



XIV. The influence the size of the reflector exerts in "Hertz's experiment"

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The apparatus has been applied to the comparison of the compressibility of solutions with that of the solvents, and the results exhibit the same general relations as with other properties of solutions. The solutions divide themselves into two classes, which may be broadly termed electrolytic and non-electrolytic. In the first there is a very considerable decrease in compressibility, as much as 8 per cent. with a 3-per-cent. solution of NaCl; whilst in the second there is but a slight diminution, quite beyond the limits of accuracy of the apparatus. For instance, a 5-per-cent. solution of naphthalene has a diminution of under 1 per cent.

A strict interpretation of the theory of osmotic pressure in solutions has been made by Prof. J. J. Thomson, in his "Applications of Dynamics to Physics and Chemistry," § 97, where he finds that 1 gram-equivalent per litre would decrease the compressibility by 1 part in a thousand. Non-electrolytes in dilute solution appear to follow this law; this is in agreement with their other properties, such as alteration in boiling- or freezing-points.

The diagram will serve to explain the general arrangement of the apparatus.

XIV. *The Influence the Size of the Reflector exerts in "Hertz's Experiment."* By FRED. T. TROUTON*.

OWING to the requirements of certain refraction experiments in which I was engaged, it became necessary to investigate more fully than had been previously done† the influence the size of the reflector has in determining the position of the nodes in Hertz's now well-known electromagnetic interference experiment.

Radiation of a suitable period was produced by Hertz for this experiment, as is well known, by taking advantage of the alternating character of the discharge of an electric condenser. For this purpose two similar conductors, generally speaking two brass cylinders, are placed together end to end with a spark-gap between them, and are charged by an induction-coil, with the poles of which they are connected. The rapidly alternating current which occurs between them at each discharge originates electromagnetic waves which spread out into space. In these waves the electric component is parallel to the common axis of the cylinders, while the magnetic component lies at right angles.

* Communicated by the Author.

† 'Nature,' Aug. 22nd, 1889.

We can now detect these waves in a variety of ways. Hertz employed in his interference experiments a simple circle of wire interrupted at one place by a short gap, the wire being of such a length that the period of electric oscillations from end to end on it is the same as that of the radiation with which it is to be used, so that the currents induced in the wire by a series of waves are synchronously reinforced until the ends, always oppositely charged, overflow, and a spark occurs.

By means of perpendicular reflexion from a metallic sheet a beam of the same period travelling in the opposite direction is obtained which will interfere with the direct one, and a series of loops and nodes result, just as in an organ-pipe. The position of these nodes Hertz detected by the use of the resonating receiver, the nodes and loops being distinguished by the variation in the intensity of the sparking across the gap as the distance of the resonator from the reflector was changed. The magnetic and electric forces in these stationary waves are everywhere complementary, that is, where one is a maximum the other is a minimum. The first magnetic node or place of minimum intensity of that force is situated at one quarter the wave-length from the reflecting sheet, and so on for the others, in the usual sequence of loops and nodes.

Some time since I observed that the distance of the nodes from the reflector was influenced by its size, and a short account was given in a paper in 'Nature,' vol. xl. p. 399, but until the present no determinations were described systematically made with various sized reflectors.

When a number of square sheets of various sizes were tried as reflectors, it was found that as the sheet became smaller the distance of the node from the sheet became greater. The increase seemed to tend towards becoming one eighth of the wave-length as the size of the reflector diminished, but with small sheets the intensity of the reflexion is very slight, and so it soon becomes impossible to make any satisfactory determination.

Perhaps the most noticeable thing in connexion with reflexion from sheets of limited size is the great difference in the effect, where the sheet is rectangular in shape, according as its long dimension is parallel to the direction of the magnetic or electric component of the incident wave. This undoubtedly is connected with the accumulation of charge on its edges, according as they lie in the direction suitable for it or not. A long narrow strip (say anywhere between one quarter and one half the wave-length in width) held with its

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length parallel to the magnetic direction, has the node nearly as far out as if it were a square. But with the same strip held at right angles, parallel to the electric direction, the node is practically at one quarter the wave-length, just as it would be for an infinite sheet.

