*Chambers's* we notice one descriptive of the Loofah, or Luffa, by Prof. Carmody.

We have received, in addition to the magazines and reviews named in the foregoing, the *Humanitarian*, *Sunday Magazine*, *National*, *English Illustrated*, and *Longman's*, but the articles in them do not call for particular comment in these columns.

## RECENT PROGRESS IN OPTICS.[1]

THE reviewer who aspires to give an account of recent progress in any department of science, is met at the outset by two causes for embarrassment. What beginning shall be selected for developments called recent? What developments shall be selected for discussion from the mass of investigations to which his attention has been called? So rapidly is the army of workers increasing, and so numerous are the journals in which their work is recorded, that the effort to keep up with even half of them is hopeless; or, to borrow a simile employed by the late Prof. Huxley, "we are in the case of Tarpeia, who opened the gates of the Roman citadel to the Sabines, and was crushed under the weight of the reward bestowed upon her."

I have selected a single branch of physics, but one which can scarcely be treated rigorously as single. From the physical standpoint optics includes those phenomena which are presented by ether vibrations within such narrow limits of wave-length as can affect the sense of sight. But these waves can scarcely be studied except in connection with those of shorter and of longer period. Whatever may be the instruments employed, the last one of the series through which information is carried to the brain is the eye. The physicist may fall into error by faulty use of his mathematics; but faulty use of the senses is a danger at least equally frequent. Physiological optics has of late become transferred in large measure to the domain of the psychologist; but he in turn has adopted many of the instruments, as well as the methods, of the physicist. The two cannot afford to part company. If I feel particularly friendly to the psychologist, more so than can be accounted for by devotion to pure physics, it may be fair to plead the influence of old association. If I am known at all in the scientific world, the introduction was accomplished through the medium of physiological optics. But, with the limitations imposed, it is not possible even to do justice to all who have done good work in optics. If prominence is assigned to the work of Americans, it is not necessary to emphasise that this Association is made up of Americans; but, with full recognition of the greater spread of devotion to pure science in Europe, of the extreme utilitarian spirit that causes the value of nearly every piece of work in America to be measured in dollars, we are still able to present work that has challenged the admiration of Europe, that has brought European medals to American hands, that has been done with absolute disregard of monetary standards; work has been recognised, even more in Europe than in America, as producing definite and important additions to the sum of human knowledge.

In drawing attention to some of this work it will be a pleasant duty to recognise also some that has been done beyond the Atlantic—to remember that science is cosmopolitan. The starting-point is necessarily arbitrary, for an investigation may last many years and yet be incomplete. To note recent progress, it may be important to recall what is no longer recent.

### LIGHT WAVES AS STANDARDS OF LENGTH.

You are therefore invited to recall the subject of an address to which we listened in this section at the Cleveland meeting in 1888, when Michelson presented his "Plea for Light Waves." In this he described the interferential comparer, an instrument developed from the refractometer of Jamin and Mascart, and discussed various problems which seemed capable of solution by its use. In conjunction with Morley he had already used it in an inquiry as to the relative motion of the earth and the luminiferous ether (*American Journal of Science*, May 1886, p. 377), and these two physicists together worked out an elaborate series of preliminary experiments (*ibid.*, December 1877, p. 427) with a view to the standardising of a metric unit of length in terms of the wave-length of sodium light. By use of a Rowland diffraction grating, Bell had determined the sodium wave-length with an error estimated to be not in excess of one part in two hundred thousand (*American Journal of Science*, March 1887, p. 167). Could this degree of accuracy be surpassed? If so, it must be not so much by increased care in measurement as by increase of delicacy in the means employed. The principle applied in the use of the interferential comparer is simple enough; the mode of application cannot be clearly indicated without a diagram, but probably all physicists have seen this diagram, for it was first brought out eight years ago (*ibid.*, December 1887, p. 427). By interference of beams of light, reflected and transmitted by a plate of plane parallel optical glass, and then reflected back by two mirrors appropriately placed, fringes are caught in an observing telescope. One of the mirrors is movable in front of a micrometer screw, whose motion causes these fringes to move across the telescopic field. If the light be absolutely homogeneous, the determination consists in measurement of the distance through which the movable mirror is pushed parallel to itself and the counting of the number of fringes which pass a given point in the field of view. According to the theory of interference the difference of path between the distances from one face of the plate to the two mirrors should be small; beyond a certain limit interference phenomena vanish, and this limit is smaller in proportion as the light is more complex. In the case of approximately homogeneous light there are periodic variations of distinctness in the fringes. For example, assume sodium light, which in the spectroscope is manifested as a pair of yellow lines near together. In the refractometer there are two sets of interference fringes, one due to each of the two slightly different wave-lengths. When the difference of path is very small, or nearly the same for both of these radiation systems, the fringes coincide. The wave-length for one is about one-thousandth less than that for the other. If the difference of path is about five hundred waves, the maximum of brightness for one system falls on a minimum of brightness for the other, and the fringes become faint. They become again bright when the difference of path reaches a thousand wave-lengths. The case is entirely similar to the familiar production of beats by a pair of slightly mistuned forks.

The method of interference thus furnishes through optical beats a means of detecting radiation differences too minute for resolution by ordinary spectroscopic methods. Spectrum lines are found to be double or multiple when all other means of resolving them fail; and the difficulty of attaining truly homogeneous light is far greater than was a few years ago supposed. By the new method it becomes possible to map out the relative intensities of the components of a multiple line, their distance apart, and even the variations of intensity within what has for convenience been called a single component. Each of the two sodium lines is itself a double whose components are separated by an interval about one-hundredth of that between the long-known main components; and an interval yet less than one-fifth of this has been detected between some of the components of the green line of mercury. Indeed Michelson deems it quite possible to detect a variation of wave-length corresponding to as little as one ten-thousandth of the interval between the two main sodium lines (*Astronomy and Astrophysics*, p. 100, February 1894.)

