Terrestrial Magnetism *and* *Atmospheric Electricity*

VOLUME XII

MARCH, 1907

NUMBER I

CONCERNING PULSATIONS OF SHORT PERIOD IN THE STRENGTH OF THE EARTH'S MAGNETIC FIELD.¹

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For a considerable length of time a general interest has been aroused by the striking, regular oscillations of short period in the Earth's magnetic force which, at times of magnetic disturbances as well as at times of perfect magnetic calm, appear in the form of short waves, ("terrestrial magnetic waves"), in the magnetograph curves.

Lamont observed such pulsations,² a fact which is to be noted because at that time there as yet existed no strong artificial electric currents of any sort whatever, and hence the oscillations mentioned must certainly have been caused by the Earth's field.

Balfour Stewart³ also very early made the observation that in certain disturbances, along with the great waves, small waves of lesser amplitude occur, which have a period of about 30 seconds.

A well known example is that noted by Friedrich Kohlrausch on the 20th of November, 1882,⁴ in which, by means of two-second readings of the deflection intensity variometer constructed by him (period of the needle 1.7 sec., damping ratio 2.0) such oscillations were found of about 12 sec. period and an amplitude of 4 γ . (1 γ . = 0.00001 C. G. S. unit). With the ordinary registration with slow-

¹ From the "Sitzungsberichten d. Kgl. bayerischen Akad. d. Wiss., München, 1906, with numerous additions and revisions by the author; the translation is by P. H. Dike.

² The author through the kindness of Dr. Messerschmitt, of the Magnetic Observatory of Munich, was allowed to examine the for the greater part unpublished observations of Lamont, from which this indubitably follows.

³ BALFOUR STEWART, Phil. Trans. 425, 1861.

⁴ FR. KOHLRAUSCH, Wied. Ann. 60, 336, 1897.

[PLATE I.]

Paul Hunsden

moving cylinder such quick oscillations of the Earth's magnetic force must be lost; they can at best appear only as a broadening and diffusion of the curve.

It was therefore a notable service of Eschenhagen, that he introduced for the study of just such small variations of the Earth's magnetism the so-called "Feinregistrierung"⁵ in which by means of a more rapid rate of the cylinder (1 mm equals 15 sec. instead of as otherwise customary 180 sec.) is made possible a far more detailed analysis of the course of the phenomena. At the same time he increased the sensitiveness of the variation instrument. His unifilar magnetometer in which a small magnetized steel mirror is turned by means of a twisted quartz fiber on which it is suspended nearly perpendicular to the magnetic meridian gave, with a period of oscillation of 8.5 sec. and a damping ratio of about 4, a sensitiveness of 1 mm to 0.3 γ . In the specimen curve accompanying the article above referred to, one can count 199 pulsations which have a period of 32.2 sec. for one complete oscillation, with a mean amplitude of 1.4 γ . Eschenhagen believed that he had discovered in these waves of constant period "certainly the most simple elementary movement of the Earth's magnetism" since (with his instrument) no further details were to be found through more extended analysis. Upon the ground of abundant material in the form of sixty such rapid rate curves he came to the following conclusion:⁶ all the collected evidence goes to show that one arrives, by the use of such a rapid rate with a well damped magnet needle of high sensitiveness relative to the changes of intensity, at the last analysis of the smallest variations of the Earth's magnetism—at a representation of the "elementary waves"—so that a further refinement of this method promises no further results."

It is worthy of notice that these short-period waves appeared mostly during the day between 6 o'clock in the morning and 6 o'clock in the evening, thus at a time in which the Sun was above the horizon of the place of observation at that time of the year, but very seldom at night, while in the night hours longer waves appeared, perceptible even with the usual rate of registration.⁷ Most interesting of all are the "wave groups" discovered by Eschenhagen which present an analogy to the beats sound; a wave motion of 34 seconds period interferes with another of 43

⁵ M. ESCHENHAGEN, Sitzungsab. d. Berliner Akad. W. XXXIX 965, 1896.

⁶ M. ESCHENHAGEN, Sitzungsab. d. Berliner Akad. W. XXXII 678, 1897.

⁷ See also TH. ARENDT, Das Wetter, Nos. 11 and 12, 1896.

seconds period and produces the characteristic beat curve corresponding to the vibration ratio of 5 to 4; the resulting amplitude of the two interfering waves amounts to about 0.6 γ .

