XLI.—*The Electrical Explosion of Tungsten Wires.*

By Henry Vincent Aird Briscoe, Percy Lucock Robinson, and George Edward Stephenson.

The phenomena accompanying heavy high-tension discharges in thin metallic wires were first studied by Anderson (*Astrophys. J.*, 1920, **51**, 37). Using a large glass plate and tin-foil condenser, he photographed the spectra of the light emitted by the electrical explosion of iron, copper, nickel, and manganin wires and observed very interesting effects, notably a reversal of many lines, producing an absorption (Fraunhofer) spectrum instead of the bright-line spectrum usually observed. These phenomena are attributable to the momentary attainment of an exceptionally high temperature in the substance of the wire. Observations with a rotating mirror showed that the duration of the flash was less than 10^{-5} second, and Anderson calculated that if the available energy of his condenser, equivalent to about 30 calories, were wholly communicated to the 2 milligrams of wire in this time, the temperature attained would be of the order of 300,000°. The intrinsic brilliancy of the wire at the moment of explosion was found to correspond with a surface temperature of 20,000°. Making liberal allowance for the inherent uncertainty of these estimates, it seems evident that the temperatures attained in such explosions are much higher than can be reached by any other means.

In 1922, Wendt and Irion (*J. Amer. Chem. Soc.*, **44**, 1887) reported the results of experiments on the explosion of fine tungsten wires by Anderson's method. When the explosions were carried out in a vacuum, some gas was formed, and this, subjected to an ordinary high-tension discharge, gave a spectrum in which the yellow helium line, D_3, was consistently observed. When the wires were exploded in an atmosphere of carbon dioxide at ordinary pressure, and the carbon dioxide afterwards absorbed in caustic potash solution, residual gas, averaging 1·42 c.c. per milligram of tungsten, remained. This gas was lost before its spectrum had been investigated. If it consisted wholly or mainly of helium, it was on the average some 25% of the weight of tungsten taken.

These results were so startling, and, if correct, of such profound significance that the experiments here described were undertaken to confirm them.

The essential idea of these experiments is, of course, extremely simple. A fine tungsten wire is supported between heavy electrodes sealed into a glass vessel; this vessel is evacuated, and a heavy discharge is passed from a condenser of large capacity. Thereafter an ordinary high tension-discharge is passed through a capillary side-tube on the bulb, and the emitted light spectroscopically examined. In practice, the experimental difficulties are considerable and arise chiefly in securing the necessary conditions of very high vacuum and very good contact between the wire and the electrodes. Unless both these conditions are fulfilled, the discharge does not pass through the wire, but passes between the electrodes (possibly through the slight conductivity of gas remaining in the bulbs or produced by local heating of the wire) in such a way that the material of the wire is unaffected.

EXPERIMENTAL.

Preparation of Bulbs.—Three containers, of the form shown in Fig. 1, were first constructed from 300 c.c. spherical Durosil bulbs, A, provided with main electrodes, EE, and a supplementary electrode, F, in a small bulb connected with A by a capillary tube, C. While A was still open at the line D, the wire, W, was sprung into place between EE by means of suitable forceps: thereafter the system of tubes, B G H, was sealed on at D. The electrodes, EE, were of heavy molybdenum wire approximately 0·1 inch in diameter: one end of each was drilled and countersunk with fine drills to receive the filament and they were then coated with glass nearly to the ends and sealed into the bulbs as shown in Fig. 3.

FIG. 1.

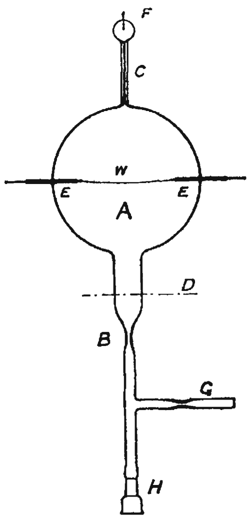
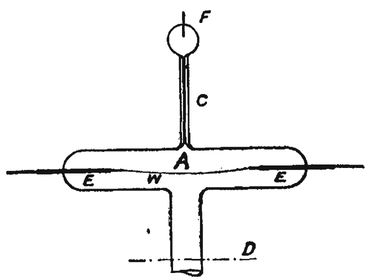


FIG. 2.