This new-found complexity of radiation, previously thought to be approximately if not quite simple, proved to be a temporary barrier to the accomplishment of the plan of using a light-wave as a standard of length. It necessitated careful study of all those chemical elements which give bright lines that had been supposed to be simple. The red line of cadmium has been found the simplest of all those yet examined. The vapour in a rarefied state is held in a vacuum tube through which the electric spark is passed, and under this condition the difference of path for the interfering beams in the refractometer may be a number of centimetres. A short intermediate standard, furnished with a mirror at each end, is now introduced into the comparer, and moved by means of the micrometer screw. Its length is thus measured in terms of the cadmium wave-length. A series of intermediate standards, of which the second is double the first, the third double the second, &c., are thus compared, and finally in this way the value of the metre is reached.

The feasibility of this ingenious method having been made apparent, Michelson was honoured with an invitation from the International Bureau of Weights and Measures to carry out the measurement at the observatory near Paris, with the collaboration of the director M. Benoît. After many months of labour, results of extraordinary accuracy were attained. For the red line of

[1] Address delivered by Prof. W. LeConte Stevens before the Section of Physics of the American Association for the Advancement of Science, at the Springfield meeting, August 1895.

cadmium at an air temperature of 15° C. and pressure of 760 mm., two wholly independent determinations were made. From the first a metre was found equal to 1553162·7 wave-lengths; from the second, 1553164·3 wave-lengths, giving a mean of 1553163·5 the deviation of each result from the mean being very nearly one part in two millions ("Travaux et Mémoires du Bureau Internationale des Poids et Mésures," Tome xi. p. 84, 1894). A determination by Benoît from the first series gave 1553163·6, which differs but one-tenth of a wave-length from the mean of Michelson's measurements.

The direct comparison of the lengths of two metre bars, though not easy, is a simple operation in comparison with the indirect method just described, but does not surpass it in accuracy. Every one knows that the metre is not an exact submultiple of the earth's circumference, and that the determination of its exact value from the seconds pendulum is full of difficulty. It may perhaps be said that the optical method is no more absolute than the pendulum method, for no human measurements can be free from error; that there is no possibility of the destruction of the original metre and all certified copies of it; and that there is no proof or probability that molecular changes are gradually producing modifications in standards of length. Even if we should grant that for all practical purposes the labour of determining the metre in terms of an unchanging optical standard has been unnecessary, the achievement is a signal scientific triumph that ranks with the brilliant work of Arago, Fresnel and Regnault. In preparation for it much new truth has been elicited, and light waves have been shown to carry possibilities of application that Fresnel never suspected.

The physicist is nearly powerless without the aid of those who possess the highest order of mechanical skill. The interferential comparer could never have been ultilised for such work as Michelson has done with it, had not Brashear made its optical parts with such an approach to perfection that no error so great as one-twentieth of a wave-length could be found upon the reflecting surfaces ("Travaux et Mémoires du Bureau Internationale des Poids et Mésures," Tome xi. p. 5, 1895). In the conception, mechanical design and execution, the entire work has been distinctly American.

The interferential refractometer has been used with much skill by Hallwachs (*Wiedemann's Annalen*, Band 47, p. 380, and Band 53, p. 1) for comparing the variation of refractive index of dilute solutions with variation of concentration. The fact of solution brings about a change of molecular constitution, affecting both the electric conductivity and the refractive index; and the changes in optical density are measurable in terms of the number of interference fringes which cross the field of view for a given variation of dilution.

### LUMINESCENCE.

While all work on the visible spectrum is confessedly optical, we can no longer make an arbitrary division point, and declare that one part of the spectrum belongs to the domain of optics and the other not. Since the days of Brewster and the elder Becquerel fluorescent solutions have enabled us to bring within the domain of optics many wave-lengths that were previously invisible. Stokes's explanation of this, as a degradation of energy quite analogous to the radiation of heat from a surface on which sunlight is shining, has been generally accepted. But whether the phenomena of fluorescence and phosphorescence are in general physical or chemical, has for the most part remained unknown or at least very uncertain. E. Wiedemann, who suggested the term luminescence to include all such phenomena, published in 1895 (*Annalen der Physik und Chemie*, p. 604, April 1895), in conjunction with Schmidt, a part of the outcome of an extended investigation undertaken with a view to clearing up these uncertainties. He has shown that it is often possible to distinguish between cases in which the emission of light springs from physical processes and those in which it is due to chemical action, or at least invariably accompanied by this. We have here, as in photography, a transformation of radiant into chemical energy, to which is superadded the retransformation of chemical into radiant energy of longer period, and this either at the same time or long after the action of the exciting rays. Indeed, between this process and that of photography in colours, the analogy is quite striking. What has generally been called phosphorescence is well known to be the effect of oxidation in the case of phosphorus itself and in that of decaying wood or other organic matter, which under certain conditions shines in the dark.

Wiedemann has shown that the shining of Balmain's luminous paint, and generally of the sulphides of the alkaline earths, is accompanied with chemical action. A long period of luminosity after the removal of the source renders highly probable the existence of what he now calls chemi-luminescence. A large number of substances, both inorganic and organic, have been examined both by direct action of light and by the action of kathode rays in a controllable vacuum tube through which sparks from a powerful electric influence machine were passed. Careful examination with appropriate reagents before and after exposure was sufficient to determine whether any chemical change had been produced. Thus the neutral chlorides of sodium and potassium, after being rendered luminous by action of kathode rays, are thereby reduced to the condition of subchloride, so as to give a distinctly alkaline reaction.

