ELECTRODELESS RING DISCHARGE

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Sir J. J. Thomson[1] pointed out many years ago that interesting electrical discharges through a gas may be obtained without the use of metallic electrodes within the discharge tube. The properties of the electrodeless discharge have been the subject of numerous investigations, both abroad and in this country.

The exciting circuit necessary to produce this electrodeless discharge consists simply of two Leyden jars and a stout copper solenoid, surrounding the tube, in series with a large induction coil whose secondary is spanned by a spark gap. When sparks pass across the gap, there are set up in the solenoid high-frequency high-potential currents which induce corresponding currents in the conducting gas within the tube. This induced discharge is in the form of a ring—hence the name. The current flowing may rise to comparatively high values, depending on the nature of the gas and more particularly on its pressure. For most brilliant effects the pressure should be about that of the gas within an ordinary Geissler tube, roughly from 0.05 mm to 0.5 mm of mercury.

Accompanying the discharge and persisting for some moments after it has been cut off, there is to be seen, oftentimes, an interesting after-glow, providing the pressure is just right. This after-glow is not in the form of a ring and is not confined to the length of the exciting solenoid as is the discharge itself, but extends throughout the whole of the tube. It is in general an apple-green illumination (though it may take on different hues), and it may persist in residual air for 5 to 10 seconds after the exciting current in the solenoid has been discontinued.

Thomson[2] also observed that the introduction of a small quantity of fresh gas (the same that was under observation) into the discharge chamber before the after-glow had disappeared (other conditions being favorable) caused the glow to "flash" or brighten up momentarily. The question naturally arose, what are the conditions that obtain within the tube to produce this flash?

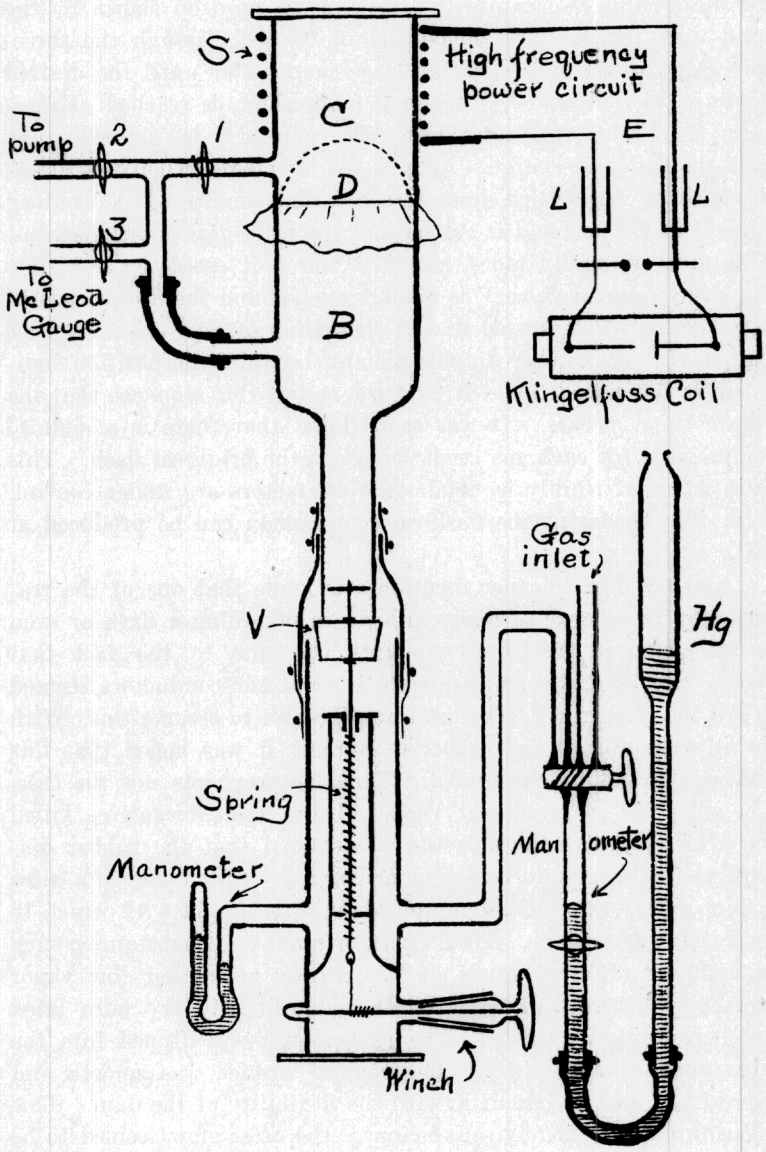
[1] Phil. Mag., series 5, Vol. 32, p. 321, Oct., 1891.
[2] Phil. Mag., series 7, Vol. 4, No. 25, p. 1128, Nov., 1927.

