



## L. On the reflection of electrical rays

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temperature due to conduction along the bar) can readily be found by experiment; or deduced by analysis, as in the case of an infinite square bar, where

$$\theta = a\mathfrak{E}^{-kx} \text{ and } \frac{d\theta}{dx} = -ak\mathfrak{E}^{-kx}.$$

As  $p$  may easily be determined by experiment, the equation can be used to determine  $\sigma$ , as

$$\sigma = \frac{I^2RS - phl}{I \frac{d\theta}{dx}}. \quad \dots \dots \dots \text{(IX.)}$$

If Tait's assumption that  $\sigma = MT$  (where  $M$  is some constant and  $T$  the absolute temperature) is true, we might obtain two values of  $\sigma$  for two points of the bar, the temperature of which was known, eliminate  $h$  from the two equations, and thus obtain a value for  $M$ . If we performed the same operation for two other points, we should get another value for  $M$ , and could verify Tait's assumption if this value was equal to the preceding.

The sources of error in the preceding investigation are due to assuming Newton's law of cooling, to neglecting the change of electrical resistance due to a change of temperature, and to partly neglecting the change of thermal conductivity due to the same cause.

# L. On the Reflection of Electrical Rays.

By Dr. E. GOLDSTEIN \*.

[Plate VII. figs. 1-8.]

IT has been usually assumed† that the (rectilinear) electrical rays radiating from the kathode of the discharge of an induction-coil terminate where they impinge upon a solid wall, and that beyond the point in which they cut the wall they cannot propagate themselves in any direction‡. The experi-

\* *Monatsber. der Königl. Akademie der Wissenschaften zu Berlin*. Translated from a separate impression communicated by the Author.

† Hittorf, *Pogg. Ann.* cxxxvi.

‡ Herr J. Puluj (*Wien. Ber.* 1880, [2] p. 886) is the only physicist who has assumed a limited power of reflection of the kathode-rays, under the assumption that the kathode-light consists of scattered particles of the electrode, since "it is not intelligible why these should in general suffer no reflection at the wall." The conditions of an experiment made by Herr Puluj to examine whether reflection takes place were not, in my opinion, such that any possible reflection would have been recognizable. That which Herr Puluj considers phosphorescence produced by reflected rays is partly phosphorescence produced by the positive light of the so-

ments which have led me to reject this assumption were suggested by an observation made by Prof. E. Wiedemann\*.

Prof. Wiedemann, in using a tube of the form of fig. 1 (Plate VII.), where the disk  $k$  at right angles to the axis of the vessel  $C$  forms the cathode, not only observed green phosphorescence such as produced by the kathode-rays on the sides of the tube up to the point  $x$  which could be reached by straight lines from  $k$ , but saw also a feeble illumination of the tube  $r$  beyond the bend, and a brighter phosphorescent surface  $F$  on the wall  $C$  opposite the mouth of the tube  $r$ . The motions of the small surface  $F$  under the influence of the magnet showed that it was produced directly by electrical rays, and not simply by optical rays possibly reflected at the glass.

Prof. Wiedemann is disposed to explain the appearance as one of the phenomena of deflection discovered by me†, assuming that the glass wall at  $x$  becomes charged and acts as a weak kathode, causing the deviation of the pencil of rays passing by it out of the direction at right angles to the plane of  $k$ , into the direction  $xF$ .

This explanation seemed improbable to me for two reasons:—

(1) Because the surface  $F$  is always much more feebly illuminated than would have been the case if the phosphorescence had been exerted by the direct kathode-rays penetrating to  $C$ . In order to make the comparison, the kathode-rays may be so curved by the influence of a weak magnet as to pass the bend  $x$ . The comparison may be more certainly made without the use of a magnet in a vessel of the form shown in fig. 2, where two paths are offered to the kathode-rays—on the one side the path as in fig. 1 through the bent tube  $r r_1$ , and on the other side the path through the equally long straight tube  $r_2$  at right angles to  $k$ .

