LVII. Evidence that röntgen rays are ordinary light

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value of $1-2n$ decreases. Hence an upper limit may be obtained by putting $1-2n$ equal to its value at the lower temperature limit, and we may write

$$e = \frac{R}{\omega \epsilon} (1-2n)_{t_1} (t_2 - t_1).$$

To take a very favourable case, we may suppose the electrolyte to be LiOH. Here we have for 18°C . $1-2n = .7$, $\omega = 1$, and $\frac{R}{\epsilon} = .0000867$ when e is expressed in volts. Taking $t_2 - t_1 = 100$ as a fairly extreme temperature-interval, we get $e = .006$ volt.

This rough calculation shows that in the case of salt-solutions the maximum initial potential-difference arising from the Thomson effect would only amount, under ordinary conditions, to a few thousandths of a volt at the most. This result justifies the neglecting of the Thomson P.D. in the measurement of thermo-electric cells, except when the experimental error is less than one-thousandth of a volt.

Holywood, Co. Down, April 1898.

LVII. *Evidence that Röntgen Rays are Ordinary Light.*

By G. JOHNSTONE STONEY, M.A., D.Sc., F.R.S.*

IN 'Nature' of the 28th of last April, p. 607, Lord Rayleigh calls attention to the fact that under Sir George Stokes's theory of Röntgen rays—that which is known as the hedge-firing theory—we are justified in expecting a large proportion of ordinary light of short wave-length in the radiation from the shield which receives and arrests the "kathode rays." This he infers generally from the properties of Fourier's theorem, without entering into the details which seem necessary; and I understand him accordingly to put forward the conclusion as an opinion we are justified in strongly holding, though not actually proved. It may therefore not be useless to publish a proof which the present writer had worked out for his own satisfaction. An explicit proof seems the more desirable inasmuch as Fourier's theorem, except where it can be applied *throughout* to the actual conditions which exist in nature, furnishes only kinematical resolutions which may differ materially from the actual physical resolutions effected by nature†.

* Communicated by the Author.

† For example, all the resolutions effected by Fourier's theorem in the paper beginning on p. 281 of the Phil. Mag. for April 1897, are of this illusory kind. The component motions furnished by that investigation do not fulfil the necessary condition that each separately can be propagated by the medium.

In analysing the motion of a vibrating string, the association of Fourier's theorem with the dynamical conditions of the problem is easy ; but it is not so simple a matter when we have to deal with events propagated through a medium in three dimensions. When, however, those events take the comparatively simple form of waves transmitted through a uniform medium, whether double refracting or isotropic, the analysis of the motion in the medium can be made to furnish components that consist *throughout* of physical events, each of which could occur separately under the operation of the forces which exist in the medium.

This essential condition can be secured by dividing the analysis into two parts, in the first of which an advancing spherical wave (such as is propagated from each centre of disturbance in a uniform isotropic medium) is resolved by the Principle of Reversal as used by MacCullagh, into the coexistence of plane wavelets propagated in all the directions towards which the spherical wave travels. In this first part of the inquiry, we are dealing exclusively with events which would spontaneously develop themselves in the medium under the conditions which are assumed in the course of the proof, and each of which could exist by itself in the medium. This preliminary analysis presents the motion of the medium in a form to which a further analysis by Fourier's theorem may be applied without travelling outside actual physical events. We thus render the whole analysis physically legitimate—*i. e.* such that it *represents what really takes place in nature*. By a wavelet is to be understood not a wave which is short, but one of infinitesimal intensity.

The steps of the proof are as follows :—

Sir George Stokes's explanation of Röntgen rays amounts to this—That kathode rays consist of negatively charged missiles shot in showers, like hedge-firing, from the negative electrode against the shield which receives and suddenly arrests them ; and that the Röntgen rays are due to the independent impulses propagated through the æther when the advances of the negative charges are thus abruptly stopped or altered.

Each impulse is a spherical impulsive wave of some complex form propagated through the æther from one of the points of impact. It started on its journey at the instant when the advance of one of the negatively charged missiles was arrested.

Each such spherical wave can, by MacCullagh's method of using the Principle of Reversal, be resolved into the coexistence of innumerable components consisting of plane impulsive

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wavelets. These wavelets are of unlimited extent laterally, each is uniform throughout, and they propagate themselves forward through the medium without undergoing change. One of them advances perpendicularly to itself in each of the directions towards which the spherical wave advances (see *Phil. Mag.* for April 1897, p. 273).

Use polar coordinates and consider some one direction $\theta\phi$. One of the plane impulsive wavelets is propagated in that direction from each of the impacts of the hedge-firing on the shield; and those which happen to travel from all the impacts in the direction $\theta\phi$, form an undulation of some kind travelling in that direction. It obviously consists of an irregular succession of uniform plane impulsive wavelets.

The whole of this irregular undulation travelling in any one direction may be represented by the equations

$$\left. \begin{aligned} \tau_1 &= F_1(r-vt) \\ \tau_2 &= F_2(r-vt) \end{aligned} \right\} \quad . \quad . \quad . \quad . \quad (1)$$

where τ_1 and τ_2 are resolved parts of the transversal in two planes parallel to the radius-vector and at right angles to one another; where v is the velocity of light; and where the forms of the functions F_1 and F_2 vary with the vector $\theta\phi$.

