

Electric Waves and Oscillations*

A Means of Investigating the Interior of the Earth

By Dr. Gotthelf Leimbach

THE attempts—which have, until very recently, been unsuccessful—to utilize electric currents and waves in the investigation of the interior of the earth extend back, respectively, to the years 1830 and 1901. The first practical results in this field, attained by Heinrich Löwy and myself in 1910 and 1911, attracted by no means the attention in mining circles that we had anticipated. Even at the present day, in the face of a great number of successful achievements, many persons are still skeptical about the development of electrodynamic methods of exploring the earth. Judging from my experience, this is due especially to the fact that neither the physical basis nor the scope of the various processes in question are correctly understood. Wireless telegraphy, the most familiar application of electric waves and oscillations, is commonly accounted one of the marvels of modern times; while the application of the same phenomena to subterranean exploration is consigned to the realm of fable. In the following remarks I hope I may be able to convince the reader that the latter application is neither impossible nor incomprehensible.

The physical principles involved in this subject were discussed in detail in the journal *Kali*, volume 7, 1913, No. 17. I there explained the principles of the wireless transmission of electrical energy through space, in order to save practical mining men the necessity of consulting a work on wireless telegraphy. Hence, I shall in the present article limit myself to a short sketch of the various processes.

The possibility of applying electrical waves and oscillations in the investigation of the earth's interior depends upon certain physical differences in the materials constituting the earth's crust. The latter fall into two classes, according as they conduct electrical currents, or, on account of their slight conductivity, are classed as insulators. Good conductors of an electrical current are impervious to electrical waves, whereas the latter pass almost unaffected through insulators.

As electrical waves differ from light-waves only in wave-length, optical phenomena may be directly reproduced by the former. With an apparatus for emitting waves (a sender) and one for recording them (a receiver), we may make qualitative observations on the material lying between the two instruments. As stated above, materials that are conductive to an electrical current will not permit the passage of the waves. Among the conductors are water,¹ salt solutions, and strata saturated with these; also a large number of ores.

I. INVESTIGATION BY MEANS OF ELECTRICAL WAVES.

a. Absorption Method.

A first practical method of investigation, the absorption process, takes the form of testing rocks for the presence of various substances by examining their capacity for admitting the passage of electrical waves. Practical investigations of substances which are opaque to such waves (ore and salt solutions) were made by Dr. Löwy and myself in the state mine of Ronnenberg, near Goslar, and also by Dr. Löwy at Scharley. These confirmed the fact that good conductors of an electrical current are opaque to electrical waves. A fair agreement with the theory, i. e., absence of marked absorption, was yielded by the rocks occurring in potash mines; viz., various salts, anhydrite, clay, etc. Numerous investigations in a large number of mines proved that there could be no doubt about the transparency to electric waves of the rock-forming minerals constituting the earth's crust—the ores excepted—when these substances are dry.

b. Reflection Method.

The reflecting power for light-waves of a great number of substances is as accurately known as their various degrees of transparency. Among the excellent reflectors of electrical waves we find, again, the substances that are conductive to an electrical current, viz., metals, ores, salt solutions, and water. With senders and receivers of electrical waves which have their antennae so arranged as to send or receive only in a selected direction it is possible, therefore, to locate these conducting substances through intervening material that is transparent to waves, merely by changing the direction of the antennae. From the angles between the antennae of the sending and receiving instruments, respectively,

and the ground when the intensity of the signals received is greatest, the depth of the reflecting layer (ore or water) can be computed. Practical investigations at the swimming hall in Göttingen, and also at Barsinghausen and Scharley, have proved the strong reflecting power of water and ore.

c. Interference Method.

In many cases, e. g., in determining the location of a water-bearing seam in the interior of a mine, it is impossible to use long antennae, movable at will. Such a seam may, however, be located with stationary sender and receiver if the wave-length of the system is so chosen that the waves running directly from the sender to the receiver are neutralized by those reflected from the conductive substance. This will happen when the path of the reflected waves is longer by $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, etc., wave-lengths than that of the direct waves. The two trains of waves have a different direction of oscillation, and opposite phase; their effect upon the receiver will be nil in case they have equal energy. On the other hand, if the difference between the length of path amounts to one or a number of whole wave-lengths, the waves will then be of the same phase and their effect upon the receiver will be reinforced. As we are able to vary at will the wave-length of a sender and a receiver, we can ascertain by this method, as by the others, the presence and the depth or distance of a conductive reflecting seam. Experiments of this sort on a small scale were made by the writer many years ago in connection with investigations of quite a different character, viz., the study of moist soils, at the geophysical institute of Göttingen University.

d. "Quarter-wave-length" process.