It was thought desirable, in making the experiments, to use long strips for reflectors, as being a somewhat simpler case than square plates. In the present determinations the position of the node was found for a number of long strips of regularly increasing widths, first, when the long dimension of the reflector was held in the direction of the magnetic component, in which case the great shifting outwards of the node occurs; and, secondly, when held at right angles, or in the electric direction, in which case there is generally little or no effect to be found.

Nothing further as to the character of the effect than had been previously observed was noticeable in the first case; but in the second case, that is where the length of the strip is held in the electric direction, a distinct peculiarity was found when the strip was very narrow. It may be remarked that good reflexion can be obtained from strips in the second case quite too narrow to afford reflexion when held at right angles in the magnetic direction as in the first set. And it is with these very narrow strips that the peculiarity is noticed. The node, which until the strip is very narrow is practically unaffected by the width of the strip, is now situated *nearer* the reflector than one quarter the wave-length. This has considerable interest attached to it because it was really observed by Hertz in his original experiments, though he attributed it accidentally to quite another cause.

The vibrator or source of radiation employed in the following experiments consisted of two brass cylinders with rounded gilt ends (about 13 cm. long and 3 cm. in diameter), placed near each other in the focal line of a cylindrical parabolic mirror so as to give a parallel beam. It afforded radiation containing waves of a variety of periods*, but that selected by the "resonator" employed had a wave-length of 68 cm. The resonator, which was of the circular type, was placed in the centre of the beam at about 2 m. from the vibrator, in front of the metallic sheet used as reflector. It was always held so as to receive the magnetic component only, that is in the plane containing the axis of the vibrator, and with the diameter of the circle through the spark-gap parallel to this axis; in this position, only the magnetic lines of force can take effect. Thus throughout the following the magnetic force alone is

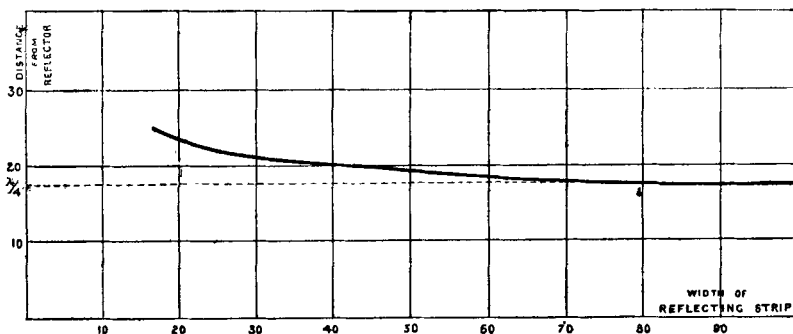
* 'Nature,' vol. xli. p. 295.

dealt with, and so, in speaking of the nodes, the places of minimum magnetic force alone are meant.

Care was taken, when determining the wave-length, to have as reflector a sheet sufficiently large so that no increase in size could produce any change in the distance of the nodes from it. When this is the case, it may be considered infinite in extent. The large sheet was then replaced in turn by smaller sheets, and the position of the node in each case observed. The experiments, as mentioned before, divide themselves into two parts. First, where an infinite reflector is, so to speak, gradually shortened in the direction of the electric component of the wave, but remains unaltered at right angles, whilst the accompanying change, if any, in the position of the node is observed; and, second, when the shortening takes place in the direction of the magnetic component.

The general results of the first set of experiments are seen at a glance by means of fig. 1. The abscissæ here represent the length of the reflector in the direction of the electric component, while the ordinates represent on the same scale corresponding to each sized reflector the distance of the resonator from the reflector when placed in the first position of minimum sparking. The length of the reflector in the direction of the magnetic component was 90 cm., as that was found to be amply sufficient, *i. e.* increase was found to produce no effect. The resonator was held in front of the centre of the reflector.

Fig. 1.



It will be seen from the curve that when the reflector is less than a wave-length the node begins to be shifted sensibly outwards from the true quarter wave-length position, so that to avoid these diffraction-effects mirrors should be at least a wave-length in the electric direction.