Such terrestrial magnetic waves can have a broad region of propagation. In 1895 on an occasion of simultaneous observations waves of 40 to 50 seconds duration were noticed which (within the limits of error of observation of 1 to 2 seconds) appeared simultaneously at Potsdam and at Wilhelmshaven. Other pertinent material was collected by Kr. Birkeland on the occasion of the Norwegian Expedition for the study of the polar light in 1899-1900.⁸ A remarkable agreement was noticeable between the simultaneous rapid registrations at Haldde, Bossekop in northern Norway and in Potsdam; thus, in two stations which are about 2000 km. apart an indication is given that this sort of pulsations can flash through enormous regions of the field of the Earth's magnetic force with the same rhythm. Birkeland has also stated the frequency of the appearance of such pulsations as a function of their period. It is shown that there is a preponderance of the appearance for certain periods, which according to the material collected at that time occurs at about 32 and 8 seconds. Here we already have vibrations of substantially shorter period than Eschenhagen's elementary waves.

W. van Bemmelen,⁹ with whom originated the designation for the forms of disturbance here under discussion, has also carefully investigated these "magnetic pulsations." He compared the simultaneous registrations of the pulsations at three different places, Batavia, Karang-Sago, in the Dutch East Indies, and at Zi-ka-wei, China; he found differences, especially in the times of beginning of corresponding trains of such pulsations, as well as in their amplitudes. Above all he established that the vertical component is always much less strongly influenced by these pulsations than the horizontal component. Besides sources of disturbing vertical electric currents, van Bemmelen is inclined to suppose in addition a system of circular electric currents which encircle the Earth parallel to the iso-chasms (lines of equal auroral frequency). Pulsations in their intensity would produce magnetic pulsations in the components directed substantially tangentially to the Earth's surface.

⁸ KR. BIRKELAND, Videnskabselsk. Skrifter Akad. Christiania, 1 Math.—naturw. Kl. No. 1, 1901, p. 3, *et. seq.*

⁹ W. VAN BEMMELEN, Sitzungsber. Akad. Wet. Amsterdam, 1899, 202-211. Arch. Néerland. d. Sciences exactes et. nat. (2) 6, 1901 und Natuurk. Tijdschrift voor Nederlandsch-Indië 62, 71-88, 1902.

Eschenhagen's rapid rate registration has been carried on further at the Potsdam Observatory and the sensitiveness has successfully been made greater than before.¹⁰

Finally, J. B. Messerschmitt¹¹ pointed out "pulsations" in the curves of the Munich Observatory.

However, the analyzing power of the arrangements of magnetometers in all of the above mentioned highly valuable investigations is limited to pulsations having a period of several seconds.

The questions therefore presented themselves: Do not pulsations of still shorter period perhaps occur in the Earth's magnetic elements? Are the small waves recorded in the rapid registration really the last constituents of the large variations of the Earth's field? Can one in the way described really analyze the magnetic phenomena into their last elements? A simple consideration shows that this must always be impossible, since we are not able to decrease the time of oscillation of magnetometric apparatus below a certain limit without a loss of sensitiveness; the magnet systems are much too heavy to follow variations of fractions of a second in period, without reducing the representation of the course of these variations beyond recognition; a quite different principle must here be brought into play.

Eschenhagen himself in 1886, referring to a proposition made by Werner Siemens in the year 1882, called attention to the inductive effect in an extended conducting circuit produced by variations in the number of lines of force passing through it.¹² Siemens had furnished the German Polar Expedition¹³ of 1882-83 with a light gutta-percha insulated single strand cable 12 km. long, which was laid out on the ice of Kingua-Fjord, the German observing station, so as to enclose an area of about 8 sq. km. Its ends were connected to a reflecting astatic galvanometer constructed by Siemens and Halske, and the deflections produced by the induced

¹⁰ Compare the contribution of A. NIPPOLDT to the Kasseler Naturforscher-versammlung (Meteor. Zs. 1904, 395-399) as well as the papers of TH. ARENDT, *Das Wetter* 241-253 and 265-280, 1896, and *Natur. Wiss. Rdsch.* 18, 105-107, 117-118, 1903. Here is discussed especially also the relation of the phenomena with atmospheric electricity.

