METHOD FOR MEASUREMENT OF TIME INTERVALS FROM 10^{-7} TO 6.7×10^{-11} SECOND

By Paul Heymans and Nathaniel H. Frank

Abstract

In this method, when a spark passes across a gap, an electric impulse travels along two nearly identical paths to two electrodes placed in contact with a photographic plate, and Lichtenberg figures are produced on this plate. The shift of the meeting line of the two Lichtenberg figures from the half-way position due to retardation in the path to one electrode is directly compensated by lengthening the electric path of the lead going to the other electrode, until the meeting line has returned to the half-way position. Thereby the use of the Pedersen calibration curves is eliminated, the range of the method extended, and the accuracy of the measurements made independent of the variations in the conditions under which the measurements are made. By this method intervals of time which require compensating leads from 30 m to 2 cm have been measured, that is intervals of from 1×10^{-7} to 6.7×10^{-11} second.

When a positive or negative traveling difference of electric potential of sufficient amplitude and proper gradient reaches the terminal of a conductor which is placed in a gaseous medium, its reflection is accompanied by the production of a figure, usually visible, such as has been photographically recorded in Figs. 1 and 2. The properties of these figures change according to the sign of the electric potential.

These figures were first observed and described by Lichtenberg[1] and are known by his name. P. O. Pedersen[2] recently reviewed the work done at different times on the Lichtenberg figures and carried further the investigation of the conditions of the production and propagation of those figures. He ascertained that their velocity of propagation varies with the distance from the electrode from which they originated, the amplitude and gradient of the applied electric potential, and other conditions which he did not succeed in identifying. He determined experimentally[3] for varying pressures, with air as surrounding atmosphere, the relations

$$r = F(t) \tag{1}$$

[1] G. C. Lichtenberg, Super nova methodo motum ac naturam fluidi electrici investigandi, Göttingen, 1777-78.

[2] P. O. Pedersen, Det. Kgl. Danske, Vid. Sels. Mat.-Fys. Medd., I, 11, 1919 and IV, 10, 1922.

[3] P. O. Pedersen, Ann. der Physik., **69**, (1922)

where r is the distance of propagation of the Lichtenberg figure from the electrode, and $F(t)$ a function of the time. Similar relations for different atmospheres surrounding the electrodes were investigated by Przibram.[4]

By using the relations (1) as experimentally determined, intervals of time can be measured in terms of the distance which a Lichtenberg figure has traveled during that interval. Because of their high velocity of propagation, the intervals of time which can thus be measured are very short. Pedersen,[3] using calibration curves corresponding to the equation (1) measured intervals of time from 10×10^{-8} to 0.5×10^{-8} second.

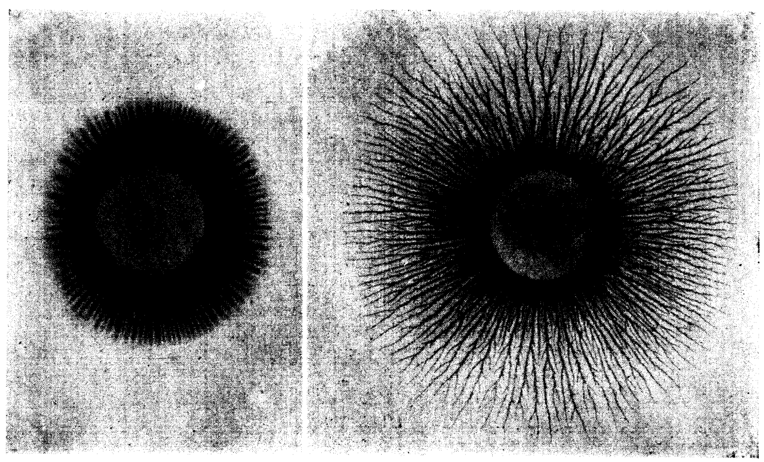

Fig. 1. Negative Lichtenberg figure. Fig. 2. Positive Lichtenberg figure.

However, the function F in the equation (1) varies with the amplitude and the gradient of the electric impulse, with the nature and density (pressure and temperature) of the atmosphere surrounding the electrode, with the emulsion and thickness of the photographic plate on which the figure is recorded, or the nature and thickness of the dielectric in case of visual observation, and also with some other unidentified conditions. These variations and the difficulty of maintaining identical conditions during the determination of the functions (1) and of reproducing these conditions in later measurements are restrictions to the Pedersen method.