In the method above outlined both a sending and a receiving system are used. About a year ago it occurred to me to ascertain whether the wave emitted by the sender and returning thereto after falling vertically upon a reflecting surface would not affect the oscillations of the sender in a manner analogous to what occurs in the interference method. A method depending upon this principle would have the advantage of great simplicity, as compared with the interference method, because it would eliminate the second receiving system. In the laboratory of the "Erforschung des Erdinnern (G. m. b. H.)" ("Subterranean Investigation Company, Ltd.") at Göttingen, experiments on a small scale gave the surprising result that reflecting surfaces could be located the length of which was less than that of the antenna and the breadth only one hundredth the length of the antenna, or less. This method is, therefore, extremely sensitive. As the sender shows particularly characteristic effects for differences of a quarter of a wave-length or multiples thereof, this process has been called the "quarter-wave-length" method. From the position of the characteristic maxima and minima of the effect of the reflected waves in relation to the wave-length the depth of the reflecting layer may be very accurately determined. This method is appropriate for seeking ore or water from the earth's surface in all cases where the intervening strata do not wholly absorb the waves. An expedition sent out by the company above mentioned, under the auspices of the Imperial Colonial Office and other interested parties, is now engaged in prospecting by this method in Southwest Africa.

II. INVESTIGATION BY MEANS OF ELECTRICAL OSCILLATIONS.

The following methods work with a single system of apparatus and depend upon the influence exerted on the apparatus by its immediate environment. The quarter-wave-length method therefore forms a connecting link between the methods in which the course of electrical waves is followed between two stations and those which involve observations of the influence exerted by the environment upon the oscillations of a single system.

a. Capacity and Damping Method.

The wave-length, λ , of an oscillating system, e. g., of an antenna, is determined by the latter's self-induction, L , and capacity, C , according to the relation $\lambda = 2\pi\sqrt{LC}$. The surroundings of the antenna have no influence on the self-induction, which therefore need not be considered further. On the other hand, the capacity of an antenna is strongly affected when the lines of force running from the positive to the negative end of the antenna pass through some medium other than air. Each substance possesses its own dielectric constant—a number analogous to specific gravity—which shows how many times the capacity of an electrical system is increased when operating in the substance in question

instead of in air, the dielectric constant of which is unity.

The use of this principle of various dielectric constants in different substances seems quite pertinent when we learn that water has a constant of 81, while most rocks have constants varying between 4 and 12. We may therefore assume that the presence of a water-bearing seam will make itself felt through an increase in the capacity of the antenna, even at considerable distances. That even the slightest differences in the dielectric constants of various rocks occurring in potash mines cause differences in the capacity of oscillating systems has been determined through the detailed investigations of Dr. Erich Mayer and myself.

A great advantage of this method consists in the fact that substances having different dielectric constants affect not only the wave-length but also the damping of the oscillations in different degrees. In conductive substances energy is used up in the production of vortical currents, and to these substances belong, as we have said, water and salt solutions. Non-conductive substances of high dielectric constant virtually affect only the capacity of the system. Hence, this method should permit not only the discovery of the presence of substances of different dielectric constant, but also at least a qualitative identification. Thus we have the basis of a method which can be applied, first of all, in mining and shaft-sinking, to the task of determining whether there is danger of an irruption of water or salt solutions.

b. Examination of Frozen Shafts.