Many substances, moreover, which manifest no luminescence at ordinary temperatures after exposure, or which do so for only a short time, become distinctly luminescent when warmed. This striking phenomenon is sufficient to warrant the use of a special name, thermo-luminescence. Among such substances may be named the well-known sulphides of the alkaline earths, the haloid salts of the alkali metals, a series of salts of the zinc and alkaline earth groups, various compounds with aluminium, and various kinds of glass. Some of these after exposure give intense colours when heated, even after the lapse of days or weeks. That the vibratory motion corresponding to the absorption of luminous energy should maintain itself for so long a time as a mere physical process is highly improbable if not unparalleled. That it should become locked in, to be subsequently evoked by warming, certainly indicates the storing of chemical energy, just as the storage battery constitutes a chemical accumulator of electrical energy. Other indications that luminescence is as much a chemical as a physical phenomenon are found in the fact that the sudden solution of certain substances is accompanied by the manifestation of light, if they have been previously subjected to luminous radiation, but not otherwise; that alteration of colour is brought about by such exposure; and that friction or crushing may cause momentary shining in such bodies as sugar. There is no conclusive direct evidence thus far that such luminescence as vanishes instantly upon the withdrawal of light is accompanied by chemical action. But Becquerel demonstrated long ago with his phosphoroscope that there is a measurable duration of luminous effect when to the unaided eye the disappearance seems instantaneous (Becquerel, *Comptes rendus* 96–121). Wiedemann now shows that when this duration is considerable there is generally chemical change. Since duration is only a relative term it seems highly probable that even cases of instantaneous luminescence, commonly called fluorescence, are accompanied with chemical action on a very minute scale, and that all luminescence is therefore jointly physical and chemical in character. We have thus colour evoked by the direct action of light, which disturbs the atomic equilibrium that existed before exposure, and the manifestation of such colour continues only until the cessation of the chemical action thus brought into play.

The influence of very low temperature upon luminescence and photographic action has been studied by Dewar (*Chemical News*, lxx. p. 252, 1894). The effect of light upon a photographic plate at the temperature of liquid air – 180° C. is reduced to only a fifth of what it is at ordinary temperature; and at – 200° the reduction is still greater, while all other kinds of chemical action cease. In like manner, at – 80° calcium sulphide ceases to be luminescent; but, if illuminated at this low temperature and then warmed, it gives out light. At the temperature of liquid air many substances manifest luminescence which ordinarily seem almost incapable of it; such are gelatine, ivory, and even pure water. A crystal of ammonium platinocyanide, on the other hand, when immersed in liquid air and illuminated by the electric light, shines faintly when this is withdrawn. If now the liquid air be poured off so that the crystal rises rapidly in temperature, it glows brightly.

### LUMINESCENCE AND PHOTOGRAPHY.

Photography, like luminescence, is a manifestation of the transformation of energy, most frequently of initial short wave-length. The production of colour by photography is nothing new. It was noticed by Seebeck nearly a century ago that silver chloride becomes tinted by exposure to ordinary light, with accompanying chemical change; that if then subjected a long time to red light it assumes a dull red hue, or a dull bluish hue if held in blue light. It is likewise possible by proper selection of luminescent salts to produce a selected series of tints during and after exposure to those rays which are most effective in photography. But such colours cannot be made fixed and permanent. The problem of securing on the photographic plate a faithful and lasting reproduction of the various tints of a spectrum thrown upon it has baffled most of those who grappled with this subject. That it has been fully and quite satisfactorily solved cannot yet be affirmed, but the last few years have brought a far nearer approach to success than an equal number of decades previously. Viewed from the scientific standpoint the goal has certainly been touched, even if commercial demands are still made in vain.

### STATIONARY LIGHT WAVES.

Two quite different methods are to be considered in tracing the recent development of this interesting application of optical principles. The first is originally due to Becquerel (*Am. de Chimie et de Physique* (3), p. 451, 1848), but lately, in the hands of Lippmann, it has been improved and brought much nearer to success than by its originator. It depends upon the production of stationary waves of light. Every one is familiar with the formation of stationary waves upon an elastic stretched cord, and with the acoustic exhibition of stationary air waves in a closed tube by Kundt's method of light powders. That similar loops and nodes must be produced under proper conditions by interference of waves of light would appear obviously possible; and so long ago as 1868 Dr. Zenker "Lehrbuch der Photochromie," Berlin, 1868), of Berlin, explained the photographic reproduction of colour, so far as it had then been accomplished, by reference to stationary light waves. But no definite proof of their production had been brought forward. A few years ago Hertz demonstrated objectively the electromagnetic waves whose existence had been foretold by Maxwell's genius; and with suitable apparatus stationary electric waves are now almost as readily made evident as are those of sound. Hertz's brilliant success stimulated his fellow countryman, Otter Wiener, to undertake the apparently hopeless task of producing and studying stationary light waves. Wiener's admirable work (*Wiedemann's Annalen*, Band xl. 1890, p. 203) excited great interest on the continent of Europe, but it has been singularly neglected in England and America. It is worth much more than a passing notice.