Is it due to the introduction of *fresh* gas, or may the same flash be obtained by merely compressing the gas?

The experimental problem is not as simple as it may seem at first thought. Obviously the compressions should be adjustable as to amounts and they must be quickly made. Some sort of frictionless piston suggested itself. L. W. Florman made a few preliminary observations in this laboratory (1927-28) using two different designs of glass pistons, and succeeded in getting a few "flashes" on *compression,* but owing to mechanical difficulties which prevented him from getting consistent results his observations were not considered conclusive. Another difficulty encountered was that the presence of metal (including mercury) in the discharge chamber seemed to kill the after-glow. The present paper gives an account of an experimental attempt to obtain more conclusive evidence as to the cause of this interesting phenomenon.

The apparatus as ultimately constructed is shown in the accompanying figure. *C* is the discharge chamber about which is placed the solenoid *S* of the high frequency exciting circuit, the details of which are shown. *D* is a rubber disphragm which is held between the two flat ground ends of the divided tube, thus separating the compression chamber *C* from the expansion chamber *B*. Rubber dental dam was used for the disphragm because of its extreme flexibility. At the lower end of the expansion chamber is a large-throated valve *V* for permitting the gas to be introduced quickly into *B* and thus causing a sudden compression of the gas in the chamber *C*. This large-throated valve consists simply of a rubber stopper mounted on a central rod and held firmly against the ground lip of the tube extending down from *B* by a stiff spring as shown. Guides are provided to keep the valve central. To the lower end of the valve stem is attached a winch *W* which permits opening the valve quickly. The small manometer gives an indication of the pressure in the system, while the large manometer is used as a means of measuring and regulating the amount of gas being introduced to bring about the desired compression. The action of this arrangement is apparent from the figure. The system is initially pumped out through the stop-cocks 1 and 2. Stop-cock 3 connects to a McLeod gauge.

The method of operation of the apparatus is to open stop-cocks 1, 2, and 3, then lower the valve *V* by the winch *W* and pump the whole system out to the pressure desired. This pressure is read on the gauge. When the desired pressure is reached stop-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High frequency
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2
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Gauge
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Gas
inlet
V
Hg
Spring
Manometer
Manometer
Winch

cocks 1 and 2 are closed and then the valve V. Thus far the pressures in C, B, and the lower part of the system are the same, and the diaphragm D occupies the unstretched position shown by the solid line. Gas is now introduced in "doses" through the three-way stop-cock by means of the large manometer until the desired pressure, as indicated by the small manometer, is reached. Everything is now ready for the test. The gas in C is excited by the high-frequency discharge. After a few moments, when the illumination in C has settled down to a constant condition, the exciting current in the solenoid is cut off and the after-glow alone remains. This glow gradually fades, and just before it ceases to be visible the large-throated valve V is quickly opened and the excited gas in C is suddenly compressed due to the excess of pressure in B over that in C. The rubber diaphragm now occupies the position indicated by the dotted line. It is at the end of this sequence that the "flash" in C occurs. It was soon found that there is a definite compression for each gas used that gives the brightest flash. This ratio is found readily by trial since all factors are under control. With this apparatus the flash on compression can be produced at will.

Earlier in this paper mention was made that one of the reasons why there were so many failures in obtaining a flash or even an after-glow in the initial attempts was due to the fact that metals and mercury, and apparently some non-conductors seemed to kill the after-glow. Thomson was the first to observe this. With the introduction of the rubber diaphragm it was hoped that this difficulty would be eliminated. This, however, was not the case. The sulfur in the processed rubber, being electronegative, killed the after-glow, and for a while it appeared that the rubber diaphragm would have to be abandoned and a return made to a glass piston, unless some flexible material could be found with which to cover the rubber dam. After trying a number of substances, such as vaseline, different kinds of tap grease, and other low vapor pressure lubricants, it occurred to the writer to try pure latex which contains no sulfur. The rubber dam was dipped into the latex and allowed to dry. The coating formed was smooth and seemed to interfere but little with the flexibility of the dam. This covering proved entirely satisfactory,—the after-glow seemed to be in no way diminished. That this was the case was thoroughly tested by introducing latex-covered rubber diaphragms into an

electrodeless discharge tube specially constructed for testing different substances.

