting struggle between love and duty; and duty won.

Such, I take it, is the inner genesis of the theory of fits—a strange mingling of two opposite systems. It was much admired, presented, as it was, by the great mathematician, who had the glory of submitting the motions of all celestial bodies to the one law of universal gravitation.

To-day this theory is abandoned; it is condemned by the *experimentum crucis* of Arago, realised by Fizeau and Foucault. One ought, however, to acknowledge that it has constituted a real progress by the precise and new notions which it contains. The ray of light, considered up till then, was simply the trajectory of a particle in rectilinear motion; the ray of light, such as Newton described it, possesses a regular periodic structure, and the period or interval of fits, characterises the colour of the ray. This is an important result. It only requires a more suitable interpretation to transform the luminous ray into a vibratory wave; but we had to wait a century, and Dr. Thomas Young, in 1801, had the honour of discovering it.

Resuming the study of thin plates, Thomas Young shows that everything is explained with extreme simplicity, if it be supposed that the homogeneous luminous ray is analogous to the sonorous wave produced by a musical sound; that the vibrations of ether ought to compose—that is to say, to interfere—according to the expression that he proposes as to their mutual actions.

Although Young had taken the clever precaution of supporting his views by the authority of Newton,[1] the hypothesis found no favour; his principle of interference led to this singular result that light added to light could, in certain cases, produce darkness, a paradoxical result contradicted by daily experience. The only verification that Young brought forward was the existence of dark rings in Newton's experiment, darkness due, according to him, to the interference of waves reflected on the two faces of the plate. But as the Newtonian theory interpreted the fact in a different manner, the proof remained doubtful; an *experimentum crucis* was wanting. Young did not have the good success to obtain it.

The theory of waves relapsed then once more into the obscurity of controversy, and the terrible argument of the rectilinear propagation was raised afresh against it. The most skilled geometers of the period—Laplace, Biot, Poisson—naturally leaned to the Newtonian opinion; Laplace in particular, the celebrated author of the "Mecanique Celeste," had even taken the offensive. He was going to attack the theory of waves in its most strongly fortified entrenchments, which had been raised by the illustrious Huygens.

Huygens, indeed, in his "Traité de la Lumière," had resolved a problem before which the theory of emission had remained mute; that is to say, the explanation of the double refraction of Iceland spar: the wave theory (on the contrary) reduced to the simplest geometrical construction the path of the two rays, ordinary and extraordinary; experiment confirmed the results in every point. Laplace succeeded in his turn (with the help of hypotheses of the constitution of luminous particles) to explain the path of these strange rays. The victory of the theory of particles then appeared complete; a new phenomenon arrived also appropriately to render it striking.

Malus discovered that a common ray of light reflected under a certain angle acquired unsymmetrical properties similar to those rays from a crystal of Iceland spar. He explained this phenomenon by an orientation of the luminous molecule, and, consequently, named this light *polarised light*. This was a new success for emission.

The triumph was not of long duration. In 1816 a young engineer, scarcely out of the École Polytechnique, Augustin Fresnel, confided to Arago his doubts on the theory then in favour, and pointed out to him the experiments which tended to overthrow it.

Supporting himself on the ideas of Huygens, he attacked the formidable question of rays and shadows, and had resolved it: all the phenomena of diffraction were reduced to an analytical problem, and observations verified calculation marvellously. He had, without knowing it, rediscovered Young's reasonings as well as the principle of interference; but more fortunate than he, he brought the *experimentum crucis*—the two-mirror experiment; there, two rays, issuing from the same source, free from any disturbance, produced when they met, sometimes light, sometimes darkness. The illustrious Young was the first to applaud the success of his young rival, and showed him a kindness which never changed.

Thus, thanks to the use of two-mirror experiment, the theory of Dr. Young (that is to say, the complete analogy of the luminous ray and the sound wave) is firmly established.

Moreover, Fresnel's theory of diffraction shows the cause of their dissimilarity; light is propagated in straight lines because the luminous waves are extremely small. On the contrary, sound is diffused because the lengths of the sonorous waves are relatively very great.

Thus vanished the terrible objection which had so much tormented the mind of great Newton.

But there remained still to explain another essential difference between the luminous wave and the sonorous wave; the latter undergoes no polarisation. Why is the luminous wave polarised?

The answer to this question appeared so difficult that Young declared he would renounce seeking it. Fresnel worked more than five years to discover it; the answer is as simple as unexpected. The sound wave cannot be polarised because the vibrations are longitudinal; light, on the other hand, can be polarised because the vibrations are transverse, that is to say, perpendicular to the luminous ray.