Assume a plane silvered mirror upon which a bundle of rays of monochromatic light fall normally so as to be reflected back upon its own path. The superposition of reflected and direct waves causes a system of stationary waves, but under ordinary conditions these are wholly imperceptible. The nodes are formed upon a series of planes obviously parallel to the reflecting plane at successive distances of a half wave-length. If now we consider a plane oblique to the mirror, it will cut these successive nodal planes in parallel lines, whose distance apart will be greater in proportion as the oblique plane approaches parallelism to the mirror. Although a half wave-length of violet light is only $\frac{1}{5000}$ of a millimetre, it is easy to conceive of the cutting plane forming so small an angle with the mirror that the distance between the parallel nodal lines shall be a thousand times a half wave-length. Such would be the case if the inclination of the cutting plane is reduced to a little less than four minutes of arc. The nodal lines would be $\frac{1}{5}$ of a millimetre apart, and readily capable of resolution if their presence can be manifested at all. Imagine a very thin transparent photographic film to be stretched along the oblique cutting plane, and developed after exposure to violet light as nearly monochromatic as possible. Then the developed negative should present a succession of parallel clear and dark lines, corresponding to nodal and anti-nodal bands along the oblique plane, the photographic effect being annihilated along an optical nodal line.

The realisation of a photographic film thin enough for such an experiment is quite conceivable when we remember that under the hammer gold is beaten into leaves so delicate that 8000 of them would be required to make a pile one millimetre thick. By electrochemical deposit, Outerbridge (*Journal of the Franklin Institute*, vol. ciii. p. 284, 1877) has made films of gold whose thickness is only $\frac{1}{100000}$ of a millimetre, or $\frac{1}{60}$ of a wave-length of sodium light. Wiener obtained a perfectly transparent silver chloride film of collodion, whose thickness was about $\frac{1}{30}$ of a wave-length of sodium light. This was formed on a plate of glass and inclined at a very small angle to a plane silvered mirror which served as reflector. From an electric arc lamp the light was sent through an appropriate slit and prism, so that a selected spectral band of violet fell normally on the prepared plate in the dark room. The developed negative presented the alternate bands, in perfectly regular order, more than a half millimetre apart. Various tests were applied to guard against error in interpretation, and the existence of such stationary waves was proved beyond all doubt.

These waves, moreover, when polarised light was employed, furnished the means of determining the direction of vibration with relation to the plane in which the light is most copiously reflected when incident at the polarising angle, and thus of subjecting to experiment the question as to whether the plane of vibration is coincident with this plane of polarisation or is perpendicular to it. The former of these views was held by Neumann and MacCullagh, the latter by Fresnel. Let a beam of polarised light fall upon the mirror at an angle of about 45°. If the vibrations in the incident beam are parallel to the mirror, and hence perpendicular to the plane of polarisation, those of the reflected and incident beams will be parallel to each other, and hence capable of interference. But if the vibrations of the incident beams are in a plane identical with that of incidence, and hence in the plane of polarisation, the vibrations of incident and reflected beams are in mutually perpendicular planes, and hence cannot interfere. Wiener obtained interference fringes when the light was polarised in the plane of incidence, while the polarised in the plane perpendicular to this gave no trace of interference. The theory of Fresnel was thus confirmed experimentally. Again, the familiar phenomenon of Newton's rings shows us that on changing media there is a change of phase of the incident light, else the central spot where the two surfaces come into optical contact would be white instead of black. But there has been difference of opinion as to whether this change of phase occurs at the upper surface of the air film, where the light passes from glass to less dense air, or at the lower surface where it passes from air to more dense glass. In the latter event, there should be a node at the reflecting surface. Replacing the silvered plane surface by a lens in contact with the photographic film, Wiener obtained circular fringes with no photographic action, at the centre, showing the nodal point to be at the point of contact, and thus again confirming the theory of Fresnel.

### COLOUR PHOTOGRAPHY.

The conditions being now specified under which stationary light waves are produced, let us imagine common instead of monochromatic light to be transmitted normally through a transparent sensitive film. Then a variety of stationary interference planes are produced. This is the underlying principle of the process employed by Lippmann in Paris, who, in 1892 (*Comptes rendus*, t. cxiv. p. 961, and t. cxv. p. 575), succeeded in obtaining a photograph of the solar spectrum in natural colours. Upon a surface backed with a reflecting mirror of mercury is a silver bromide albumen film, which has been treated with one or more aniline dyes to render it equally sensitive to waves of long and short period. After exposure and development the natural colours are manifested with brilliancy. Apart from the fundamental principle already expressed, it can scarcely be said that the *rationale* of the process has yet been very fully and clearly explained. Lippmann recognises the stationary wave systems, with maxima and minima of brightness in the film and corresponding maxima and minima of silver deposit. If the incident light is homogeneous, a series of equidistant parallel planes of equal photographic efficiency are produced in the film. If the plate after development is illuminated with white light, then to every point within the film there comes from below a certain amount of reflected energy which is a continuous periodic function of the distance from the reflecting surface. The total reflected light of any colour becomes then represented by the integral of this periodic function for the entire thickness of the layer. The solution of this integral brings the result that the intensity of the reflected light decreases with increasing thickness of the layer, approaching zero as a limit, so long as this light is of different wave length from the homogeneous light employed for illumination of the plate. Only light of the same wave-length, or of an entire multiple of this, maintains a finite value. A similar consideration applies to each of the hues composing white light. By such mathematical considerations Lippmann (*Journal de Physique*, p. 97, 1894) reaches the conclusion that the light reflected from the plate must have exactly the same relations of wave-length as that with which the plate was illuminated.