The following table served for plotting the curve. In the first column are the dimensions of the reflector in the direction of the electric component. Six determinations were made of the position of the node with each sized reflector. The mean of these is given in the last column. The reading taken was in each case the nearest quarter centimetre, the nature of the observations making further exactitude unnecessary. The effect from a 12 cm. reflector was too weak to admit of an observation.

TABLE I.

16	$24\frac{3}{4}$	$23\frac{3}{4}$	$22\frac{1}{2}$	$24\frac{3}{4}$	$24\frac{1}{2}$	$24\frac{3}{4}$	$24\cdot2$
20	22	$22\frac{1}{2}$	$23\frac{1}{4}$	$22\frac{1}{2}$	$22\frac{3}{4}$	$22\frac{1}{4}$	22·5
24	21	$22\frac{1}{4}$	$22\frac{3}{4}$	$21\frac{1}{2}$	$21\frac{3}{4}$	$21\frac{1}{4}$	21·8
28	$21\frac{3}{4}$	$20\frac{1}{2}$	$21\frac{3}{4}$	$21\frac{1}{2}$	$20\frac{3}{4}$	$21\frac{1}{4}$	21·2
32	$20\frac{1}{2}$	$20\frac{3}{4}$	$21\frac{1}{4}$	$21\frac{1}{4}$	$20\frac{1}{2}$	$20\frac{3}{4}$	20·7
36	$20\frac{1}{2}$	20	$20\frac{3}{4}$	21	$20\frac{1}{2}$	$20\frac{1}{2}$	20·5
48	19	$19\frac{1}{4}$	$19\frac{1}{2}$	$18\frac{3}{4}$	$18\frac{1}{2}$	$18\frac{1}{2}$	18·9
60	$17\frac{3}{4}$	18	$18\frac{1}{4}$	$18\frac{1}{2}$	$18\frac{1}{4}$	$17\frac{1}{2}$	18
75	17	17	17	$16\frac{3}{4}$	$17\frac{3}{4}$	$17\frac{1}{2}$	17·2
Large sheet }	$17\frac{3}{4}$	$16\frac{1}{4}$	$17\frac{1}{4}$	17	$16\frac{3}{4}$	$17\frac{1}{4}$	17

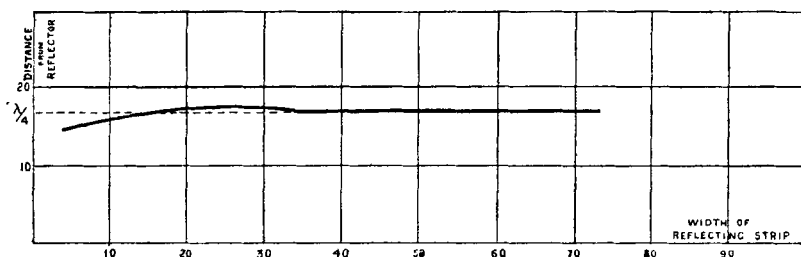
The effect produced in the reflected wave by shortening the reflector in the direction of the electric component can be considered equivalent to an acceleration or change of phase on reflexion. This equivalent change of phase is at least double that corresponding to the distance the node is shifted, because of the double journey back and forwards which the reflected wave has to make. But the complete change in phase must be really greater than this, for it is to be remarked that the node observed in these experiments is peculiar, and differs from that ordinarily considered where two non-divergent beams travelling in opposite directions interfere. The beam reflected from a small reflector is divergent, and consequently diminishes rapidly in intensity on proceeding outwards. This causes the node or minimum sparking-position to be a little nearer the reflector than the true position of opposite phase. The intensity of the reflected vibration at this point, before it can be subtracted from the incident one, has no doubt to be diminished in proportion to the cosine of the difference in phase between them; but this is more than made up for by the increase in intensity due to its nearer position, so that the approximation towards complete interference is better here than at the true phasial position. That the interference, then, is comparatively slight is seen by the fact that with the smaller sized reflectors it is

always easy, by diminishing the sparking-gap, to obtain sparking in the minimum position; this is not possible when large sheets are employed as reflectors.