Next let all the events of the Röntgen experiment be regarded as repeated at definite equal intervals of time, say at intervals of a day—*i. e.* of 86,400 seconds.

The functions F_1 and F_2 are thereby rendered periodic functions; the period being

$$T = 86,400 \text{ seconds.}$$

These functions then become resolvable by Fourier's theorem into pendulous terms, of which the periods are T and integer submultiples of T .

Equations (1) when thus expanded by Fourier's theorem represent the plane wavelet component in the direction $\theta\phi$ of the whole motion in the æther due to the radiation from the target, along with the same component of previous and subsequent repetitions of this motion in the æther at intervals of a day.

Each *term* of the expansions represents physically a complete undulation consisting of an unlimited train of exactly similar plane pendulous wavelets of some one wave-length, filling the whole of space*, and advancing with the velocity v in the direction $\theta\phi$.

* If it fill the whole of space, what is represented by it includes, in addition to the actual radiation, that preceding condition of the æther which would have produced the radiation without external aid.

Accordingly the radiation from the target against which the kathode rays impinge, along with repetitions of the same at intervals of a day, may be resolved into the coexistence of component undulations, each filling the whole of space, and each consisting of an unlimited train of uniform plane pendulous wavelets. The periodic times of these will be T and its integer submultiples.

Next form the series of ascending prime numbers, viz :—

$$2, 3, 5, 7, 11, 13, 17, 19, \&c.,$$

and call the continued product of the first n of these

$$M_n.$$

Then instead of repeating the Röntgen events at intervals of a day, let them be repeated at intervals of M_n days. Thereby the period of the Fourier's series becomes $M_n T$; and the radiation of the Röntgen experiment, repeated at these longer intervals, is represented by the coexistence of series of pendulous terms of which the periods are

$$M_n T, \text{ and its integer submultiples.}$$

If n be changed into $n + 1$, these series will include new terms.

The limit of this process, when n is increased without limit, is that the series can contain terms with periodic times of *any* period, whether commensurable or incommensurable with T .

And that it then represents the Röntgen event *isolated*—*i. e.* without any repetition. It is obvious that one condition which must be fulfilled by a series of the nature of Fourier's series in order that it may be competent to represent an event of limited duration without repetitions of the same, is that it shall contain terms the periodic times of which are incommensurable with one another.

Hence, finally, the impulses which are propagated through the æther, as the consequence of the kathode hedge-firing however irregular, may be resolved into the coexistence of component undulations travelling in the various directions, each of which is a train of perfectly similar plane wavelets, and of which there need be only one of each wave-length in each direction.

It follows from the known properties of Fourier's expansions that the more abrupt and irregular the hedge-firing is, the more prominent a place will terms furnishing undulations of very short wave-length have in the final expansions.

If we choose we can compound these undulations of short

wavelets, by working in the inverse direction through the MacCullagh analysis; and thus we learn that the more abrupt and irregular the hedge-firing, the more abundant will be the proportion of rays of ordinary light consisting of spherical waves of short wave-length in the radiation from the target.

If, as appears almost certain, these are what we know under the name of Röntgen rays, it follows that anything which increases the intensity, the abruptness, and the irregularity of the hedge-firing will increase the abundance of the Röntgen emanations.

Moreover, inasmuch as a certain amount of abruptness and irregularity is present in the emission of light from every visible object or luminous source, it follows that Röntgen rays—*i. e.* rays of very short wave-length—are present in all light throughout nature; only the quantity present is usually inconspicuous.

LVIII. Notices respecting New Books.

Lehrbuch der Algebra. Von HEINRICH WEBER. Zweite Auflage, Erster Band: pp. xvi + 704. (Braunschweig, Vieweg & Sohn, 1898.)

THIS is no hastily composed treatise. The Author tells us in his Preface (p. v) that he had cherished for some years the idea of writing such a work, and the result is the comprehensive one before us. He has traversed the field described several times in his university lectures. That he has not failed in his attempt may be inferred from the fact that the first edition was published so recently as 1895, and then was limited to 654 pages. The book is clearly conceived in plan, and is very thorough in its execution. This first volume contains three books, which are prefaced by an excellent arithmetical introduction which discusses the theory of multiplicities, the theory of rational and irrational numbers, and further gives a proof of the continuity of real numerical magnitude. Here the author refers mainly to Dedekind (‘*Stetigkeit und irrationale Zahlen*,’ and ‘*Was sind und was sollen die Zahlen*’) and to G. Cantor.

The first book, which is headed *the Foundations*, in six chapters, treats of Rational functions of one or more Variables, Determinants, the roots of Algebraical Equations, Symmetric functions, Invariants and Covariants, and the Tschirnhausen transformation (the application of which to cubic, biquadratic, and quintic equations is shown in chapter iv., and in chapter vi. Hermite’s modification is introduced). The second book, which is devoted to *the Roots*, is also broken up into six chapters, the first four of which deal with the reality of the roots of real equations, with their number in a given interval, with their superior and inferior limits, and with the numerical approximation method. The eighth