Serious difficulties were encountered in making this apparatus: unless the bulbs were of heavy glass they cracked at the electrode seals and when the seals stood they frequently leaked at pinholes so minute that they could only be detected by a pressure test under water. A T-shaped bulb of about 70 c.c. capacity constructed as in Fig. 2 from Durosil tubing 1″ in diameter proved much more satisfactory.

All attempts to seal heavy tungsten wires into Pyrex glass, as described by Wendt and Irion, failed completely, but, fortunately, it was found that molybdenum sealed fairly well into Durosil glass and could, unlike tungsten, be obtained as drawn wire of the heavy section required to carry the discharge without material loss.

We are indebted to Messrs. Duram Ltd., and to their chemist, Mr. S. C. Radford, who very kindly supplied us with several samples of fine tungsten wire, both hard-drawn and annealed. The annealed wire proved much less springy and easier to handle than the hard-drawn wire and was used throughout: pieces about 4 cm. long were cut from a soft wire 0·035 mm. in diameter. It was quite impossible to spring these wires unsupported between the electrodes as Wendt and Irion stated they had done. With much patience and luck, crystalline filaments from an old drawn-wire lamp could be fitted in this way, but they were so fragile as to be useless in practice. Therefore the wire was threaded through a very fine and light capillary glass tube, bent back outside the tube at both ends, and then the tube and wire were sprung between the electrodes as shown in Figs. 2 and 3.

FIG. 3.

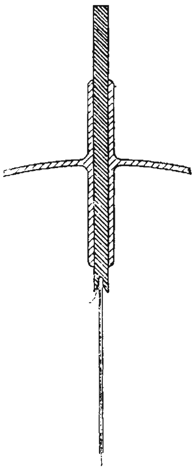
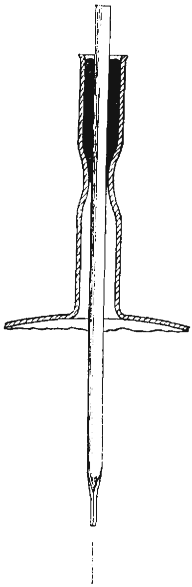


FIG. 4.



Bulbs made as described were connected by the mercury-sealed ground glass joint H (Fig. 1) to a large all-glass Töpler pump and McLeod gauge, and, after a preliminary evacuation by a water-pump connected to G, which was then sealed off at the constriction, were further evacuated with the Töpler pump. The first bulb was kept at 300° in an electrically heated air-bath, evacuated to 0·005 mm., and left at 300° over-night. Next morning, the pressure in the bulb was 0·02 mm. This difference appeared to be too large to be accounted for by the release of gases from the glass. The bulb was allowed to cool and each electrode seal was tested, in turn, by coating it with sealing wax and carrying out a series of evacuations. By this means it was established that leakage was occurring in the neighbourhood of the seals. After treating a large surface of the glass with a collodion varnish, a vacuum of 0·001 mm. was maintained over-night. As a further test of this vacuum, an induction coil discharge was passed between the supplementary electrode and one of the main electrodes: there was at first no visible discharge, but after a time, possibly through the release of gas from the wires or accidental breakage of the wax seals, a noisy visible discharge occurred and set up vibration which dislodged the wire and capillary and so rendered the bulb useless.

The details given above for one case will serve to indicate the difficulties attendant on the use of molybdenum–glass seals: As a result of a series of experiments, another metal–glass seal was tried, which promised to be more satisfactory, because, *inter alia*, it permitted the proper support of a naked wire inside the bulb. The essential features of this seal are shown in Fig. 4. The glass tube was constricted to allow the tinned copper electrode to pass through neatly without play. The upper part of the glass was heated nearly to redness and molten lead poured into the tube; the lead chilled so quickly at the constriction that it solidified there and prevented passage of lead into the bulb. The preliminary tests were carried out on single joints, which were sealed to the pump and evacuated. It is interesting to observe that where the glass had been hot, lead which had overflowed on the outside of the tube adhered strongly to the glass and at the colder portions of the tube the lead peeled off quite easily.

