that its occurrence is not merely a question of the size of the plant, as some have supposed, but that it has a deeper meaning, and corresponds more closely than has been supposed with the exogenous developments seen equally in large and small examples of living plants.

IV. "Experiments on Stratification in Electrical Discharges through Rarefied Gases." By William Spottiswoode, M.A., Treas. R.S. Received May 27, 1875.

In the stratified discharges through rarefied gases produced by an induction-coil working with an ordinary contact-breaker, the striæ are often unsteady in position and apparently irregular in their distribution. Observations made with a revolving mirror, which I hope to describe on another occasion, have led me to conclude that an irregular distribution of striæ does not properly appertain to stratification, but that its appearance is due to certain peculiarities in the current largely dependent upon instrumental causes.

The beautiful and steady effects obtained by Mr. Gassiot with his Leclanché battery, and also more recently by Mr. De La Rue with his chloride-of-silver battery, have abundantly shown the possibility of stratification free from the defects above mentioned; but it must be admitted that the means employed by those gentlemen are almost gigantic. The present experiments were undertaken with the view of ascertaining, first, how far it was possible to approach towards similar results with instruments already at my command; and secondly, whether these would afford other modes of attack, beside the battery, on the great problem of stratified discharges.

The induction-coil used was an "18-inch" by Apps, worked occasionally by 6 large chloride-of-silver cells, kindly lent to me by Mr. De La Rue, but more usually by 10 or by 20 Leclanché cells of the smallest size ordinarily made by the Silvertown Company. I have also, in connexion with the same coil, 120 of the latter cells, connected in twenties for quantity, and forming 6 cells of 20 times the surface of the former: these work the coil with the ordinary contact-breaker very well, giving 11-inch sparks whenever required. A "switch" affords the means of throwing any of the three batteries in circuit at pleasure.

Having reason to think that the defects in question were mainly due to irregularity in the ordinary contact-breaker, I constructed one with a steel rod as vibrator (figs. 1 & 2, p. 456), having a small independent electromagnet for maintaining its action. The natural vibrations of the rods which were tried varied from 320 to 768 per second; while under the action of the battery-current and electromagnet they varied from 700 to 2500, or thereabouts, per second. The amplitudes of the vibrations were exceedingly small, in fact not exceeding ·01 of an inch; and it is to this fact,

Fig. 1.

End elevation of Contact-breaker. Half size (linear).

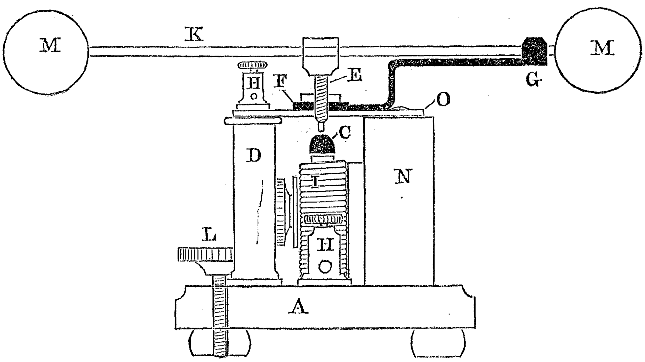
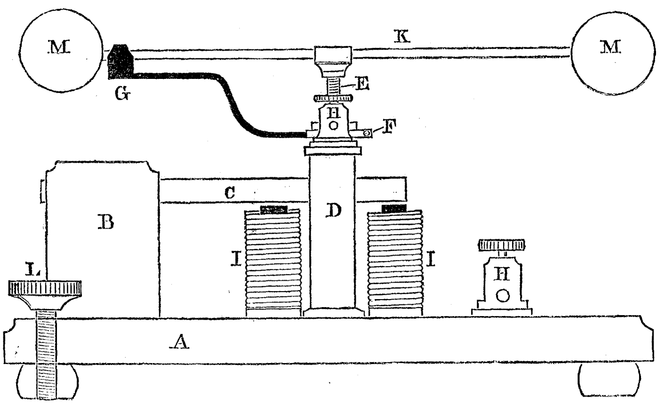


Fig. 2.

Side elevation of Contact-breaker. Half size (linear).