(2) Because the surface  $F$  totally disappears if the tube  $r r_1$  has a second bend in it, in whatever direction this second bend is made. This would not happen with the phenomena of deflection, which I have examined, where a ray may be bent any number of times.

If now the rays which produce the surface  $F$  are not direct rays from the kathode  $k$ , then we may suppose either (*a*) that the portions of the tube about  $x$ , upon which the rays from the

called reflex currents in the system of tubes, partly phosphorescence produced by direct kathode-rays, which Herr Puluj unintentionally produced by touching the glass with the finger in order to concentrate the light.

\* E. Wiedemann, Wied. *Ann.* xi. p. 236; *Phil. Mag.* [5] x.

† Goldstein, *Monatsber. d. Königl. Akad. der Wiss.* 1876, p. 285; *Phil. Mag.* [5] iv. Also 'A new Form of Electrical Repulsion' (Berlin, 1880).

kathode impinge directly, become charged with negative electricity, which reaches such a tension that they themselves form a second kathode and radiate electric rays, which then produce F; or (b) that the rays which produce F are rays from the kathode  $k$ , which suffer reflection when they fall upon the solid wall. In this reflection, either the power of producing phosphorescence of the rays becomes weakened or their density, thus explaining the small intensity of light emitted by F.

The hypothesis (a) may be excluded, as shown further on; for the phenomenon in question is not altered if the surface upon which the kathode-rays impinge directly be metallic, and if this metal surface be made the anode of the discharge.

If in accordance with this assumption we suppose that reflection takes place, then again reflection according to the optical law is at once to be excluded, since the position and form of the surface F remain unchanged even when the angle of the bend at  $x$  varies from  $25^\circ$  to  $80^\circ$ . Consequently the law of the equality of the angles of incidence and reflection, or the rule that when the reflecting surface is rotated while the incident ray preserves the same direction, the reflected ray rotates through twice the angle, is not obeyed.

We may, however, easily make numerous experiments which agree in showing the presence of diffused reflection, in consequence of which each point of the wall on which the rays impinge directly diffuses rays in all directions.

If diffuse reflection is proved, we have at once the explanation of the small luminosity of F in comparison with portions of the tube reached by the direct rays in the diminution in density of the incident pencil of rays.

In the next place, if we employ a vessel such as fig. 3, we obtain phenomena corresponding to the surface F in the cylinders  $C_1$  and  $C_2$  at the same time. The rays which travel as far as  $x$  nearly parallel to each other, therefore, after reflection, follow at least two directions at right angles to each other.

The following experiment forms an *experimentum crucis*:—A chamber B was introduced between the portion of the tube containing the kathode and the bend at  $x$ , which contained a paper diaphragm which could be turned round the axis  $a$ , and which had a slit cut in it about 1 millim. broad and parallel to  $a$ . If the plane of the diaphragm falls along the axis  $rr$ , its edge intercepts no perceptible portion of the pencil of rays which reaches the tube  $r$  from the kathode, and which is about 7 millim. across. But if, on the other hand, D is at right angles to the axis of  $r$ , then only the portion of this pencil which passes through the narrow slit can reach the bend  $x$

If the reflection were similar to that of a mirror, the form and magnitude of the surface  $F$  would change perceptibly. This surface, in all the experiments so far described, and in this one also, resembles an ellipse of small excentricity, where  $D$  has the position first mentioned. Its smaller axis, which falls in the plane of  $r$   $r_1$ , is about twice as large as the diameter of  $r_1$  in the vessel  $C$ , which is about 3 centim. in diameter. If now we mark the position, form, and magnitude of  $F$  on the outside of the tube  $C$  when the diaphragm presents its edge only to the kathode-rays, and then place the diaphragm at right angles to the rays, we find that *the position, form, and magnitude of  $F$  remain unchanged*; only its *luminosity* is now considerably diminished.