For the Lippmann photographs, which at first required a very long exposure, and could even then be satisfactorily viewed at only a single definite angle, it is now claimed that an exposure of only a few seconds is needed, and that the colours are visible at all angles of incidence so long as the plate is moist (*Journal de Physique*, p. 84, 1894). But, like the daguerreotypes of fifty years ago, they are incapable of multiplication, and great as is the scientific interest connected with them, it seems scarcely probable that they can long continue to hold an important place practically. The problem of ascertaining definitely the cause of the return of a colour the same as that which falls upon a given surface may seem to be solved mathematically, but the mastery of the physical conditions required to produce a single coloured negative, from which may be had any desired number of positives with varied hues accurately reproduced, is still in the future. From the very nature of stationary light waves it does not appear probable that the Becquerel method as improved by Lippmann will give the means of multiplying copies of a single picture. Wiener has lately published an elaborate research upon this subject (O. Wiener, *Wiedemann's Annalen*, pp. 225-281, June 1895), in which he recognises the necessity for the employment not of interference colours but rather of what he calls body colours (Körperfarben) due to chemical modification of the reflecting surface. M. Carey Lea (*American Journal of Science*, p. 349, May 1887), in 1887 obtained a rose-coloured form of silver photochloride which "in the violet of the spectrum assumed a pure violet colour, in the blue it acquired a slate blue, in green and yellow a bleaching influence was shown, in the red it remained unchanged." But in the absence of any means of fixing these colours, a promising prospect brings disappointment.

While it is abundantly possible that coloured illumination upon suitable colour-receptive materials can give rise to similar body colours, we are still far from having these materials under control. There seems at present to be greater promise in another and quite different application of optical principles. The suggestion appears to have been first named by Maxwell (Royal Institution Lecture, May 17, 1861) in 1861 that photography in colours would be possible if sensitising substances were discovered, each sensitive to only a single primary colour. Three negatives might be obtained, one in each colour; and three complementary positives from these, when superposed and carefully adjusted, would present a combination that includes all the colours of nature. In 1873 H. W. Vogel in Berlin discovered that silver bromide, by treatment with certain aniline dyes, notably eosine and cyanine blue, can be made sensitive to waves of much longer period than those hitherto effective in photography. In 1885 he proposed to sensitise plates for each of a number of successive regions in the spectrum, and to make as many complementary pigment prints as negatives, which should then be superimposed. This somewhat complicated plan proved difficult in practice. In 1888 F. E. Ives (*Journal* of the Franklin Institute, January 1889), of Philadelphia, adopting the more simple Helmholtz-Maxwell modification of Young's theory of colour, applied it to the preparation of suitable compound colour screens which were carefully adjusted to secure correspondence with Maxwell's intensity curves for the primary colours. The result was a good reproduction of the solar spectrum. But to reproduce the compound hues of nature it is necessary specially to recognise the fact that although the spectrum is made up of an infinite number of successive hues, the three colour sensations in the eye are most powerfully excited by combinations rather than by simple spectral hues. Thus according to Maxwell's curves, the sensation of red is excited more strongly by the orange rays than by the brightest red rays, but the green sensation is excited at the same time. This fact has to be applied in the preparation of the negatives, while images or prints from these must be made with colours that represent only the primary colour sensations. Properly selected colour creens must therefore be used for transmission of light to plates sensitised with suitable aniline dyes; and the adjustment of ratios with this end in view is not easy. But it has been successfully accomplished. From three negatives thus made, each in its proper tint, positives are secured; and these are projected, each through its appropriate colour screen, to the same area upon a white screen. The addition of lights thus sent from the triple lantern gives the original tints with great fidelity.

Mr. Ives has devised a special form of camera by which the three elementary negatives are taken simultaneously, and also an instrument, the photochromoscope, in which a system of mirrors and lenses brings to the eye a combination similar to that projected with the triple lantern. A double instrument of this kind forms the most perfect type of stereoscope, bringing out with great vividness from the prepared stereographs the combined effect of colour, form and binocular perspective. It is only within the past year that these improvements have been perfected. By further application of the same principles, Mr. Ives has produced permanent coloured prints on glass, which do not require to be examined by the aid of any instrument. Each of these negatives is made with a coloured streen which transmits tints complementary to those which it is desired to reproduce. The three gelatine films are soaked in aniline dyes of suitable tint, and superimposed between plates of glass. When viewed as a transparency such a print gives a faithful reproduction of the natural colours.

The problem of colour reproduction is thus solved, not indeed so simply, but more effectively, than by the method of interference of light, or by those body-colour methods that have thus far been applied. To the imaginative enthusiasts who are fond of repeating the once novel information that "electricity is still in its infancy," it may be a source of equal delight to believe that photography in colours, a yet more delicate infant, is soon to take the place of that photography in light and shade with which most of us have had to content ourselves thus far; but so long as an instrument is needed to help in viewing chromograms, the popular appreciation of these will be limited. We may take a lesson from the history of the stereoscope. Yet it is gratifying to recognise the great impetus that this beautiful art has received during the last few years. We may quite reasonably expect that the best is yet to come, and that it will have an important place among the future applications of optical science.