¹¹ J. B. MESSERSCHMITT, *Sitz. Ber. d. Münchner Akad.* 35, 135-168, 1905.

¹² M. ESCHENHAGEN, *Sitzungsb. Berliner Akad.* No. XXXII, 1897, p. 685 and *Verh. Phys. Ges. I. Jahrg.* No. 9, p. 151, 1899.

¹³ *Die Internationale Polarforschung 1882-1883. Die Beobachtungs-Ergebnisse der Deutschen Stationen, Band I, Kingua-Fjord, etc. Die Erdstrom-Beobachtungen, bearbeitet von W. Giese, p. 411, Berlin, 1886; See also M. ESCHENHAGEN l. c. p. 597.*

currents were compared with the variations of vertical intensity as shown by a Lloyd balance. It was shown that the currents observed in the cable followed throughout the change of the vertical component, so that there could be no doubt that the inductive action of the field variations in the closed circuit offered a method of studying these variations. In fact the sensitiveness of the cable apparatus for the smallest observed variations of the vertical intensity proved in these researches to be about a hundred times as great as that of the Lloyd balance,—up to that time the only instrument that had shown itself permanently useful for the registration of the vertical component. W. Giese who, as above indicated, worked out these observations of the German station, called attention to the fact that the cable was never free from electromagnetic impulses, and that the whole arrangement was too sensitive for those high latitudes. Eschenhagen therefore proposed to use, instead of great and very extended plane loops, less extended coils of wire, which would offer the advantage that one could investigate according to their orientation any desired component of the Earth's field or its total intensity. Whether it would be desirable to produce a condensation of the lines of force by filling the coil with soft iron could be decided by special experiments. Eschenhagen did not himself return to this.

In Kiel, during 1897-98, I had used with great success flat iron-filled coils of great total area of windings, connected with a sensitive Du Bois-Rubens galvanometer and mounted in a Julius suspension (this is the experiment to which Eschenhagen refers, *Verhandl. der Phys. Ges. I Jahrg. No. 9*, bottom of p. 151, 1899). At times when the street car service had stopped there still remained weak current impulses of extraordinary variability which apparently depended on the variations of the various components of the Earth's magnetic field. It was proved that the iron core worked unfavorably for the study of the rapidly completed variations; since, though the field intensity is increased within the coil, the iron itself has too much inertia to follow the slight, rapid magnetic changes and damps them out, even when one uses short wires of the softest iron lying in the direction of the lines of force. Since the induction is proportional to the rate of change of the component with which we have to deal, the soft iron core was soon abandoned and extended loops of wire again used.

Meanwhile at Kiel at the suggestion of Professor Leonh. Weber,

experiments have been carried on by Mr. Andreesen¹⁴ in which a cable was laid 96 times around the magnetic observatory so that a total area of 7200 sq. m. was enclosed. The ends of the cable were connected to a moving coil galvanometer of the Dèprez-d'Arsonval type made by Siemens and Halske having a period of 2.5 to 3 minutes. The registration curves obtained, aside from very irregular peaks, occasionally showed at night smaller serrations of shorter period which Andreesen is inclined to ascribe to stray currents, just as the large peaks are shown to have an unmistakable relation to the operation of electric car lines. Only once, on a night in September, 1904, were seen quite fine, regular wave series of about 30 sec. period, which thus correspond to the waves discovered by Eschenhagen.

2. Had the previous investigations shown that the induction principle is really fitted to furnish a vertical intensity variometer of high sensitiveness, the attempt to penetrate further in this way into the details of the course of the more rapid magnetic pulsations would up to this time have appeared hopeless. Instead of the suspended system of the magnetometer, now appears that of the galvanometer; since one cannot reduce the period of oscillation and the moment of inertia of the galvanometer system below a certain limit, the galvanometer is quite as incapable of following the shorter waves as the registering apparatus giving the variation of the Earth's magnetic force directly. Besides that, in galvanometers with suspended magnets and fixed coils, there is the further consideration that the orientation of their movable parts depends itself upon the variations of the Earth's magnetic field. In suspended coil galvanometers this objection disappears, but there remains the disadvantage, that being shortcircuited through the cable, they are very strongly damped and are therefore very sluggish, unless the sensitiveness is greatly reduced by introducing a large resistance in the circuit.