A. Mahogany base.
B. Heavy brass column for supporting vibrating spring.
C. Vibrating spring.
D. Brass column for supporting horizontal plate, O.
E. Platinum-tipped screw for contacts.
F. Friction-collar for holding steadying-arm.
G. Steadying-arm.
H H. Terminals.
I I. Electromagnet.
K. Lever-arm for fine adjustment.
L. Levelling-screw.
M M. Compensating weights.
N. Wooden pillar for electromagnet.

coupled with the extreme rapidity and consequent decision of make and break, that I mainly attribute the steadiness of the results.

The rod bore a plate of platinum, hammered hard, on its upperside; and when contact was made this plate met a thin platinum pin connected with the circuit. In order to avoid, as far as possible, any uncertainty in contact, the diameter of this pin was small; and one difficulty to be obviated was the heating and even fusion of the platinum when the circuit was completed. This was met by using the small-sized cells mentioned above, and employing a fine copper wire (No. 26) round the electromagnet. The very slight "strength of current," or minute "quantity," required for the illumination of vacuum-tubes made it possible so to reduce the surface of the battery-cells and the diameter of wire as to render the overheating in a great measure avoidable. This reduction of dimensions, however, is limited, first, by the amount of magnetism required to keep up the vibrations, and, secondly, by the diameter of the tubes used for the experiments; for it is obvious that, since wire and tube both form parts of the same circuit, in order to produce an equal illumination (other things being the same), we must for a tube of large diameter use a thicker wire than would be necessary for one of small diameter.

With a contact-breaker of this kind in good action, several phenomena were noticeable; but first and foremost was the fact that, in a large number of tubes (especially hydrocarbons), the striæ, instead of being sharp and flaky in form, irregular in distribution, and fluttering in position, were soft and rounded in outline, equidistant in their intervals, and steady in proportion to the regularity of the contact-breaker. These results are, I think, attributable more to the regularity than to the rapidity of the vibrations. And this view is supported by the fact that, although the contact-breaker may change its note (as occasionally happens), and in so doing may cause a temporary disturbance in the stratification, yet the new note may produce as steady a set of striæ as the first: and not only so, but frequently there is heard, simultaneously with a pure note from the vibrator, a strident sound, indicating that contacts of two separate periods are being made; and yet, when the strident sound is regular, the striæ are steady. On the other hand, to any sudden alteration in the action of the break (generally implied by an alteration in the sound) there always corresponds an alteration in the striæ.

It is difficult to describe the extreme delicacy in action of this kind of contact-breaker, or "high break," as it may be called. The turning through 2° or 3° of a screw, whose complete revolution raises or lowers the platinum pin through ·025 of an inch, is sufficient to produce or to annihilate the entire phenomenon. A similar turn in a screw forming one foot of the pedestal of the break is enough to adjust or regulate the striæ; and a slight pressure of the finger on the centre of the mahogany

stand, apparently rigid, or even on the table on which the contact-breaker stands, will often control their movements.

The discharges described above are usually (although not always) those produced by breaking contact; but it often happens, and that most frequently when the strident noise is heard, that the current produced by making contact is strong enough to cause a visible discharge. This happens with the ordinary as with the high break; but in the latter case the double current presents the very remarkable peculiarity that the striæ of one current are so arranged as to fit exactly into the intervals of the other; and, further, that any disturbance affecting the column of striæ due to one current affects similarly, with reference to absolute space, that due to the other, so that the double column moves, if at all, as a solid or elastic mass. And this fact is the more remarkable if we consider, as is easily observed in a revolving mirror, that these currents are alternate, not only in direction, but also in time, and that no one of them is produced until after the complete extinction of its predecessor. And it is also worthy of note that this association of striæ is not destroyed even when the two currents are separated more or less towards opposite sides of the tube by the presence of a magnetic pole. There seems, however, to be a tendency in that case for the striæ of one current to advance upon the positions occupied by those of the reverse current, giving the whole column a twisted appearance. But as there is no trace, so far as my observations go, of this association of alternate discharges when produced by the ordinary break, we seem led to the conclusion that a stratified discharge, on ceasing, leaves the gas so distributed as to favour, during a very short interval of time, a similar stratification on the occurrence of another discharge, whether in the same or in the opposite direction. An explanation of the fact that the striæ of alternate discharges occupy alternate and not similar positions is not obvious, and probably demands a better knowledge of the nature of the striæ than we possess at present.