### THE INFRA-RED SPECTRUM.

Among the splendid optical discoveries of this century, probably the most prominent are photography and spectrum analysis, each belonging jointly to optics and chemistry. Photography was at first supposed to be concerned only with the most refrangible rays of the spectrum, but Abney and Rowland have photographed considerably below the visible red. Beyond the range thus attained qualitative knowledge was secured by Herschel, Becquerel, Draper, Melloni, Müller, Tyndall, Lamansky and Mouton. But our quantitative knowledge of this region began with the invention and use of the bolometer by Langley ("Selective Absorption of Solar Energy," *Am. Journal of Science*, March 1883, p. 169), whose solar energy curve has been familiar to all physicists during the last dozen years. During this interval the bolometer has been used with signal success by Ångström, Rubens, Snow and Paschen, who have made improvements not only in the instrument itself but in the delicacy of its necessary accompaniment, the galvanometer. The work of Snow (*Physical Review*, vol i. pp. 28 and 95), particularly, on the infra-red spectra of the voltaic arc and of the alkalies, and that done by him in conjunction with Rubens (*Astronomy and Astrophysics*, March 1893, p. 231), on refraction through rock-salt, sylvite, and fluorite, exhibited the capacities of the bolometer even better perhaps than Langley's previous work on the sun. But more recently with the collaboration of several able assistants, and more particularly the great ingenuity and mechanical skill of Wadsworth, the sensitiveness of Langley's galvanometer has been so exalted, and the bolometer connected in such manner with photographic apparatus as to make it an automatically controlled system, by which an hour's work now brings results superior in both quantity and quality to what formerly required many weeks or even months (Langley, "On Recent Researches in the Infra-red Spectrum": Report of Oxford Meeting of British Association, 1894). Not only is an entire solar energy curve now easily obtained in a single day, but even a succession of them. It becomes thus possible by comparison to eliminate the effect of temporary disturbing conditions, and to combine results in such a way as to represent the infra-red cold bands almost as accurately as the absorption lines of the visible spectrum are indicated by use of the diffraction grating. It will undoubtedly become possible to determine in large measure to what extent these bands are due to atmospheric absorption, and which of them are produced by absorption outside of the earth's atmosphere.

With the diffraction grating, supplemented by the radiomicrometer, Percival Lewis (*Astrophysical Journal*, June 1895, p. 1, and August 1895, p. 106), has recently investigated the infra-red spectra of sodium, lithium, thallium, strontium, calcium and silver, attaining results which accord well with the best previously attained by those who had employed the bolometer, and which demonstrate the exceeding delicacy of the radiomicrometer as an instrument of research.

### THE VISIBLE SPECTRUM.

To follow out all the applications of the spectroscope that have resulted in recent additions to our knowledge would carry us far beyond the scope of a single paper. It is possible only to make brief mention of a few.

For a number of years Rowland (*ibid.*, January to August 1895) has been investigating the spectra of all the chemical elements, photographing them in connection with the normal solar spectrum, and reducing them to his table of standards, which is now accepted everywhere. The work is of such magnitude that years more must elapse before its completion. It now includes all wave-lengths from 3722 to 7200, and of these the list already published extends as far as wave-length 5150, or from ultra-violet nearly to the middle of the green.

Through the spectroscope chiefly has been established during the present year the discovery of the new atmospheric element, argon, by Lord Rayleigh and Prof. Ramsay (*Proc. Royal Society*, January 31, 1895); its remarkable property of green fluorescence when the electric spark is passed through it in presence of benzene, by Berthelot and Deslandres (*Comptes rendus*, June 24, 1895); and its association in meteoric iron and various minerals with helium, now proved to be a terrestrial as well as solar element, by Ramsay (NATURE, April 4, May 16, July 4 and 25, 1895), Crookes, Lockyer, and others.

With the diffraction spectroscope Rydberg (*Wiedemann's Annalen*, 1893–94) and Kayser and Runge (*ibid.*, 1888–95) have discovered interesting relations among the spectral lines of a large number of terrestial elements, arranging them into series whose distribution manifests chemical relationship quite analogous to that indicated in Mendelejeff's periodic law.

By photographing the spectrum of Saturn's rings and noting the relative displacement of the different parts of a spectral line, Keeler (*Astrophysical Journal*, May 1895, p. 416) has obtained a beautiful direct proof of the meteoric constitution of these rings, a confirmation of the hypothesis put forth by Maxwell in 1859, that the outer portion of the rings must revolve more slowly than the inner portion, and yet not satisfy the conditions of fluidity. His work has been repeated and confirmed by Campbell (*ibid.*, August 1895, p. 127) at the Lick Observatory.

The spectroheliograph devised by Hale (*Astronomy and Astrophysics*, March, 1893, p. 256) has enabled him to photograph, on any bright day, not only the solar photosphere and spots, but also the chromosphere and protuberances. He has made some remarkable attempts with this instrument to photograph the corona without an eclipse, unsuccessfully thus far, but not without promise of future success.

### POLARISED LIGHT.

In the domain of polarised light, there have been several noteworthy recent researches. Nichols and Snow (*Philosophical Magazine* (5), vol xxxiii. p. 379) have shown that calcite, though readily transparent for the brighter rays of the spectrum, rapidly diminishes in power of transmission for waves of short period, so that for the extreme violet this power is scarcely half so great as for the yellow. The transmissive power of this crystal for the infra-red rays, between the wave-length limits of 1 micron and 5·5 microns, has been investigated with the bolometer by Merritt (*Physical Review*, May–June 1895, p. 424) who reaches the interesting result that the transmission curve for the ordinary ray is wholly independent of that for the extraordinary, the absorption being in general much greater for the former. Several sharp absorption bands are found for each ray. For radiations whose wave-length exceeds 3·2 microns, the absorption of the ordinary ray is almost complete, so that calcite behaves for such radiation just as tourmaline does for the rays of the visible spectrum. The independence of the two transmission curves is found to exist also for quartz and tourmaline, these curves for the latter crossing each other twice in the infra-red region.