A considerable advance can now be made in this direction by the use of the "Saiten" galvanometer first devised by Ader and then so much improved and perfected by Einthoven and later by Edelmann, Jr.¹⁵ In this a very thin silvered quartz fiber or a fine

¹⁴ H. ANDREESSEN. Inaug. Diss. Kiel, 1905, p. 32, *et seq.*

¹⁵ See reference to ADER'S apparatus; LÉAUTÈ, *Compt. Rend.* **124**, 1440, 1897, or *La Nature*, **2**, 115, 1897, *L'Eclairage électrique*, 1897, 295, *Electrotechn. Zs.* 1897, 561. W. EINTHOVEN, *Ann. der Phys.* (4) **12**, 1059, 1903; **14**, 182, 1904; **16**, 20, 1905. M. EDELMANN, JR., *Phys. Zs.*, **7**, No. 4, 115, 1906.

metal wire is stretched out in the constant field of a strong auxiliary magnet, perpendicular to its lines of force along the knife like edges of the pole pieces; if a current passes through the fiber, the "Saite," this will be deflected perpendicularly to the lines of force with a force proportional to the strength of the current, to the strength of the magnetic field and to the length of the fiber; the deflection is followed with a microscope or by a suitable optical arrangement reproduced on a moving sensitized film. Here one has a system of nearly negligible mass, which is capable of following almost momentarily the quickest changes in the current strength,—an arrangement which with the advantage of complete independence of external magnetic disturbances combines that of the highest sensitiveness to currents.

With such a galvanometer, in the summer of 1905, I again took up my long interrupted investigation of the action of rapid magnetic pulsations on large closed circuits, in which Dr. Max Edelmann, Jr., of Munich, rendered me most able assistance, for which I wish to express to him on this occasion my warmest thanks.

In order not to be limited in the choice of a place of observation by the necessity of a source of electric current, in addition to galvanometers with electro-magnets, galvanometers having powerful permanent magnets and corresponding to the original construction by Ader were also used. It is true that in this way some sensitiveness was lost, but still the Edelmann Institute succeeded in constructing a very convenient galvanometer.¹⁶

The galvanometer used in the research contained platinum or gold fibers of 43 to 120 ohms resistance. The microscopic magnification was usually 50; currents of 10^{-8} amperes were, however, conveniently and accurately measured. In order to have a time mark on the photographic record, we arranged the pendulum of a metronome or the pointer of a Jacque chronograph to swing before the slit of the registering drum, so that once for each full swing it moved from the side part-way across the slit and made small serrations on the edge of the record strip from which the time determinations could be carried out with great exactness.

The portion of the closed circuit lying in the open outside the building consisted of a cable furnished by the firm Felten and Guillaume made up of 15 copper strands, insulated from each other, each one of 0.8 mm. diameter, that is 0.5 sq. mm. cross section and

¹⁶ For the description of the method of reading, as well as of the photographic recording apparatus see the above referred to work of M. EDELMANN.

0.03463 ohms resistance per strand per running meter. The cable was 210 meters long; its 15 strands were connected in series, so that the total length of wire was 3150 meters, and on laying it out to enclose a circular area the total surface enclosed was 52640 sq. m. and the total resistance was 109 ohms. If such a cable is laid in the open, disturbances caused by "cable currents" can exist; these are superimposed upon the induction currents sought for without being influenced by them, but cause a continual deflection of the galvanometer fiber out of the zero position and eventually also out of the field of vision. This undesirable feature was overcome when it occurred by placing in shunt with the cable a dry cell with variable resistance in series, thus introducing a constant electromotive force so as to compensate the disturbing electromotive force.

In later experiments (winter 1906-07) we have connected the two ends of the cable inside a water tight closed metallic box in the open to a lead covered cable of two strands, the other end of which was brought into the house. As long as the cable was well insulated the disturbances did not appear and the compensation was unnecessary. However, it is to be recommended that a shunt be arranged so that the sensitiveness of the galvanometer can be suitably regulated.