The column of striæ which usually occupy a large part of the tube from the positive towards the negative terminal have hitherto been described as stationary, except as disturbed by irregularities of the break. The column is, however, frequently susceptible of a general motion or "flow," either from or towards the positive pole, say a forward or backward flow. A similar phenomenon was observed by Mr. Gassiot in some tubes with his large battery; but I am not acquainted with the exact circumstances under which it was produced. This flow may be controlled, both in velocity and in direction, by resistance introduced into the circuit, or by placing the tube in a magnetic field. The resistance may be introduced in either the primary or the secondary circuit. For the former arrangement I have successfully employed a set of resistance-coils supplemented by a rheostat. For the secondary current, as well as for the Holtz machine, I have used an instrument devised and constructed by my

assistant, Mr. P. Ward, to whose intelligence and skill I am much indebted throughout this investigation, intended for fine adjustment. Wherever the resistance be introduced the following law appears to be established by a great number and variety of experiments, viz. that, the striæ being previously stationary, an increase of resistance produces a forward flow, a decrease of resistance a backward flow. I have generally found that a variation of 3 or 4 ohms, or, under favourable conditions, of 1 or 2 ohms, in the primary current is sufficient to produce this effect. But as an alteration in the current not only affects the discharge directly, but also reacts upon the break, the effect is liable to be masked by these indirect causes. The latter, so far as they are dependent upon a sudden alteration of the resistance, may be diminished by the use of the rheostat; but when the striæ are sufficiently sensitive to admit the use of this delicate adjustment, some precautions are necessary to insure perfect uniformity of current, so as to avoid disturbances due to uneven contact in the rheostat itself.

When the striæ are flowing they preserve their mutual distances, and do not undergo increase or decrease in their numbers. Usually one or two remain permanently attached to the positive electrode; and as the moving column advances or recedes, the foremost stria diminishes in brilliancy until, after travelling over a distance less than the intervals between the two striæ, it is lost in darkness. The reverse takes place at the rear of the column. As the last stria leaves its position, a new one, at first faint and shadowy, makes its appearance behind, at a distance equal to the common interval of all the others: this new one increases in brilliancy until, when it has reached the position originally occupied by the last stria when the column was at rest, it becomes as bright as the others. The flow may vary very much in velocity; it may be so slow that the appearances and disappearances of the terminal striæ may be watched in all their phases, or it may be so rapid that the separate striæ are no longer distinguishable, and the tube appears as if illuminated with a continuous discharge. In most cases the true character of the discharge and the direction of the flow may be readily distinguished by the aid of a revolving mirror. In some tubes, especially in those whose length is great compared with their diameter, the whole column does not present the same phase of flow; one portion may be at rest while another is flowing, or even two conterminous portions may flow in opposite directions. This is seen also in very wide tubes, in which the striæ appear generally more mobile than in narrow ones. But in all cases these nodes or junction-points of the flow retain their positions under similar conditions of pressure and current; and it therefore seems that, under similar conditions, the column in a given tube always breaks up into similar flow-segments.

These nodes will often disappear under the action of a magnetic pole. Thus if the first segment, measured from the positive terminal, be sta-

tionary and the second be flowing backwards (*i. e.* from − to +), a magnetic pole of suitable strength, placed at the distant end of the latter, will stop its flow, and the whole column will become stationary throughout. An increase in the strength of the magnet, or a nearer approach of it to the tube, will produce a general forward flow of the column.

The phenomena of the flow, as well as others of not less interest, are capable of being produced with the Holtz machine. It is well known that stratified discharges, similar to those produced by an induction-coil working with an ordinary break, may be produced by such a machine, provided that it be furnished with the usual Leyden jars, and a high resistance (usually a piece of wetted string) be interposed in the circuit. The absence of either of these conditions was supposed to destroy the striæ and to render the discharge continuous. Experiments which I have recently made, but do not describe on the present occasion, tend in part, but only in part, to confirm this view. They show that for the production of striæ both quantity and resistance are necessary, that the discharge must occupy a certain short, perhaps, but finite time, or, as it may also be expressed, that a continuous current is an essential element.

Now, seeing that every tube must offer some resistance, and also that by adjusting the height of the vertical condensors of the machine (or length of air-spark interposed in the circuit) we had the means of altering the quantity in the discharge, it seemed worth while to try whether, by a suitable adjustment of the parts, phenomena similar to those brought out by the coil and high break might not be produced by the machine. And this proved to be very easy of attainment in tubes which had been successfully used by the coil; and not only so, but the character of the flow therein shown confirmed in a very striking and simple manner the effects of resistance described above.