If, instead of the diaphragm with a slit, a plate without openings is introduced into the chamber  $B$  capable of free motion, so as to cut off at pleasure either the upper or lower half (and also the right-hand or the left-hand half of the kathode-pencil) by covering the corresponding portion of the mouth of  $r$ , then also the position, form, and magnitude of the surface  $F$  remain unchanged; the luminosity only of the whole surface decreases, but most in the half which is opposite to the half that has been intercepted. Thus, for example, the surface is darkest in the upper half when it is the lower half of the kathode-pencil which is intercepted.

We easily see how these observations, inconsistent with optical reflection, entirely agree with the assumption of a diffuse reflection of the kathode-rays.

Tubes of the form of fig. 5 are better adapted for the further study of this diffuse reflection than the vessels employed by Wiedemann. The rays emitted by the kathode  $k$  which pass through the connecting tube  $r$  into the wider cylinder  $Z$  fall then upon the plate  $P$ , which is fastened to a wire  $d$  insulated with glass inside  $Z$ . The cylinder is closed air-tight by the caoutchouc stopper  $k$ , by removing which the plate  $P$  can be exchanged for another; or other changes in the apparatus can be made.

If the plate  $P$  consists of phosphorescent glass, then the rays which fall upon it directly produce at the plate  $s$  simply an oval very bright green phosphorescent surface. We see, however, distinctly how the diffuse reflection from this surface causes the whole wall of the tube  $Z$  lying above the plane of  $P$  up to the stopper  $k$  to phosphoresce with subdued green light, which is weaker the further the portion of the wall is removed from  $s$ .

If the plate  $P$  be covered with chalk, its surface at  $s$  shines with orange-red light, but the wall of  $Z$  presents a green

luminosity as before—a proof that this luminosity does not depend upon optical reflection. So also the phosphorescence produced by diffuse reflection remains unaffected if P be constructed of some material which does not phosphoresce at all. It is further a matter of indifference whether P is metallic or consists of an insulator. In the former case P may even be made the anode of the discharge, without the reflection of the rays appearing in any way weakened.

The kathode-rays are therefore not absorbed by the anode, even when they play directly upon the surface of the anode. Further we see, as already mentioned above, that the phenomenon in question cannot be explained by supposing that the surface struck by the direct kathode-rays is itself converted into a kathode.

If we bring small objects between the plate P and the phosphorescent surface of Z, such, for example, as the wire D (fig. 6), whose distance from P can be varied by rotation round the axis D, we can very well recognize the character of the diffuse reflection which the place *s* causes in the rays which fall directly upon it. For the shadow of the wire D only appears narrow and sharp when the wire is brought close to the wall of the vessel; if D is moved from the wall towards P, its shadow soon becomes broad and indistinct. If we cut off a further portion of the kathode-rays, by means of a small movable plate of mica introduced into Z at the mouth of *r*, the space *s*, directly impinged upon by the rays, of course becomes smaller. The further this decrease proceeds the narrower and sharper does the shadow of D become, exactly as we should expect on the theory of diffuse reflection.

I will here cite only one other consequence of this theory which has been experimentally verified. I may take it as known that a pencil of rays emitted by a plane kathode after it has passed, as in fig. 7, through the aperture (supposed circular) of a diaphragm occupying the whole area of the tube, gives on the flat wall W a well-defined circular luminous figure on a dark ground.

Upon our assumption of the diffusion of the kathode-rays, this ought not to happen any more if the rays are made to pass through a cylindrical tube open at both ends (fig. 8), in place of the thin diaphragm. For since the different rays of a plane kathode are not altogether parallel to each other, but also diverge somewhat around the central portion of the kathode, a part of them must play upon the wall of the tube *r*, and be then diffusely reflected. The portion of the diffuse rays which reach C must then form an extended luminous space round the bright surface resulting from the direct rays. We find

this confirmed by experiment ; and if we bring into C a wire  $\delta$  throwing a shadow, we find that its shadow is sharp and narrow in the region illuminated by the direct rays, but broader and ill defined in the surrounding region. This takes place also when  $\delta$  is made the anode. We see from this that the difference in breadth of shadow does not depend upon a stronger deflection which  $\delta$ , apparently neutral but really acting as a weak kathode, causes in the reflected rays\*. These last are indeed themselves capable of deflection, as we see if, instead of making  $\delta$  an anode, we connect it with the earth, or give to it a small portion of the current from the kathode.