With this annoyance removed, a complete series of experiments was undertaken to determine under what conditions a given gas could be made to give this "flash." The discharge itself was found to occur in residual air over a pressure range of 1mm to .0056 mm of mercury (the limit of the Hyvac pump used), and the after-glow was visible over a more limited range from .3 mm to .05 mm mercury. As was previously mentioned, the after-glow in residual air continued for from 6 to 8 seconds under favorable conditions. The "flash" was noticeable at any time from immediately after the excitation of the gas ceased until just before the after-glow disappeared. In fact, it was obtained over the whole range of pressures for which the after-glow was visible. It was not obtained after the after-glow had disappeared.

It was found that the after-glow in residual air seemed to be of two distinct types. One was a glow of quite long duration (4 to 8 seconds) which was prominent at higher pressures (.3 mm to .06 mm). This was of a yellowish hue which changed to a pale apple-green color as the pressure was reduced and the glow gradually disappeared. Over a very limited range of pressure (about .01 mm) no after-glow was noticeable. As the pressure was reduced from .06 mm to .05 a different type of after-glow appeared. This lasted for only a very short time, one or two seconds, and was of a brilliant bluish color, but soon disappeared on further reduction in pressure. At times it was impossible to get a definite separation of the two after-glows, one gradually merging into the other.

Oxygen was next introduced into the apparatus, and the same investigations were carried out with it as with air. The after-glow was found to be a very brilliant bluish-white for the higher pressures, which gradually changed to a blue for the lower pressures. The pressure range of the after-glow for oxygen was roughly the same as that for residual air. The maximum life of the after-glow was also approximately the same as the maximum life in residual air, namely, 6 to 8 seconds. And as was the case in air, oxygen also showed a "flash" upon compression of the excited gas over approximately the same range of conditions.

Nitrogen was in marked contrast to oxygen and air. The after-glow in nitrogen was a brilliant yellow or orange at the higher pressures, changing to a bluish hue and disappearing completely as the pressure was reduced. This after-glow was apparent

over practically the same range of pressures as the first type of after-glow in air. It had, however, a maximum life of about 125 seconds, which varied with the pressure. This after-glow died out very slowly, in sharp contrast to oxygen, which diminished gradually for a few seconds then winked out completely. The "flash" in nitrogen could be obtained at any time while the after-glow was visible. The brilliancy of the "flash" was in direct proportion to the brilliancy of the after-glow. At no time in air, oxygen, or nitrogen, the three gases studied, was a "flash" formed if the compression took place *after* the after-glow had completely disappeared.

A curious thing in the case of nitrogen was that, following the "flash," the after-glow was still visible and continued to die out gradually instead of disappearing completely with the flash as in the case of oxygen. Other interesting results were observed that seemed to be wholly lacking in the case of oxygen; these, however, may have been due to the greater intensity of the after-glow and "flash" in nitrogen. This phase should be studied at greater length. Another curious phenomenon observed in the after-glow of nitrogen was that if the gas was excited and allowed to stand without being disturbed until the after-glow entirely disappeared, then the after-glow could not be made to appear again on subjecting it to the high frequency discharge *without* introducing fresh nitrogen and readjusting the pressure. This also bears further study and verification.

The fact that the after-glow was present when a pure latex rubber diaphragm was used and absent when vulcanized or processed rubber was used seems to indicate quite conclusively that the sulfur and other impurities present in the processed rubber were responsible for the killing of the after-glow. Thomson considered that the after-glows were caused by "systems" formed in the excited gas when the discharge is passing. These systems, which last for only a short time, may be different aggregates from those resulting from chemical combinations and decompositions, and hence may be more easily ionized than the normal gas molecule. Since certain metals placed in the discharge chamber stop the after-glow, it appears that these metals must destroy the "system" formed in the excited gas.