Henceforth the nature of light is completely established, all the phenomena presented as objections to the undulatory theory are explained with marvellous facility, even down to the smallest details.

I would fain have traced by what an admirable suite of experiment and reasoning Fresnel arrived at this discovery, one of the most important of modern science: but time presses.

It has sufficed me to explain how very great the difficulties were which he had to overcome in order to establish it.

I hasten to point out its consequences.

You saw, at starting, the purely physiological reasons which make the study of light the necessary centre of information gathered by human intelligence. You judge now, by the march of this long development of optical theories, what preoccupations it has always caused to powerful minds interested in natural forces. Indeed, all the phenomena which pass before our eyes involve a transmission to a distance of force or movement; let the distance be infinitely great, as in celestial space, or infinitely small, as in molecular intervals, the mystery is the same. But light is the agent which brings us the movement of luminous bodies; to fathom the mechanism of this transmission is to fathom that of all others, and Descartes had the admirable intuition of this when he comprehended all these problems in a single mechanical conception: here is the secret bond which has always attracted the physicists and geometers towards the study

1 The Bakerian Lecture, "On the Theory of Light and Colours." By Thomas Young. *Phil. Trans.* of the R.S. for the year 1802.

of light. Looked at from this point of view, the history of optics acquires a considerable philosophical importance; it becomes the history of the successive progress of our knowledge on the means that nature employs to transmit movement and force to a distance.

The first idea which came to the mind of man (in the savage state) to exercise his force beyond his reach is the throwing of a stone, of an arrow or of some projectile; this is the germ of the theory of emission. This theory corresponds to a philosophical system which assumes an empty space in which the projectile moves freely. At a more advanced degree of culture, man having become a physicist, has had the more delicate idea of the transmission of movement by waves, suggested at first by the study of waves, afterwards by that of sound.

This second way supposes, on the other hand, that space is a plenum; there is no longer here transport of matter; particles oscillate in the direction of propagation, and it is by compression or rarefaction of a continuous elastic medium that movement and force are transmitted. Such has been the origin of the theory of luminous waves; under this form it could only represent a part of the phenomena; it was therefore insufficient.

But geometers and physicists before Fresnel did not know of any other undulatory mechanism in a continuous medium.

The great discovery of Fresnel has been to reveal a third mode of transmission quite as natural as the preceding one, but which offers an incomparable richness of resources. These are the waves of transverse vibrations excited in an incompressible continuous medium, those which explain all the properties of light.

In this undulatory mode the displacement of particles brings into play an elasticity of a special kind; this is the relative slipping of strata concentric to the disturbance which transmits the movement and the effort. The character of these waves is to impose on the medium no variation of density as in the system of Descartes. The richness of resource mentioned above depends upon the fact that the form of the transverse vibration remains indeterminate, and thus confers on waves an infinite variety of different properties.

The rectilinear, circular and elliptical forms characterise precisely the polarisations, so unexpected, which Fresnel discovered, and by the aid of which he has so admirably explained the beautiful phenomena of Arago produced by crystallised plates.

The possible existence of waves which are propagated without change of density, has profoundly modified the mathematical theory of elasticity. Geometers found again in their equations, waves having transverse vibrations which were unknown to them; they learnt besides, from Fresnel, the most general constitution of elastic media, of which they had not dreamt.

It is in his admirable memoir on double refraction that this great physicist set forth the idea that in crystals the elasticity of the ether ought to vary with the direction, an unexpected condition and one of extreme importance, which has transformed the fundamental bases of molecular mechanics; the works of Cauchy and Green are the striking proofs of it. From this principle Fresnel concluded the most general form of the surface of the luminous wave in crystals, and found (as a particular case) the sphere and ellipsoid that Huygens had assigned to the Iceland spar crystal. This new discovery excited universal admiration among physicists and geometers; when Arago came to expound it before the Académie des Sciences, Laplace, who had been such a long time hostile, declared himself convinced. Two years later Fresnel, unanimously elected a member of the Academy, was elected with the same unanimity foreign member of the Royal Society of London; Young himself transmitted to him the announcement of this distinction, with personal testimony of his sincere admiration.

The definite foundation of the undulatory theory imposes the necessity of admitting the existence of an elastic medium to transmit the luminous movement. But does not all transmission to a distance of movement or of force imply the same condition? To Faraday is due the honour of having, like a true disciple of Descartes and Leibnitz, proclaimed this principle, and of having resolutely attributed to reactions of surrounding media the apparent action at a distance of electrical and magnetic systems. Faraday was recompensed for his boldness by the discovery of induction.