Water-bearing and unstable soils are now, with increasing success, frozen in connection with shaft-sinking, in order to produce a cylinder of resistant material within which the sinking of the shaft can proceed without danger. That this operation has not always been successful is due to the fact that it has hitherto been difficult to determine whether the frozen layer was sufficiently solid at all points. The efforts to remedy this difficulty have been limited practically to the construction of more or less trustworthy sounding-devices for testing the behavior of the various freezing-pipes. From the behavior of any two successive pipes, and with the aid of the data deduced from past experience, it is decided whether the amount of cold applied is sufficient to freeze the section of ground between the pipes, or whether a supplementary freezing-pipe ought to be installed between them. Moreover, in order to freeze with tolerable certainty any strata containing salt solutions, which have led to many breaks and accidents, very low temperatures are used. In spite of all improvements, the fact remains that there has heretofore been no means of promptly detecting the presence of disturbing factors within the earth. Here again the aid of electrical oscillations may be invoked. Unfrozen water-bearing or solution-bearing seams lose their electrical conductivity in proportion as the water they contain is changed to ice. Hence, the iron freezing-tubes must be used as antennae and made to give rise to electrical oscillations, which will be effected by the immediate environment in the same manner as in the capacity method. Experiments on a small scale confirmed the utility of this process; ice was found to be transparent to electrical waves. The conductivity of water containing a small admixture of salts was reduced to about $\frac{1}{100,000}$ of its original value by cooling from room temperatures to 10 degrees below zero Centigrade.

Meanwhile it remained to be determined whether these assumptions would be as perfectly realized in an actual shaft-freezing operation, with its envelope of frozen soil, as in experiments on a small scale. We had no difficulty in transferring our laboratory experiments to the practical conditions of such an undertaking. My collaborator, Dr. Mayer, and myself were able within a few minutes to excite oscillations of a previously determined wave-length in any freezing-tube we happened to select, at an installation between Rössing and Barnten where the necessary facilities were kindly placed at our disposal by the "Tiefbau- und Kälteindustrie A.-G." of Nordhausen (formerly Gebhardt & Koenig). The last preliminary condition of the proposed method was thus fulfilled; the frozen envelope of the shaft gave an effect exactly analogous to that produced under artificial conditions in the laboratory.

Our request for permission to continue our experiments at the Glitten shaft was cheerfully complied with by the "Deutsche Schachtbau-Aktiengesellschaft" of Nordhausen. With funds raised on the strength of our success at Rössing-Barnten, we only succeeded in test-

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¹ Pure water is a non-conductor. The author's statement is, however, true of all water found in nature, this being conductive in virtue of the substances it holds in solution.—Translator's note.

ing the frozen wall of the shaft so far as to discover, at the outset, the presence of an unbroken layer near the surface, which hindered the penetration of the electrical waves to the lower end of the freezing-tubes. This layer, according to our measurements, lay at a depth of barely 2 meters. Subsequent investigation showed that a thin layer of the freezing-mixture lay upon the cement block in which the drive-pipes were installed, and this had not frozen.

Had not the shaft been, for the most part, already lined with iron, we should have been able to apply successfully here a method which we have applied, with good results, in a Hanoverian potash mine, where we had to work through a much more strongly conductive layer than the one above mentioned. However, both here and also a few weeks later in a shaft-freezing installation kindly placed at our disposal at Heerlen, Holland, by the "Deutscher Kaiser" Mining Company, we had to content ourselves with the positive result of having been able to detect not only the presence but also the depth of an unfrozen seam, which lay even deeper at Heerlen than in the case just referred to.

Recognizing the fact that we must, for the future, generally expect such layers of disturbance near the earth's surface, and a more or less extensive iron lining in the shaft, I endeavored to devise another method in which the investigation of the freezing wall of the shaft would be entirely unaffected by such obstacles. The ample equipment of our physical laboratory greatly facilitated this undertaking. Setting out from certain very definite experimental conditions, my colleagues, Drs. Mayer and Kröncke, and myself succeeded in exciting electrical oscillations in two bare wires buried in wet earth—representing a freezing-tube system on a small scale—and in determining the constants which furnish information as to the separation of the tubes and the location of unfrozen places in the frozen wall. After experimenting under a variety of conditions we

came to the conclusion that the presence of a conductive layer under the sill of the superstructure, due to the often practically unavoidable spilling of the freezing solution in filling the tubes, and also the existence of an iron lining ("tubbing") in however advanced a stage of construction, need not interfere with the examination of the frozen earth; indeed, the iron lining can be turned to good advantage in connection with this process.

c. Investigations in Connection with the Cementation Process.