The application of polarised light to the investigation of internal stress in transparent media was made more than forty years ago by Wertheim (*Comptes rendus*, 32, p. 289, 1851), who demonstrated that the retardation of the rays is proportional to the load. An extended series of such experiments has been lately made in America by Marston (*Physical Review*, September, October, p. 127, 1893) who, besides confirming Wertheim's conclusion, shows that, "for small strains at least, the colours seen in a strained glass body, when polarised light is passed through it in a direction parallel to one of the axes of strain, are measured by the algebraic difference of the intensities of those two principal strains whose directions are perpendicular to the direction of the polarised light."

A new substance with double rotatory power, like quartz, has been discovered by Wyrouboff (*Journal de Physique* (3), 3, 452, 1894), the neutral anhydrous tartrate of rubidium, which is unique in one respect. The rotatory power of the substance in the crystalline state becomes reversed in solution. This wholly new phenomenon introduces some perplexity in connection with certain molecular theories that have been formulated to account for double rotatory power.

Crehore (*Transactions* of the American Institute of Electrical Engineers, October 1894, p. 91) has ingeniously applied Faraday's principle of electro-magnetic rotation of the plane of polarisation in carbon bisulphide to the photographing of alternate current curves. Every variation in the magnetic field causes variation in the amount of light transmitted through a pair of crossed Nicol prisms. The combination becomes a chronograph with an index as free from inertia as the beam reflected from a galvanometer mirror. The same instrument has been applied to measurement of the velocity of projectiles (*Journal of the United States Artillery*, p. 409, July 1895), with results of exceeding interest to the student of gunnery.

### PHYSIOLOGICAL OPTICS.

The temptation to dilate upon recent progress in physiological optics has to be resisted. The revision of Helmholtz's great book on this subject was interrupted by the death of the distinguished author, but the last part is now approaching completion under the care of his pupil, Arthur König, who, in conjunction with Diederici, has done much important work in this domain. The selection of hues for the three primary colour sensations has been slightly modified. Young selected the two extremes of the spectrum, red and violet, together with green, which is about midway between them. The hues now accepted by Helmholtz and those who follow his lead, including the great majority of physicists, are a highly saturated carmine red, an equally saturated ultramarine blue, and a yellowish green, corresponding somewhat to that of vegetation. The red and blue agree with those previously determined by Hering, but the rivalry between the two schools on the subject of colour sensation continues, and perhaps will last through a period commensurate with the difficulty of devising crucial experiments.

Independent theories of colour sensation have been brought out by Mrs. Franklin (Christine Ladd Franklin, "Eine neue Theorie der Lichtempfundungen," *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, 1892) in America, and by Ebbinghaus ("Theorie des Farbensehens," *ibid.*, 1893) in Germany. The former particularly is worthy of much more extended notice than can here be given. It may perhaps be quite properly called a chemical theory of vision. Light is always bringing about chemical changes in external objects, and the eye is the one organ whose exercise requires the action of light, while such chemical action is implied in the performance of most of the bodily functions, such as the assimilation of food and the oxidation of the blood. The bleaching action of light upon the visual purple, which is continually formed on the retina, has been known ever since the discovery of this in 1877 by Kühne, who secured evanescent retinal photographs in the eyes of rabbits. Mrs. Franklin considers that light sensation is the outcome of photo-chemical dissociation of two kinds of retinal molecules that she denominates grey molecules and colour molecules, of which the latter arise from the grey molecules by differentiation in such a way that the atoms of the outer layer group themselves differently in three directions, and the corresponding action of light of proper wave-length gives rise to the three fundamental colour sensations. She develops the theory with much skill, applying it particularly to the phenomena of retinal fatigue and colour blindness. To the objection that there is no direct proof of the existence of the assumed grey and colour molecules, it may be answered that Helmholtz himself fully recognised the uncertainty of the assumption that three different sets of nerves respond to the three fundamental colour sensations, and he admitted that these may be only different activities in the same retinal cone. The supposition of three adjacent cones, responding respectively to the three fundamental sensations, is made only for the sake of greater convenience in discussion.

Indeed there is still much for us to learn regarding the nature of colour sensation. Among the yet unexplained phenomena are those of simultaneous colour contrast. The fact that a small brightly-coloured area on a grey background appears surrounded by its complementary tint is familiar enough. For its explanation it has been common to assume that there is unconscious motion of the observer's eyes, incipient retinal fatigue, an error of judgment, or fluctuation of judgment. This has been tested by A. M. Mayer (*American Journal of Science*, July 1893), who ingeniously devised methods for showing these contrast phenomena on surfaces large enough to match the colours with those of rotating colour discs, and thus to arrive at quantitative statements of their hues. When viewed through a small opening in a revolving disc the subjective contrast colour was unmistakably perceptible when the duration of passage of the opening was less than $\frac{1}{1000}$ of a second. The same effect was obtained in a dark room with instantaneous illumination of the coloured surface by the strong spark of an electric influence machine. The duration of illumination is thus almost infinitestimal, certainly not more than $\frac{1}{1000000}$ of a second. The hypothesis of fluctuation of judgment is thus shown to be wholly untenable. I have performed most of these experiments, either with Prof. Mayer or separately, and my testimony can therefore be united with his. The case is quite analogous to that of the perception of binocular relief, which was once explained as the product of a judgment, but was found to be always possible with instantaneous illumination. Prof. Mayer has devised a disc photometer based on colour contrast, with which the error of a single reading was found much less than with the Bunsen photometer.