In the method which is reported here, the use of calibration curves is eliminated, the range of the method extended and the accuracy of the measurements made independent of the variations in the conditions under which the measurements are made.

[4] K. Przibram, Phys. Zeits. **21**, pp. 480-484 (1920)

The circuit used is shown in Fig. 3. This circuit is similar to those used by P. O. Pedersen, Przibram, Toepler,[5] and J. P. Peters.[6] When the electric impulse resulting from a spark at the gap *G*, reaches the electrodes *E* and *E'* with a relative retardation, the two Lichtenberg figures emitted by the electrodes meet along a line which is displaced from the half-way position of the electrodes. Pedersen and others recorded the figures on a photographic plate, measured the shift, and from their calibration curves obtained the corresponding time interval.

If, however, in the lead going to the "retarded" electrode, an additional length of wire is introduced, the meeting line of the two figures can be made to return to the half-way position between the two electrodes. When this is obtained, the unknown interval of time which produced the shift has been entirely compensated and its value is equal to the quotient

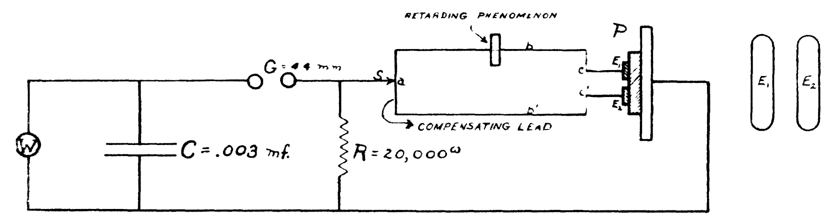

Fig. 3. Circuit for producing an electric impulse relatively retarded with respect to another impulse.

$\Delta l/c$, of the additional length Δl of wire and the velocity of propagation c of the electric impulse. This compensation is independent of the variables which may affect the measurements by the previous methods. It also extends the range of the method for the longer intervals of time to the maximum length Δl which can be practically used. When a great length of compensating wire is used, inductive and capacity effects between the different parts of the compensating lead must be carefully avoided. For the shorter intervals, this method of compensation extends the method to the limit of the precision with which a displacement of the meeting line from the half-way position can be detected. The position of the meeting line was measured in the present work by means of a comparator.

In the arrangement shown in Fig. 3, a sliding contact on a graduated scale provides an easy means of adjusting the length of the compensating lead.

By the above method, intervals of time which required compensating leads of a length from 30 m to 2 cm have been measured. Using as

[5] Max Toepler, Phys. Zeits. **8**, pp. 743-748 (1907)
[6] J. F. Peters, Electrical World, April, 1924.

velocity of propagation of the electric impulse along the compensating lead the value 3×10^{10} cm/sec.,[7] these lengths correspond to intervals of time from 1×10^{-7} to 6.67×10^{-11} of one second.

A picture of two positive Lichtenberg figures where compensation was obtained, is given by Fig. 4. By using positive figures accuracy is gained as their velocity of propagation is approximately three times that of the negative figure, and their meeting line usually presents better definition.

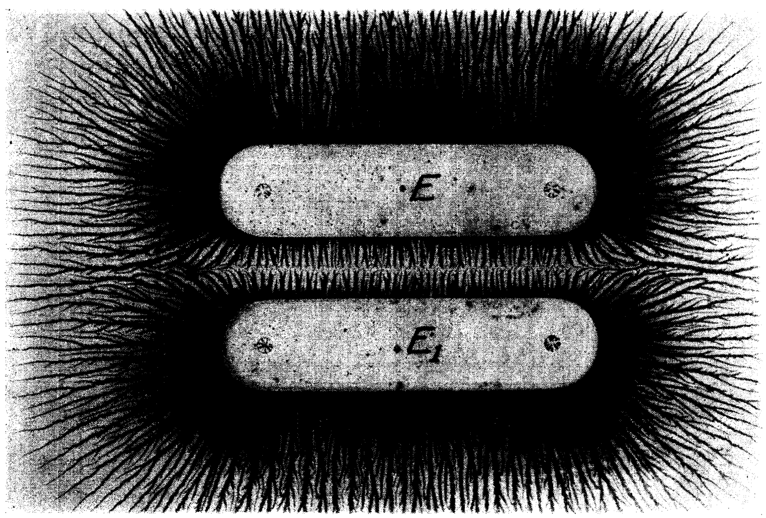

Fig. 4. Lichtenberg figures obtained with circuit adjusted for compensations of the retardation.