And since induction acts even across a space void of ponderable matter, one is forced to admit that the active medium is precisely that which transmits the luminous waves, the ether.

The transmission of a movement by an elastic medium cannot be instantaneous; if it is truly luminous ether that is the transmitting medium, ought not the induction to be propagated with the velocity of luminous waves?

The verification was difficult. Von Helmholtz, who tried the direct measurement of this velocity, found, as Galileo formerly, for the velocity of light a value practically infinite.

But the attention of physicists was attracted by a singular numerical coincidence. The relation between the unity of electrostatic quantity to the electro-magnetic unit is represented by a number precisely equal to the velocity of light.

The illustrious Clerk Maxwell, following the ideas of Faraday, did not hesitate to see in the relationship the indirect measure of the velocity of induction, and by a series of remarkable deductions he built up this celebrated electro-magnetic theory of light, which identifies in one mechanism three groups of phenomena completely distinct in appearance, light, electricity, and magnetism.

But the abstract theories of natural phenomena are nothing without the control of experiment.

The theory of Maxwell was submitted to proof, and the success surpassed all expectation. The results are too recent and too well known, especially here, for it to be necessary to insist upon them.

A young German physicist, Henry Herz, prematurely lost to science, starting from the beautiful analysis of oscillatory discharges of Von Helmholtz and Lord Kelvin, so perfectly produced electric and electro-magnetic waves, that these waves possess all the properties of luminous waves; the only distinguishing peculiarity is that their vibrations are less rapid than those of light.

It follows that one can reproduce with electric discharges the most delicate experiments of modern optics —reflection, refraction, diffraction, rectilinear, circular. elliptic polarisation, &c. But I must stop, gentlemen. I feel that I have assumed too weighty a task in endeavouring to enumerate the whole wealth which waves of transverse vibrations have to-day placed in our hands.

I said at the beginning that optics appeared to me to be the directing science in modern physics.

If any doubt can have arisen in your minds, I trust this impression has been effaced to give place to a sentiment of surprise and admiration in seeing all that the study of light has brought of new ideas on the mechanism of the forces of nature.

It has insensibly restored the Cartesian conception of a single medium refilling space, the seat of electrical, magnetic and luminous phenomena; it allows us to foresee that this medium is the depositary of the energy spread throughout the material world, the necessary vehicle of every force, the origin even of universal gravitation.

Such is the work accomplished by optics: it is perhaps the greatest thing of the century!

The study of the properties of waves, viewed in every aspect, is therefore, at the present moment, the most fertile study.

It is that which has been followed in the double capacity of geometer and physicist by Sir George Stokes, to whom we are about to pay so touching and deserved a homage. All his beautiful researches, both in hydrodynamics as well as in theoretical and practical optics, relate precisely to those transformations which various media impose on waves which traverse them.

In the many phenomena which he has discovered or analysed, movements of fluids, diffraction, interference, fluorescence, Röntgen rays, the dominant idea which I pointed out to you is always visible; it is that which makes the harmonious unity of the scientific life of Sir George Stokes.

The University of Cambridge may be proud of the Lucasian Chair of Mathematical Physics, because from Sir Isaac Newton up to Sir George Stokes it has contributed a glorious part towards the progress of Natural Philosophy! A. CORNU.

NOTES.

WE are glad to be able to publish this week a translation of the Rede Lecture delivered at Cambridge by Prof. Alfred Cornu, professor of experimental physics in the École polytechnique, Paris, and a Foreign Member of the Royal Society, on the occasion of the recent celebration of the jubilee of Sir George Stokes as Lucasian professor of mathematical physics. Prof. Cornu delivered the lecture in French, and we are indebted to him for the translation of his brilliant discourse, which immediately precedes this Note.

AN interesting gathering took place at the Star and Garter Hotel, Richmond, on Thursday last, when a number of friends joined with the members of the Physiological Society in giving a congratulatory dinner to Sir John Burdon-Sanderson, Bart., F.R.S., and Prof. Michael Foster, K.C.B., Sec.R.S., in honour of Her Majesty's recent recognition of the great services they have rendered to science. The chair was taken by Prof. Schäfer, F.R.S., and the friends who assembled to support him in doing honour to the distinguished guests numbered considerably over a hundred. The principal speeches of the evening were made by the chairman, by Sir John Burdon-Sanderson, and by Prof. Michael Foster, all of whom were able to give interesting reminiscences of the early days of physiology in England, and of the great difficulties which used to be thrown in the way of those who wished to study the subject. Owing to the exigencies of the various examinations now in progress, many physiologists were unable to be present in the earlier part of the evening, but the great interest taken in the proceedings was shown by the long journeys undertaken by several in order that they might take part at the dinner.