The connexions being made in the usual way, and no air-spark being admitted into the circuit, a vacuum-tube of carbonic oxide, about 60 centims. in length and 4·5 centims. in outside diameter, gave, when the plates of the machine revolved at about six times per second, a rather confused discharge. As the speed was increased, a rapid forward flow of the striæ was readily discerned; and on a still further increase to about ten revolutions per second, the flow, first in one part and then throughout nearly the whole length of the tube, slackened its pace and stopped, and ultimately reversed its motion. An increase of speed is equivalent to an overcoming or a diminution of resistance in the circuit, a diminution of speed to an augmentation of resistance. Hence the phenomena of flow produced by the machine agree with those produced by the coil.

It is unnecessary to detail the effects obtained with many other tubes, as they all agreed in their main features.

In a sulphurous-acid tube, which with the induction-coil and ordinary break gave broad flocculent striæ but unsteady and fluttering in posi-

tion, the effects with the Holtz machine were very striking: the striæ, with steady revolution of the machine, became fixed in position and well defined. This tube, some carbonic-acid-gas tubes, and one or two others, generally containing acid residua, form a class in which the action of the machine more nearly approaches that of Mr. Gassiot's battery than in any others. The striæ thus formed were not easily brought into a state of flow; but an increase in the rapidity of the machine, or a diminution of resistance, increased the number of the striæ. As the rapidity was augmented, the striæ might be seen pouring themselves out, as it were, from the positive pole; the length of the column was slightly increased, but by no means in proportion to the number of striæ.

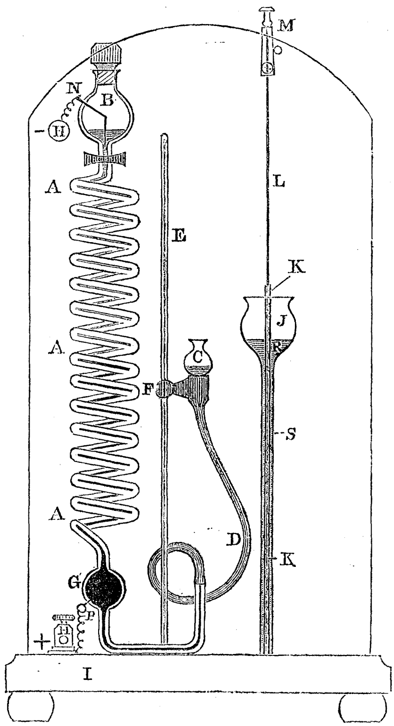
One modification of this effect, although almost fantastic in its appearance, seems to deserve a special notice. It is well known that if a sufficient interval of air be thrown into the circuit all trace of stratification disappears, and at the same time the dark interval between the positive and negative parts and the negative halo itself are obliterated. If, however, the interval of air be very small, the two kinds of discharge may be seen coexisting; a narrow column of the continuous discharge extends along the tube, and on it the striæ appear to be strung. These effects are easily produced by slightly lowering one of the vertical conductors of the machine; and perhaps the best effects are shown if the conductor on the side connected with the positive terminal of the tube is lowered. When this is done the striæ occupying the portion nearest to that terminal become widely separated at unequal and varying intervals; they appear to oscillate along the tube with independent motions, as if attached to an elastic string which at each instant is unequally stretched at its various parts. The portion of the column so affected varies with the length of the interval of air; and when, for instance, that portion amounts to two thirds of the entire length, the striæ in the remaining third appear crowded together. As the interval of air is further increased more striæ become disturbed, the continuous discharge becomes wider and more prominent, and ultimately overpowers and obliterates the striæ.

The resistance-coil used for the secondary current or the machine consists of a hollow glass spiral, A A A (fig. 3), having a length of about 50 inches and an internal diameter of $\frac{1}{40}$ of an inch. At the head is a small glass bulb B, having an opening at the top, which is closed by a glass stopper. A platinum wire, N, connected with one of the terminals, H, dips to the bottom of the bulb B, which is partially filled with sulphuric acid. C is a small glass bulb containing mercury, and is connected with the lower end of the spiral by a flexible tube, D. The height of this bulb can be regulated by means of the slide F, which moves on the steel rod E. P is a small platinum wire fused into the interior of the bulb G, and is in connexion with the other terminal, H.