When measuring the distance of the meeting line from the electrodes, it is found that the density of the radiations along the edges of the electrodes causes a chemical fogging of the photographic emulsion sufficient to broaden the image of the edge and impair the quality of this reference line. Therefore a series of small holes were drilled in each electrode, their line of centers being parallel to the edge of the electrodes. These holes themselves emit Lichtenberg figures and the centers of these figures define an accurate reference line on the photographic plate. The distance of the reference line from the edge of the electrode is measured on the electrodes themselves and subtracted from the subsequent readings on the photographic plates. The electrodes are mounted rigidly in a parallel position on a plate of insulating material such as bakelite.

[7] M. Mercier, Ann. de Physique, **20**, p. 5, (1923)

In the following table are given the measured shifts of the meeting line from the half-way position for six photographs taken in the neighborhood of compensation. Between columns A and B, B and C, the length of the compensating lead differs by 2 cm. Two plates, selected to have the same thickness, have been taken for each case.

	A	B	C
Plate I	.068 mm	.019 mm	−.014 mm
	.091	.010	−.036
	.071	.026	−.037
	.093	.021	−.034
	.059	.013	−.030
Plate II	.066	.019	−.020
	.062	.028	−.021
	.066	.025	−.017
	.063	.023	−.014
	.065	.021	−.026
Mean shift	+.070	+.020	−.024
Mean square error*	.004	.002	.003

* Calculated in the ordinary way from the sum of the squares of the differences of each of the n observations from the mean.

The inspection of this table shows that (1) the compensation takes place for a value of Δl intermediate between the values corresponding to columns B and C; (2) the shift of the meeting line for variations in the compensating lead of 2 cm and the interval of time corresponding to that variation in length, can be measured with a probable error of about ten per cent.

Department of Physics,
Massachusetts Institute of Technology,
February 19, 1925.

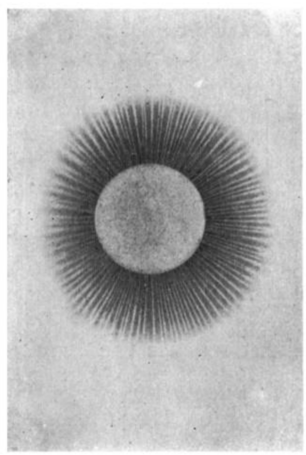

Fig. 1. Negative Lichtenberg figure.

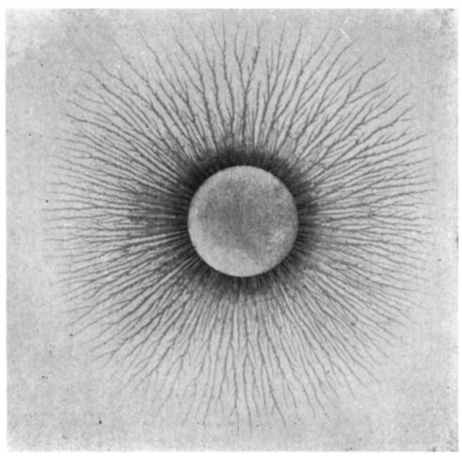

Fig. 2. Positive Lichtenberg figure.

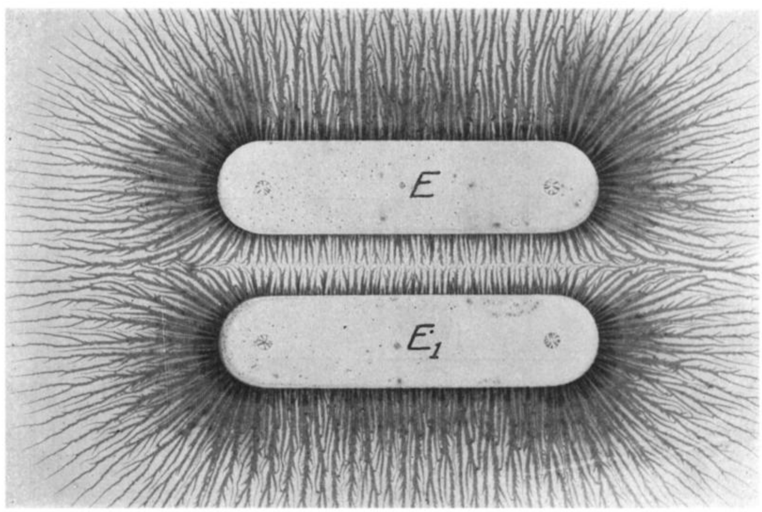

Fig. 4. Lichtenberg figures obtained with circuit adjusted for compensations of the retardation.