After some practice, a satisfactory seal was obtainable and a T-shaped bulb was constructed using this type of joint for the electrode seals. In this bulb the tungsten wire was stretched between the two electrodes and a supporting capillary tube was unnecessary.

One end of each copper electrode was hammered flat and folded into a small trough; then the end of the wire was laid along the trough and secured by hammering the sides together. Good electrical contact and a secure hold for the wire were thus obtained. The electrode and wire were passed through one side tube of the bulb; the upper electrode was then sealed in with molten lead, and finally the bulb was reversed and the second electrode similarly sealed in. This bulb was connected to the pump and evacuated; the following figures show the efficiency of the seals.

28/12/23	4 p.m.	Pressure = 0·0003 mm. of mercury.
8/1/24	10 a.m.	Pressure = 0·0080 ,, ,, ,,

Thus these seals, while useful for many purposes, did not appear tight enough for the present experiments.

At this stage it was decided to conduct several explosions, using the highest vacuum attainable, with a number of bulbs, having molybdenum–glass seals, which had been prepared. The electrode seals were coated externally with sealing wax in such a manner as to give an even, well melted coating of wax: such coatings had been found to enable the bulbs to hold very high vacua, and were really excellent except that they precluded strong heating of the bulb during evacuation. A bulb was evacuated to the limit of the pump, being heated meanwhile to about 100° by means of a soft, luminous gas flame. The evacuated bulb was allowed to stand over-night on the pump, and the state of the vacuum noted. In each case a single stroke of the pump removed a minute bubble, so small that it could not be driven down the capillary fall-tube of the pump. The bulb was again heated and another stroke of the pump showed that no gas had been released from the glass: it was then sealed off at the vertical capillary.

The Explosions.

Messrs. A. Reyrolle & Co. Ltd., electrical engineers, of Hebburn-upon-Tyne, very courteously placed their high-tension testing plant at our disposal and we desire to record here our thanks to Mr. H. W. Clothier and Mr. Harle for their interest and active co-operation in carrying out the experiments at their works.

FIG. 5.

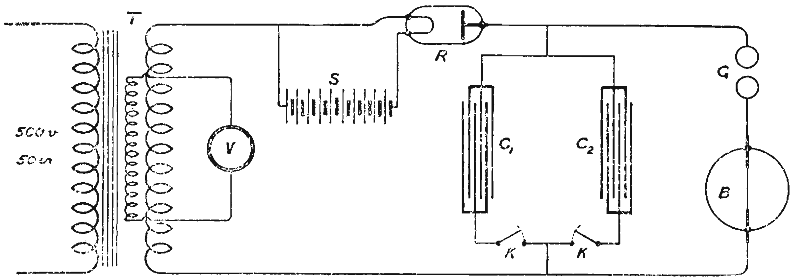


Fig. 5 is a diagram of the circuit used. The two condensers, C_1 C_2, each consisted of 100 glass plates, 24 inches square, having on each face tinfoil coatings 18 inches by 17 inches: the plates were carried on porcelain insulators in a wooden frame: heavy brass leads connected alternate coatings with two copper busbars on opposite sides of the condenser. The condensers were not oil-immersed. Each had a capacity of 0·3 microfarad, the normal working pressure was 30,000 volts, and the highest permissible pressure was 45,000 volts. The connexions permitted the use of either condenser singly or of both in parallel.