Without being able to calculate in the case of a given sized reflector what the amount of the equivalent acceleration in phase should be, it can be seen that there should be a difference in phase between the current induced in the reflector and the incident wave when the reflector is short in the electric direction. For the edges afford a capacity and become charged each vibration, the charges opposing the inducing electromotive force, so that the effective electromotive force will reach its zero value sooner than when there are no edges for the accumulation of charge.

The problem of finding the reflexion from a reflector of limited size presents considerable difficulties. An approximation, however, has been obtained by the author* by taking advantage of Hertz's solution in the case of his "vibrator." The short reflector is assumed equivalent to another vibrator, and Hertz's equations of the wave are found for it, by making the total magnetic force due to both primary and secondary vibrator behind the sheet zero. This necessitates assuming that the reflexion comes from the central part only. This condition renders it very limited in its application; nevertheless calculation made by it of the position of the node shows it displaced at all events in the right direction, and to an extent comparable with observation. This method leads naturally to looking at the cause of the displacement, from the point of view of an increased velocity of the wave in the neighbourhood of the reflector, for so it appears in Hertz's theory of his "vibrator."

Fig. 2.



In the second set of experiments the narrowing of the reflector is in the magnetic direction. It will be seen from the curve, fig. 2, plotted from the results, that the large outward

* *Phil. Mag.* March 1890.

displacement of the node or minimum sparking-position is absent in this case.

On reaching comparatively small dimensions the inward shifting of the node takes place. This is probably best attributed not to a change in phase on reflexion or diminution in velocity in transit, but to the fact that the beam is rapidly diminishing in intensity on passing outward from the reflector, and, as mentioned before, the minimum sparking-position is a compromise between the phase and the intensity.

It might be thought that this action would never displace the node by a sensible amount, but the following consideration shows this not to be so. Let

$$y_1 = \sin 2\pi \left(\frac{t}{\tau} + \frac{x}{\lambda} \right),$$

where x is distance measured from the reflector, represent the incident wave; and let us make some assumption as to the rate the intensity of the reflected disturbance diminishes as the distance increases. Of several tried, that which happened to give results most nearly in agreement with the observations assumed the amplitude to diminish as the square of the distance from a point situated behind the reflector at a distance equal to its width. In this case, calling the width b , we have as the reflected wave

$$y_2 = \left(\frac{b}{b+x} \right)^2 \sin 2\pi \left(\frac{t}{\tau} - \frac{x}{\lambda} \right).$$

On addition the stationary wave is determined by

$$y_1 + y_2 = A \sin 2\pi \left(\frac{t}{\tau} + \phi \right),$$

where

$$A^2 = 1 + \left(\frac{b}{b+x} \right)^4 + 2 \left(\frac{b}{b+x} \right)^2 \cos 4\pi \frac{x}{\lambda}.$$

Differentiating and equating to zero as being the condition for a minimum, we find the position of the node to be given by

$$\left(\frac{b}{b+x} \right)^2 + (b+x) \frac{2\pi}{\lambda} \sin 4\pi \frac{x}{\lambda} + \cos 4\pi \frac{x}{\lambda} = 0.$$

When b , the width of the reflecting sheet, is taken as 4 cm., this equation requires x to have the value of about 14.3. That means a shifting inwards of the node by 2.7 cm., which is a little more than is required to correspond with observation, the nodal position given in Table II. for a 4 cm. sheet being at 14.6 cm. from the reflector.

If the amplitude of the reflected beam be taken simply as $\frac{b}{b+x}$, instead of its square, a somewhat more natural assumption, the value found for x is about 15.8—which is a shifting inwards considerable in deficit. It is thus evident that, apart from other considerations, a rapid falling-off in the intensity of the reflected disturbance is quite competent to effect an appreciable inward displacement of the node. However, it must be remembered that in cases like the present, where the intensity of one component changes rapidly with the distance, the minimum sparking-position must only be considered as a kind of *pseudonode*, not a true phasial one.