In general, the results of this investigation show that the more electropositive the metal, the smaller is the effect of that metal upon the after-glow. The exception seems to be aluminum. It stands at the head of the electromotive series; yet it had the

greatest effect on the after-glow—killing it almost completely. The aluminum that we worked with, however, lost this anomolous property after a few excitations, and the after-glow returned to almost normality. This would indicate that the sample of aluminum accumulated a charge or protective covering which neutralized its destructive effect first exhibited on the after-glow. It would also indicate the correctness of the explanation advanced by Thomson. His suggestion is that the more electronegative a substance is, the greater is its affinity for electrons and, consequently, the faster it removes electrons from the gas, and hence the more difficult it is for the discharge to pass and for the after-glow to be sustained. Thus the more strongly electronegative the substance, the greater would be its effectiveness in killing the discharge and after-glow.

The "flash" of the after-glow occurs, as seen by the eye, in the form of a flat disc which travels upward from the diaphragm when the gas is suddenly compressed. It seems to accompany a pressure pulse. That it is due to change of pressure and not to the introduction of fresh gas is shown by the fact that the "flash" is obtained when compression is produced by the diaphragm without the introduction of fresh gas into the discharge chamber. This, and other experiments not here enumerated, tend to indicate that the after-glow is due to the illumination which accompanies the recombination of an ionized gas. Since the gas in the discharge tube is ionized the *compression of this gas would push the ions closer together, and thereby facilitate recombination, which is made evident by more intense illumination in the form of a "flash."* After a large part of the gas has recombined, no after-glow is visible, and of course, no "flash" would be obtained. If, however, a "flash" could be obtained upon *sudden expansion* of the excited gas, it could not be explained on the basis of recombination in the ionized gas. Although the effect of expansion has not been exhaustively investigated by the writers, preliminary simple tests indicate that expansion of an ionized gas does *not* cause a "flash."

SUMMARY

1. The vapor pressure of the sulfur in vulcanized rubber is great enough to destroy the after-glow in an electrodeless discharge. Pure rubber (latex) does not affect the after-glow.

2. Many metals (including a few non-metals) affect the after-glow. The more electropositive the metal is, the less is its destructive effect on the after-glow.

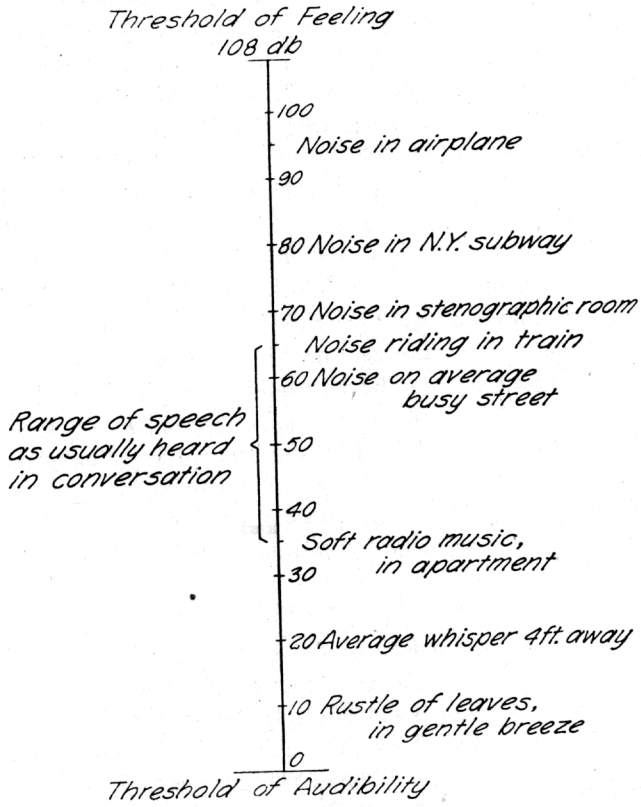
3. The after-glow in air is of two distinct types, one due to a predominance of oxygen and the other to an excess of nitrogen.

4. The "flash" of the after-glow is dependent upon change of pressure, whether the change takes place with or without the introduction of fresh gas into the discharge chamber.

5. The "flash" of the after-glow occurs in a pressure pulse in the excited gas, i. e., in a region of increased pressure. *This suggests that compression facilitates recombination with resulting illumination.*

6. The "flash" of the after-glow does *not* occur when the excited gas is *suddenly expanded* by decrease in pressure. This supports the view expressed above in 5.

7. The compression of the excited gas must take place *before* the after-glow has disappeared. No "flash" can be obtained if the after-glow is not visible at the time of compression.



A Loudness Scale (after Waterfall).