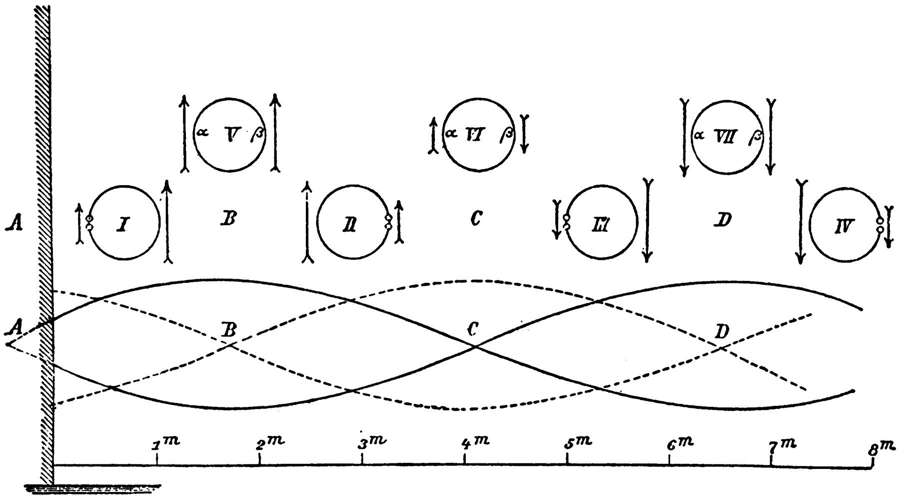
CLASSICS OF SCIENCE:

Hertz on Electric Waves

Physics



ELECTRIC AND MAGNETIC WAVES reflected from the wall, as traced out in Hertz' experiment

In performing these experiments, Hertz covered one wall of the laboratory with sheet zinc to act as a reflector, and suspended the apparatus here described high in the air above the laboratory desks.

ELECTRIC WAVES; being researches on the propagation of electric action with finite velocity through space. By Dr. Heinrich Hertz. Authorised English translation by D. E. Jones, with a preface by Lord Kelvin. London and New York, 1893.

The Apparatus

Before we proceed to develop the theory, we may briefly describe the apparatus with which the experiments were carried out, and to which the theory more especially relates. The primary conductor consisted of a straight copper wire 5 mm. in diameter, to the ends of which were attached spheres 30 cm. in diameter made of sheet-zinc. The centres of these latter were 1 metre apart. The wire was interrupted in the middle by a spark-gap ¾ cm. long; in this oscillations were excited by means of the most powerful discharges which could be obtained from a large induction-coil. The direction of the wire was horizontal, and the experiments were carried out only in the neighbourhood of the horizontal plane passing through the wire. This, however, in no way restricts the general nature of the experiments, for the results must be the same in any meridional plane through the wire. The secondary circuit, made of wire 2 mm. thick, had the form of a circle of 35 cm. radius which was closed with the exception of a short spark-gap (adjustable by means of a micrometer-screw).

Plotting the Electric Wave

If the experiment is arranged at a distance of about 0.8 metre from the wall the sparks are much stronger when the spark-gap is turned towards the wall. The length of the sparks can be so regulated that a continuous stream of sparks passes over when the spark-gap is turned towards the wall, whereas no sparks whatever pass over in the opposite position. If we repeat the experiment at a distance of 3 metres from the wall we find, on the contrary, a continuous stream of sparks when the spark-gap is turned away from the wall, whereas the sparks disappear when the spark-gap is turned towards the wall. If we proceed further to a distance of 5.5 metres, a fresh reversal has taken place; the sparks on the side towards the wall are stronger than the sparks on the opposite side. Finally, at a distance of 8 metres from the wall, we find that another reversal has been executed; the sparking is stronger on the side remote from the wall, but the difference is no longer so noticeable. Nor does any further reversal occur; for it is prevented by the preponderating strength of the direct action and by the complicated forces which exist in the neighbourhood of the primary oscillation. Our figure (the scale in which indicates the distances from the wall) shows at I., II., III., IV., the secondary circle in those positions in which the sparks were most strongly developed. The alternating character of the conditions of the space is clearly exhibited.

At distances lying between those mentioned both sets of sparks under consideration were of equal strength and in the immediate neighbourhood of the wall too the distinction between them diminishes. We may therefore denote these points—namely, the points *A, B, C, D* in the figure—as being nodal points in a certain sense. Still we must not consider the distance between any one of these points and the next as being the half-wave length. For if *all* the electrical disturbances change their direction in passing through one of these points, then the phenomena in the secondary circle should repeat themselves without reversal; for in the spark-length there is nothing which corresponds to a change of direction in the oscillation. We should rather conclude from these experiments that in passing through any one of these points one part of the action undergoes reversal, while another part does not. On the other hand, it is allowable to assume that double the distance between any two of the points corresponds to the half wave-length, so that these points each indicate the end of a quarter wave-length. And, indeed, on the basis of this assumption and of the fundamental view just expressed, we shall arrive at a complete explanation of the phenomenon.