THE special number of the *Atti*, containing the report of the anniversary meeting of the Reale Accademia dei Lincei, announces the annual awards of prizes. The Royal prize for astronomy for 1896 remains unawarded. The Royal prize for philology and languages is divided equally between Prof. Pio Rajna, for his critical edition of Dante's "De Vulgari Eloquentia," and Prof. Claudio Giacomino, for his studies on the Basque language. The prize for history and geography is unawarded, and the same is true of a prize offered for 1898 for perfecting the theory of motion of a rigid body. The Ministerial prize of 3400 lire for history for 1898 is divided, a prize of 1700 lire being awarded to Prof. Gaetano Salvemini, and smaller awards being made to Profs. Alberto Pirro, Niccolò Rodolico, and Michele Rosi. Of the Ministerial prize of 3400 lire for mathematics for 1898, a prize of 2000 lire is awarded to Prof. Ettore Bortolotti, and awards of 700 lire each are made to Profs. Federico Amodeo and Francesco Palatini. The adjudicators state that the works of Prof. Pirondini would have gained an award had not some of them received recognition on a previous occasion. The adjudicators of the Ministerial prize for philosophical and social sciences for 1897 award 500 lire each to Profs. Albino Nagy, Luigi Ambrosi, and Tarozzi. The Mantellini prize is unawarded. Of the Santoro prize for electro-technics one half is awarded to Signor R. Arnò, for his share in the joint invention with the late Prof. G. Ferraris of a new transformer. The Santoro prize for chemistry as applied to agriculture is unawarded, and from the Carpi prize for mathematical physics for 1897–8 a sum of 500 lire is awarded to Signor C. Canovetti, for his papers on the direction of aerostats and on the resistance of the air.

IN connection with the preparation of argon, a good deal of attention has been paid to the absorption of nitrogen by metals. Prof. Ramsay, it will be remembered, used magnesium. Later, lithium was proposed by Ouvrard, and a mixture of lime and magnesium by Maquenne. The subject has recently been systematically investigated by Dr. Hempel, who finds that a mixture of calcium magnesium and sodium is very much more effective than the agents just named. The mixture is obtained by using 1 gramme of finely divided magnesium, 5 grammes coarsely powdered lime, and 0·25 grammes sodium. In a comparative time experiment the rates of absorption of nitrogen by magnesium, lithium, lime-magnesium, and lime-magnesium-sodium were in the ratio 1, 5, 8 and 20.

TO commemorate the completion of the twenty-five years of active work as a teacher of physiology of Prof. Purser, of Trinity College, Dublin, a movement is on foot among the professor's former pupils to raise funds for the bestowment annually of a "Purser Medal" to the candidate who, in the half M.B. examination, shows the highest proficiency in physiology and histology. Subscriptions, which are not to exceed a guinea, should be forwarded to the honorary treasurer, Dr. W. J. Houghton, 30 Lower Fitzwilliam Street, Dublin.

DR. MAXWELL T. MASTERS, F.R.S., has been made an officer of the Order of Leopold by the King of the Belgians.

THE Neill Prize for 1895–98 has been awarded to Prof. J. Cossar Ewart, F.R.S., by the Royal Society, Edinburgh, for his experiments and investigations bearing on the theory of heredity.

THE King of Sweden has conferred upon Mr. E. P. Martin, past-President of the Iron and Steel Institute, a Knight-commandership of the Royal Order of Wasa, and upon Mr. Bennett H. Brough, present Secretary of the Institute, a Knighthood of the same Order.

A DEPUTATION from the Iron and Steel Institute, consisting of Sir W. C. Roberts-Austen, K.C.B., F.R.S., President, Sir Lowthian Bell, Bart., F.R.S., Mr. E. P. Martin, past-Presidents, and Mr. Bennett H. Brough, Secretary, waited upon the Queen last week for the purpose of presenting to Her Majesty an illuminated address and the Bessemer Gold Medal, in commemoration of the great progress made in the iron and steel trade during the Queen's reign.

THE Meteorological Council have appointed Captain Campbell M. Hepworth, R.N.R., to fill the post of Marine Superintendent in succession to the late Mr. Baillie. Captain Hepworth has been an observer for the Meteorological Office for twenty-three years, and almost all of his logs have been classed "excellent."

A MEETING of the Aeronautical Society will be held at the Society of Arts to-morrow (July 28) at eight p.m.

THE summer meeting of the Institution of Mechanical Engineers was opened at Plymouth on Tuesday. In connection