The motions of the shadow of  $\delta$  under the influence of a magnet, and with other arrangements the motions of the surface F under similar influence, show that the reflected rays are deflected, as far as one can observe, in the same way as the direct kathode-rays would be if their course were the same as that of the reflected rays.

If  $r$  be placed equatorially above a horseshoe magnet of suitable strength, the direct kathode-rays before reaching C are compressed against the upper or under wall of  $r$ , and the phosphorescent surface ( $\phi$ ) produced by the direct rays disappears ; but the feebly illuminated region remains, occupying now the position of the surface  $\phi$  : this corresponds exactly to Wiedemann's surface F ; its production here is due to the diffuse rays which issue from the portions of the straight tube  $r$  struck by the magnetized rays. The further the terminal point of the direct rays is forced towards C by the action of the magnet, the less luminous does the surface F become, since then a continually smaller portion of  $r$  is able to reflect rays.

On the whole, the foregoing series of experiments leads to the following result, which I propose to describe more fully in a further communication:—A pencil of kathode-rays does not end (at any rate under the conditions suitable for producing phosphorescence) where it strikes upon a solid wall, but electric rays radiate in all directions through the space occupied by the gas from each point of the wall struck by the direct rays. These rays may be called reflected rays. Any solid wall, no matter what its properties are, may serve as reflecting surface. It is a matter of indifference whether it is capable of becoming phosphorescent or not, whether it consists of a conductor or of an insulator. The reflection is diffuse, equally whether the reflecting surface is dead or as smoothly polished as possible. An anode apparently reflects the kathode-rays, the same as a neutral conducting surface or an insulator. The reflected rays, like the direct kathode-rays, have the property

\* 'A new Form of Electrical Repulsion,' p. 124.

of exciting phosphorescence at their ends. They are capable of being deflected; and their ends are bent aside by a magnet in the same direction as the ends of the kathode-rays would be which radiated from the reflecting surface to the points reached by the reflected rays.

LI. *On the Influence of the Shape of the Kathode on the Distribution of the Phosphorescent Light in Geissler's Tubes.*  
By Dr. E. GOLDSTEIN\*.

[Plate VII. figs. 9-35.]

CYLINDRICAL wires cut off at right angles have been almost exclusively employed as kathodes in systematic investigations on the discharge of the induction-coil in rarefied gases, or, in particular cases, spherical electrodes or plane circular disks. Kathode-surfaces, which can be divided into two halves of similar shape by an infinite number of cuts, do not give rise to a class of phenomena which I have observed with kathodes of regular surface, in which nevertheless there is no axis of symmetry corresponding to an infinite number of equivalent sections.

We are concerned with extremely regular figures, in which the phosphorescent light of the walls illuminated by the rays from those kathodes arranges itself, which, however, are for the most part altogether unlike the shape of the kathode itself. Reserving a detailed description, I may here give the general characters of the most important types of these figures†.

Kathodes of concave spherical form were first examined constructed of thin soft iron, which was first of all stamped and then ground into the desired form.

The kathodes were soldered at the middle points of their convex sides to wires which conveyed the current, and which were insulated by being covered with glass thermometer-tubing between their junction to the kathode and the point at which they entered the vessel.

The discharge-tubes were glass bulbs of 4 to 5 centim. radius; the axis of the spherical concave mirror which formed the kathode was placed in a diameter of the bulb. The distance of the kathode from the wall, measured along this diameter from the centre of the mirror, could be varied; in the

\* *Monatsber. der Königl. Akademie der Wissenschaften zu Berlin*, July 1881. Translated from a separate impression communicated by the Author.

† A preliminary notice appeared in the *Wien. Akad. Anzeiger* of the 13th Jan. 1882. The phenomenon of figures in phosphorescent light dissimilar from the kathode was described by me for the case of a kathode of cylindrical curvature so long ago as 1876 (*Wien. Sitzungsber.* lxxiv. [2] p. 465).