Current at 500 volts and 50 cycles A.C. from the supply mains fed to the transformer, T, was stepped up to any desired voltage (up to a maximum of 100,000 volts) and the output was rectified by a two-electrode thermionic valve, R, the filament current for which was supplied by the accumulator, S. The knife switches, K, being closed, this rectified output charged the condensers. When the potential difference across the condensers reached a certain value dependent on the width of the adjustable air-gap, G, between two large polished brass spheres, the condensers discharged across the gap and through the bulb B. The whole of this apparatus was contained in a large cage of expanded steel, well earthed, and the necessary switches were actuated from the outside of the cage.

A kilovoltmeter, V, across a tertiary winding of the transformer gave an approximate indication of the discharge potential. Throughout the experiments the spark-gap was kept constant and at the conclusion of the tests a precise measurement showed that the potential difference required for discharge across the gap was 29,000 volts.

In one case, contact between the leads and the electrodes of the bulb was made through mercury contained in rubber tubing slipped over the latter. This bulb fractured on discharge, probably because this method of securing contact was defective, and the other bulbs were connected up in turn by twisting the leads tightly round the external parts of the electrodes.

The phenomena associated with the explosions may best be described by giving the details with reference to one of the several bulbs exploded. Bulb No. 4 was spherical, had molybdenum electrodes sealed in through the glass and a filament fitted in a capillary tube as already described. Both condensers were used connected in parallel, giving a total capacity of 0·6 microfarad. At discharge, the kilovoltmeter, K, indicated 30,000 volts. The air-gap was screened from sight and the explosion was well seen by four observers: it was attended by a dull thud in the bulb, and by a bright flash in which the whole of the filament was seen to be involved. Both the noise and the brightness of the flash were much less than we had anticipated.

On examining the bulb, it was found that the filament had completely disappeared: the capillary, now loose in the bulb, was intact, showed a mere trace of a metallic mirror at one end, and was slightly bent at both ends, having evidently been softened there by heat.

It will be remarked that these effects differ substantially from those described by Wendt and Irion: we nevertheless regarded this explosion as complete and satisfactory.

Within a few hours after explosion, the contents of the bulbs were investigated. An induction coil discharge was passed between the supplementary electrode, F, and one of the main electrodes, and the light emitted in the capillary tube, C, was examined visually with a Hilger constant deviation spectrometer. In each of the bulbs there was a small amount of gas which permitted a discharge to pass and gave a faint banded spectrum on which were superposed a few bright lines, the wave-lengths of which were read directly on the spectrometer drum. The lines observed were the green lines of mercury and the red and blue hydrogen lines; none of the bulbs at any time gave any yellow line whatever, although the spectrometer showed the two sodium lines bright and well defined in the light from an ordinary Bunsen flame.

We conclude, therefore, that our experiments afford no evidence that tungsten can be made to yield helium when exploded by an electrical discharge. At the same time, it is clear that extreme difficulties attend any attempt at a crucial experiment on these lines, and we attach much more importance to experiments now in progress on the electrical explosion of tungsten wires in relatively dense and non-conducting atmospheres of absorbable gas.

Our conclusion is supported by the results, published since our tests were completed, of a similar series of experiments conducted in Dr. Anderson's laboratory (Sinclair Smith, *Proc. Nat. Acad. Science*, 1924, **10**, 4). This investigator encountered difficulties in the construction of gas-tight containers, and in attaining satisfactory vacua, precisely similar to those we have described, but he finds no evidence of any formation of helium by the electrical explosion of tungsten.

A still more recent publication (Harkins and Allison, *J. Amer. Chem. Soc.*, 1924, **46**, 814) describes experiments in which heavy electrical discharges were passed (a) *between* fine wire electrodes, and (b) through fine metallic wires, and the gases (if any) were examined for helium by absorption in heated metallic calcium by Soddy's method. In most cases, the gas was completely absorbed and in no case was there any evidence of helium. Hence it seems clear that the statements made by Wendt and Irion must be attributed to erroneous observations and have no foundation in fact.

Our thanks are due to the Chemical Society for a grant which has defrayed the major part of the expenses incurred in this investigation and to the Department of Scientific and Industrial Research for a grant enabling one of us (G. E. S.) to take part therein.

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