When not in use, the cable was always shortcircuited and connected with the earth so that possible static charges would at once be neutralized. One can also, during the measurements themselves, earth one end of the measuring fiber as well as the whole frame work of the apparatus with the magnetic system, though this did not appear to be absolutely necessary.

The cable must be laid quite flat and firmly on the ground, for if any part of it—even a relatively short one, owing to the great sensitiveness of the apparatus—moves, possibly set swinging as a pendulum by the wind, it cuts lines of force of the Earth's field and produces induction currents which will follow exactly the rhythm of the motion.¹⁷ Besides this the cable was to be protected as far as possible from direct electrostatic influences, such as that

¹⁷ Upon this may be based a noteworthy use of the whole apparatus. Since the Earth's lines of force are everywhere at one's disposition in sufficient numbers, one needs only to connect a part of a conducting circuit cutting lines of force with the moving part of a system such as a water gauge, or a flood meter whose motion it is desired to record at a distance, the circuit being connected by double conductor to such a highly sensitive "Saitengalvanometer." On many occasions we convinced ourselves how truly the inducing motion is imitated by the course of the current.

of the atmospheric electric field; in winter, therefore, it was laid *under* the snow. If our cable had had a lead covering we would have buried it in the earth, by which means the sources of disturbance mentioned would most surely have been eliminated. In the continuation of the investigation this spring, we intend indeed to use a lead-covered telephone cable of many strands (naturally not bound with iron) which, at a distance from the greater centers of traffic and industry, will be laid so that it surrounds a definite area. To the researches up to the present time we would attach only the significance of preliminary experiments which were intended primarily to prove the practicability of the new apparatus.

3. The first researches were carried out on a piece of ground lying in the Nymphenburger suburb of Munich and belonging to Dr. M. Th. Edelmann, Sr. Here during the day and evening we had abundant opportunity to study disturbances which were caused by street car traffic, passing wagons and the electric street lighting. These consisted throughout of suddenly appearing impulses of very irregular and varied form, which quickly disappear.

Together with these, however, there always appeared quite long series of regular waves of a period of a few tenths of a second. These persisted also during the night at the time between 1 and 5 o'clock when the street car traffic in the whole city was stopped, and also in the morning from 4 to 5 o'clock when in summer the lights were not in use. Naturally we at once thought of distant electric sources which were kept in operation through the entire night. According to information collected, the nearest, 1130 m. distant, was a substation of the city electric plant.

The large, 12 pole direct current dynamos which supplied the lighting system make 165 revolutions per minute; the time of one revolution then is 0.363 sec. The time elapsed during the passage of one element of winding from its position before one field magnet to that before the next is one-twelfth of this or 0.030 sec. Neither period is found in the curves.

The three phase alternating current used for driving these dynamos has the usual 100 periods per second; pulsations of $\frac{1}{100}$ second duration could be expected from this source, but they were not to be discovered.

If for the projection of the image of the fiber on the sensitive sheet one uses an arc light, there is special danger of a disturbance. The flaming arc, under certain circumstances when its circuit contains suitable self induction or capacity, is apt to set up oscillations

and to radiate them. It causes so-called "wave currents," that is, alternating currents superimposed upon the direct current feeding the lamp, such as are used at present, as is well known, directly in "wave telegraphy." In order to be free from this sort of disturbance also, we later used in registration only the very intense light from a disk of Zircon earth brought to incandescence in the oxy-hydrogen flame.

Even from these first investigations it can be presumed that certain of these waves belonged to the Earth's magnetism itself.

However, a not unjustified lack of confidence must be felt in this sort of observations made in the neighborhood of a great center of traffic. We therefore changed the place of observation to a piece of woodland belonging to Professor M. Th. Edelmann, which lay far outside the city—25 km. south of Munich between Icking and Wolfratshausen—in the colony of villas "Schlederlohe." Below this, it is true, the "Isar-tal" railway passed in a deep cut, and the trains in passing make themselves felt each time in quite characteristic current impulses in the circuit; but since these moments of disturbance by the passing masses of iron are exactly determinable, and since besides they do not occur too often, they can easily be eliminated from the observations. The nearest electric plant, the "Drehstromwerk" in Weidach, is 2.2 km. distant; no period of vibration corresponding to their machines could be established.