For let us suppose that a vertical wave of electric force proceeds towards the wall, is reflected with slightly diminished intensity, and so gives rise to stationary waves. If the wall were a perfect conductor a node would form at its very surface. For inside a conductor or at its boundary the electric force must always be vanishingly small. Now our wall cannot be regarded as a perfect conductor. For, in the first place, it is only metallic in part, and the part which is metallic is not very extensive. Hence at its surface the force will still have a certain value, and this in the sense of the advancing wave. The node, which would be formed at the wall itself if it were perfectly conducting, must therefore lie really somewhat behind the surface of the wall, say at the point *A* in the figure. If double the distance *A B*, that is the distance *A C*, corresponds to the half wave-length, then the geometrical relations of the stationary wave are of the kind which are represented in the usual symbolic fashion by the continuous wave-line in the

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figure. The forces acting on both sides of the circle in the positions *I, II, III,* and *IV* are correctly represented for any given instant in magnitude and direction by the arrows at the sides. If, then, in the neighborhood of a node the spark-gap is turned towards the node, we have in the circle a stronger force acting under favorable conditions against a weaker force, which acts under unfavorable conditions. But if the spark-gap is turned away from the node. the stronger force now acts under unfavourable conditions against a weaker force, which in this case is acting under favourable conditions. And whether in this latter case the one preponderates or the other, the sparks must necessarily be weaker than in the former case. Thus the change of sign of our phenomenon every quarter wave-length is explained.

Our explanation carries with it a means of further testing its correctness. If it is correct, then the change of sign at the points *B* and *D* should occur in a manner quite different from the change of sign at *C*. At *V, VI,* and *VII* in the figure the circle and the acting forces in these positions are represented, and it is easily seen that if at *B* or *D* we transfer the spark-gap from one position to the other by rotating the circle within itself, the oscillation changes its direction relatively to a fixed direction within the circle; during this rotation the sparks must therefore become zero either once or an uneven number of times. On the other hand, if the same operation is performed at *C*, the direction of the oscillation does not change; and therefore the sparks must either not disappear at all, or else they must disappear an even number of times. Now when we actually make the experiment, what we observe is this:—At *B* the intensity of the sparks diminishes as soon as we remove the spark-gap from *a*, becomes zero at the highest point, and again increases to its original value when we come to *B*. Similarly at *D*. At *C*, on the other hand, the sparks persist without change during the rotation, or, if anything, are somewhat stronger at the highest and lowest points than at those which we have been considering. Furthermore, it strikes the observer that the change of sign ensues after a much smaller displacement at *C* than at *B* and *D*, so that in this respect also there is a contrast between the change at *C* and that at *B* and *D*.

The representation of the electric wave which we have thus sketched can be verified in yet another way, and a very direct one. Instead of placing the plane of our circle in the plane of oscillation, let us place it in the wave-plane; the electric force is now equally strong at all parts of the circle, and for similar positions of the sparks their intensity is simply proportional to this electric force. As might be expected, the sparks are now zero at the highest and lowest points of the circle at all distances, and are strongest at the points along the normal in a horizontal plane. Let us then bring the spark-gap into one of these latter positions, and move slowly away from the wall. This is what we observe:—Just at the conducting metallic surface there are no sparks, but they make their appearance at a very small distance from it; they increase rapidly, are comparatively strong at *B*, and then again diminish. At *C* again they are exceedingly feeble, but become stronger as we proceed further. They do not, however, again diminish, but continue to increase in strength, because we are now approaching the primary oscillation. If we were to illustrate the strength of the sparks along the interval *A D* by a curve carrying positive and negative signs, we should obtain almost exactly the curve which has been sketched. And perhaps it would have been better to start from this experiment. But it is not really so striking as the first one described; and furthermore, a periodic change of sign seems to be a clearer proof of wave-motion than a periodic waxing and waning. * * *

The Magnetic Wave

We are now quite certain that we have recognised nodes of the electric wave at *A* and *C*, and antinodes at *B* and *D*. We might, however, in another sense call *B* and *D* nodes, for these points are nodes of a stationary wave of magnetic force, which, according to theory, accompanies the electric wave and is displaced a quarter wave-length relatively to it. This statement can be illustrated experimentally as follows:—We again place our circle in the plane of oscillation, but now bring the spark-gap to the highest point. In this position the electric force, if it were homogeneous over the whole extent of the secondary circle, could induce no sparks. It only produces an effect in so far as its magnitude varies in various parts of the circle, and its integral taken around the circle is not zero. This integral is proportional to the number of lines of magnetic force which flow backwards and forwards through the circle. In this sense, we may say that in this position, the sparks measure the magnetic force, which is perpendicular to the plane of the circle. But now we find that in this position near the wall there is vigorous sparking which rapidly diminishes, disappears at *B*, increases again up to *C*, then again decreases to a marked minimum at *D*, after which it continuously increases as we approach the primary oscillation. Representing the strength of these sparks as ordinates with positive and negative signs, we obtain approximately the dotted line of our figure, which thus represents correctly the magnetic wave. The phenomenon which we first described can also be explained as resulting from the co-operation of the electric and the magnetic force. The former changes sign at the points *A* and *C*, the latter at the points *B* and and *D*; thus one part of the action changes sign at each of these points while the other retains its sign; hence the resulting action (as the product) changes sign at each of the points. Clearly this explanation only differs in mode of expression, and not in meaning, from the one first given.

Heinrich Rudolf Hertz was born at Hamburg, Germany, February 22, 1857, and died at the age of 37 at Bonn, January 1, 1894. In 1878 he became a pupil of Kirchoff and of Helmholtz in Berlin. He plunged at once into original research, and was regarded by Helmholtz as the most brilliant student he had ever had. In 1880, at the age of 23, he published "Kinetic Energy of Electricity in Motion" and took his doctor's degree with "Induction in Rotating Spheres." Between 1885 and 1889 he made his famous discoveries in electromagnetic phenomena.

Science News-Letter, May 26, 1928

X-rays of a singer's skull reveal considerable information about the range of a voice and its possibilities, a professor of music has reported.

A model community, with fast motor routes for automobiles, and parkways and garden paths for children and pedestrians, is planned 18 miles from New York City.

Sightseers are now admitted to the Great Mosque of Hebron, built over a cave said to contain the bodies of Abraham and Sarah, Isaac and Rebecca, and Jacob and Leah.