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To cite this article: T. Mizuno (1901) XX. The function of self-induction in Wehnelt's interruptor , Philosophical Magazine Series 6, 1:2, 246-250, DOI: [10.1080/14786440109462608](https://doi.org/10.1080/14786440109462608)

To link to this article: <http://dx.doi.org/10.1080/14786440109462608>



Published online: 16 Apr 2009.



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or apertures. In fact, crossed cylindrical lenses, whether the lenses are at right angles or are inclined obliquely, and also spherical and cylindrical combinations, may be replaced by their equivalent ellipsoidal or quadric lenses, or for an ellipsoidal lens a pair of cylindrical lenses, or a spherical and a cylindrical lens, may be substituted; for the arrangement or distribution of refracting substance is similar in such lenses or combinations. And, moreover, the preceding geometrical constructions afford a ready means for effecting the transformation from any assigned type of the combinations named to the type of any other. The method is applicable to astigmatic lenses or combinations in which the curvatures are not all of the same sign.

XX. *The Function of Self-Induction in Wehnelt's Interruptor.*

By T. MIZUNO *.

WEHNELT † discovered a very interesting interruptor and made a minute investigation on its properties. Soon after this discovery, Simon ‡ also carried out experiments on the new interruptor and gave the theory of its action. According to his theory, an electric current i sent through the interruptor of the resistance w grows logarithmically, and finally attains such a value that the Joule's heat expressed by the integral

$$0.24 \int i^2 w dt, \quad (1)$$

where

$$i = \frac{E}{w} \left(1 - e^{-\frac{w}{L}t} \right), \quad (2)$$

E being the impressed electromotive force, and L the coefficient of self-induction of the circuit, is sufficient to call forth the vaporization of the electrolyte in the neighbourhood of the active electrode. By this vaporization the current is suddenly broken, but immediately there takes place a cooling process in consequence of which the vapour is condensed, the circuit being thereby re-established, and the action of the interruptor continued.

However, the condensation of the vapour is not the sole requisite for maintaining the action of the interruptor.

In fact, the self-induction of the circuit plays a very important part at the instant of break in re-establishing the once-broken circuit. This important fact was first found by

* Communicated by the Author.

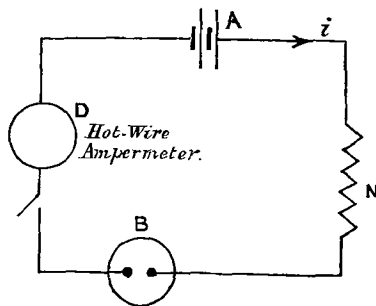
† A. Wehnelt, Wied. *Ann.* lxviii. p. 233 (1899).

‡ H. T. Simon, Wied. *Ann.* lxviii. p. 273 (1899).

Ruhmer *, and much light was thereby thrown on the action of the interruptor. The following experiments, which I have recently performed, may be considered as confirmation of Ruhmer's view :—

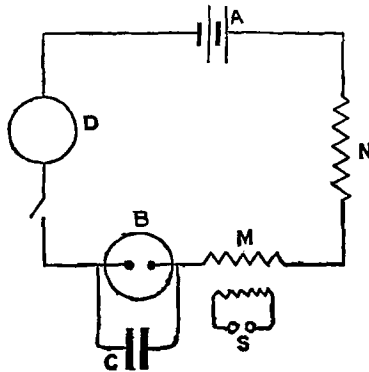
(a) A Wehnelt's interruptor B was placed in series with a coil N as shown in the annexed figure (fig. 1). When the

Fig. 1.



strength of the current i was below a certain value, the interruptor did not act, the active electrode of the latter becoming simply red-hot, and the process was simply an electrolysis. But inserting iron bundles in the coil so as to increase its self-induction, the interruptor began to act at once when the circuit was closed. The same thing also took place even when there were no iron bundles in the coil, by merely increasing the current to a certain requisite value.

Fig. 2.



(b) A given induction-coil M and a coil N were joined in series with the interruptor B, the latter being shunted by a condenser of large capacity (fig. 2).

* E. Ruhmer, *Elektrotechnische Zeitschrift*, Heft 26, 1899.

In this case, the following phenomena were observed :—

- (i.) When the secondary S of the induction-coil was open, *i.e.* its terminals were so far apart that no sparks could take place across them, the interruptor was active.
- (ii.) The terminals were placed at such a distance that the play of sparks could occur. In this case, the action of the interruptor immediately stopped, and the active electrode became red-hot, the main current indicated by the amperemeter being very much reduced.
- (iii.) The iron bundles were put in the coil N, and the terminals of S were maintained in the same condition as in the case (ii.). In this state of affairs, the action of the interruptor went on without any hindrance, and the incessant play of the sparks of the secondary was observed.
- (iv.) During the above experiment (iii.), taking away the iron bundles from the coil N, the action of the interruptor ceased at once, the main current being simultaneously reduced to a large extent. It is to be remembered that when the interruptor is thus once made inactive, the re-introduction of the iron bundles into the coil N has, of course, no effect at all.