The rotating colour disc has been applied by O. N. Rood (*American Journal of Science*, September 1893) to the determination of luminosity independently of colour, by taking advantage of the flickering appearance on a rotating disc upon which two parts have different reflecting powers. An extreme case of this is that of a white sector upon a black disc. At a certain critical speed the retinal shock due to momentary impression by white light becomes analysed into the subjective impression of spectral colours, the duration of the retinal sensation varying with the wave-length of the incident light. The law of this variation has been studied by Plateau ("Dissertation sur quelques propriétés des impressions produits par la lumière sur l'organe de la vue," Liège, 1829), Nichols (*American Journal of Science*, October 1884), and more recently with much precision by Ferry (*ibid.*, September 1892), who showed that retinal persistence varies inversely as the logarithm of the luminosity. For a given source of light separated into its spectral components, the yellow is the brightest. For this hue accordingly the retinal impression is shortest, and for violet it is longest.

Under appropriate conditions the after-effect on the retina has a certain pulsatory character, as first noted by C. A. Young (*Philosophical Magazine*, vol. xliii. p. 343, 1872) in 1872, and carefully studied within the last few years by Charpentier ("Oscillations rétiniennes," *Comptes rendus*, vol. cxiii. p. 147, 1891) in France, and Shelford Bidwell ("On the Recurrent Images following Visual Impressions," *Proc. Royal Society*, March 27, 1894) in England. A disc with properly arranged black and white sectors, if brightly illuminated and looked at while revolving at a moderate rate, becomes apparently coloured, just as a momentary glance at the sun causes the perception of a succession of subjective spectral hues which may last a number of seconds. The phenomenon in relation to the disc was known as early as 1838 (Fechner, *Poggendorff's Annalen*, 1838), and explained by Rood (*American Journal of Science*, September 1860) in 1860. The re-discovery of what has been long forgotten arouses all the interest of novelty. The "artificial spectrum top," devised by Benham (NATURE, November 29, 1894, p. 113) last autumn, excited interest on two continents, and was promptly copy righted by a prominent firm of opticians (*ibid.*, March 14, 1895, p. 463) in England. It would perhaps be equally enterprising to copyright the solar spectrum.

The limits of a single address forbid my touching upon the large and practically important subject of colour blindness. Indeed, in both physical and physiological optics much has been omitted that is abundantly worthy of attention. In behalf of my hearers it may be wise to take heed, once more, of the fate of Tarpeia, who was overwhelmed with the abundance of her reward.

## *UNIVERSITY AND EDUCATIONAL INTELLIGENCE.*

THE Technical Education Board of the London County Council has just awarded 278 minor scholarships, viz. 178 to boys and 100 to girls in Elementary Schools; 334 scholarships of the same class were awarded last spring, upon the results of examination, so that altogether the number awarded by the Board in 1895 was 612.

AT a meeting of the Fellows of the Royal College of Surgeons, held on Thursday last in the theatre of the college, a resolution was carried, "that, in the opinion of the Fellows of this college, women should be admitted to the diplomas of the college," forty-seven Fellows voting for the resolution and only ten against. The Fellows alone form the electorate who vote for election to the council, and the effect of this resolution will probably cause the council (who are understood not to be unwilling) to open the examinations to women candidates. At a mixed meeting of Fellows and members, called by the President last November to consider an application from the Dean of the London Medical School for Women for this privilege, Mr. Clement Lucas's proposal to the same effect was negatived by the narrow majority of ten in a house of over a hundred.

IN connection with the new Technical Institute recently opened at Wandsworth, the London *Technical Education Gazette* recalls the interesting fact that the first technical school in this country was opened in Wandsworth. The third annual report issued by the Science and Art Department, in 1856, gives an interesting account of this first technical school, which was called the Wandsworth Trade School. The curriculum included partly subjects of general instruction and partly courses of trade instruction classified under three heads, according as they had relation to (1) the building trades, (2) the mechanical and engineering trades, and (3) the chemical and manufacturing trades. The new Technical Institute will, it is hoped, revive the traditions established by the pioneer school of 1856. In addition to an equipment grant of £500, the Technical Education Board has agreed to contribute £1000 to the maintenance of the institute for the current year, apart from any grants which it may make for the maintenance of the technical day school.

## *SCIENTIFIC SERIALS.*

*Bulletin of the American Mathematical Society*, vol. ii. No. 2, November 1895.—Concerning Jordan's linear groups, is a paper by Prof. E. H. Moore, which was read before the Society in August last. It is a continuation of a paper read in November 1894, entitled "The group of holoedric transformation into itself of a given group" and is an exhaustive one supplemented by numerous bibliographical details.—Prof. A. S. Hathaway presented, at the same meeting in August, an elementary proof of the quaternion associative principle. Hamilton in his "Elements" writes: "The *associative principle* of multiplication may also be proved without the distributive principle, by certain considerations of *rotations of a system*, on which we cannot enter here." This note states that it is easy to see that such a proof is possible; but the details of it could not have presented themselves to Hamilton in an elementary form, or he would have seen that it was just the demonstration for which he was looking, simple in character, and direct in its application. We are not sure that we have not seen a proof somewhat similar to the Professor's, but we cannot recall it to our recollection. The proof given is a simple one.—The next article is a paper read at the October meeting of the Society, entitled "Moral Values," by Mr. R. Henderson. The author reminds us that the question of moral values in connection with the theory of probability has given rise to great diversity of opinion among mathematicians, and that Bertrand, in his classical work, dismisses it with contempt. More than the usual space is devoted to the notes and new publications.

*American Meteorological Journal*, December 1895.—Psychrometer studies, by Dr. Nils Ekholm. This article chiefly refers to the peculiar action of the wet-bulb thermometer near the freezing point of water. The author's observations and other investigations show that in an air saturated with water-vapour, the ice-covered bulb reads higher than the water-covered one, which, under those conditions, reads exactly as the dry bulb. These results are explained by Prof. W. Ramsay's experiments, which prove that there is a difference in the tension of water-