If the bulb C be placed in any position, the mercury will rise in the spiral to the same level as that in the bulb. The mercury will act

as a metallic conductor, and a current flowing between the terminals will undergo the resistance due to the acid in the upper part of the spiral.

Fig. 3.



Attached to the same stand is a coarse resistance-tube, adapted also to currents of high tension, such as a 3- or 4-inch spark from an induction-coil. It consists of a tube, S, of about 4 millims. diameter, terminating at its upper end in a funnel-shaped bulb, J, and having a platinum wire fused into its lower end. This tube is filled to R with a mixture of glycerine and water, in the proportions of 6 to 1. L is a long steel rod, extending from the clip M to the bottom of the tube, and capable of sliding up and down; its lower half is coated with a very small glass tube, K K, so that its extremity alone is exposed to the contact of the fluid. If the steel rod L be in the position shown in the diagram, no resistance will be offered to a current passing through the system; but if it be raised, the resistance offered will be in proportion to the length of column of resisting fluid through which it has to pass.

Fig. 1.

End elevation of Contact-breaker. Half size (linear).

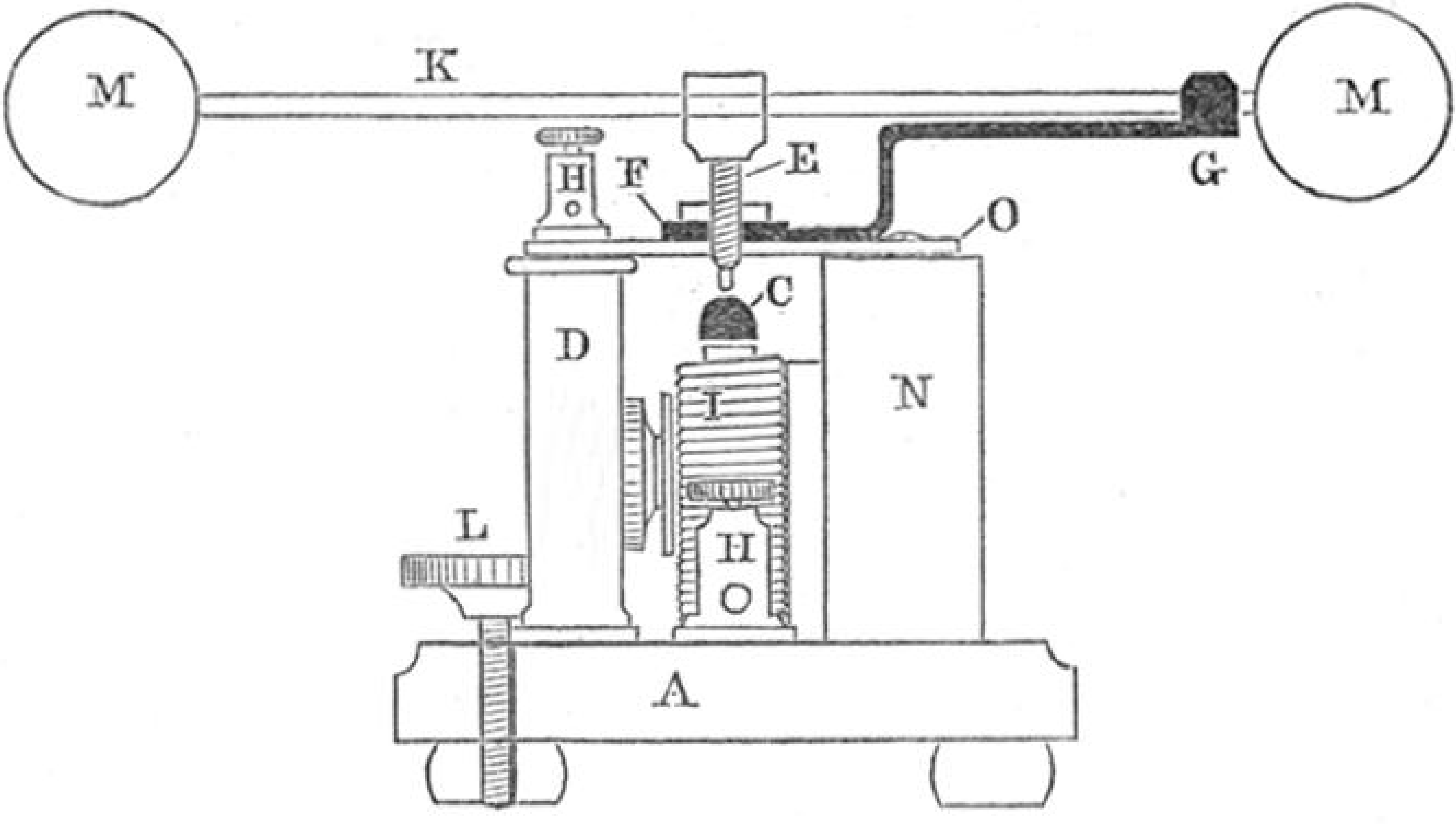
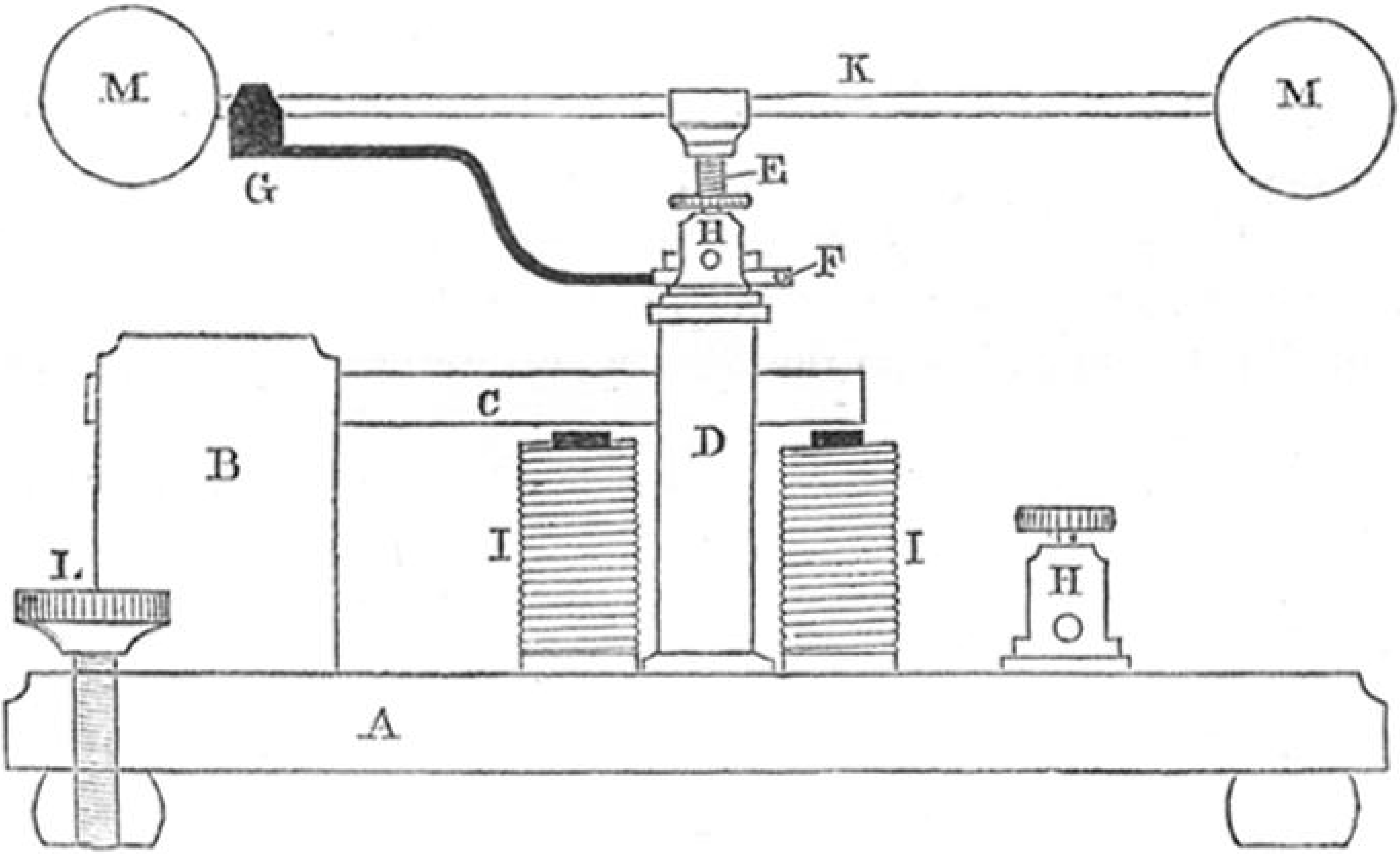


Fig. 2.