(c) The coil N, the induction-coil M, and the interruptor B were joined in series, and they were shunted by the condenser. In this case, the interruptor was found to act well, as might be *a priori* expected, whether the coil N contained the iron bundles or not, and also whether the spark-gap of the secondary S was opened or closed.

So far, I have given a mere description of the phenomena observed with the interruptor.

Now the experiment (a) tells us that with a given current, or, more strictly speaking, a given electromotive force, a certain particular value of the self-induction is necessary for the action of the interruptor ; and that when the self-induction becomes less than this particular value, the interruption cannot then go on, the process being simply an ordinary electrolysis. As to the experiment (b), we also see that a certain value of self-induction is indispensable in order to maintain the action of the interruptor.

The cases (iii.) and (iv.) prove this. Again, the cases (i.) and (ii.) can be explained by the following theoretical consideration : that when the secondary of a given induction-coil is closed, the effective self-induction of the primary coil is

diminished to $L - M^2/N$; L , M , and N being respectively the coefficients of self-induction of the primary, of mutual induction between the primary and the secondary, and the coefficient of self-induction of the secondary.

To sum up, the experiments mentioned above all point out the necessity of a certain self-induction in the circuit for the action of Wehnelt's interruptor. Now, as noticed by Simon, the rise of the current in the interruptor is given by the equation (2), and it increases until the integral (1) expressing the Joule's heat attains a certain particular value, and then a sudden vaporization occurs, the circuit being consequently broken.

But it is very important to observe that this vaporization may not always necessarily repeat itself, and that its occurrence wholly depends upon the magnitude of self-induction of the circuit. In other words, with a given applied electromotive force, the action of the interruptor goes on or stops according as the self-induction is greater or less than a certain particular requisite value, as shown by the experiment (a).

It is clear that after the break of the circuit in consequence of vaporization, what plays the most important part is the electromotive force $L \frac{di}{dt}$ of the extra-current at the instant of break.

When this electromotive force is sufficiently large to call forth the spark across the vapour, the current is re-established, because the vapour at the active electrode is thereby cleared off. Since the whole vapour is simultaneously being condensed again, the value of the current again grows according to the equation (2), and the process of vaporization recurs. On the contrary, when the electromotive force of self-induction is not sufficient, the spark cannot take place, and the current is greatly reduced in virtue of presence of the vapour which adheres to the surface of the active electrode, the process becoming a simple electrolysis. The legitimacy of the above view can be tested thus. Insert a condenser of a given capacity across the interruptor. If this capacity be very large in comparison with the self-induction of the circuit, the electromotive force of the extra-current will be then wholly employed in charging the condenser, and consequently re-establishment of the normal current cannot take place.

But, if the self-induction is sufficiently large, the part of the energy due to the extra-current may of course be used in clearing away the vapour at the active electrode, giving a new start to the main current. The experiment (b) is the very confirmation of the truth. Again, when the condenser is

shunted across the coils and the interruptor as in experiment (c), its effect on the extra-current at the interruptor must be evidently null.

Thus we see that, while the rise of current up to the critical value at break is governed by the equation (2), a new start of the current is effected principally by means of the electromotive force due to the self-induction. It is now very interesting to compare Wehnelt's interruptor with the induction-coil. In the induction-coil the suppression of the spark due to the extra-current is indispensable, so that a capacity of a certain requisite value must be inserted across the interruptor. The deficiency of capacity diminishes the oscillations in the primary circuit in consequence of the spark due to the extra-current, and therefore the latter spark must be avoided as much as possible. On the other hand, in Wehnelt's interruptor the spark due to the extra-current is necessary in order to keep up its action. Without such spark, the vapour at the active electrode cannot be got rid of, and consequently sufficient current cannot be established anew. The actions of capacity and self-induction are thus directly opposite to each other in the two cases.

In conclusion, I wish to acknowledge my indebtedness to Prof. Warburg for encouragement in performing the above experiments.

Berlin, December 1900.

XXI. *On the Effect of a Magnetic Field on the Discharge through a Gas.* By R. S. WILLOWS, B.A., D.Sc., Trinity College, Cambridge, 1851 Exhibition Scholar*.

IT is well known that if a discharge is passing through a tube containing rarefied gas, the effect of a transverse magnetic field is to increase the potential-difference at the terminals and to decrease the current passing through it, while a longitudinal field renders the passage of the discharge easier†. These results are easily explained by the ionic theory.

While working with tubes in which the pressure varied from .1 mm. to 1 mm. it was noticed that under certain conditions the imposition of a transverse field caused a large increase in the current passing and a decrease in the potential-difference of the terminals, just the opposite of what generally occurs. As this did not appear to be due to any peculiarity of the tube, further experiments were made. The results of these are contained in the following paper.

A remarkable effect of a longitudinal field has already

* Communicated by Prof. J. J. Thomson, F.R.S.

† See 'Rec. Researches,' p. 105.