However, there appeared here a disturbance which could not at first have been expected. Pulsations appeared in the registrations which at times repeated themselves with such great regularity and with such strongly marked characteristics, that their source could not possibly be a natural one; but the suspicion was not far to seek that by means of the cable circuit Morse signals were caught. This was proved by direct experiment. The occurrence was in so far surprising, as the telegraph line causing it passed about the center of our cable circuit in a semicircle of about 300^m radius, and is worked with a current of only 13 miliamperes. But, remembering that our instrument reacts according to the rate of change of current strength, this high sensitiveness seemed plausible. Presumably it would be possible with such a cable simply stretched out on the ground, fitted with a fiber galvanometer, to catch dispatches from even greater distances.

Besides all these disturbances there appeared by day as well as by night short period pulsations, both in the summer and winter observations. The meteorological elements appear to have no

direct influence, at least we could discover no noticeable difference in wind or in calm, in sunshine or with clouded sky, in rain or in weather free from precipitation, in high or in low temperature; even an approaching thunderstorm did not change the general appearance especially. Only in the neighborhood of descending lightning flashes Dr. Edelmann observed distinct jerks of the galvanometer fiber, which agrees with the experience of Th. Arendt.¹⁸ Clearly, the cause of the "magnetic pulsations" includes in general wide regions, so that the local character of the weather in a fixed place is irrelevant.

The sensitiveness of our apparatus is reckoned as follows: At Schlederlohe we had laid the cable about an almost rectangular area of from 53.2 to 54.0 m. length and from 33.1 to 37.8 m. width, so of about 1900 sq. mm. or 1.9×10^7 sq. cm. area; the remaining 32 m. were laid close together as conductors to and from the galvanometer set up in the villa of the piece of ground. Later the whole cable length was made use of and it was stretched out in the woods in a square 52.5 m. on a side, thus enclosing an area of 2756 sq. m., that is 1.45 times as great a surface as before. Connection was made to the galvanometer standing in the villa by means of the previously described special cable. Since the 15 strands were connected in series the total area of windings amounted to 28,500 sq. m. or 2.8×10^8 sq. cm. in the first experiments, later 4.1×10^8 sq. cm. With a vertical intensity of 0.41 C. G. S. unit, which is the mean at the place of observation, a change of 17 in this component, that is, of the 41000th part of its mean value, in a second would correspond to an electromotive force of 2.8×10^{-5} volt or 4.1×10^{-5} in the second case. The resistance of the total circuit amounted to 229 down to 160 ohms. This inductive impulse produced a deflection of more than a scale division, which can be exactly measured with the microscope. A tenth of the given field variation could be clearly seen. Since the fiber follows very brief current impulses with complete accuracy the sensitiveness increases as the rate of change of field strength increases. Herein lies an important advance over the older methods which fail far above the given limit of sensitiveness.

Besides this it is certainly of special importance to possess so highly sensitive a variometer for the *vertical intensity* in particular.

¹⁸ TH. ARENDT, Das Wetter 241-253 and 265-280, 1896, and Natur. Wiss. Rdsch. 18, 105-107, 117-118, 1903. Here is discussed especially also the relation of the phenomena with atmospheric electricity.

The former researches suffer from the suspicion that in the almost always predominant disturbances of the horizontal component more or less local influences come into play, perhaps due to electric currents—vertically or horizontally spread out earth currents—while it may be assumed that the vertical component is less disturbed because the *local* influences can produce only a smaller effect, and hence that the general regional disturbances are here more clearly and purely represented.

4. Naturally the periods of the waves found in these observations are of special interest. Aside from pulsations of a duration such as had before been observed, thus of a period of several seconds, we could also establish the existence of very much shorter magnetic waves, the period of which amounted to only 0.025 sec. It is thus shown that one does not, as was supposed, even with the "rapid registration," approach the last elements of the terrestrial magnetic disturbances, (see above p. 2) but that these on further analysis are capable of presenting an abundance of smaller details.

In view of such rapid pulsations it might be supposed that they are possibly the result of an electromagnetic oscillation in the closed circuit itself. The cable it is true has a certain self induction and a not unimportant capacity (the corresponding quantities for the galvanometer are negligible in comparison).