Taking a long shaped strip of zinc about 20 cm. wide, the experiment alluded to above, one somewhat analogous to Stokes's 'Experimentum Crucis,' is easily made. The position of the node when the strip is stretched in the electric direction, that is with its small dimension in the magnetic, will be found to be distant about one quarter the wavelength, much the same as with an infinite sheet; but on rotating the strip through 90° into the magnetic direction the node will be displaced outward, showing clearly the dependency of the effect on the two directions.

In Table II. are given the results of the experiments from which the second curve was plotted. In the first column are the dimensions of the reflector in the direction of the magnetic component. The mean of the four determinations with each sized reflector is given in the last column.

TABLE II.

4	$14\frac{3}{4}$	$14\frac{1}{2}$	$15\frac{1}{2}$	$14\frac{1}{2}$	14.6
8	$15\frac{1}{4}$	$14\frac{3}{4}$	$16\frac{1}{4}$	$15\frac{1}{4}$	15.3
12	$16\frac{1}{2}$	$16\frac{1}{4}$	$16\frac{1}{4}$	$16\frac{1}{2}$	16.4
20	$17\frac{1}{2}$	17	$17\frac{1}{4}$	$16\frac{3}{4}$	17
24	17	$17\frac{1}{4}$	$17\frac{1}{4}$	$17\frac{1}{4}$	17.2
28	$17\frac{1}{2}$	18	$17\frac{1}{4}$	$17\frac{1}{2}$	17.6
32	18	$17\frac{1}{2}$	17	$17\frac{3}{4}$	17.5
36	$16\frac{3}{4}$	17	$17\frac{1}{4}$	$17\frac{1}{4}$	17.1
48	$16\frac{3}{4}$	$17\frac{1}{2}$	$16\frac{3}{4}$	$17\frac{1}{4}$	17
Large sheet }	$16\frac{1}{2}$	17	$17\frac{1}{2}$	$16\frac{3}{4}$	16.9

It will be seen that it was possible to obtain determinations with much narrower reflectors in the present experiments than was previously found possible when dealing with the strips held so as to be short in the electric direction. Thus a given sized strip evidently must reflect less strongly when held so that its longest edge is the one which becomes charged

each oscillation, that is to say, with this edge at right angles to the electric component. And, indeed, this is as we should expect, since on comparison we see that in this case there is less area which can act effectively as a source of reflexion through the passage on it of current each oscillation. For all the electricity of course does not go to the very edge, but there is gradual accumulation of charge over the surface approaching the edge, increasing no doubt up to it. Consequently the current diminishes in intensity towards the edges, and thus it is only those parts of the reflector remote from the charged edges which can be considered completely effective in producing the magnetic component of the reflected beam. Each centimetre of charged edge, so to speak, reduces the effective area of a reflector, so that with a rectangular sheet strongest reflexion is obtained when the edge charged is shortest.

A very slight increase in the nodal distance is seen by the table to occur when the reflector is somewhat less than half a wave-length wide; this may require further experiments of a more sensitive character before being finally accepted. If it be the case, it would seem as if there were really an acceleration of phase on reflexion from mirrors small in the magnetic direction also, but so slight as to be almost entirely masked by the inward tendency due to divergency in the reflected beam. If we look at it from a purely optical point of view, Fresnel's theory indeed represents a linear reflector as having an acceleration of phase of $\frac{1}{8}\pi$; however, this is omitting all considerations of direction in the vibration; but we have seen that the whole phenomenon requires a treatment introducing a difference depending upon the magnetic and electric directions. An acceleration of $\frac{1}{8}\pi$ might suit very well in the magnetic case, but it is certainly insufficient when the reflector is narrow in the electric direction, as is seen from Table I. With a quarter wave-length of 17 cm., the effect of a change in phase of $\frac{1}{8}\pi$ on reflexion would be to shift the node out to 21.25 cm., that is out through $\frac{1}{16}$ the wave-length; but this is seen by the Table to be much too little, especially so when we remember that the observed minimum sparking-position must always be somewhat nearer the reflector on account of the divergency effect than the true position of opposite phases.

