X-RAY RADIATION FROM HOT SPARKS

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Millikan has been able to study extreme ultra-violet spectra by using a high potential condensed discharge in a high vacuum as a source of light and specially ruled gratings, and he has found that many of the strongest spectrum lines are emitted by stripped atoms, that is, atoms with no valence electrons left. As these hot sparks also were found to radiate X-rays, the spectrum of which, however, has never been analyzed, the author undertook the problem of studying this spectrum, and this paper gives the first results.

In such a condensed discharge where the time during which the discharge takes place is a very small fraction of the total time, the current density during the instant of discharge is enormously high. For this reason an extraordinarily large proportion of the radiating atoms are *multiply ionized*, doubtless as a result of *successive impact*. If it is possible to remove an electron from the inner shells in such a stripped atom, we might expect that the X-radiation would be slightly different from the radiation emitted by a normal atom.

Another process of multiple ionization is that suggested by Wentzel[1] as an explanation of the so-called enhanced lines in X-ray spectra, and which involves the removal of more than one electron from the inner shells of the atom. In his first paper on this subject Wentzel supposed that this multiple ionization also was caused by successive impact, but later Rosseland[2] showed that this is extremely improbable, and that the simultaneous removal of two electrons by a single impact like that directly observed by Millikan[3] in the case of helium is much more probable. Coster,[4] furthermore, in his experiment was unable to get the enhanced line $L\alpha_4$ for silver at a voltage of 4700 volts, although the critical potential for the L-series of silver is only about 3350 volts. Siegbahn also has found an absorption edge for sulphur at a wave-length corresponding to about the double critical voltage of the K-series. All these facts seem to indicate that the atom is *multiply ionized* by a *single impact*. On the other hand Bäcklin[5] has recently been able to photograph the line $K\alpha_4$ for aluminum at a voltage lower than that required for the removal of both K-electrons by a single impact.

In the case of successive ionization as applied to the inner shells we should expect, as has been pointed out by Wentzel, that the relative intensity of the enhanced lines and the ordinary lines corresponding to them would increase with the second power of the current density. In a condensed discharge we should expect on this account a very great increase in this relative intensity, but in the case of multiple ionization by a single impact we might expect the same intensity as is observed with an ordinary X-ray tube.

The vacuum spectrograph which was used is one of Siegbahn's type, and has been described by him.[6] Instead of the X-ray tube a spark chamber of the construction shown in figure 1 was connected with the spectrograph. The chamber is made of a brass tube about three inches in diameter the end of which carries the slit *A*. The tube is soldered in the wall of the spectrograph in such a way that the slit and the photographic plate in the spectrograph are on the same distance from the rotating axis of the crystal (focus condition). *B* and *C* are two conical grindings made of bakelite, and in each of them is another grinding, *E* and *F*, of brass. These serve as holders for the two metal pieces, *G* and *H*, in which the electrodes are fastened. In order to obtain a more concentrated spark the electrodes are pointed. The distance between the spark and the slit is about 1 cm. The upper electrode holder *G* is threaded on the rod *E*, and by turning this rod at the upper end the distance between the electrodes can be regulated from outside. The electrode holder is prevented from turning by means of a glass rod, *I*, and a fork, *K*, fastened on the wall of the chamber. The spark can be observed through the glass window, *L*. The spark chamber and the spectrograph are connected through a series of holes, shown in the figure, and thus both compartments can be evacuated to the same high vacuum through a tube in the side of the spark chamber by means of mercury condensation pumps.

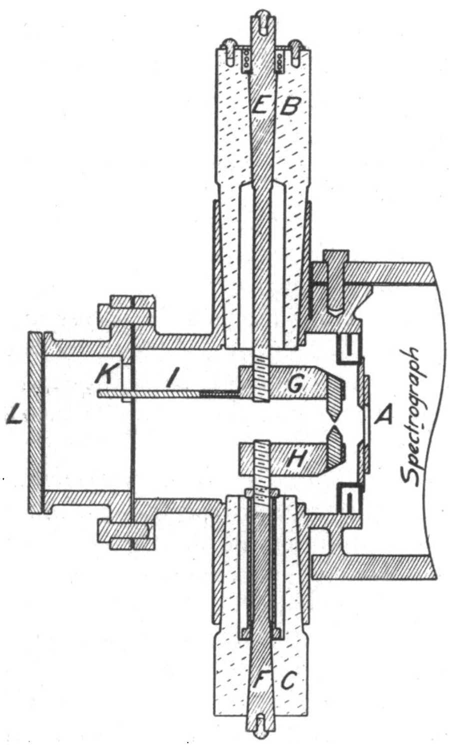

FIGURE 1

The electrodes *E* and *F* are arranged in series with another outside spark gap, provided for the purpose of controlling the energy in the vacuum spark. The two spark gaps, shunted by a capacity of four Leyden jars, were connected across the secondary of a Thordarson wireless transformer of 1 K.V.A. capacity at 25,000 mean volts. On account of the production of excessive heat the spark was run intermittently so that the actual time of sparking was about one sixth of the total time.

The slit must be covered with a filter which absorbs the visible light but is as transparent as possible for the X-rays. As the atomic absorption increases approximately as the fourth power of the atomic number—provided one is not working with wave-lengths longer than the K absorption edge—it is evident that the filter ought to be composed of elements of low atomic number. I used as filter a thin film of celluloid, which was obtained by letting a drop of celluloid-solution in amyl-acetate fall on water, and which was rendered opaque by means of a thin coat of India ink. Such a film was found more transparent for soft X-rays than filters of aluminum (7μ), colored goldbeaters skin, and carbon paper, ordinarily used.

I tried silver, aluminum, silicon, sulphur and copper as electrodes, and used a gypsum crystal as grating. *The plates which were obtained show beautifully all the earlier known characteristic lines in the spectrum of the L-series for silver, and the K-series for the other elements, including the so-called spark-lines, but no new lines could be observed, nor could one notice any shift or broadening in the old ones.* This result indicates that the X-rays obtained are not produced by the stripped atoms in the vapor. In order to find out from what region of the spark the X-rays originate, I used as electrodes two pieces of aluminum sheet, and arranged them with their edges parallel to the slit. On the other side of the slit I placed a photographic plate and secured in this way a picture of the spark as through a pinhole camera. The result of this test is shown in Fig. 2. The picture indicates definitely that the X-rays to a very great extent originate at the solid electrodes, and that the X-radiation from the vapor in the spark itself, where we have stripped atoms, is practically negligible.

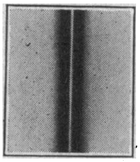

FIGURE 2

The relative intensity of the lines also was, as far as could be judged by looking at the plates, the same as that obtained from an ordinary X-ray tube. *This fact shows rather definitely that the multiple ionization giving rise to the enhanced X-ray lines of the K-series must be due to simultaneous ejection by a single impact.*

The work is being continued, and by rearranging the apparatus in order to get much more energy in the spark, I hope to be able to get X-radiation from the vapor.

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[1] G. Wentzel, *Ann. d. Phys.*, **66**, 437 (1921); and **73**, 647 (1924).

[2] S. Rosseland, *Phil. Mag.*, **45**, 65 (1923).

[3] R. A. Millikan, *Phys. Rev.*, **18**, 456 (1921).

[4] D. Coster, *Phil. Mag.*, **44**, 546 (1922).

[5] E. Bäcklin, *Zeits. f. Phys.*, **27**, 30 (1924).

[6] M. Siegbahn, *Spektroskopie der Röntgenstrahlen*, Berlin, 1924.