The use in shaft-sinking of the cementation process, in which crevasses in the wall of the shaft are closed by forcing cement into them, has steadily gained adherents notwithstanding numerous failures. Unquestionably this process has its advantages in many cases, especially when water needs to be kept out in comparatively small areas at great depths. While in the freezing process it is possible to form a tolerable idea, through various modes of observation, of the successful progress of the work, in the cementation process the measurement of the water flowing into the drill-holes, or of the amount of cement forced out by the water, furnishes the only method of testing the solidification of the dangerous crevassed strata. The strong outward resemblance of the cementation to the freezing process led me to consider the applicability to the former of the electrical method of testing for water. The method used in the freezing process could not be applied without modification, since in this case it was not a question of insulating the drill-holes from water-bearing seams. However, preliminary experiments at Göttingen and also in an actual shaft where cementation was in progress showed that the waves from a highly isolated antenna can penetrate so deep in the earth that from the reaction of the earth upon the antenna it is possible to gain a knowledge of the presence of water in crevassed strata. An advantage offered by the electrical

test consists in the fact that the antenna is not essentially affected by thin newly-formed layers which diminish the flow of water, take up little cement, and thus give a deceitful effect of solidity, but which, with further sinking of the shaft, do not offer sufficient resistance to the pressure, and thus may ruin the shaft. So long as the water is not effectually held back by the cement, so as to furnish the conditions necessary for forming a cement wall strong enough to withstand the very heavy pressures to which it may, under some circumstances, be subjected, the danger of a break may still be detected by our instruments, even in cases where the almost complete cessation of flow would, according to previous experience, apparently justify the further sinking of the shaft.

CONCLUSION.

The foregoing remarks will, it is hoped, help to give the reader some idea of the principles underlying the various methods of investigating the interior of the earth by means of electrical waves and oscillations, and to stimulate his interest in the practical results thus far attained. These results will be discussed in another article.

[In addition to the article in *Kali* mentioned above, several accounts of the methods of investigation described in the foregoing memoir have been published by Dr. Leimbach and his collaborators in German and Austrian scientific journals, the more important being:

H. Löwy and G. Leimbach, "Eine Elektrodynamische Methode zur Erforschung des Erdinnern (Erste Mitteilung)," *Physikalische Zeitschrift*, 11, 1910, p. 697 ff. *Ibid.* (Zweite Mitteilung), *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 60, 1912, p. 627 ff. and p. 640 ff.

H. Löwy, "Systematische Erforschung des Erdinnern mittels elektrischer Wellen," *Zeitschrift für praktische Geologie*, 19, 1911, p. 297 ff.—Editor of SCIENTIFIC AMERICAN SUPPLEMENT.]

German System and Method*

The Effect of the War on Her Industries

THE significance of the two words "system" and "method," and of all that these words connote, has been demonstrated to the full in the present war by the Germans, who, with much pride and satisfaction, make innumerable references to them in the press, in public meetings, and in private conversation. We all know that Germany, in every conceivable field, has carried her principle of systematizing to a length and degree of perfection unapproached and, perhaps, even hardly attempted in other countries, and however difficult her position may be at the present day and in the future, it would have been infinitely worse had she not had her system of systems to fall back upon. Its immense machinery was at once put in action, and the Germans claim for it that, when put to the tremendous test set it by the war, it has done all that could possibly have been expected from it.

At the recent general meeting of the Allgemeine Elektrizitäts Gesellschaft a statement was made that "the first task for the German industry, which through the war had experienced an unprecedented 'narrowing in,' was that of standing on its legs. To do this, a transformation of the entire industry was to some extent necessary. Although it certainly was by no means a simple matter for a country with many imports suddenly to get substitutes, the necessary transformation or alteration within the whole industry has been completed with admirable ease." Commenting upon these remarks, a writer in a Berlin journal says this only confirms what every day and every hour they see and hear and read. There is hardly an industrial report which does not bear out that, after the shock, work has been resumed with 40, 50, or 70 per cent of the usual staff, and that part of the work, directly or indirectly, has been devoted to war purposes. A factory for incandescent lamps all at once took up the manufacture of cartridges; machine works made "Gullasch-cannons"; a maker of artificial flowers went in for bread-bags, a bijouterie concern for knapsacks; a hotel kitchen was turned into a jam factory. It only took a couple of weeks, and the necessary plant was available. Hands were trained, and energetic merchants looked to the supply of raw materials, or where the usual ones were unobtainable, of substitutes, and to means to bring producer and buyer in contact, though often by a round-about way. The system has worked admirably, and at a time when people were compelled to work with the utmost economy it has managed to call forth from the darkest and narrowest corners raw materials, to secure that nothing was wasted, and that no possibly accessible foreign source of supply was neglected. The fact

that a number of earnest and financially strong business men were compelled to apply themselves to opportunistic dealings has also helped to augment the exceptional work done in this connection.