Side elevation of Contact-breaker. Half size (linear).



A. Mahogany base.
B. Heavy brass column for supporting vibrating spring.
C. Vibrating spring.
D. Brass column for supporting horizontal plate, O.
E. Platinum-tipped screw for contacts.
F. Friction-collar for holding steadying-arm.
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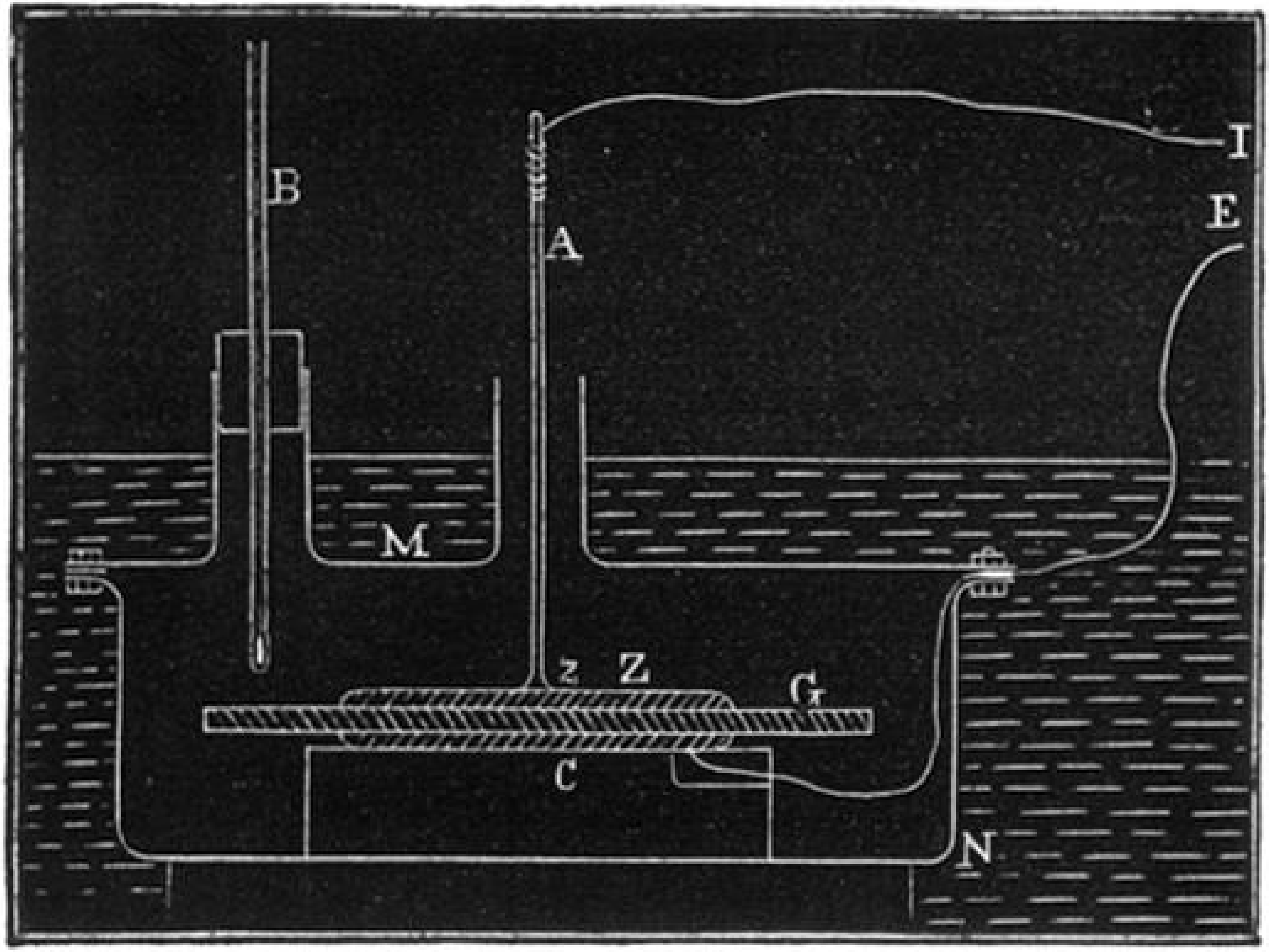
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Fig. 3.