The result of diminishing the reflecting sheet simultaneously in both directions was also examined, but though it was very evident that the reduced dimension in each direction tended towards possessing its own respective effect, no simple relation between them exhibited itself; thus with a reflector

24 cm. square, the node was found at 22.4 cm., a little further than 21.8, which it is at when the sheet is long in the magnetic direction (Table I.), and this is as it should be, shifted out owing to both. Again, a reflector 24 cm. in the electric direction, and 10 cm. in the magnetic, had a node at 21.5 cm., a little less than with a long sheet, and this also is in the direction to be anticipated. Some few other experiments were made, but in the absence of a workable theory for the whole phenomenon, it was thought undesirable to pursue the matter further at present.

An interesting point arises in connexion with those experiments made with the reflector narrow in the magnetic direction, in which an inward shifting of the node was observed. In Hertz's original determinations he found that the first node was situated not quite so much as $\frac{1}{4}$ the wave-length from the reflector. He attributed this to imperfect reflexion arising from imperfect conductivity in the material of his reflector, which was a large sandstone wall with a number of gas-pipes across it, and had on it besides to increase the effect a zinc sheet 2 m. long in the magnetic direction and 4 m. long in the electric; there were also wires attached to the ends of the sheet for leading off the charges, so that it must have been equivalent to a much longer one in the electric direction. Now it seems probable that the sheet was sensibly the only thing that reflected, and that the inward displacement was really due to its comparatively small size in the magnetic direction, for the wave-length he employed was nearly 10 m., so that the reflector was about $\frac{1}{5}$ the wave-length in width. This corresponds to about a 14 cm. mirror with a wave-length of 68 cm.

Hertz found the inward displacement correspondingly greater than is given in Table II., but his incident beam must have been divergent, as he worked nearer the vibrator in proportion to the wave-length, while my beam was rendered fairly parallel by the parabolic mirror employed.

To make quite sure that in reflexion off a large sheet the first nodal distance 17 cm. was really one quarter the wave-length, the position of the second node was redetermined and found to be distanced from the reflector about 51 cm.—the mean of five determinations*. The vibrator in these experiments was over three wave-lengths away from the reflector.

It is very convenient, in carrying out these experiments, to have an arrangement for moving the resonator backwards and forwards a known amount. A simple arrangement for effecting this is to support the resonator at one end of a rod

* 2nd node. || 49 $\frac{3}{4}$ | 51 $\frac{3}{4}$ | 50 $\frac{1}{2}$ | 50 | 51 || 50.6

pivoted in the middle, and kept vertical by a weight attached to the other end. By means of two screw-stops the excursion to either side of the vertical position is limited to any desired amount. The method of procedure in identifying a node is, then, to find a position for the resonator such that on moving it an equal amount to either side, sparking just takes place. This can of course be done with facility in a darkened room.

When possible, it is still more convenient to move the reflector backwards and forwards a known amount, instead of moving the resonator, and the node is found similarly to before as the position where sparking just occurs in the extreme position of the reflector; this admits of being done when the reflector is small. The reflector was suspended by vertical cords about 3 m. long, and could be thus moved backwards and forwards practically parallel to itself with the greatest ease even in the dark, the amount of the movement being limited by stops. The advantage of this arrangement is that the adjustment of the resonator is unaffected, for when it is the resonator that is moved the disturbance is very liable to alter the spark-gap.

I have much pleasure here in thanking Prof. Fitzgerald for his advice and material encouragement on many occasions throughout the investigation.

Note.—Since sending off to the printers' I have learnt that MM. Sarasin and De la Rive (*Phil. Mag.* June 1891) have, unlike Hertz, observed no inward displacement of the node towards the reflector. Their experiments are quite in agreement with the explanation given above, for their reflector was about a wave-length in the direction of the magnetic component.

XV. Mr. Sydney Lupton's *Method of Reducing the Results of Experiments.* By SPENCER UMFREVILLE PICKERING, M.A., F.R.S.*

THE conclusions which I drew from an examination of various properties of sulphuric-acid solutions (*Chem. Soc. Trans.* 1890, pp. 64 and 331; *Phil. Mag.* xxix. p. 427) have recently been made the subject of an adverse criticism by Mr. Sydney Lupton in the pages of this Magazine (vol. xxxi. p. 418).

* Communicated by the Author.