In examining into the reasons why German industry has escaped being brought to a standstill by the war in nearly every one of its more important sections and, after a short reorganization and with partly altered objects in view, has worked on with an imposing certainty and without any suspicion of nervousness, it becomes clear that the most potent factor is that the German army quickly succeeded in carrying the war into foreign countries. In addition to this, the industrial and financial authorities succeeded, by wise measures, in establishing confidence in the power of resistance of the German industrial organization, which, in its turn, rested upon the German military successes. The causes of the uniform continuity in German industrial growth, however, in the last instance are to be found in the fact that German development, more than that of any other country, has grown systematically, and shows no gaps of any moment in the manufacturing processes. With regard to certain raw materials which the German soil does not produce, or, in any case, not in sufficient quantities, Germany will also in the future have to depend upon foreign countries, even if the efforts of its scientifically working industry are systematically centered upon replacing artificially the natural raw materials which Germany lacks. In this connection mention is made of the successful attempts at producing artificial nitrogenous manure instead of Chile nitrates, at producing home-manufactured benzol in place of foreign benzine, and of the not yet quite successful attempts at producing artificial leather and rubber.

Still more important than the raw-material question for the maintenance of the collective German industry under the present conditions is the fact that no indispensable intermediate link is missing in the large processes of production. Germany produces herself all her half-finished goods, and she utilizes the residuary products of her industrial processes for the manufacture of valuable auxiliary commodities with such financial results that no other industrial nation in the world even approaches her in this respect. What these auxiliary products mean to Germany at present is more especially demonstrated by sulphate of ammonia and benzol. How much the want of important links in production can harm a country in her industrial processes is demonstrated in England, where the inadequate development of many auxiliary and vital industries has almost crippled some of the country's chief lines of manufacture. Thus, the stoppage of the German dyestuff import,

which, in money, only represents about a million sterling, threatens the English textile industry, the English wall-paper industry, and many other branches, with a turn-over of many millions. In the same way the absence of cheap German half-finished goods has deprived the English iron industry of an important intermediate link. Further, the stoppage of mining timber has gravely inconvenienced the collieries.

Industrially, the long established and growing British principle of producing entirely finished goods, and importing the raw and intermediate products of great industries, has proved inferior to the German method in time of war. This latter aims at a complete organization of an entire manufacturing process in comprehensive works, which, separately or together, cover the entire series of operations needed. The industrial expansion of Germany, although it is much younger than that of England, has been laid out on more systematic lines, and in such a way as to render the country more independent of foreign aid. Under the difficult and strenuous conditions of war it has demonstrated the extreme value of system and method, and the advantages which they confer on a nation when it is cut off from the lands from which it draws its raw materials.

The Government to Certify Timepieces

THE test and certification of watches, chronometers, and other timepieces has been carried on for many years at the Kew Observatory in England, at the Besançon Observatory in France, and at the observatories of Geneva and Neuchâtel in Switzerland, but no such tests have been made for the public in this country, except for a few years at Yale University many years ago. This line of work is now started at the Bureau of Standards, and Circular No. 51, entitled "Measurement of Time and Tests of Timepieces," has just been issued giving the regulations under which the tests will be made, the methods employed, together with sections on the use and care of watches, and on standard time and the sources of reliable time standards with which one may make frequent comparisons of his watch. This first edition of the circular announces the regulations for the test and certification of watches only; the test of other timepieces will be taken up later. It is expected that the tests will be especially valuable in cases where watches are to be used for scientific purposes or exploration, and also to purchasers of high grade watches in giving them assurance that the watch is reasonably adjusted and in good condition at the time of the test. Copies of the circular and also of the application blank may be obtained upon request from the Bureau of Standards, Washington, D. C.

* From *Engineering*.