If one considers the cable as a flat coil of 15 single turns its self induction can easily be computed; it is true that even then the period of oscillation of such a coil can not be computed from the usual formula for the period of a circuit consisting of a self induction and a capacity, if the capacity is determined, because here the two quantities are not in series. However, it can easily be seen that the oscillation period of the cable is far shorter than the shortest of the current peaks that can be distinguished on the record with the velocity of the registering strip used (up to 24 mm. per sec.).

It can hardly be expected to record all these single vibrations continuously; for that purpose extraordinary lengths of the recording paper would be necessary. But what has gone before, even if the evidence is insufficient, seems to indicate that the periods of the waves observed are not distributed at random, but that certain periods recur more frequently.

The question suggests itself: May we not predict certain periods in these pulsations of the Earth's magnetism and search for them?

For exciting electric waves of small wave length, spheres which

are gotten out of electrical equilibrium by means of a spark discharge are often used, e. g., in Righi's demonstration of Hertz's experiment, for setting up electrical oscillations, and thus giving rise to electromagnetic waves. The length of these waves is of the order of magnitude of the circumferences of the spheres. The theory of such "spherical oscillators" was first rigidly investigated by J. J. Thomson.¹⁹ Recently the Thomson theory was extended by A. Lampa for the case where the medium surrounding the sphere has a dielectric constant different from unity.²⁰

They agree in finding that the period of the oscillations of a sphere surrounded by air is: $T = \frac{4 \pi a}{V \sqrt{s}}$,

where a is the radius of the sphere in cm. and V the velocity of light, ($V = 3.10^{10}$ cm./sec.).

The Earth presents a sphere freely floating in space, surrounded by air on all sides, with a surface of good conducting material. If one supposes its electric equilibrium to be disturbed by any process within or without the Earth, it can return to a condition of equilibrium only through a series of oscillations. The period of these oscillations, computed according to the above formula is 0.15, or $1/6$ to $1/7$ sec.

The wave length of this oscillation in air is equal to 46130 km., i. e. equal to 1.155 times the circumference of the Earth, and hence not to be confused with the wave lengths used in wireless telegraphy. It would be premature to state that a short oscillation of just this period appears especially often in the observations; in order to make this certain the observations must be extended over a much greater interval of time, and verified in other places, under other conditions and with different apparatus. Should by such means this supposition be verified, another way would at once be pointed out, by which presumably a substantially new glimpse into the character of terrestrial magnetic disturbances would be afforded. It is not impossible to construct a circuit of a period of oscillation of 0.15 sec. By inserting suitable condensers one would be able to exactly regulate a period of the given order of magnitude. The fiber galvanometer would be inserted in the circuit exactly diametrically opposite to this additional capacity, so that between each end of the fiber and the nearest condenser plate the same length of conductor is included.

¹⁹ J. J. THOMSON, Recent Researches in Electricity and Magnetism, Oxford, 1893, p. 360 *et seq.*

²⁰ A. LAMPA, Wiener Sitzungsab. III, Abt. II, p. 37, 1903.

At the condenser there would be an anti-node of tension, the galvanometer would be at the node of the tension and the anti-node of the current. Presumably one could measure the amplitude of the oscillation by means of both tension and current. Such a conductor equipped with the suitable self induction and capacity would then present a resonator tuned to the primary electromagnetic vibrations of the Earth as a whole. This would probably "sound" as often as those regional magnetic disturbances occur, to whose presence former observations have already pointed, (see above p. 3). Then in the place where the condenser is inserted, large variations in tension are set up; as is well known, the amplitude rapidly increases as the period of oscillation of the resonator is approached by the oscillations to which the resonator responds.²¹ It is then no longer necessary to record the single oscillations themselves but the increase and decrease of the excitation of the resonator.

This sort of research would commend itself especially in higher latitudes in which the "magnetic unrest" is always very great, (see above p. 5). Here one needs only a relatively unsensitive galvanometer of the fiber type, or apparently the variations in tension appearing in the capacity could be directly measured with an electrometer. Above all it would be extremely valuable if Siemen's experiment described on page 5 should be repeated in the far north of North America near the North Magnetic Pole with a great loop of cable, the period of oscillation of which could be regulated in a definite way.

²¹ See for example the measurements carried out by V. BJERKNES, on a simple square wire-resonator, Ann. d. Phys. (3) 44, 74, 1891.

Munich, March 26, 1907.